AIR UNIVERSITY SPACE PRIMER

Air University
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Foreword

Over the last 50 years our military space activities have rested on an information-centric spacepower theory. The distinct advantages the medium of space provides for the collection and dissemination of information are reflected in our space policy, capabilities, and warfighting operational concepts.

The importance of space, however, is no longer limited to the military domain. Weather and imagery satellite information, satellite communications, space launch, and even turn-key space systems are all commodities available in the commercial market to those willing to pay. The Global Positioning System could be considered the first true global utility; a GPS hand-held receiver can provide free unlimited world-wide access to precision navigation and timing information.

As our national security and that of our allies becomes increasingly reliant on space systems as a means to generate wealth, power, and influence; their significance as critical capabilities continues to increase. History shows us that military operations become necessary to protect vital national interests. The global availability of space capabilities makes it incumbent upon civilian and military leaders to have a broader knowledge of the capabilities, limitations, and vulnerabilities of space systems and the medium in which they operate. The *Air University Space Primer* is intended to be a reference source to help with that task.

As with any published work, the material immediately dates itself, thus at times becoming less relevant. This primer was prepared with the intent of imparting an educational framework to build upon rather than current and specific facts that often change quickly. We hope the reader will learn principles and be stimulated in thought, rather than struggle with errata induced by rapid changes.

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Chapter 1

SPACE HISTORY

Few events in our history have been more significant than the dawn of the space age. This chapter will discuss early space pioneers, the space race, the manned space programs, the formation of NASA and some of the first satellites ever launched into orbit above the earth.

EARLY DEVELOPMENTS IN ROCKETRY

No one really knows when the first rocket was created; however, most historians agree that the Chinese were the first to produce a rocket around 1212 AD. This first rocket was essentially a solid fuel arrow powered by gunpowder, which was also invented by the Chinese sometime around 800 AD. These very early rockets contained black powder, or something similar, as the propellant (fuel). According to legend, a man named Wan Hu made the first attempt to build a rocket powered vehicle in the early 1500s. He attached 47 rockets to a cart and at a given signal, 47 workers simultaneously lit all of the rockets. In the ensuing explosion, the entire vehicle disappeared in a cloud of smoke and Wan Hu was never seen in this world again.

The principles by which rockets operated were not understood until the late 1800s when man began thinking about using rockets for the transportation of people. Up to this point, rockets had been used in warfare in a limited capacity. For example, rockets were used by the British during the War of 1812 shelling of Fort McHenry (i.e., "the rockets' red glare"). Yet even in warfare, the rockets' potential was not fully realized. Major advances in rocket technology did not occur until the early 1900s.

Events in America: 1909-1929

Dr. Robert Goddard, commonly referred to as "The Father of Modern Rocketry," is responsible for the advent of space exploration in the United States. He achieved most of the American accomplishments in rocket science in a somewhat autonomous effort. In 1909, he began his study of liquid propellant rockets and in 1912, he proved that rockets would work in a vacuum such as exists in space. The year 1919 brought the end of World War I as well as the publication of Dr. Goddard's book, <u>A Method of Attaining Extreme Altitude</u>. This document laid the theoretical foundation for future American rocket developments.

On 16 March 1926 in Auburn, Massachusetts, Dr. Goddard made history as the first person to launch a liquid-fueled rocket. The strange looking vehicle covered a ground distance of 184 feet in 2.5 seconds and rose to an altitude of 41 feet while achieving a speed of 60 mph. In 1929, Goddard launched an improved version that was the first rocket to contain weather instruments. This vehicle rose to a maximum altitude of 90 feet and provided some of the earliest weather readings from "on-board" sensors.

Dr. Goddard and Rocket Technology in New Mexico

In 1930, with financial backing from Charles Lindbergh and the Guggenheim Foundation, Dr. Goddard moved his operation to New Mexico where he continued his work until his death in 1945. His work centered on a number of improvements to his rockets, which resulted in a number of "firsts" in rocket science and technology. For example, Dr. Goddard was the first to develop a gyro-control guidance system, gimbaled nozzles, small high speed centrifugal pumps and variable thrust rocket engines. All of these technologies are used on modern rockets today.

Dr. Goddard's rocket project was a privately funded effort with absolutely no government funding, aid of any sort or interest in his work. Notwithstanding, his accomplishments in rocketry were truly extraordinary. Meanwhile, a team of German scientists were also interested in rocket development and their advances would prove to have a devastating effect upon the world.

Events in Germany

The German rocket development effort can be divided into two phases. Phase I occurred between 1923 and 1931 and involved Herman Oberth, Walter Hohmann, Johannes Winkler and the Society for Space Travel. Phase II occurred between 1932 and 1945 and involved only one man, Wernher Von Braun.

Phase I

Although he never actually built any rockets, Herman Oberth inspired others in both Germany as well as abroad to do so (e.g., Dr. Goddard). He accomplished this through his 1923 publications on space and upper atmosphere exploration. His book "*The Rocket into Planetary Space*" laid the foundation for the German rocket development effort. Oberth suggested that if a rocket could develop enough thrust it could deliver a payload into orbit. Many people thought this impossible, but a man named Johannes Winkler was so inspired by Oberth's work that in 1927 he formed the Society for Space Travel, of which Oberth later became president. Also known in German as the "Verein fur Raumschiffahrt," this society became the spawning ground for the most significant breakthroughs in space technology. Members of the organization would later include rocket pioneers such as Dr. Von Braun.

In 1925, Walter Hohmann published his book "*The Attainability of Celestial Bodies*," in which he defined the principles of rocket travel in space (to include how to get into geosynchronous orbit). In recognition of Hohmann and his work in rocketry, the orbital transfer technique used to place payloads into geosynchronous orbit is called the "Hohmann Transfer."

Johannes Winkler invented the first liquid propellant rocket, the HW-1. The first launch attempt was a failure but the second launch was successful in 1931, achieving an altitude of 295 feet.

Phase II

In 1932, the National Socialist dictator Adolf Hitler rose to power in Germany and directed the German Army to pressure Dr. Von Braun to develop rockets which could be employed in warfare. Hitler used the resulting rocket technology to terrorize London during World War II. Ironically, the rocket technology which resulted from Dr. Von Braun's early work would eventually enable the United States to send a man to the moon.

Under direction of the German Army, Dr. Von Braun began experimenting with liquid fuel rockets, leading to the development of the "A" series. The A-1, which did not appear promising, was abandoned after a number of launch failures. The A-2 subsequently emerged and was successfully launched in 1934, thus opening the door for development of even larger rockets.

In 1937, General Dornberger, the head of the German Army's rocket development effort, Dr. Von Braun and their development team moved to Peenemunde (a peninsula in northern Germany). From this installation

(**Fig. 1-1**) would come the vengeance weapon, the V-2 (**Fig. 1-2**), which Hitler

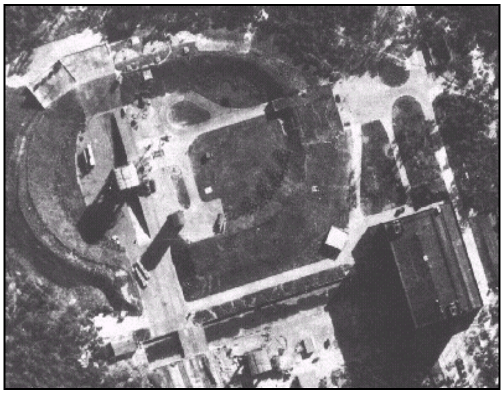

Fig. 1-1. Peenemunde

Fig. 1-2. V-2 Rocket

would unleash against England. By 1942, the A-4 test rocket had been successfully launched. Research and development continued until 7 September 1944, when the first V-2 rocket boosted a 2000 lb. warhead to 3,500 mph and burned out with the warhead continuing on a ballistic trajectory to a range of 200 miles, literally "falling" on London.

Events in the Soviet Union

If it could be agreed upon that the space age was born in one place, most historians would say that it would have been in the home of Russian schoolmaster Konstantin Eduardovich Tsiolkovsky. In 1883, he first explained how it would be possible for a rocket to fly in space. This was a time when most people believed it was not possible for man to fly. Consequently, Tsiolkovsky was thought to be eccentric by his fellow Russians. In 1895, he published "*Dream of the Earth and Sky*" in which he initially postulated the feasibility of an artificial earth satellite. In 1903, he began publishing parts of another book describing the theory of rocket flight and the prospects of space travel.

Tsiolkovsky had a unique depth of understanding. He was the first to recommend the use of liquid propellants because they performed better and were easier to control than solid propellants. His notebooks contain many ideas and concepts that are used by rocket engineers today. His works also include detailed sketches of spaceship fuel tanks containing liquid oxygen and hydrogen (the same fuel used in the Saturn V moon rocket). Tsiolkovsky further recommended controlling a rocket's flight by inserting rudders in the exhaust or by tilting the exhaust nozzle, just as Dr. Goddard would suggest some thirty years later.

Tsiolkovsky determined a way of controlling the flow of liquid propellants with mixing valves and advocated cooling the combustion chamber by flowing one of the liquids around it in a double-walled jacket, as seen in the space shuttle engines of today. His spaceship cabin designs included life support systems for absorption of carbon dioxide and proposed reclining the crew with their backs to the engines throughout the acceleration phase, also as is currently done. Tsiolkovsky further suggested building the outer wall of spaceships with a double layer to provide better protection against meteors and increased temperature. Tsiolkovsky foresaw the use of an airlock for space-suited men to leave their ship and suggested that gyro-stabilization as well as multiple-stage boosters were the only way to attain the velocities required for space flight. Finally, he anticipated the assembly of space stations in orbit with food and oxygen supplied by vegetation growing within.

Tsiolkovsky designed extensive calculations to ensure all his proposals were mathematically possible, but without funding, he was unable to perform any meaningful experimentation. Because of his considerable technical foresight and realistic approach to space problems, he is now known as the "Father of Space Travel."

ROCKET DEVELOPMENT AFTER WORLD WAR II

This section will address booster and missile development in the Soviet Union and the U.S. between 1945 and the early 1960s.

Soviet Efforts

When the Red Army captured Peenemunde in May 1945, they found that most of the important personnel and documents were gone. The Soviets learned of the American effort to seize important German space technology and began a similar program of their own. They ended up with a majority of the hardware and a few remaining scientists and technicians.

In 1946, Stalin was not satisfied with the progress of the Soviet rocket effort at Peenemunde so he moved it to the Soviet Union. There, like in America, the expatriated German scientists and technicians worked with Soviet rocket scientists in an effort to improve the basic V-2 design. However, the Soviet team decided to strike out on their own, thus relegating the German team to a support role. By the end of 1953, all the expatriated German rocket team members had been returned to Germany.

Decision to Build the Intercontinental Ballistic Missile (ICBM)

The U.S. was well ahead of the Soviet Union in nuclear technology and possessed the most powerful bomber force in the world. This unnerved the Russians and forced them to probe for an equalizer. In their search for this weapon, the Soviets began to realize the potential of the ICBM for striking over long distances. The Soviets envisioned a missile capable of striking the U.S. from the Soviet Union. This thinking dominated all of Soviet rocket research and by the end of 1947, the consensus in the Soviet Union was to build an ICBM with this capability. In their quest to build an ICBM, a whole family of short and medium range ballistic missiles were developed, the most important of which was the Shyster Medium Range Ballistic Missile (MRBM), which became the world's first operational MRBM in 1955.

In 1951, biological experiments with dogs convinced Soviet scientists that manned rocket flights were possible. They were also convinced that they would soon have the capability to place large payloads into orbit. Thus, along with the development of the ICBM, emerged the idea of space flight, which included the beginning of research into space suits, life support systems and emergency escape systems for manned flights.

While Soviet scientists contemplated putting things into space, the vehicles required to accomplish this were developing at an astonishing rate. The Soviet missile program was well on its way to becoming reality. In 1953, two more missiles entered the development phase: the SS-4 Sandal and the SS-6 Sapwood.

SS-4 Sandal

The SS-4 was required to carry a one megaton (MT) warhead across more than 1,118 miles. It used storable propellants which improved its launch rate capability. The SS-4 became operational in 1959 and remained in use for two decades. The SS-4 was the weapon at the heart of the Cuban Missile Crisis, when the Soviet Union deployed ICBM missiles to the island of Cuba in 1962.

SS-6 Sapwood

The SS-6 was still under development in 1956, but the Soviets were so sure of its success that they began discussing its use as a launcher for an artificial satellite. The Soviets announced to the world that they would launch a satellite into earth orbit as part of International Geophysical Year (IGY) activities. The western world did not take this proclamation seriously, oblivious to the great strides that the Soviets had made in rocketry.

The SS-6 (**Fig. 1-3**) was ready for its first test launch in May 1957. The Soviets traded off stylish design for brute strength. They did not yet have powerful rocket engines built so they used more engines to compensate for the lack of powerful engines.

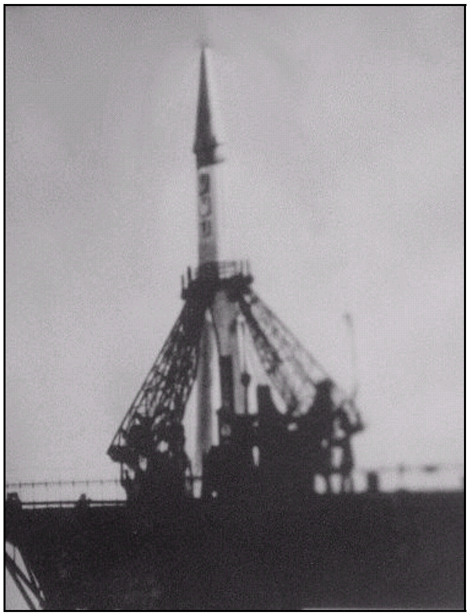

Fig. 1-3. SS-6 Sapwood

The SS-6 was a single stage missile with clustered engines and had twice the power of the U.S. Atlas or Titan ICBMs. To avoid making the missile in several stages, the Soviets opted to go with a centralized cluster of motors. These clusters would be ejected after they had used up their fuel, while the central core motor continued to burn. By October 1957, the Soviets were ready to prove to the West that their missile capabilities were more than just a proclamation.

Sputnik

On 4 October 1957, the Soviets used their SS-6 Sapwood ICBM to launch the world's first artificial satellite, Sputnik 1 (**Fig. 1-4**). On 3 November 1957, Sputnik 2 was launched with Laika, a Soviet research dog, on board. At this point, the Soviet Union had become the first nation to enter outer space with a biological life form.

Fig. 1-4. Sputnik 1

United States Efforts

While the Soviets had a well coordinated rocket program, the U.S. did not. After the Soviets exploded their first hydrogen bomb (H-bomb) on 12 August 1953, the Armed Services of the U.S. began to concentrate on missile development. Around this time, the Air Force had begun work on their Atlas ICBM.

Air Force ICBM Program

Due to the Soviet's H-bomb capability, in 1955, President Eisenhower directed that the Atlas ICBM project become the nation's number one priority. The Atlas was a one and one half stage missile with external boosters that separated after burnout. Powered by liquid oxygen and kerosene, it required fueling prior to launch. By mid-1955, Atlas test launches were being conducted and by August 1959, the system was approved. During the development of Atlas, the Air Force was also working on another ICBM called the Titan I.

The Titan I was a two-stage missile powered by oxygen and kerosene, also requiring fueling prior to launch. This fueling operation did not allow for a quick response if the U.S. were to come under attack. This deficiency led to the development of the Titan II.

The Titan II was much more powerful than the Titan I and could stand alert fully fueled and ready to launch. Although the Titan IIs stayed in the inventory until 1987, these liquid giants were expensive to build and maintain, leading to the development of the Minuteman solid-fuel ICBM.

Work on the solid-fueled Minuteman ICBM began in 1957. These missiles were lighter, smaller and more easily stored. A reduced payload capacity was offset by the fact that the system could be built in larger numbers and its warheads had improved accuracy. By 1961, the Minuteman had met all of its test objectives and was in service by 1962.

Army Missile Program

Near the end of World War II, the U.S. 7th Army captured many intact German V-2 rockets along with Dr. Von Braun and his rocket team. In 1945, the Army began moving the scientists to Fort Bliss, Texas to establish a guided missile program which began with the test firing of the captured V-2s (A-4). This effort, which began in July 1946, was called "Operation Paperclip." When asked about the design of their V-2, the Germans said it had been replicated from a rocket Dr. Goddard flew in 1939. These V-2s were converted to carry various scientific instruments. The A-4 Upper Atmosphere Research Panel was established in January 1947 to coordinate these tests. This panel later became the Upper Atmosphere Rocket Research Panel in 1948 and the Satellite Research Panel in 1957.

In 1950, the Army moved its missile development group to the Redstone Arsenal in Huntsville, Alabama. After the Korean War, the Army was looking for a missile with a range of about 500 miles, leading to the development of the Redstone missile (**Fig. 1-5**). The Redstone was first fired on 20 August 1953 and many additional test firings were conducted until 1958, when it entered service with Army units stationed in Germany.

The Redstone was designed and developed between 1952-54, which proved critical to the history of the entire U.S. missile program, as this missile became the foundation for all future U.S. missiles. The Army also ventured into a joint missile project with the Navy, referred to as the Jupiter missile program.

Fig. 1-5. Redstone Missile

The Jupiter missile made use of Redstone missile technology, thereby saving time and money. In fact, Redstone missiles were used to test Jupiter nose cones. As the project progressed, the Navy lost interest because they wanted a small solid-fuel missile for submarine use and the Jupiter was shaping up to be a large liquid-fueled missile. The Navy would break away to develop the Polaris missile. The first Jupiter launch occurred in 1957 but the range was only 60 miles. By the third flight, developments improved and its range had increased to 1,600 miles, making it the first successful American Intermediate Range Ballistic Missile (IRBM). The Army Ballistic Missile Agency delivered its first Jupiter to the Air Force in 1958 and more than sixty missiles saw active service with Air Force units based in Italy and Turkey.

Navy Efforts

The Navy's rocket development project revolved around three different missiles: the Aerobee sounding rocket, the Viking sounding rocket and the Polaris Submarine-launched Ballistic Missile (SLBM). The Aerobee project was initially designed to develop a missile capable of carrying a 100 lb. payload to an altitude of 75 miles. It consisted of two levels, the lower being solid fuel and the upper using liquid fuel. The first flight of the Aerobee took place in November 1947 and since then, has served all three branches of the military. Despite its numerous revisions, it is still used today.

The Navy began looking into a missile program where they could launch a missile to extreme altitude with enough stability to allow accurate measurements to be taken. This resulted in the development of the Viking sounding rocket, much of which was based upon the V-2 design. Engine tests began in 1947 and the first Viking was delivered for testing in 1949. In May 1949, the Viking had its successful maiden flight. One was even launched from the USS NORTON SOUND to evaluate the concept of launching rockets and missiles from ships at sea.

In September 1958, the Navy began to consider launching missiles from ships. The Polaris project was started and was to be a solid-fuel missile with a range of over 2,900 miles. At the start of the project it became apparent that a special vessel would be required to handle this missile, leading to the development of the Polaris submarine (**Fig. 1-6**). By 1958, approval for the first three Polaris

Fig. 1-6. U.S. Polaris SSBN

submarines was granted and construction began.

The USS GEORGE WASHINGTON was the first such Polaris submarine to be constructed, launched (June 1959) and commissioned (December 1959). The USS GEORGE WASHINGTON participated in actual test firings of the Polaris missile in July 1960 (**Fig. 1-7**) and in November of that same year, the new weapon system became operational.

Fig. 1-7. Polaris Missile Test

Military aspects of rocket development were not all that was being considered during this time period. In order to support President Eisenhower's "Space for Peace" policy, the government was also investigating booster development to send satellites into orbit.

U.S. Booster Development and the International Geophysical Year (IGY)

The original U.S. military services appraisals concerning the possibility of developing an effective ICBM were rather discouraging, as nuclear weapons of the day were large and bulky. At the time, it was felt that U.S. nuclear deterrence would rest on the back of the bomber force, since bomber aircraft were the only delivery systems which could carry these large weapons. However, the situation soon changed because:

- the Soviets demonstrated that they were serious about missile development,
- the Atomic Energy Commission announced the development of the hydrogen bomb,
- nuclear weapons were getting smaller,
- the Soviets obtained a hydrogen bomb of their own
- and the Sputnik satellites were launched.

This series of events was enough to alert the U.S. government to turn its efforts towards large scale rocket development. The hope of closing the gap in the missile race lay in the development of military missiles. However, President Eisenhower was determined to separate the military programs from the IGY program in order to support his peaceful intentions for space policy. The Redstone, Jupiter C and Atlas missiles were ready to launch as early as September 1956, but a different decision was made. Our non-military satellite program for IGY would be the Vanguard project.

The Vanguard Project

Vanguard was designed to have as few links to the military as possible. Although an honorable idea, it was not practical because the military had the money, scientists and hardware to get the job done. Funding for the project came from the National Science Foundation. The program was plagued with problems from the start, such as inexperienced contractors, tensions of the space race and trying to get a configuration that worked. But President Eisenhower insisted that Vanguard become the space launch vehicle for U.S. satellites.

The Vanguard launch attempted on 6 December 1957 was a disaster. After lifting several feet off the ground, the booster lost power and fell back, bursting into flames. Five days later, President Eisenhower approved a satellite launch using a modified Jupiter rocket, now called the Juno (Project Orbiter).

The Juno booster/lift vehicle was launched and the first U.S. satellite, Explorer I (**Fig. 1-8**), a 30-lb. cylinder, went into orbit on 31 January 1958. Although the U.S. did not launch the world's first artificial satellite, the nation did discover the Van Allen Radiation Belts, which may have been the most important discovery of the IGY. Explorer transmitted until 23 May 1958. Vanguard finally did succeed in getting off the ground on 17 March 1958, but this success was short lived, as only 2 of the 11 total launch attempts between December 1957 and September 1959 were successful.

Fig. 1-8. Dr. Pickering, Dr. Van Allen And Dr. Von Braun Holding Up A Model Of Explorer 1.

Early U.S. booster types were based on IRBM first stages instead of ICBM first stages. These new boosters were known as the Juno 2, Thor Able, Thor Delta, Thor Epsilon and Thor Agena. The Thor boosters later evolved into the successful Delta boosters. For the larger payloads, boosters began to be developed from the larger successful ICBMs and these were based upon the first stages of Atlas and Titan II development. The Atlas and Titan II-derived boosters have launched many U.S. satellites. With all of this space activity, the government decided a civilian agency was needed to coordinate and give direction to the U.S. space effort.

The National Aeronautics and Space Administration (NASA)

President Eisenhower's administration came up with the concept of a coherent space effort. In order to help support this concept, Eisenhower appointed James R.

Killian, president of the Massachusetts Institute of Technology, to be his scientific advisor. The military lobbied to maintain control of managing the national space effort, but Dr. Killian was a wise man and carefully weighed all the arguments against the President's aspirations. President Eisenhower was committed to his "Space for Peace" policy and civilian control of the space program was concordant to that concept. This civilian agency would handle all aspects of research and development, with scientists playing the leading role in guiding the space program.

While plans for this new agency were tied up in red tape, the President could not let time and events override our space program. He then established the Advanced Research Projects Agency (ARPA), whose plans for space exploration were soon approved by the President. Although short-lived, ARPA was essentially the first official U.S. space agency.

At this time, much maneuvering was occurring in Congress by various agencies who aspired to take control of the space program. One of these agencies, and the leading contender, was the National Advisory Committee on Aeronautics (NACA). At the time, there was no other agency which could rival NACA's expertise in the field of aeronautics and NACA felt that space would be a logical extension of its duties. Eisenhower was against this idea because he felt the NACA was, at times, too autonomous. Dr. Killian came to the rescue by proposing the National Aeronautics and Space Act, which was adopted on 1 October 1958. Under this plan, a broad charter for *civilian* aeronautical and space research was created, allowing the administration to absorb NACA. The core of NASA's facilities came from NACA and in a few years, NASA became organized and equipped to carry out the nation's space program.

SATELLITE PROGRAMS

This section will address some of the early satellite programs, broken down into four types: communication, weather, data collection and exploration.

Communication Satellites

One of the most important and profound aspects of space utilization has been in the area of communication satellites. The use of communication satellites has brought the world's nations closer together.

In May 1945, Arthur C. Clarke proposed that satellites could be placed in a position over the Earth's equator at a distance of approximately 22,000 miles. The satellite would maintain a constant position over the earth and three satellites would give total communication coverage. This position is called a geosynchronous, geostationary or Clarke's orbit. Today, most of the world's communication satellites are placed in this type of orbit.

Project Score

The first voice returned from space was President Eisenhower's in 1958 under Project Score. The satellite was placed in orbit by an Atlas ICBM with a tape-recorded Christmas message from the President to the world. It was the first prototype military communications satellite.

Echo

Echo was a NASA project consisting of a 100 ft diameter plastic balloon with an aluminum coating which passively reflected radio signals transmitted from a huge earth antenna. A number of projects were attempted using balloons, but this proved to be somewhat impractical and a better solution was needed.

Telstar

Telstar was the free world's first commercially funded communication satellite. AT&T financed the project and it was launched on 10 July 1962. Telstar's orbit was low earth, but when in sight of its ground station, it did provide communications between the U.S., the U.K. and France. Telstar proved that satellites could be used as communications devices across vast distances.

Syncom

Syncom, another NASA project launched in 1963, was the first communications satellite in geo-synchronous orbit. It was used for many experiments and transmitted television of the Tokyo Olympic Games in 1964.

Molniya

Launched in 1968, this was the first of many Soviet communication satellites using high altitude, elliptical orbits which positioned the satellite over the entire Soviet Union during the day.

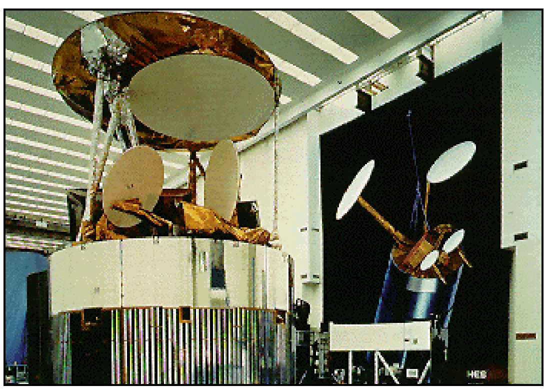

Fig. 1-9. Intelsat 2 under construction

International Telecommunications Satellite (Intelsat)

The International Telecommunications Satellite (Intelsat) Organization provided nations with a way of sharing the cost of satellite communications, based on the amount of use.

Intelsat 1, or Early Bird, was the first of the series and became operational on 28 June 1965 with 240 telephone circuits. It was designed to only last one and a half years but endured for four.

Intelsat 2 (**Fig. 1-9**) was launched in 1967 and provided an additional 240 circuits with a design life of three years.

Intelsat 3 was launched in 1968 and had an increase of 1,500 circuits with a design life of five years.

Intelsat 4 was launched in 1971 with 4,000 circuits plus two color TV channels and spot-beams to increase broadcast efficiency. The design life was advertised as seven years.

Intelsat 5 was launched in 1980 and is three axis-stabilized versus spin stabilized. It has 12,000 circuits and two TV channels.

Westar

Launched in 1974, Westar was a Western Union project and the United States' first domestic satellite.

Weather Satellites

Satellite weather photos are routinely shown on the local evening news. This section discusses some of the satellite systems which originate these pictures.

Television InfraRed Operational Satellite (TIROS)

Fig. 1-10. TIROS Weather Satellite

TIROS (**Fig. 1-10**) was the first weather satellite program undertaken by the U.S. Its objective was to test the feasibility of obtaining weather observations from space. TIROS-1 was launched in April 1960, achieving all of its objectives. Nine additional TIROs were launched.

ESSA 3

Based on the success of the TIROS program, a fully operational version of the same satellite was introduced in 1966 called TIROS Operational System (TOS). The system used a pair of Environmental Science Service Administration (ESSA) satellites and was designed to provide uninterrupted world-wide observations.

Improved TIROS Operational Satellite (ITOS)

With the launch of ITOS-1 in 1970, a second generation of meteorological satellites was introduced and proved to be very successful.

TIROS-N

Following the ITOS series of weather satellites, a third generation series was developed and provided global observation service from 1978 through 1985. These satellites employed advanced data collection instruments. Included on the payload package was a very high resolution radiometer which was used to improve sea surface temperature mapping, for the location of snow and sea ice as well as conducting night and day imaging.

Since the TIROS weather satellites proved their worth by collecting data on weather patterns and after the first astronauts made detailed observations of the Earth, scientists began to consider using satellites to collect data on the Earth's land and water resources.

Data Collection Satellites

LANDSAT

In the early 1970's, the LANDSAT series (**Fig. 1-11**) of data collection satellites were employed. This series, because of its infrared microwave and imagery capability, opened up new areas of research never before explored in such detail. The government hoped LANDSAT would aid in locating new oil and mineral deposits and allow the mapping of ocean currents and temperature to help locate schools of fish. This capability has not yet been fully realized; however, LANDSAT has aided in estimating the extent of damage from forest fires, control of timber cutting and world crop yields.

Fig. 1-11. LANDSAT

SEASAT 1

Based on the LANDSAT series, NASA launched SEASAT 1 in 1978. Using microwave instruments, SEASAT 1 measured surface temperatures to within two degrees Centigrade, wind speed and direction and provided all weather pictures of waves, ice phenomena, cloud patterns, storm surges and temperature patterns of the ocean currents.

Terrestrial and Extra-terrestrial (ET) Exploration Satellites

Explorer

The largest U.S. exploration satellite program was the Explorer series. This particular group of satellites studied a wide range of space activities from Earth radiation to solar wind. Approximately 50 satellites in this series were launched, of which, the Explorer 1 discovered the Van Allen Radiation Belts.

U.S. ET Exploration Satellites

The U.S. has launched approximately twenty-four planetary probe satellites visiting most of the planets in our solar system. The first deep space probe was launched in 1960, returning data from 22.7 million miles. Since then, six have launched to Venus, six to Mars, four to Jupiter and three to Saturn. These probes were of the Mariner, Pioneer, Viking and Voyager types. Voyager 2 flew by Uranus and Neptune and will eventually fly by Pluto.

USSR Space Probes

The Soviets, while launching more planetary probes than any other country, have confined themselves to Mars, Venus, the Moon and Sun. Most of the Soviet initial attempts to send probes to Venus and Mars failed. These probes were of the Venera, Mars, Cosmos, Zond and Vega series. An ambitious probe to Mars in 1996 weighing 7 tons failed to escape Earth orbit and is believe to have impacted in a remote area of South America.

The Future

Both the U.S. and the Russians are planning future missions back to Mars, Venus, the moons of Jupiter and other interesting places within the solar system. As time goes on, more countries have entered the space exploration business (Japan, Germany, France, etc.) by sending probes into the cosmos.

MANNED SPACE EXPLORATION BY THE U.S. AND USSR SINCE 1960

Now that *unmanned* space exploration efforts have been discussed, *manned* space efforts will be addressed.

Historical Overview

The U.S. had placed its prospects on project Vanguard getting into space first. However, the Russians were the first to enter orbit and this resulted in a public outcry. Senator Lyndon Johnson (later to become President) of the Armed Forces Subcommittee, recommended a national space program be established. This became a reality when NASA was formed.

National Space Program

In 1958, the consensus was that the U.S. needed a consolidated national space program to give its space efforts coordination and guidance. The program would consist of two parts; the military under the control of the Department of Defense and the civilian part under the control of NASA.

Space Race

With the launch of Sputnik, the U.S. and the Soviet Union were now firmly entrenched in the space race that was nothing other than an extension of the Cold War. The U.S. had been beaten in the unmanned race and the same would occur in the manned race. On 12 April 1961, the Soviets shocked the world again when Yuri Gagarin became the first person to orbit the earth. Public outcry wasn't as strong as when Sputnik went up, but Presidential concern was. President Kennedy addressed Congress and committed the nation to a project that would land a man on the moon and return him safely. The President's decision to undertake this task was endorsed virtually without dissent.

Mercury (USA) 1961 - 1963

In addition to sending a man into space, Mercury was designed to further our knowledge of man's capabilities in space. The Soviets had already proven that man could survive reentry. Mercury had a number of objectives, the most important of which were putting a man in orbit and devising a stepping stone for an eventual journey to the moon. In the Mercury capsule, all systems were redundant, control was manual or automatic and the control system technology was new.

The main objective of the Mercury project was to investigate man's ability to function in the space environment. Mercury gained valuable information for the building and flying of more complex spacecraft, such as the Gemini and Apollo. The milestones began with the chimpanzee "Ham" flight in a capsule on 31 January 1961; followed by Alan Shepard's suborbital flight on 5 May 1961 (He rose to an altitude of 116 miles in 15 minutes and 22 seconds) and then on 20 February 1962, John Glenn became the first American to achieve earth orbit, completing three revolutions.

Vostok (USSR)

Unlike the Mercury capsule, the Vostok capsule was composed of two parts; the round shaped "manned section" and the lower equipment bay located underneath the manned section. Vostok crew recovery was also different. With Mercury, the astronaut and capsule parachuted into the ocean, while the Soviet cosmonaut was recovered on land with Vostok. Vostok led the space race by carrying the first man into space in 1961 (Yuri Gagaran), the first woman in orbit in 1963 (Valentine Tereshkova), supported the first dual flight mission and set flight endurance records.

Gemini (USA) 1962 - 1966

The Gemini capsule was designed to carry two astronauts and had two sections; the upper or manned section and a lower equipment section. Because of the greater lift needed, the Titan II ICBM was used instead of the Atlas. The objectives of the Gemini program were to develop procedures for practicing maneuvers, rendezvous, docking and Extravehicular Activity (EVA). Finally, Gemini would allow astronauts to gain experience in longer missions and perform complicated maneuvers.

All the objectives set by NASA for Gemini were met. However, some tasks turned out to be more difficult than anticipated, such as spacewalks. Gene Cernan's exertion during the space walk portion of the *Gemini IX* mission overtaxed his suit system and fogged his helmet visor. Cernan had to terminate his EVA early due to fatigue. The problem wasn't solved until the last flight, Gemini XII in November 1966. Edwin (Buzz) Aldrin used footholds, Velcro covered tools and hand grabs to work in space with ease.

The Gemini milestones were vast and diverse, they included; the first orbital plane change, the first U.S. dual flight, hard docking and one-orbit rendezvous. Gemini's success gave the U.S. confidence to press ahead with the Apollo program and in effect, placed the U.S. ahead of the Russians in the race to the Moon.

Voskhod (USSR)

The Voskhod capsule was a Vostok modified to accept three cosmonauts. A terminal thrust braking system was added to achieve a soft landing. The Voskhod program was a stopgap measure instituted by the Soviet Union to makeup for the stalled Soyuz program.

The objectives of the Voskhod program were the same as those of Gemini and resulted in some notable accomplishments, including; the first three men in orbit, the first flight without space suits and the first emergency manual reentry.

Apollo (USA)

The Apollo program was the final step to the Moon. The objective of the program was two-fold. First, the program was to gather information needed for a lunar landing. Secondly, Apollo was to actually land on the Moon.

A new "tear drop" capsule was used, thus departing from the traditional "bell" shape of the Mercury/Gemini capsules. The Apollo system consisted of three parts, the command module (or manned portion) the service module and the lunar module (as shown in **Fig. 1-12**).

Fig. 1-12. Apollo System

The booster for this program had to be designed from scratch. With the help of Dr. Von Braun, Saturn boosters were developed, which included the Saturn 1B and the Saturn V (**Fig. 1-13 and Fig. 1-14**).

Fig. 1-13. Saturn 1B

The advent of Apollo, as in the tradition of Mercury and Gemini, was a step-by-step process. However, the U.S. suffered a tragic event on 27 January 1967 when Apollo I developed a fire in the capsule which cost the lives of three astronauts: "Gus" Grissom, Ed White and Roger Chaffee. The space program was halted while NASA investigated the accident. Within 19 months, the manned portion of the Apollo program was back on track and corrections to the Apollo capsule had been made.

The program pressed ahead, testing docking maneuvers, lunar landing procedures and a slew of other experiments designed to get us to the eventual landing. Then on 20 July 1969, Apollo 11 was the first of the Apollo series to land on the moon. Six more missions to the moon followed, culminating with Apollo 17. The only mission that didn't land on the moon was the Apollo 13 moon landing which was aborted some 205,000 miles from earth when an oxygen tank exploded. An anxious world watched as NASA worked feverishly through one problem after another to bring the crew back alive. Their success in doing so was one of the agencies finer moments and inspired a 1995 feature film which ignited the interest of a new generation in the Apollo program.

The U.S. met President Kennedy's goal and proved man could react to and solve in-flight emergencies (Apollo 13). Although the Apollo Moon program concluded, an abundance of valuable scientific information had been obtained.

Fig. 1-14. Saturn V

Soyuz (USSR)

This Soviet program also began on a tragic note when in April 1967, Colonel Komarov was killed when his parachute failed to deploy properly and his capsule slammed into the ground. The Soyuz program was also halted for about 19 months. Soyuz objectives included maneuvering in group flights and dock, prolonged space flights and development of new navigation and spacecraft control systems.

After July 1969, the Soviets turned their emphasis towards manned space stations and away from the moon. The Soyuz would be used as a ferry to the Salyut Space Station. Today it is used to take cosmonauts to the MIR Space Station.

Follow-On Manned Programs

Skylab

Skylab (**Fig. 1-15**) was launched by a Saturn V from Kennedy Space Center on 14 May 1973. Its primary objective was to test the effects of long term weightlessness and how well humans readapt to zero gravity. Five major experiments were planned covering solar physics and astronomical observations using a solar telescope.

Fig. 1-15. Skylab

An electric furnace was used to make perfectly round ball bearings and grow large crystals. It was later discovered that major repairs could be performed in orbit (i.e., restoration of the damaged Skylab).

Due to a number of factors, such as increased solar activity and delays in getting the Shuttle off the ground (the Shuttle was to boost the satellite into a higher orbit), Skylab's orbit continued to decay until it made its final plunge on 11 July, 1979.

Salyut

The Soviet Union space station program began in 1971 with the launch of Salyut 1, which gave the USSR another first in space. The objectives of the Salyut program were virtually the same as for Skylab. However, the Salyut program was replaced by the MIR (peace) space station. Soviet Cosmonauts have set space endurance records in the MIR, with some missions lasting up to one year.

Apollo-Soyuz (July 1975)

The primary objectives of the Apollo-Soyuz program were: the development of a rescue system, rescue procedures and crew transfer between the U.S. and Soviet spacecraft. Additional objectives dealt with conducting astronomy, earth studies, radiation and biological experiments. NASA used their last remaining Apollo spacecraft for this mission. The crew consisted of Apollo veteran Tom Stafford, Vance Brand and astronaut office chief and original Mercury seven astronaut Deke Slayton medically cleared to make his first flight.

Space Transport System (STS)

The primary motivation for NASA's perseverance of the STS was to find a cost effective manned system. The current STS can trace its roots back to the lifting body research conducted at Edwards AFB. On 5 August 1975, an X-24B made a textbook landing after a powered flight to 60,000 feet. The X-24B was America's last rocket research aircraft and concluded the manned lifting body program. The X-series research developed many concepts that would eventually be incorporated into the space shuttle, such as dead stick landings, flat bottoms and others.

The actual conceptual design for the STS began in 1969 when President Nixon directed top Department of Defense and NASA scientists to devise a post-Apollo manned program. The Space Shuttle

Task Group was formed to study the problem; they recommended the STS.

Due to its design philosophy, the STS looked promising and was approved by President Nixon. The system concept included the use of reusable components, autonomous operations, large payload, relatively simple on-board operation, a cargo compartment designed for a benign launch environment, throttleable engines, on orbit retrieval and repair of satellites. This design scheme (**Fig. 1-16**) would provide the U.S. with routine access to space.

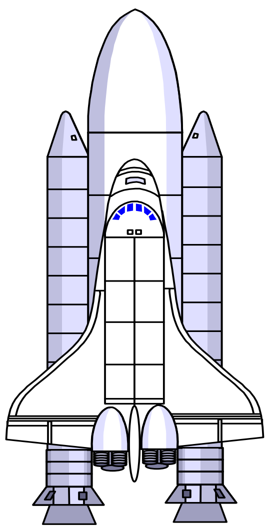

Fig. 1-16. STS

Components of the STS include orbiter, external tank and the reusable solid rocket boosters. The first STS launch occurred on 12 April 1981, with landing on 14 April. The astronauts for the mission were Robert Crippen and Gemini and Apollo veteran John Young.

After many successful missions between 1981 and 1985, tragedy struck in January 1986, when the Challenger exploded after lift-off, caused by a faulty solid rocket booster. As in 1967 with Apollo I, NASA investigated the cause and made corrections, but this time the manned space program was halted for 32 months. It was not until 29 September 1988 that America reentered space with the launch of the Discovery.

Hubble Space Telescope (HST)

The idea for the Hubble Space Telescope was conceived back in the 1940's, but work was not started on the telescope until the 1970's and 1980's. The telescope did not become operational until the 1990's. The HST program is a cooperative program between NASA and the European Space Agency (ESA). The program objective is to operate a long-lived space-based observatory which will be primarily used for astronomical observation. The HST is the largest on-orbit observatory ever built and is capable of imaging objects up to 14 billion light years away. The resolution of HST is seven to ten times greater than earth based telescopes. Ground-based telescopes can seldom provide resolution better than 1.0 arc-seconds, except momentarily under the very best observing conditions. HST's resolution is, depending on conditions, .1 arc-seconds, which is ten times better than ground based telescopes.

Originally planned for 1979, the Large Space Telescope program called for the satellite to return to Earth every five years for refurbishment and on-orbit servicing every two and one half years. Contamination as well as structural concerns negated the concept of ground return for the project. NASA then decided that a three year cycle of on-orbit servicing would work out just as well as the first plan. The three HST servicing missions in December 1993, February 1997 and mid- 1999 were enormous successes.

Future services are planned. Flights could also be added for emergency repairs. The years since the launch of HST have been momentous because of the discoveries made by the HST.

MIR

The MIR (loosely translated "peace", "world", or "commune") complex is described as a third generation space station by the Russian Space Program. The MIR (**Fig. 1-17**) is modular in

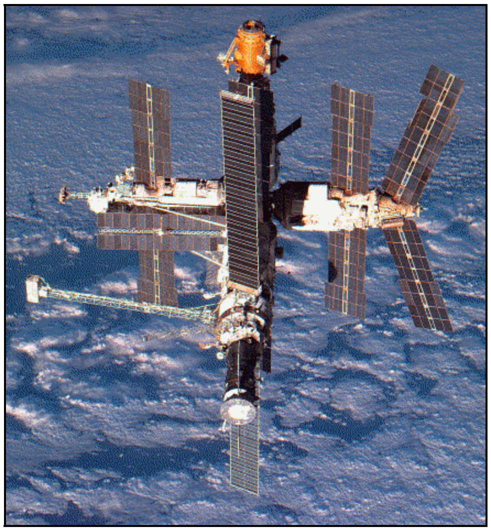

Fig. 1-17. MIR Space Station Complex

design, which allows the adding and subtracting of different modules. This also allows the modules to be moved from place to place, making the MIR very versatile. One of the most important features of MIR is that it is permanently manned, which is a giant step toward breaking earthly ties.

The MIR is the central portion of the space station, and is the core module for the entire complex. MIR is currently made up of four other compartments. These compartments are the transfer, working, intermediate and assembly compartments. All compartments are pressurized except for the assembly compartment.

The usual missions begin with a launch of either two or three crew members. It usually takes about two days for the spacecraft to reach and dock with MIR. Docking always takes place on an axial port. During docking, as a precautionary measure, the crew that is already occupying MIR puts on activity suits and retreat to the resident Soyuz-TM. This is the capsule the Cosmonauts ride to and from the MIR. The Soyuz-TM stays attached so they can escape if necessary. At the time hatches are open, both crews remove their suits and begin change over procedures, which take differing amounts of time depending on what needs to be accomplished. After change over is complete, the crews put their suits back on and return to the Soyuz-TM, the crew that has been there the longest gets in the older of the two capsules, leaving the newer one for the newer crew.

The MIR has had its share of problems in recent years. Originally designed to last only five years, the Russian space station is still flying. In recent years, a NASA astronaut has been part of the crew aboard MIR. In 1997, however, there were two life-threatening incidents which almost forced abandonment of the station. In February, a fire broke out triggered by a chemical oxygen generator which filled the station with choking smoke and blocked one of the escape routes to a docked Soyuz capsule. Although no major damage ensued, it was a frightening 14 minutes for the six men on board. In June, an unmanned Progress cargo ship collided with the Spektr module and the ruptured module began to decompress. The three man crew sealed off the damaged module but the power on the station was reduced by half. In the last two years, the Russians have tried desperately to secure outside funding to keep the MIR flying concurrent with meeting their obligations to the International Space Station (ISS). So far they haven't been successful. They need $250 million to keep the station on orbit. It was reported that as of June 1999, a grass roots fundraising campaign had only yielded 80 dollars. Despite this, another MIR mission was mounted in April 2000 to tidy up the station after a prolonged period where the station was unmanned. A private corporation, MirCorp was still looking for funding to keep the station going longer. All this interest in keeping MIR on station has concerned NASA who has given the Russians large amounts of money for the new ISS modules which were running well behind schedule.

Pathfinder

The Pathfinder mission is a discovery mission being conducted by NASA. The idea behind this mission is to prove that NASA is committed to low cost planetary exploration. When describing this project, the words "faster, better and cheaper" have been commonly used. Pathfinder was developed in 3 years and cost under $150 million to construct. Overall, the project cost was $280 million, which included the launch vehicle and mission operations. Another objective of this project was to prove the utility of a micro-rover on the surface of Mars. Pathfinder was launched on 4 December 1996 and touched down on Mars 4 July 1997. The rover functioned for a short time before contact was lost and the mission ended. More bad news was in store for subsequent missions to Mars. In September 1999, contact was lost with the Mars Climate Orbiter. The likely (and highly embarrassing) cause was the orbiter burned up in the Martian atmosphere on Sept 23rd due to a failure to convert English measurements to metric units. Its companion, the Mars Polar Lander apparently suffered a design flaw problem which cut off its braking thrusters too high above the Martian surface causing it to crash on 3 December 1999. These failures contributed to much criticism of NASA's "faster, cheaper, better" credo. The whole Martian exploration program is currently being reviewed.

International Space Station

The ISS is a partnership of nations that spans the continents. Through the work of many people and organizations, preparations are being made for the launch of the most complex structure that has ever been placed in orbit. The ISS will sprawl across an area nearly the size of two football fields and will be visible to the naked eye when it passes over head. The ISS will weigh nearly one million lbs., which is five times the mass of the first U.S. space station, Skylab.

The ISS program began in 1994 and moved into the first stage in 1995. Phase one is the joint MIR/Shuttle rendezvous program. The main objective of this program is to provide operations experience to Americans. The ISS is also using the basic schematics of the MIR Space Station. Countries all over the world are responsible for different parts of the space station. The U.S. is responsible for the building of the main structure, which is 28 feet long and 14 feet wide. The U.S. is also responsible for the nearly 80,000 lbs. of hardware that go along with the station. The U.S. had many of their requirements fulfilled in 1995. This included solar array panels, rack structures, and hatch assemblies. Canada is building the Mobile Service System (MSS) which will provide external station robotics. Japan is developing the Japanese Experiment Module (JEM). ESA is developing both a pressurized laboratory called the Columbus Orbital Facility (COF) and the Automated Transfer Vehicle (ATV), which will be used for supplying logistics and propulsion. Hauling the pieces and parts of the space station will require 45 space flights on three different types of launch vehicles over a five year period. The three launch vehicles are the U.S. Space Shuttle, Russian Proton and Soyuz rockets. Launch of space station began on 20 Nov 98 (five months behind schedule) with the Russian Zarya control module. It was joined by the US Unity connecting node on 6 Dec 98. The station is in an orbit of 251 x 237 statute miles with a period of 92 minutes. The second shuttle mission to the station was in May 1999 to transfer equipment to the existing modules and perform some installation functions. The next module mated with the station was the Service Module (Zvezda) launched from Russia on July 12, 2000, well behind schedule. The first crew departed for the station aboard Atlantis on 8 Sept 2000 to turn on systems, fix problems and haul supplies to the station.

Chinese Manned Space Program

As the decade wound down the Chinese also began testing a spacecraft to carry three astronauts. They tested the first unmanned capsule, called "Shenzhou" in 1999. After incorporating several improvements to the original capsule, the Chinese were planning to attempt another unmanned launch by the end of 2000.

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TOC

Chapter 2

US SPACE ORGANIZATIONS

Several organizations are responsible for DoD space operations. US Strategic Command is the joint warfighting command which directs space forces from Air Force Space Command (14^{th} and 20^{th} Air Forces), Army Space Command and Naval Space Command. The current USSTRATCOM resulted from the Oct. 1, 2002 integration of two previous unified commands: U.S. Space Command, which oversaw DoD space and information operations; and the former USSTRATCOM, responsible for the command and control of U.S. strategic forces. (In October 1999, US Space Command had assumed responsibility for the DoD Joint Task Force - Computer Network Defense (JTF-CND) and the Joint Information Operations Center (JIOC) located in San Antonio, TX. The Computer Network Attack (CNA) mission was added in Oct 2000.)

USSTRATCOM provides space support for unified commanders worldwide. In addition, space organizations provide warning data for the North American Aerospace Defense (NORAD) Command mission and theater ballistic missile defense units. Several national level organizations, such as the National Reconnaissance Office (NRO) and the National Imagery and Mapping Agency (NIMA) [proposed new name is National Geospatial Intelligence Agency (NGA] are also involved in satellite operations. This chapter addresses the responsibilities of the various space organizations and includes the SPACEAF Aerospace Operations Center (AOC) at 14AF, Vandenberg AFB, CA.

USSTRATCOM has broad missions: Establish and provide full-spectrum global strike, coordinated space and information operations capabilities to meet both deterrent and decisive national security objectives; provide operational space support, integrated missile defense and specialized planning expertise as well as global command and control, communications, computers, intelligence, surveillance and reconnaissance to the joint warfighter.

UNITED STATES STRATEGIC COMMAND (USSTRATCOM)

Overview

The command consists of a Joint Forces Headquarters for Information Operations and four directorates:

- Combat Support -- provides acquisition, contracting, combat logistics and readiness, C4, and global C2.
- Global Operations – coordinates the planning, employment and operations of DoD strategic assets and combines all current operations, global command and control operations, and intelligence operations. The directorate includes all command center operations, the Joint Intelligence Center, Current Operations, and the National Airborne Operations Center.
- Policy Resources & Requirements – develops overarching policy to support execution of all the command's missions. It is responsible for the articulation and development of all command requirement processes to ensure that STRATCOM has the tools to accomplish its mission, and it ensures appropriate decision support tools and assessment processes are in place to enhance operational capabilities. The directorate includes comptroller support;

strategy, policy and policy formulation; concepts and experimentation, and force assessments.

- Strike Warfare – includes the Targeting Intelligence Center and three divisions to deliver rapid, extended range, precision effects in support of theater and national objectives: Global Strike, Combat Plans, and Planning/Targeting tools.
- Joint Forces Headquarters Information Operations – incorporates, integrates, and synchronizes various information operation disciplines.

History

The space part of USSTRATCOM began when US Space Command was created in 1985, but America's military actually began operating in space much earlier. With the Soviet Union's unexpected 1957 launch of the world's first man-made satellite, Sputnik I, President Eisenhower accelerated the nation's slowly emerging civil and military space efforts. The vital advantage that space could give either country during those dark days of the Cold War was evident in his somber words: "Space objectives relating to defense are those to which the highest priority attaches because they bear on our immediate safety."

During the 1960s and 1970s, the Army, Navy and Air Force advanced and expanded space technologies in the areas of communication, meteorology, geodesy, navigation and reconnaissance. Space continued to support strategic deterrence by providing arms control and treaty verification, and by offering unambiguous, early warning of any missile attack on North America.

USSPACECOM was a *unified* command under the Department of Defense with headquarters at Peterson AFB, Colorado, commanded by an AF general. It was activated on 23 Sep 1985 in order to form an organization to consolidate assets affecting US activities in space. The command was composed of the Air Force, Naval and Army Space Commands, and supported other US unified and specified military commanders.

USSPACECOM's area of operation was the operational medium of space. Both Navy and Army three-star flag officers served as Deputy CINCSPACE.

As part of the ongoing initiative to transform the U.S. military into a 21st century fighting force, the DoD merged US Space Command with USSTRATCOM on Oct. 1, 2002. The merger was to improve combat effectiveness and speed up information collection and assessment needed for strategic decision-making. The merged command is responsible for both early warning of and defense against missile attack as well as long-range strategic attacks.

Fig. 2-1 USSTRATCOM Emblem

Missions

The space-related missions of USSTRATCOM remain those of its predecessor: to conduct joint space operations in accordance with its Unified Command Plan's assigned missions of Space Forces Support, Space Force Enhancement, Space Force Application and Space Force Control.

Space Forces Support

Space Forces Support includes launch and on-orbit satellite command and control operations provided by Army Space Command, Naval Space Command and 14th Air Force (Air Force Space Command). The 30th Space Wing at Vandenberg AFB, CA and the 45th Space Wing at Patrick AFB and Cape Canaveral, FL conduct space launch operations. Satellite tracking and operations are conducted by the 50th Space Wing at Schriever AFB, Colorado.

Space Force Enhancement

Space systems provide direct support to land, sea and air forces. To meet this requirement, USSTRATCOM has control of a fleet of satellites that provide ballistic missile warning, communications, weather and navigation, precise positioning support, and intelligence, reconnaissance and surveillance (ISR). In addition, US forces employ commercial communications satellites, civil weather satellites and civilian Multi-Spectral Imagery (MSI) satellites.

Space Force Application

The Missile Defense Act of 1991, as amended by Congress in 1992, directs the DoD to provide protection of the US and forward deployed US forces, friends and allies from limited ballistic missile strikes.

Ballistic Missile Defense (BMD) systems are divided into theater defense systems to counter short, medium and intermediate range ballistic missiles. Future systems may also be developed to counter Intercontinental Ballistic Missiles (ICBMs).

USSTRATCOM provides space-based ballistic missile support (warning, surveillance, cueing, etc.) to theater commanders for theater ballistic missile defense. The same support is also provided to NORAD for the protection of North America against ballistic missile threats.

Space Control

The Space Control mission is essential to the success of present and future US land, sea and air military operations. Assured access to, and unimpeded operations in space as well as the denial to an enemy of the same, are the key tenets of space control operations. This mission falls under the 21st Space Wing located at Peterson AFB.

The three pillars of space control are Surveillance, Protection and Negation.

The worldwide Space Surveillance Network (SSN) is tasked to detect, track, identify and catalog all space objects to ensure space operations are conducted without interference.

The USSTRATCOM Space Control Center (SCC) in Cheyenne Mountain provides warning to US space system operators in order to protect their satellites from potentially hostile situations or dangerous natural events.

Disrupting, degrading, denying or destroying space-based support to hostile military forces are the basic principles of negation. This could be accomplished by using conventional weapons to strike an adversary's space launch or ground relay facility.

The US does ***not*** have an operational anti-satellite (ASAT) weapon system. However, research and development into anti-satellite technology is continuing. An operational ASAT system would deter threat to US space systems, enabling the US to negate hostile space-related forces and ensure the right of self-defense.

In addition to the above missions, USSTRATCOM is responsible for planning and executing ballistic missile defense of North America operations. It also advocates the space and missile warning requirements of the other Combatant Commanders.

Computer Network Defense Mission

On 1 Oct 99, USSPACECOM had assumed responsibility for the DoD Joint Task Force - Computer Network Defense (JTF-CND) mission. JTF-CND is located in Arlington, VA and orchestrates the defense of all DoD computer networks and systems.

In concert with the military services and the Defense Information Systems Agency (DISA), the JTF-CND monitors cyber intrusions and potential threats to DoD computers and coordinates actions to stop or contain damage and restore computer network operations. The National Infrastructure Protection Center (NIPC), located at FBI Headquarters in Washington, D.C., coordinates the same service with other federal agencies.

The JTF-CND mission is a "logical fit" because USSTRATCOM has the unified, global and operational focus necessary for the mission of computer network defense. This new mission capitalizes on mission similarities between space and information operations.

Joint Information Operations Center

Also on 1 Oct 99, USSPACECOM had assumed responsibility for the Joint Information Operations Center (JIOC) located in San Antonio, TX. The Center provides "full spectrum" Information Operations support to operational commanders and is the principal field agency for Joint Information Operations support of the Combatant Commands.

The Center provides support to planning, coordination and execution of DoD Information Operations worldwide. The Center also assists in the development of Information Operations doctrine, tactics and procedures.

"Full Spectrum" IO support includes operational security, psychological operations, electronic warfare, targeting of command and control facilities, military deception, CND and CNA, Civil Affairs and Public Affairs.

The JIOC was formerly known as the Joint Command and Control Warfare Center and had been under the command of the Commander in Chief, US Atlantic Command.

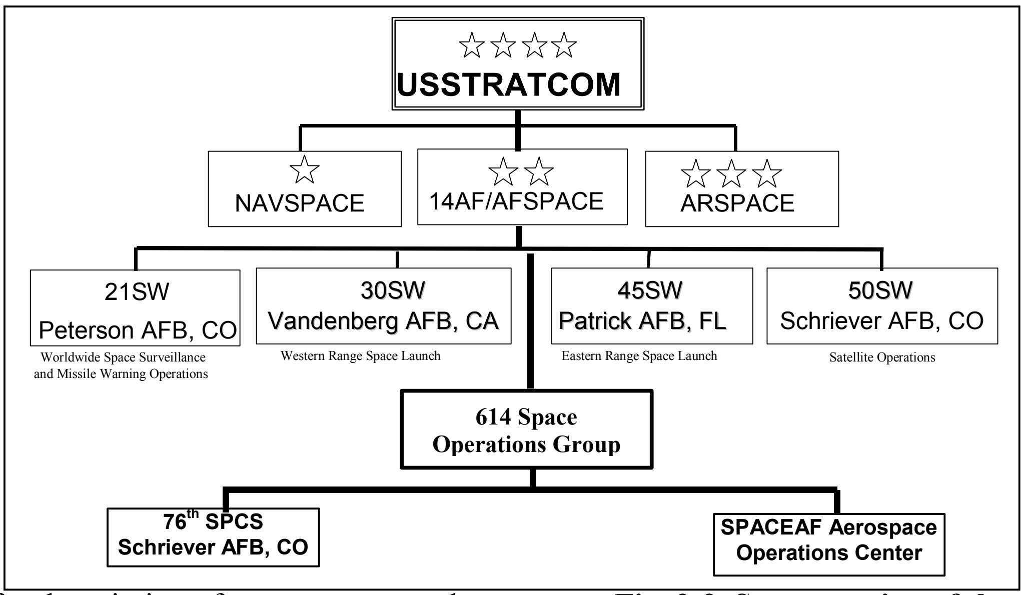

Fig. 2-2 Space portion of the USSTRATCOM Organization

Organization

With headquarters at Offutt Air Force Base, USSTRATCOM is a functional combatant command responsible for synchronizing and integrating US military space components and executing assigned missions. The assigned missions are outlined for each unified command in the JCS Unified Command Plan (UCP). These include Space Control, Space Support, Integrated Tactical Warning and Attack Assessment (ITW/AA), Ballistic Missile Defense (BMD), Force Enhancement, and Force Application.

The three component commands **(Fig. 2-2 above)** under USSTRATCOM are Air Force Space Command/14AF, Naval

Space Command and Army Space Command. Each of these commands will be discussed separately and in detail. Acting jointly, USSTRATCOM personnel pull together several US military space assets previously operated and maintained separately by the services.

Responsibilities

As a result of the President's approved changes to the Unified Command Plan, operational command of US military space assets is similar to that of tanks, ships and aircraft.

The activation of the United States Space Command put the infrastructure in place that allows the DoD to consolidate and integrate DoD space forces into a single joint military organization, thus enhancing the deterrence capability of US space forces.

- The new command arrangement is directly responsible to the President, Secretary of Defense and Joint Chiefs of Staff.
- The Command provides positive, centralized control over space systems.
- The Command provides joint operational focus for requirements.

AIR FORCE SPACE COMMAND (AFSPC)/14th Air Force

AFSPC **(Fig. 2-3)** is a major command of the US Air Force and is the Air Force service component which supports the USSTRATCOM mission through its functional component, the 14th Air Force (14AF).

AFSPC is also a component for Inter-Continental Ballistic Missile (ICBM) forces; 20th Air Force at Warren AFB, WY provides the ICBM forces for AFSPC.

Background

During the 1960s and 1970s, Air Force operation of space systems was primarily the responsibility of Air Force Systems Command and the Strategic Air Command. As the number and type of space systems increased, and as US military forces became more dependent on the support they provided, the Air Force determined a single major command should be established to support and direct operational space activity.

Finally, the US Space Policy (announced in July 1982) stated that the most important goal of the US space program was to strengthen national security and maintain the US technological leadership in space.

AFSPC was established on 1 Sep 1982 to consolidate Air Force space activities and is responsible for operating assigned military space systems. AFSPC headquarters is located at Peterson AFB.

Mission

Air Force Space Command (AFSPC) is an AF Major Command (MAJCOM) whose primary role is to organize, train and equip Air Force space forces. These forces include both 14th and 20th Air Forces and their subordinate units.

Fig. 2-3
AFSPC Emblem

Fig. 2-4 14th AF Emblem

14th Air Force (14AF)/SPACEAF

14AF **(Fig. 2-4)** is both the AF component for space (AFSPACE was redesignated SPACEAF on 7 Sep 00) and a Numbered AF. Under the SPACEAF mission, it plans and executes assigned missions to bring space effects to warfighting forces worldwide. COMAFSPACE plans and executes assigned space control, space support, force enhancement and force application missions. (This change from AFSPACE to SPACEAF aligned 14AF with 9AF (CENTAF) and 12AF (SOUTHAF) and eliminated some confusion with AFSPACECOM.)

14th Air Force, located at Vandenberg AFB, California, ensures the readiness of assigned forces, prepares forces for deployment and employment, and exercises operational control of assigned forces. It also serves as an operational component to USSTRATCOM and established the SPACEAF Aerospace Operations Center (AOC). 14th Air Force provides the day-to-day operators and managers of AFSPC's space forces. 14AF is also responsible for AFSPC's operational planning and employment in wartime and during major worldwide exercises and contingencies.

The 14AF consists of four wings (21st, 30th, 45th, and 50th Space Wings) and the 614th Space Operations Group which operates the SPACEAF Aerospace Operations Center, the 2nd Command and Control Squadron (2CACS), and the 76th Space Control Squadron (76 SPCS).

<u>21st Space Wing</u>**.** The 21st Space Wing was activated 1 January 1983 at Peterson AFB. It was the first operational space wing in the Air Force. 21st Space Wing operates AFSPC's worldwide network of dedicated missile warning sensors. These sensors provide Integrated Tactical Warning and Attack Assessment (ITW/AA) of sea and land-launched ballistic missile attack against the continental US and Canada. Resources include the Defense Support Program (DSP, a space-based early warning system), phased-array radars and mechanical radars. The Wing provides day-to-day management, training and evaluation for missile warning, intelligence and communications sites assigned to it.

The ITW/AA system detects, tracks and predicts the impact of intercontinental ballistic missiles and Sea-Launched Ballistic Missiles (SLBMs) targeted for the North American continent.

Included in the worldwide network are the PAVE PAWS SLBM warning system radars at Cape Cod AFS, Massachusetts and Beale AFB, California.

Ballistic Missile Early Warning Systems (BMEWS) are located at Thule AB, Greenland, Clear AFS, Alaska and Fylingdale's Moor in the U.K.

DSP ground stations are located in Colorado, Europe and Australia.

On 1 April 1991, the 30th and 45th Space Wings were activated to establish operational space wings at Vandenberg AFB, California, and Patrick AFB, Florida, respectively. Reporting to these wings are Space Launch Squadrons (SLSs) for each respective DoD booster program. The SLSs plan, support and execute launches of DoD boosters.

<u>30th Space Wing</u>**.** The 30th Space Wing at Vandenberg AFB, CA manages testing of space and missile systems for DoD and is responsible for launching expendable boosters for placing satellites into near-polar orbit from the west coast of the US The Wing launches Delta II and Titan IV (**Fig. 2-5**), and a variety of other expendable boosters.

In addition to operating the Western Test Range, the Wing provides launch operations and management of DoD space programs as well as launch and tracking facilities.

45th Space Wing. The 45th Space Wing at Patrick AFB, FL provides space launch and tracking facilities, safety procedures and test data to a wide variety of users.

Fig. 2-5. Titan IV launch

The Wing launches a variety of expendable vehicles, including the Delta II, Titan IV, and Evolved Expendable Launch Vehicles (EELVs). It also provides support to the space shuttle program. The Wing operates Cape Canaveral AS, and the Eastern Range.

Additional responsibilities include the provision of launch operations and management of DoD space programs, and launch and tracking facilities for NASA, foreign governments, the European Space Agency and various private industry contractors.

50th Space Wing**.** The 50th Space Wing (originally the 2nd Space Wing) was activated 8 July 1985, at Schriever AFB. Its mission is to provide command and control of operational DoD satellite systems and to operate and manage the common user portion of the Air Force Satellite Control Network (AFSCN). The AFSCN is a worldwide network of eight satellite tracking stations linked by sophisticated communications equipment.

The eight Remote Tracking Stations are: Vandenberg Tracking Station, CA; Hawaii Tracking Station, HI; Colorado Tracking Station, CO; New Hampshire Tracking Station, NH; Thule Tracking Station, GN; Oakhanger Tracking Station, UK; Guam Tracking Station, GU; and the Diego Garcia Tracking Station, British Indian Ocean Territory (BIOT). This $6.2-billion network supports more than 145 DoD satellites by allowing satellite operators at Onizuka AS and Schriever AFB to communicate with and control the satellites for which they are responsible.

The 21 Space Operations Squadron (21 SOPS) is a component of the 50th Space Wing, and is located at Onizuka AS, California (**Fig. 2-6**). This organization is responsible for operations, maintenance and logistics support for the common user resources of the AFSCN. It monitors, maintains and updates the status of AFSCN resources and provides the status of configurations and readiness of controlled resources to multiple users and command centers.

Fig. 2-6. Onizuka AS

The two Resource Control Complexes belonging to the 50 OG (21st SOPS at Onizuka AS and the 22nd SOPS at Schriever AFB) give the network dual node capability, ensuring continual support for on-orbit satellites. They are responsible for scheduling the use of tracking stations for satellite operators at Onizuka AS and Schriever AFB. This enables them to make contact through the tracking stations to communicate with the satellites for which they are responsible.

The Space Operations Squadrons (SOPSs) under the 50th Space Wing at Schriever AFB perform tracking, telemetry and command functions for orbiting spacecraft. They are compatible with the SOPS located at Onizuka AS and provide support to the Defense Meteorological Satellite Program (DMSP), DSP, NAVSTAR Global Positioning System (GPS), Defense Satellite Communications System (DSCS), NATO IV/Skynet IV, the UHF Follow-On, MILSTAR and the Midcourse Space Experiment.

Also located at Schriever AFB (**Fig. 2-7**) are the GPS Master Control Station (GPS MCS) operated by the 2nd SOPS; the MILSTAR Master Control Center operated by the 4th SOPS; and the 50th Space Wing Command Post.

Collocated on Schriever AFB are the dual Defense Satellite Communications Systems terminals, the Colorado Tracking Station of the AFSCN and a GPS monitor station.

50th Space Wing subordinate units include the 50th Operations Group (1st through 4th SOPS), 50th Operations Support Squadron, 50th Communications Group, and the 21st, 22nd, and 23rd Space Operations Squadrons:

- **1st SOPS** was activated on 30 January 1992 and is located at Schriever AFB. They provide routine, consolidated command and control support for three distinct systems: DSP, GPS, Technology for Autonomous Operational Survivability (TAOS) and other assigned Research and Development (R&D) spacecraft.

The 1st SOPS operates and maintains 24-hour AFSCN command and control capability for GPS and DSP systems. The squadron also operates and maintains R&D space systems possessing potential residual capabilities to support military forces.

Early orbit operations for GPS and DSP systems performed by the 1st SOPS include satellite activation, initial check-out and transfer to mission orbit. The squadron plans and executes Tracking, Telemetry and Commanding (TT&C) functions for GPS, DSP and assigned R&D satellites to maintain spacecraft state of health, sustain on-orbit operations and accomplish mission tasking. They also support satellite end-of-life testing and conduct satellite disposal operations or GPS, DSP and assigned R&D satellites as directed.

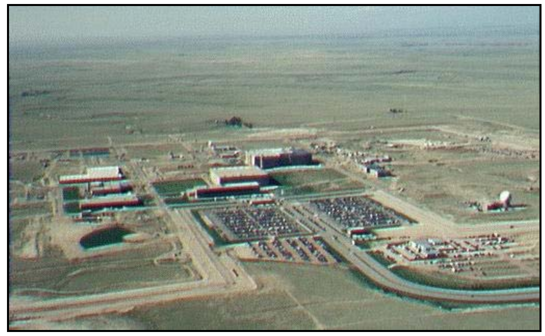

Fig. 2-7. Schriever AFB, Colorado

The 1st SOPS maintains DSP spacecraft positional knowledge to 200 meters and distributes data to worldwide users. The squadron maintains the capacity to support at least six contacts for each DSP satellite per day. When required, the squadron can relocate, within 48 hours, to their back-up node at Onizuka AS to perform limited command and control to sustain on-orbit operations of assigned GPS and DSP satellites.

- **2nd SOPS** was also activated on 30 January 1992 and is located at Schriever AFB. They provide command and control for the GPS constellation of satellites. GPS provides worldwide precision navigation service for US and allied military forces as well as a host of civilian users.

The 2nd SOPS operates and maintains the GPS MCS and a dedicated network of monitor stations and ground antennas to control and monitor the satellite constellation. The monitor stations passively track the navigation signals on all the satellites. Information is then processed at the MCS and is used to update the satellites' navigation messages. The MCS then sends updated navigation information to GPS satellites through ground antennas. Ground antennas are also used to transmit commands to satellites and to retrieve the satellites' state of health (SOH) information (telemetry).

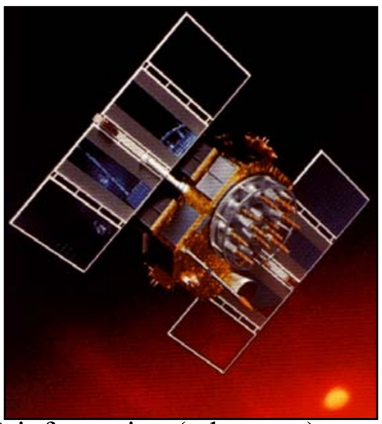

Fig. 2-8. GPS Satellite

• **3rd SOPS**, also located at Schriever AFB, was activated on 30 January 1992, along with 1, 2 and 4 SOPS. The 3rd SOPS conducts both launch and on-orbit operations for military communications satellites for the DoD and AFSPC.

The 3rd SOPS conducts launch and on-orbit operations for DoD communications satellites, which include the DSCS III, UHF F/O and MILSTAR. These satellites relay communications for the Defense Information Systems Agency (DISA) and Naval Space Command. These organizations manage and maintain all primary peacetime and wartime communications links for the President and SECDEF, theater commanders and all strategic and tactical forces worldwide. The 3rd SOPS also has the AF Satellite Communications (AFSATCOM) mission. AFSATCOM provides reliable, enduring, worldwide command and control communications to users based on a priority system outlined by the Joint Chiefs of Staff (JCS).

Operational crews at the 3rd SOPS are responsible for providing telemetry analysis, tracking data for orbit determination and commanding of on-board subsystems for the DSCS III program. In addition, they are responsible for launch and early orbit operations for the Navy's UHF F/O spacecraft, a replacement for the Fleet Satellite (FLTSAT) Communications System.

The 3rd SOPS also shares with the 4th SOPS operational control of MILSTAR, a highly advanced communications satellite program. The 3rd SOPS was primarily responsible for launch and emergency operations, but all operational control of MILSTAR was turned over to the 4th SOPS in December 1996.

As the 3rd SOPS has been gaining control of new satellite systems, it has been working to focus its operations on these newest generation communications satellites. As a result, the operational mission for NATO III and DSCS II was transferred to the newly activated 5th SOPS at Onizuka AS. Control of the aging FLTSAT constellation was surrendered to the Navy at Pt. Mugu, California, in June of 1996.

• **4th SOPS,** located at Schriever AFB, was also activated on 30 January 1992, and is responsible for overall command and control of the MILSTAR satellite constellation.

The 4th SOPS is responsible for ensuring that the MILSTAR system provides survivable, enduring, minimum essential command and control communications through all levels of conflict for the President and SECDEF and warfighting commanders worldwide. The 4th SOPS operates the $31 billion MILSTAR system, executing communications management, satellite command and control and ground segment maintenance for the MILSTAR constellation.

MILSTAR is the most advanced military communications satellite system to date. The five-satellite constellation links command authorities to high priority US forces via MILSTAR terminals on aircraft, ships, submarines, trucks and ground sites through encrypted voice, data, teletype or facsimile communications.

Fig. 2-9 MILSTAR Satellite

4th SOPS performs its functions through the MILSTAR Operations Center (MOC), Mobile Constellation Control Stations (CCSs) and the MILSTAR Support Facility (MSF).

MOC personnel perform satellite command and control, communications resource management, systems engineering support, mission planning and anomaly resolution for the MILSTAR system. The MOC has two fixed CCSs which interface with the geographically distributed mobile CCSs to execute satellite command and control. The MSF controls maintenance and testing as well as hardware and software configuration control.

Communications resource management includes satellite communications channel apportionment and monitoring payload use; more specifically, planning, executing and monitoring payload use allocations from the Presidential-level to tactical users in the field.

The 4th SOPS provides operators for the mobile CCSs located at the 721st Mobile Command and Control Squadron, Peterson AFB, and the 55th Operations Squadron, Offutt AFB, Nebraska. At higher readiness levels and during exercises, these personnel deploy with COMUSSTRATCOM, to provide survivable, enduring and secure communications.

- **21 SOPS**, located at Onizuka AS, is responsible for planning and conducting launch and on-orbit operations for a wide spectrum of vital DoD, allied and commercial space systems.

The 21 SOPS plans for and conducts launch, on-orbit and specialized communications operations for several DoD, allied, civil and commercial space missions, including Inertial Upper Stage (IUS) for NASA and DoD space assets, NATO Satellite Communications Systems and DSCS. In addition to satellite programs, the squadron provides tracking and telemetry support on every Space Shuttle mission and to several commercial launches.

It schedules, allocates, and configures Air Force Satellite Control Network common user resources; resolves resource allocation conflicts; monitors, maintains and updates the status of AFSCN resources and provides status, configurations, and readiness of controlled resources to multiple users and command centers.

The 21st SOPS maintains the facilities necessary to support a full deployment by 1st and 3rd SOPS, in the event of an emergency or routine relocation. Additionally, 21st SOPS maintains a backup scheduling facility for the 22nd SOPS facility at Schriever AFB. It also manages communications systems for network operations and maintains and operates base communications.

The squadron provides access to the worldwide Air Force Satellite Control Network and specialized support to the international space community by providing network communications, inter-range operations, and on-orbit test, checkout and troubleshooting services. The unit is also responsible for maintaining Onizuka's two 60-foot DSCS antennas. The 21st SOPS acts as the back-up for scheduling tracking station usage for satellite operators.

As host unit for Onizuka Air Force Station, 21st SOPS provides resources to operate and maintain the OAFS facility and to provide limited administrative and support services to base units and agencies, including security, civil engineering and safety. Further, the squadron provides some base support to units on Moffett Federal Airfield. The 21st Space Operations Squadron commander is designated the installation commander for Onizuka Air Force Station.

SPACEAF Aerospace Operations Center (SPACEAF AOC)

In Aug 1998, 14AF/CC established the new 14AF Space Operations Center (SOC) at Vandenberg AFB, CA. as the focal point for space support to the warfighter.

On 2 Jul 99, Maj Gen Hinson, then 14AF commander, announced that the 14AF Space Operations Center's name would be changed to AFSPACE Aerospace Operations Center (AOC) to create common terminology, enhance air and space integration and highlight the close relationship between air and space assets. (AFSPACE changed to SPACEAF AOC in September, 2000.)

Fig. 2-10 SPACEAF Aerospace Operations Center

The SPACEAF AOC is a synergistic C2 weapon system focused on planning and executing COMAFSPACE's mission. The SPACEAF AOC provides COMAFSPACE with C4I infrastructure to plan, execute and exercise operational control of AFSPC forces; supports COMUSSTRATCOM and theater warfighters; is the focal point for employment of AFSPC forces; and enables COMAFSPACE *to integrate spacepower into global military operations.*

The SPACEAF AOC is divided into a Strategy Division, a Combat Plans Division and a Combat Operations Division.

The Strategy Division focuses on long-range planning of space operations and includes developing, refining and disseminating the COMAFSPACE strategy for support to the warfighter.

The Combat Plans Division looks at near-term space operations and determines how space systems can best be used to achieve joint military objectives. This division develops and disseminates the Space Tasking Order (STO) to all users.

The Combat Operations Division is the tasking agency for space units and includes the missile warning sensor sites as well as providing users with the products from these space units. It receives information from the Cheyenne Mountain Operations Center (CMOC), the central collection and coordination center for a worldwide system of satellites, radars, and sensors that provide early warning of any missile, air, or space threat to North America.

In summary, the SPACEAF AOC has control and operational tasking of space units through the Space Operations Team to support joint military operations and executes that support through the Space Tasking Order. The AOC has the ability to adjust the STO to respond to operational dynamics in a wartime or crisis situation.

On 8 Sep 00, during JEFX 2000, Gen. Ryan declared the AOC to be a new AF operational weapons system after three years of experimentation.

76th Space Control Squadron (76 SPCS)

The 76th Space Control Squadron was activated at Schriever AFB, CO on 22 Jan 2001. It was the first counterspace technology unit, and will explore future space control technologies by testing models and prototypes of counterspace systems for rapid achievement of space superiority. It will consider how each concept might be deployed and employed in harsh combat environments; i.e., think through operational issues with an eye on improving potential designs.

20th Air Force

"America's ICBM Team deterring conflict with professional people and ready, secure missiles."

Fig. 2-11 Minuteman Ripple Launch

That's the 20th Air Force mission statement. ICBMs will continue to be the backbone of America's Strategic deterrent force well into the 21st century, as they are the only on-alert strategic force available to the Air Force. With a readiness rate above 99 percent, they are the nation's fast-reaction, long-range force, deterring any adversary from launching a preemptive attack against the US.

Deterring an attack against the US by weapons of mass destruction (nuclear, radiological, biological or chemical) remains America's highest defense priority. In today's rapidly changing world, a quick-response deterrent nuclear capability is essential **(Fig. 2-11)**. As more countries strive to develop weapons of mass destruction and sophisticated delivery systems, ICBMs serve as an insurance policy for the US and the world against rogue nations and terrorists.

Space Warfare Center (SWC)

The SWC **(Fig. 2-12)** was established at Schriever AFB on 8 December 1993 and forms a nucleus of operators and space personnel to develop space support systems and provide assistance to warfighters.

SPACE WARFARE CENTER

Fig. 2-12 SWC Logo

The SWC performs operational testing and develops tactics for space-related systems; works with theater commanders on integration of space systems into exercises and war plans; and develops concepts and prototypes for employing emerging technology for advanced space systems and missions. Among its initiatives is Project Hook, a combination of GPS navigation and survival radios designed to improve search and rescue operations for downed pilots. Project Hook essentially takes the "search" out of "search and rescue" by pinpointing the location of the pilot on the ground and relaying it via "burst transmission" to a Search and Rescue Center and airborne rescue forces.

Another SWC initiative, the Multi-Source Tactical System (MSTS), provides a six-layered picture of the operational theater for aircrews. It combines tactical, intelligence and digital mapping information with near real-time Airborne Warning and Control System (AWACS) information to update flight crews en route to their targets or drop zones. Overall, there are more than 30 initiatives currently underway in the SWC to improve the tactical use of space by warfighters.

The SWC is developing space models and simulations for inclusion in wargaming centers operated by all the services. They are helping develop operational plans for theater commanders that provide access to space assets and training in their use.

Finally, the Space Operations School (SOPSC) is providing space education and training to space staff members and planners throughout the military community so they can better understand and plan for space support to warfighting efforts.

NAVAL SPACE COMMAND (NAVSPACECOM)

The naval service's growing dependence on space prompted the Secretary of the Navy to establish a new command which would consolidate space activities and organizations that operate and maintain naval space systems. This organization, the Naval Space Command (NAVSPACECOM) **(Fig. 2-13)**, was commissioned on 1 October 1983.

Fig. 2-13 NAVSPACECOM Emblem

It was a decisive move to bring together several activities under a single command. The command strengthens operational control, provides a central focal point for naval space matters and more effectively guides future operational uses of space.

NAVSPACECOM headquarters is located at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), at Dahlgren, Virginia. The Dahlgren Division now includes a Dahlgren headquarters site with detachments or operating facilities at White Oak, Maryland, Wallops Island, Virginia and Naval Coastal Systems Center, Panama City, Florida. When NAVSPACECOM was established, NSWCDD already served as host for two other major tenant activities; the AEGIS Training Center and the Naval Space Surveillance Center (NAVSPASUR).

A major advantage to locating NAVSPACECOM at Dahlgren was the fact that NAVSPASUR was already located there and had the necessary communications to other space-related command centers.

Mission

NAVSPACECOM uses the medium of space and its potential to provide essential information and capabilities to ashore and afloat naval forces by:

- Operating surveillance, navigation, communication, environmental and information systems;
- Advocating naval warfighting requirements in the joint arena; and
- Advising, supporting and assisting naval services through training and by developing space plans, programs, budgets, policies, concepts and doctrine.

For additional information on the Naval Space Command and Navy space operations, see Chapter 3: **Navy Space.**

US ARMY SPACE AND MISSILE DEFENSE COMMAND (SMDC)/ARMY SPACE COMMAND

The Army Space and Strategic Defense Command (SSDC) was created in 1992 to unite key Army space organizations under a Lieutenant General. This command was a combination of two former Army commands, the Army Space Command (ARSPACE), located in Colorado Springs, and the Strategic Defense Command (SDC) in Huntsville, Alabama. Since 1992, additional Army space-related elements have been added: the Army Space Program Office (ASPO), which runs the Army TENCAP program; and the Army Space Technology Office (now called the Army Space Technology Program), which guides Army R&D activities.

Fig. 2-14 SMDC Emblem

In October 1997, Army SSDC was renamed Army Space and Missile Defense Command (SMDC). The headquarters for SMDC is in Arlington, Virginia, reporting directly to the Army's Deputy Chief of Staff for Operations (DCSOPS).

As of 7 Aug 00, the commanding general at SMDC is now the headquarters and commander for Army Space Command as well.

Mission

US Army SMDC activities in Huntsville trace their lineage to Werner von Braun and the Redstone Arsenal space activities of the 1950s. Today, SMDC maintains a place within DoD as a superior research facility supporting not only Army initiatives, but the Ballistic Missile Defense Organization, the Advanced Research Program Agency (ARPA) and matrix support to a myriad of other DoD research and applications initiatives. SMDC at Huntsville is organized into two main centers: the Missile Defense and Battlefield Integration Center supporting modeling and simulation activities; and the Missile Defense and Space Technology Center focusing on space and strategic defense-oriented research and development.

Primary functions of SMDC originally included three areas: commanding and controlling Army space forces, integrated missile defense and computer network operations: Specifically, these functions were performed:

- Operation of the Advanced Research Center (ARC), a government-owned, contractor-operated research center for BMD activities. ARC is part of the National Testbed and works with the Joint National Test Facility (JNTF) at Schriever AFB.
- Operation and maintenance (O&M) of the High Energy Laser System Test Facility (HELSTF) at White Sands Missile Range, New Mexico.
- Development of technologies associated with Army space capabilities.

Now five mission areas include global strike, space operations, integrated missile defense, strategic information operations, with Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) as the enabler.

SMDC Organizations

For additional detailed information on Army space, see Chapter 4: **Army Space.**

NORTH AMERICAN AEROSPACE DEFENSE COMMAND (NORAD)

The North American Aerospace Defense Command (NORAD) **(Fig. 2-15)** is the US-Canadian command for the strategic aerospace defense of the North American continent.

Air Force Space Command provides data for the NORAD mission.

Fig. 2-15 NORAD Emblem

Background

Strategic aerospace defense traces its roots to the Air Defense Command, which was formed in 1946 at Mitchell Field, New York. The designated mission for that command was to defend the United States against a manned bomber attack. In 1957, the United States and Canada jointly assumed responsibility for the strategic aerospace defense mission with the establishment of NORAD. Over time, the warning and assessment mission expanded to include ballistic missiles. This evolution was formally recognized in the 1981 NORAD Agreement when the name was changed from "Air" to North American "Aerospace" Defense Command.

Mission

The two primary missions established for NORAD, as stated in the 1996 NORAD Agreement, are:

- Aerospace warning for North America
- Aerospace control for North America

Aerospace warning includes the monitoring of man-made objects in space and the detection, validation and warning of attack against North America; whether by aircraft, missiles or space vehicles, utilizing mutual support arrangements with other commands. Aerospace control includes providing surveillance and control of the airspace of Canada and the United States.

Organization

NORAD provides cooperative defense planning between the governments of Canada and the United States and places strategic defensive forces under a single Commander-in-Chief.

The NORAD Commander and Deputy are responsible to the United States and Canadian governments through the Chairman of the Joint Chiefs of Staff of the United States and the Chief of the Defense staff of Canada. They cannot be from the same country, and their appointments must be approved by the Canadian and United States Governments. During the absence of NORAD Commander, command shall pass to the Deputy. Canadian forces and members of the United States Air Force, Army, Navy and Marine Corps occupy key NORAD positions. There are no Army or Naval components dedicated to North American Air Defense, but the Navy and US Marine Corps would augment NORAD and USNORTHCOM with resources during air defense contingencies. The Navy and Army provide space surveillance resources that are responsive to NORAD. During heightened defense conditions, NORAD could have more than 50,000 people under operational command.

NORAD forces (**Fig. 2-16)** are supplied by Canadian Forces Air Command; AFSPC (with supporting forces from 14th Air Force and 20th Air Force); Air Combat Command (ACC), 11th Air Force in Alaska; Air Force Communications Command (AFCC); the Air National Guard; Air Force Reserve; and by the US Army, Navy and Marine Corps.

Canadian Forces Air Command provides fighter interceptors, radar stations and control centers. Air Combat Command's 1st Air Force at Tyndall AFB, Florida is responsible for management of air defense resources in the Continental United States (CONUS), such as fighter interceptors, radar sites and control centers.

The 11th Air Force at Elmendorf AFB, Alaska operates the air defense units in Alaska. Other interceptors are provided by the Air National Guard, US Navy and Marine Corps.

AFSPC provides the missile warning and space surveillance sensors that report information to NORAD and other users.

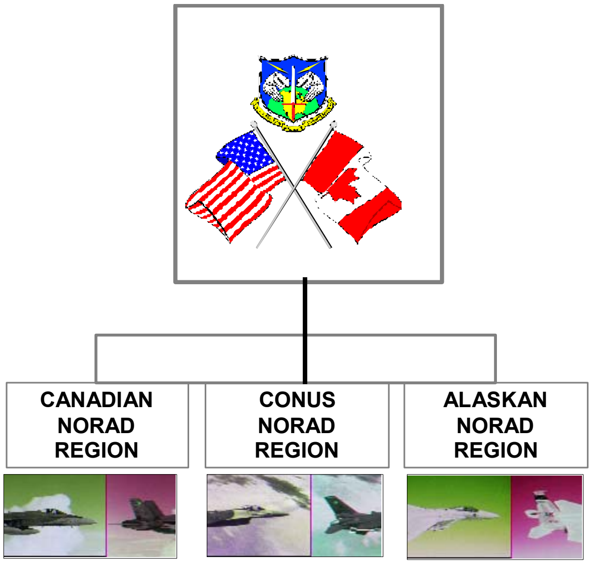

Fig. 18-16 NORAD Organization Chart

Tasks

The increasingly versatile strategic threat provides the enemy planners many more options for a coordinated attack designed to confuse and delay a coordinated response. An integrated warning and assessment capability is essential for protection against an orchestrated enemy attack.

Aerospace Warning

NORAD's most important task is to warn of a missile attack against North America. To accomplish the aerospace warning mission, NORAD is responsible for providing Integrated Tactical Warning and Attack Assessment (ITW/AA) of an aerospace attack on North America to the governments of Canada and the US. This is accomplished by using information made available by the ITW/AA system. Portions of that system are under the operational control of NORAD, while other portions are operated by commands supporting NORAD. For example, ground-based radars located throughout Canada and the US to detect air-breathing threats are under operational control of NORAD, while missile warning and space surveillance are provided by USSTRATCOM.

The NORAD Commander maintains his headquarters at Peterson AFB, and at a command and control center at Cheyenne Mountain Air Station (CMAS), which is a short distance away. The CMAS serves as a central collection and coordination facility for a worldwide system of sensors designed to provide the Commander and the President of the US and Prime Minister of Canada with an accurate picture of any aerospace threat to their respective areas of responsibility.

NORAD uses information from missile warning systems. This means assessing hundreds of missile launches worldwide per year to determine if they are a threat to North America. The Commander provides an assessment to the national leadership of both Canada and the United States on whether North America is under attack.

As the ITW/AA system executive manager, the NORAD Commander is responsible for the technical integrity of the missile warning system. The NORAD/J3 and USSTRATCOM/J3 are Co-functional managers of the ITW/AA system, charged with carrying out the command's charter. All proposed changes to the ITW/AA system are reviewed and validated through a controlled board process. The details of the process can be found in two documents, System Management for the Integrity of the ITW/AA System, NUPD 10-25, and Configuration Control Process, AFSPC Instruction 21-104.

<u>Threat</u>. Since the mid-1970s, despite SALT and START, the USSR, now Russia, has upgraded its ICBM force through improved on-alert rates, reliability, range, payload, accuracy, and survivability. The new missiles are, for the most part, equipped with Multiple Independently Targetable Reentry Vehicles (MIRVs). Together, this force has the capability to destroy a large percentage of US ICBMs using only part of its total inventory. The START II negotiations promised to eliminate MIRVs and to reduce the land-based inventories of both sides. In addition, Russia continued to expand and modernize its SLBM force. Its current Delta and Typhoon class nuclear powered fleet ballistic missile submarines permit Russia to strike targets in NATO, Europe, North America and Asia from their home ports.

<u>Current Capability</u>. In the face of the missile threat, NORAD must provide timely, reliable and unambiguous warning. The warning is done by surveillance of potential enemy launch areas or flight corridors with infrared and radar sensors. The use of two different sensor types to confirm an event is called dual phenomenology. Infrared sensing satellites detect a launch, while radar systems pick up the missile shortly thereafter. The radar systems track the missile and provide impact predictions.

Following initial detection by an early warning satellite, confirmation of an ICBM or SLBM launch from northern waters is made by one of the three Ballistic Missile Early Warning System (BMEWS) radar sites located in Alaska, Greenland and the United Kingdom **(Fig. 2-17)**.

The command employs a system of high-speed, phased-array radars called PAVE PAWS. These radars, at Cape Cod AFS and Beale AFB, provide coverage to a range 3,000 nautical miles. To cover northern launch areas behind BMEWS, NORAD uses the Perimeter Acquisition Radar Attack Characterization System (PARCS) at Cavalier AFS,

Fig. 2-17. BMEWS, Clear AFS, Alaska

North Dakota. This phased-array radar was originally built as part of the Army Safeguard Anti-ballistic Missile System and was redesignated as an Air Force missile warning radar in 1977.

To support a capability for massive retaliation, most of the sensors were originally designed to detect a raid and simply indicate incoming missiles. The BMEWS radars could do so by detecting and tracking the large missile fuel tanks. In the late 1970s, Soviet ICBMs, through increased accuracy and multiple warhead systems, acquired the capability to threaten US ICBMs in their silos. As a counter, NORAD's responsibility was increased to not only report missile encroachment, but also to provide an assessment by informing the President of the missiles' intended targets.

Aerospace Control

In March 1981, the United States and Canada redefined NORAD's aerospace control mission. The new definition recognized the continued upgrading of Soviet bomber capabilities and emphasized the need for providing reliable atmospheric early warning.

The aerospace control mission of NORAD includes detecting and responding to any air-breathing threat to North America. To accomplish this mission, NORAD utilizes a network of ground based radars and fighters to detect, intercept and, if necessary, engage the threat.

These fighters consist of US F-15s and F-16s and Canadian CF-18s.

As a part of its aerospace control mission, NORAD assists in the detection and monitoring of aircraft suspected of illegal drug trafficking. This information is passed to civilian law enforcement agencies to help combat the flow of illegal drugs into North America.

In 1989, the US government decided to attack the drug problem along three lines: countering the production of illegal drugs at their source; detecting and stopping their transit into North America; and reducing distribution and use throughout the US In 1991, NORAD was tasked with carrying out the second line of defense, the detection and monitoring of the aerial drug smuggling threat into North America.

The US government consulted with the Canadian government on the counter drug mission and Canada fully concurred with proposed NORAD drug interdiction efforts. In cooperation with US drug law enforcement agencies and the Royal Canadian Mounted Police (RCMP), the Canadian NORAD Region (CANR) is responsible for monitoring all air traffic approaching the coast of Canada. Any aircraft that has not filed a flight plan may be directed by Canadian NORAD assets to land and be inspected by the RCMP and Customs Canada.

Threat. Russia has bombers that can reach North America with air-to-surface missiles, gravity bombs and air launched cruise missiles. They also have Backfire bombers and a Blackjack bomber, similar to the US B-1 bomber. Russia is also producing a cruise missile and is developing four other versions. Three of these are similar to the US long-range Tomahawk and can be launched from air, land and sea platforms. The other two versions are larger cruise missiles which have no counterpart in the US inventory. The cruise missile threat will take on more importance as more of these missiles are deployed on aircraft and submarines off North American coasts. The Blackjack can carry these missiles, as can a variant of the Bear (the Bear H), which is now deployed as a cruise missile carrier.

Current Capability. In the early 1960s, NORAD had an extensive air defense capability, thousands of interceptors, radars and surface-to-air missiles. Since then, this equipment has been significantly reduced. Further, the current Distant Early Warning (DEW) Line was built in the 1950s to provide a tripwire warning capability. It consists of a 3,000-mile long 200-mile wide network of 50 radars along the Arctic Circle from Alaska eastward to Greenland; however, it has become increasingly expensive to operate and maintain.

Fig 2-18. E-3A AWACS

Airborne radar coverage is provided by the E-3A Airborne Warning and Control System (AWACS) aircraft (pictured above) on an as-required basis. Canada contributes military personnel to AWACS operations. The USAF AWACS assets provide a quantum leap improvement over ground-based radars and augment the perimeter radar system in times of increased alert. AWACS aircraft can detect targets out to ranges of about 350 miles, and guide Canadian or US interceptors to those targets.

In 1983, NORAD modernized its airspace control capability by closing the old region control centers and replacing the Semi-Automatic Ground Environment (SAGE) computer system with Region Operations Control Centers (ROCCs). The ROCC designation was changed to Regional Air Operations Center (RAOC). Three subordinate region headquarters, located at Elmendorf AFB (Alaskan NORAD Region, ANR), Canadian Forces Base Winnipeg, Manitoba (CANR), and Tyndall AFB (CONUS NORAD Region, CONR), receive direction from NORAD and control air operations within their respective areas of responsibility. There are three Sector Air Operation Centers (SAOCs) in the CONUS region: two collocated SAOCs cover the Canadian region, while a third provides coverage of Alaska. These SAOCs provide decentralized management for airspace surveillance while funneling all air defense information to computers inside Cheyenne Mountain for assessment by NORAD. Replacement of the SAGE system with RAOCs resulted in a savings of about $140 million a year.

The first air defense priority is to deploy an atmospheric early warning system around North America to complement the missile warning capability.

System Improvements

The Over-The-Horizon Backscatter (OTH-B) radar provided NORAD with a long-range missile detection capability. Two systems were built, one on the west coast and one on the east coast. Both systems were successfully tested but with the decline of the USSR in 1989, it was determined that only the east coast system would become operational. The west coast system was put into storage with a regeneration time of 18 months to 2 years. The east coast system did come on line and was operational for a number of years. In 1995, the east coast system was shut down and put into storage with a regeneration time of 18 months to 2 years.

To the north, a modernized DEW Line, the North Warning System (NWS), consists of minimally attended long-range and unattended gapfiller radars to provide an all-altitude bomber detection capability. The 13 military radars in Alaska were replaced by minimally attended radars, called SEEK IGLOO, to reduce maintenance and personnel costs. The NWS/SEEK IGLOO upgrade plays a major role in providing long range bomber and cruise missile detection.

Space-based radar is a possible future option being considered jointly by the Air Force and Navy. The space-based radar has the potential for meeting both fleet defense and NORAD needs.

The important point is that an early-warning system will deprive the enemy of having a no-warning atmospheric attack option. An atmospheric early-warning system will also permit a more effective employment of the limited number of E-3 AWACS aircraft and interceptors.

Space Surveillance

USSTRATCOM provides NORAD with both surveillance of space activities of strategic or tactical interest and warning of space events that may threaten North America.

Task Integration

The NORAD Commander exercises operational control of widespread forces supporting NORAD tasks from a combined command center inside Cheyenne Mountain near Colorado Springs. Cheyenne Mountain Air Station (CMAS), built inside a network of tunnels, consists of interconnected steel buildings resting on anti-shock springs. The facility operates 24-hours a day, 365 days a year. The NORAD communications and computer systems form the largest and most complex command and control network in the free world. The mission of CMAS is to provide NORAD and the military as well as national leadership, with an integrated picture of the threat. This includes potentially hostile missile, air and space activities.

NORAD 2010 and Beyond

NORAD has developed concepts to meet the challenges of the 21st century. These include:

- **Precision Tracking.** Required to detect and track any air or space threat to North America from its origin because NORAD must know exactly where a threat is to precisely engage.

- **Precision Engagement.** Provides NORAD the capability to precisely engage threats throughout the full range of our surveillance coverage to ensure off-shore threat engagement well before air and space weapons threaten Canada or the U.S. This requires agile platforms with lethal munitions to engage targets more responsively and accurately from longer distances and precise, immediate operational assessments with the agility to re-engage if required. This system will include a flexible, near real-time targeting architecture, including space-based wide area surveillance, rapid identification, tracking, and near real-time sensor to shooter links.

- **Integrated Battle Management.** A system of systems providing seamless battle management from NORAD regions to receive and give effective support to our forces during peacetime and wartime.

- **Focused Logistics.** NORAD will require an agile and responsive logistics system in 2010 to support rapid crisis response. This system will fuse information, logistics and transportation technologies to deliver tailored logistics packages and sustainment when and where needed.

- **Information Superiority and Technological Innovation.** Information superiority is the ability to collect, process, and disseminate an uninterrupted flow of information while exploiting or denying an adversary the ability to do the same. A system of systems linking networks of sensors, command and control, and shooters will allow NORAD to use "network centric warfare" to increase our joint/combined combat power.

The Future of Aerospace Forces

Not everyone is in agreement that space is the way to go.

During his testimony before the Senate Armed Services Committee in March 1999, Dr. John Hamre, the Deputy Secretary of Defense, stated that DoD's primary policy is space force enhancement to the warfighter and that weapons in space, including the physical destruction of satellites, is NOT the preferred DoD solution at this time. DoD prefers "tactical denial" of adversary space-based capabilities.

The View from Senator Smith

Senator Bob Smith of New Hampshire jumped into the fray in a speech in Nov 99 in which he said that "the Air Force devotes too much of its space budget for information and support capabilities only." He said the AF should be working on delivery of force from space. He wanted to create a separate Space Force which would allow space power to compete for funding within the entire defense budget, lessening the pressure on the AF to make tradeoffs with more popular and well-established programs.

On the other hand, Senator Charles Robb of Virginia was concerned about a military budget that cannot support the force structure required to fulfill existing US national military strategy. He is definitely on the side of those who want to keep operational forces as top priority.

America's AF: Global Vigilance, Reach and Power

In June 2000, F. Whitten Peters, Secretary of the Air Force, and General Michael Ryan, AF Chief of Staff, released their new visions for the 21st century called "America's Air Force: Global Vigilance, Reach and Power", which updates the previous "Global Engagement." General Ryan notes that

General Ryan notes that aerospace integration is a "pillar" that supports the new AF vision.

Gen. Ryan further stated that aerospace integration should not be confused with the AF vision which deals with 'core competencies.'

Regarding a separate space service, General Ryan said that "it would not be able to push space technology any faster than it is moving now and that creating an expensive, separate service bureaucracy would rob funds from the space research initiatives already under way."

The Space Commission

On 5 June 2000, an independent commission officially began a six-month examination of ways to enhance US military space power. The panel was charged with proposing ways to increase space's contribution to US military power and reviewing new ways to organize space effort.

Chairing the commission was Donald Rumsfeld, former (and now current) Secretary of Defense. Members included Gen. Howell Estes III, former USCINCSPACE; Gen. Ronald Fogelman, former AF Chief of Staff; Gen. Charles Horner, former USCINCSPACE; Gen. Thomas Moorman Jr., former USAF Vice Chief of Staff and commander, AFSPC; Adm. David Jeremiah, former Vice Chairman of the JCS; Gen. Glenn Otis (US Army), former commanding general, Army Training and Doctrine Command; and Lt Gen Jay Garner (US Army), former commanding general, Army Space and Strategic Defense Command.

Civilian members included Duane Andrews, former assistant secretary of defense for C3I; Robert Davis, former deputy undersecretary of defense for space; William Graham, former chairman of DoD's Ballistic Missile Defense Advisory Committee; Douglas Necessary, former professional staff member, House Armed Services Committee; and Malcom Wallop, former US Senator from Wyoming.

The commission played an important role in ensuring that our forces are properly structured to gain maximum benefit from space operations. Follow-on actions by various commands began in 2002 and are still being implemented in 2003.

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Chapter 3

SPACE OPERATIONS AND TACTICAL APPLICATION - U.S. NAVY

As the naval component of the U.S. Space Command (USSPACECOM), Naval Space Command (NAVSPACECOM) directs naval space forces and operates space and space support systems. NAVSPACECOM's goal is to provide effective space support to naval forces in peace, crisis or war. This chapter looks at the space systems the U.S. Navy and U.S. Marine Corps currently employ.

NAVAL SPACE COMMAND (NAVSPACECOM)

NAVSPACECOM (**Fig. 3-1**) advises the Commander in Chief (CINC) U.S. Space Command (USSPACECOM) on employment of assigned forces in support of various space missions.

Fig. 3-1. Naval Space Command Emblem & Headquarters Building, Dahlgren, VA

A second-echelon command reporting to the Director of Space and Electronic Warfare (N6) and the Director of Naval Warfare (N7), NAVSPACECOM trains, equips and maintains assigned forces. NAVSPACECOM does this in three ways. First, it conducts, supports, plans and budgets space operations for worldwide naval forces. Second, it represents naval services to USSPACECOM. The Command's final role is to advise, support and assist the naval services' development of inter-operable space plans, programs, policies, concepts and doctrine. These objectives ensure that naval forces have access to responsive space support to successfully execute their missions.

Background

From the beginning of the Space Age, the Navy's research and development community has provided national leadership in space science. The Navy introduced major systems for navigation, surveillance and communications. Following World War II, the Naval Research Laboratory (NRL) in Washington, DC began a program to probe the earth's higher atmosphere using captured German V-2 rockets. From 1946 to 1952, NRL's rocket flights successfully measured temperature, pressure and winds in the upper atmosphere and electron density in the ionosphere. The NRL flights also recorded the ultraviolet spectra of the sun. To continue high-altitude research, NRL developed the Viking rocket, which carried the first gimbaled rocket motor for flight control.

In 1955, the Navy was tasked to develop one of the nation's first satellites, VANGUARD (**Fig. 3-2**), which success-

Fig. 3-2. VANGUARD Satellite

fully orbited on 17 March 1958 from a new satellite launch facility constructed by the Navy at Cape Canaveral, Florida.

VANGUARD satellites were the first to be powered by solar cells, and data provided by the spacecraft enabled Navy scientists to prove the theory of a "pear-shaped" earth.

When the National Aeronautics and Space Administration (NASA) was formed in 1958, about 200 Navy scientists transferred from the NRL to form the nucleus of NASA's space expertise. Nevertheless, the Navy's research community continued to be active in space-related projects. Navy scientists developed a satellite tracking system in 1961 operated by the Naval Space Surveillance Center (NAVSPASUR) in Dahlgren, Va.

The same period saw the Navy fund the research and development that produced the nation's first satellite-based global navigation system called TRANSIT. The Naval Satellite Operations Center (NAVSOC), established in 1962, operated and maintained TRANSIT -- a navigation satellite built for the Navy by the Applied Physics Laboratory. TRANSIT was the nation's first operational satellite navigation system and the first system to experiment with nuclear powered spacecraft.

In 1970, the Navy established the Navy Space Program Office to consolidate fragmented space programs. Under its new charter, the Space Program Office began several projects, including the Fleet Satellite Communications (FLTSATCOM) System. Today that office exists as the Space Program Directorate in the Space and Naval Warfare Systems Command (SPAWAR).

The 1980s ushered in a series of major Naval initiatives to further consolidate existing activities and organizations that operate and maintain space systems for the fleet. In 1981, the Chief of Naval Operations (CNO) established the Navy Space Systems Division to act as the single point of contact for Navy space programs. Later that year, space systems subspecialties were established for Naval officers, and in 1982, the Naval Postgraduate School initiated courses in space systems operations and space systems engineering. In 1983, the Naval Space Command assumed operational management of space systems in direct support of the fleet. NAVSPACECOM is also responsible for coordinating naval space activities with unified and specified commands. Finally, the Marine Corps expanded its space commitment in 1986 when the service formed the Tactical Space Plans Branch within the Plans, Policy and Operations Division at Headquarters, U.S. Marine Corps.

Naval Satellite Operations Center (NAVSOC)

A component of the Naval Space Command, the NAVSOC is one of the nation's oldest space-related military commands. Established in 1962 at the Pacific Missile Test Center in Point Mugu, California (**Fig. 3-3**) it was originally known as the Navy Astronautics Group (NAVASTROGRU). Its mission was to operate the Navy Navigation Satellite System (NNSS) commonly known as TRANSIT.

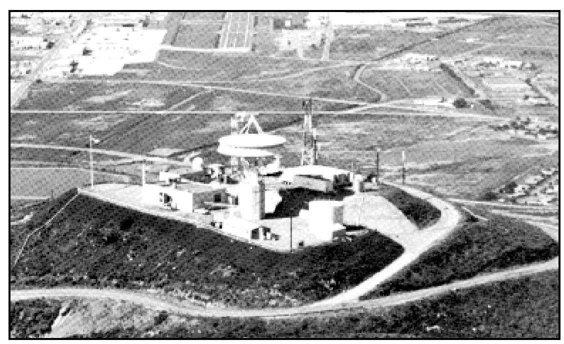

Fig. 3-3. Point Laguna (Pt. Mugu)

In October 1983, NAVASTROGRU became a component of the newly formed Naval Space Command. At that time, they also assumed the additional responsibility to operate and maintain naval satellite systems for naval space operations. The group was formally redesignated the NAVSOC on 12 June 1990.

The NAVSOC headquarters' complex

at Point Mugu includes a satellite operations control center, a satellite systems computer center and a satellite ground systems test and evaluation station. The command also maintains four detachments called tracking and injection stations at Prospect Harbor, Maine, Rosemount, Minnesota, Laguna Peak (Point Mugu), and Wahiawa (Oahu), Hawaii.

Navy Space Operations Center (NAVSPOC)

Around-the-clock operational space support to Navy and Marine Corps customers is coordinated and disseminated through the Naval Space Operations Center (NAVSPOC) -- the "service center" hub of the command, located at Dahlgren, Virginia. They provide space-related operational intelligence to deployed Navy and Marine Corps forces through a number of tactical communications channels. The command's space reports and analyses are activated on request and are tailored to a deploying unit's operations and geographic area of movement. They provide users with tactical assessments of space system capabilities and vulnerabilities to potentially hostile space sensors.

The NAVSPOC maintains a "space watch" around the clock to track satellites in orbit, operating a surveillance network of nine field stations located across the southern United States. The field stations comprise a bi-static radar that points straight up into space and produces a "fence" of electromagnetic energy that can detect objects in orbit around the Earth out to an effective range of 15,000 nautical miles.

Over 1 million satellite detections, or observations, are collected by surveillance sensors each month. Data gathered is transmitted to a computer center in Dahlgren, Virginia where it is used to constantly update a database of spacecraft orbital elements. This information is reported to Fleet and Fleet Marine Forces to alert them when particular satellites of interest are overhead.

NAVSPACECOM's tracking information is also used to maintain a catalog of all earth-orbiting satellites and support the U.S. Space Command as part of the nation's worldwide Space Surveillance Network.

Naval Space Command provides facilities and staffs a command center 24 hours a day to serve as the Alternate Space Control Center (ASCC) for U.S. Space Command's primary center located at Cheyenne Mountain Air Force Base, Colorado. ASCC missions include operational direction of the global Space Surveillance Network for CINCSPACE. They detect, track, identify, and catalog all man-made objects in space and provide ephemerides on these objects to about 1,000 customers. As ASCC, they also monitor the space environment and inform owners and operators of U.S. and allied space systems of potential threats to their assets.

The Navy has long realized that national space systems can be leveraged to detect and report targets of significant tactical interest. Today, detachments of Naval Space Command are deployed to operate the Joint Tactical Ground Station (JTAGS). This joint Army/Navy program provides enhanced capability to detect tactically significant targets using the Defense Support Program (DSP) satellites. JTAGS detachments are located in theater with direct connectivity to the theater CINC and various weapon systems such as AEGIS and Patriot. JTAGS is one element of a comprehensive joint-service Tactical Event System (TES) architecture built by U.S. Space Command.

The main effort of the Naval Space Command and NAVSOC revolves around providing space support to day-to-day operations of the Fleet and Fleet Marine Forces worldwide. The support varies from routine deployments, to exercises or actions in response to a crisis. Headquarters' personnel manage naval use of several existing satellites as well as assist in the development of future space systems to meet the projected requirements of the fleet. This support to terrestrial forces can be categorized into four areas: communications, navigation, surveillance and remote sensing.

Communications

Naval Space Command manages naval use of a number of space-based communications systems. These systems include (but are not limited to) the Fleet Satellite Communications System (FLTSATCOM), the FLTSAT EHF Package (FEP), the UHF Follow-On (UHF F/O) and LEASAT.

FLTSATCOM

FLTSATCOM **(Fig. 3-4)** is owned by the Department of Defense and provides primary UHF communications to naval forces deployed worldwide.

The FLTSATCOM system, which has been operational since 1978, provides worldwide ultra-high frequency (UHF) communications between naval aircraft, ships, submarines, ground stations, U.S. Strategic Command and the National Command Authority. A minimum of four satellites in geo-stationary orbits, spaced equidistant around the globe, provide near worldwide coverage.

FLTSATCOM spacecraft also serve as host vehicles for the strategic AF Satellite Communications System. Acting as the operational agent for the FLTSATCOM system, NAVSOC assumed on-orbit responsibilities for FLTSATCOM from the Air Force on 1 October 1991.

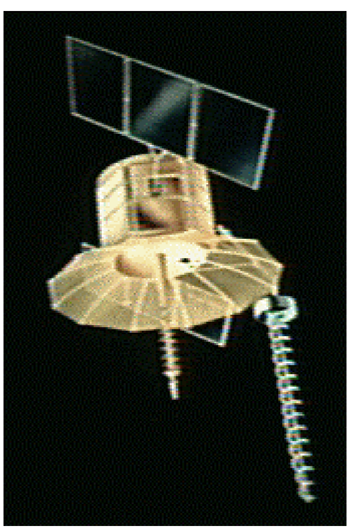

Fig. 3-4. FLTSATCOM

FLTSAT EHF Package (FEP)

To further enhance satellite communications capabilities for the future, NAVSPACECOM manages a joint-service project, the FLTSAT EHF Package (FEP) program, placing extremely high frequency (EHF) communications test modules into orbit. Designed and built by the Lincoln Laboratory at MIT, NAVSOC became the operating agent in June 1987. Carried into space aboard FLTSAT spacecraft in 1987 and 1989, these experimental FEP modules provide U.S. naval forces with limited operational capability at EHF. This has also allowed them to test EHF terminals developed for the Milstar satellite system that now provides an enhanced, survivable, jam-resistant communications capability.

A transportable FEP Operating Center was relocated from the MIT's Lincoln Laboratory to the NAVSOC's Detachment Alfa in Prospect Harbor in August 1988. Since September 1988, it has been the primary controlling station for FEPs. During Operation DESERT STORM, FEP provided an EHF communications link between U.S. Central Command (USCENTCOM) and the National Military Command Center (NMCC). The success of this EHF link represented the first operational use of EHF communications.

UHF Follow-On (UHF F/O)

The Navy has ordered 10 UHF F/O spacecraft built by Hughes Space and Communications Company. The first operational satellite (satellite F2) was turned over to the Navy by Hughes on 2 December 1993. The latest UHF F/O satellite, F7, was launched 25 July 1996 from Cape Canaveral. Launch dates of the remaining satellites have been delayed. Number eight is planned for launch in January 1998 and completion of the series is scheduled by January 1999.

The UHF F/O satellite represents a new class of spacecraft being purchased by the Navy to replace the aging FLTSATCOM and LEASAT satellites. UHF F/O, like its predecessors, will serve ships at sea as well as a variety of other U.S. military fixed and mobile terminals.

Each UHF F/O spacecraft **(Fig. 3-5)** features 11 solid-state UHF amplifiers and provides 39 UHF channels at a total bandwidth of 555 kHz. An EHF package will be added to UHF F/O satellites beginning with satellite four (F4). This addition will include 11 EHF channels distributed between earth coverage beam and a steerable spot beam and will be compatible with Milstar ground terminals. The completed UHF F/O constellation will consist of eight satellites in a geosynchronous orbit. The NAVSOC will provide technical, operational and management support for all UHF F/O spacecraft once operational. The USAF's 3rd Space Operations Squadron (3 SOPS) performs telemetry and control functions.

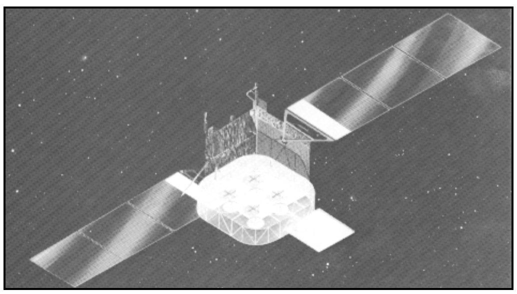

Fig. 3-5. UHF F/O Satellite

LEASAT

LEASAT was a Navy-leased UHF satellite communications system that supplemented FLTSATCOM and UHF F/O. It was first deployed from the Space Shuttle Discovery in 1984. Four LEASAT satellites are in geostationary orbits over the CONUS and Atlantic, Pacific and Indian Oceans. The last operational spacecraft among the constellation of LEASAT communcations satellites was retired in February 1998.

Defense Satellite Communications System (DSCS)

Naval Space Command coordinates Navy usage and requirements for the Defense Satellite Communications System (DSCS). This satellite system includes spacecraft in geosynchronous orbit that provide near worldwide communications at super-high frequency (SHF) for U.S. and allied forces.

Navigation

Naval Space Command exercised overall operational management of the Navy Navigation Satellite System (NNSS). The system, originally referred to as TRANSIT, was conceived in the early 1960s to support the precise navigation requirements of the Navy's fleet ballistic missile submarines. The TRANSIT system was previously used worldwide by all U.S. Navy and U.S. flagged merchant ships as well as foreign commercial and military vessels.

Today, the NAVSTAR Global Positioning System (GPS) **(Fig. 3-6)** greatly increases the accuracy with which ships, aircraft and ground forces can navigate. The Navy, involved in the joint-service program from its inception, has developed time standards for the NAVSTAR satellites and has participated in platform terminal development.

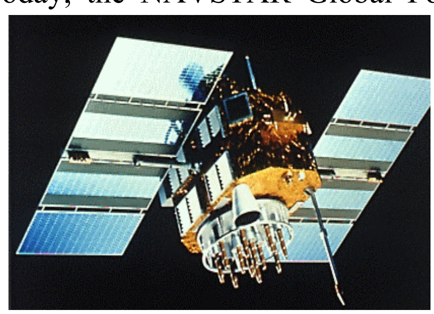

Fig. 3-6. NAVSTAR GPS Satellite

NAVSOC personnel are known as

leading authorities in navigation satellite operations. Besides having operated and maintained the TRANSIT satellite system, NAVSOC has also supported several other space-related programs.

Surveillance

The NAVSPACECOM surveillance mission is to maintain a constant surveillance of space and provide satellite data as directed by the CNO and higher authority to fulfill Navy and national requirements. For naval requirements, Naval Space Command supports the maritime forces of the U.S. and its allies. It provides information on the threat from space that enables battlegroup and other tactical commanders to take appropriate countermeasures.

NAVSPACECOM surveillance functions also support USSPACECOM. As a dedicated sensor in the worldwide Space Surveillance Network (SSN), the Naval Space Surveillance (NAVSPASUR) system provides satellite observations, elements and look angles to the Space Control Center (SCC) [previously known as the Space Surveillance Center (SSC)] at Cheyenne Mountain Air Station (CMAS), Colorado. Further, NAVSPASUR has functioned as the Alternate SCC, serving as the backup for the SCC since December 1984. This role involves activation for computational support, SSN reporting or SSN command and control as directed by the SCC.

Naval Space Command manages two distinct surveillance efforts in support of Fleet and Fleet Marine Forces: tracking satellites in orbit through the aforementioned NAVSPASUR; and monitoring over-the-horizon threats from sea and air forces via the Fleet Surveillance Support Command (FSSC).

"The Fence"

With the launch of Sputnik I (the first artificial satellite) on 4 October 1957, the U.S. soon recognized the importance of detecting and tracking nonradiating satellites. This capability was needed to maintain an awareness of advances in space technology by the Soviets and to support U.S. space projects. The Naval Research Laboratory (NRL), under the management of the Advanced Research Projects Agency (ARPA), started work in 1958 to build and prove a space surveillance network capability.

The Naval Weapons Laboratory in Dahlgren, Virginia hosted the headquarters and computational facility for the prototype network. Dahlgren was selected because the Naval Ordnance Calculator located there was the only computer in the Navy that could handle the advanced calculations needed to support the effort.

The initial surveillance network also included six field stations. Two transmitter sites were at Jordan Lake, Alabama and Gila River, Arizona. Four receiver stations were built: San Diego, California; Elephant Butte, New Mexico; Silver Lake, Mississippi and Fort Stewart, Georgia.

This project successfully proved the

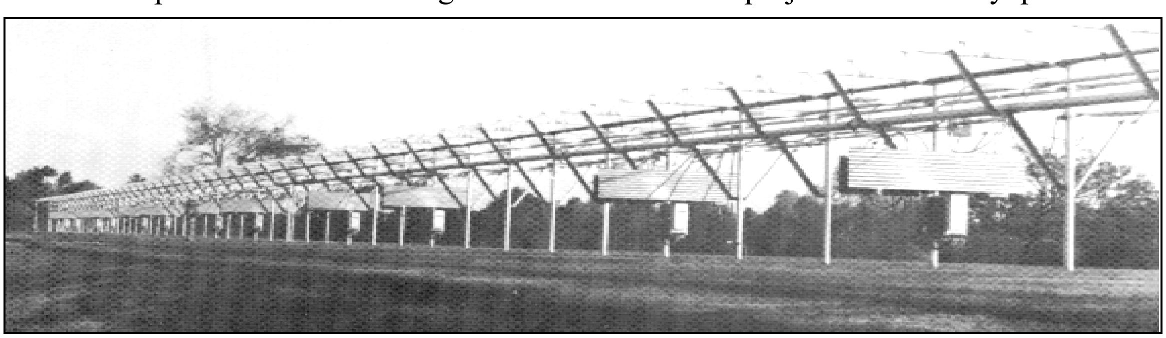

Fig. 3-7. NAVSPASUR Surveillance Transmitter

NRL's idea. In June 1960, the Navy commissioned the Naval Space Surveillance System (NAVSPASUR), later to become known as the "Fence." NAVSPASUR was the Navy's first space-related operational command, and is still headquartered in Dahlgren.

Later additions to the NAVSPASUR network included a two-mile-long transmitter at Lake Kickapoo, Texas and two gap-filler receivers at Red River, Arkansas, and Hawkinsville, Georgia. These sites were built between 1961 and 1965, completing the system as it is deployed today.

NAVSPASUR Sensor Operations

The system's network of field stations produces a "fence" of electromagnetic energy roughly 5,000 nautical miles long that extends across the continental U.S. and portions of the Atlantic and Pacific Oceans. In the North-South direction, the fence **(Fig. 3-7**) is about two miles wide and can detect payloads at a height of 15,000 nautical miles. Together, the system's nine field stations **(Fig. 3-8**) comprise one of the world's largest antenna systems. With a total length of over 15 miles, the antenna sites incorporate 150 miles of transmission lines, 10,000 feet of steel posts and 18,000 dipoles.

The three transmitters emit a fan of continuous wave radio energy at a frequency of 216.98 MHz. The largest transmitter, at Lake Kickapoo, has a two-mile long antenna array composed of 2,556 dipole elements. It has an output power of 766.8 kW divided into 18 separate segments, each of which can be operated independently. This pattern provides a reliability over 99 percent, since a few segments can be inoperative without significantly affecting the operational capability of the system. The two smaller transmitters at Gila River (40.5kW) and Jordan Lake (38.4kW) provide low-altitude coverage at the East and West extremities of the network.

Six receiver sites collect the transmitted energy reflected from satellites as they pass through the fence. Each receiver site has individual antennas spaced at precise intervals. The longest antenna at each site is known as the "alert" antenna, as it is more sensitive and can detect a signal before the other antennas. It then electronically alerts the system controller to the presence of a target, which tunes the receiver to the precise frequency of the reflected energy from the satellite.

Two receiver sites, Elephant Butte and Hawkinsville, are "high-altitude"

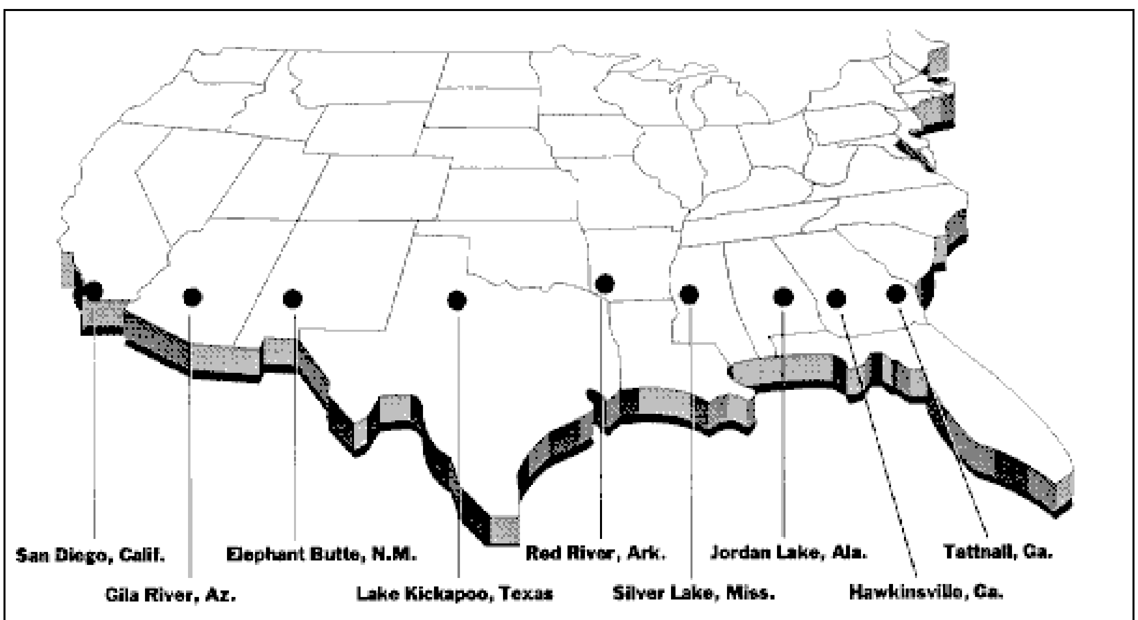

Fig. 3-8. NAVSPASUR Transmit and Receive Sites ("The Fence")

sites. Their antenna arrays have higher gain and their electronics make them more sensitive to the reflected energy from higher altitudes. All together, the receiver sites collect over one million satellite observations each month.

A Relentless Vigilance

NAVSPASUR maintains an up-to-date catalog of all objects in space. This catalog, which serves as a direct backup to the space object catalog kept by USSPACECOM, contains over 8000 objects. As all objects in orbit are affected by space weather, this number will decrease as the Solar Max occurs during the years 1999-2000. The Solar Max is expected to cause the earth's atmosphere to extend further into space causing low orbiting objects to fall to earth due to the increased friction from the air molecules.

In addition to those analysts concerned with the catalog, a small group of analysts are dedicated to the evaluation of unusual satellite on-orbit activity. These analysts maintain an accurate database on all foreign launches. They provide observations and conclusions about satellite orbital behavior using tailored databases and information from other command analysts and the SSN.

Direct CINCSPACE Mission Support

NAVSPASUR assumed the role of Alternate Space Control Center (ASCC) from the site at Eglin AFB, Florida in December 1984. The Space Control Center (SCC) at CMAS and its alternate, the ASCC at Dahlgren, can provide operational direction of the entire global SSN for CINCSPACE. The information provided to USSPACECOM by the ASCC enhances its capability to provide timely and accurate threat evaluation and decision making support of the JCS.

Critical missions the ASCC performs for USSPACECOM encompasses new foreign and domestic (including Space Shuttle) launch processing. The ASCC provides on-orbit support, tracking and impact prediction for objects that could reenter the earth's atmosphere intact.

NAVSPASUR has also been an essential part of space defense operations for many years. At the recommendation of Naval Space Command, CINCSPACE decided in November 1986 to assign the Navy responsibility for establishing and maintaining USSPACECOM's Alternate Space Defense Operations Center (ASPADOC -- now also part of the ASCC). Naval Space Command directed NAVSPASUR to assume this function and integrate this with its other duties. On 1 October 1987, the center, collocated with the former ASSC, became operational. The ASCC backs up the SCC in case of natural disaster, equipment outage, or hostile action, causing a loss of capability at CMAS.

The ASCC monitors the space environment and informs owners and operators of U.S. and allied space systems of potential threats to their assets. This is done by maintaining liaison with the systems' operations centers. The ASCC also has the missions of protection and negation. In order to fulfill these roles, systems are being developed to give the center new and more comprehensive capabilities. These new systems will culminate years of joint and cooperative development efforts by all services.

Fleet Surveillance Support Command (FSSC)

The U.S. Navy has long had a requirement for wide-area, over-the-horizon surveillance to support tactical forces in selected geographic areas. Surveillance of key ocean areas, maritime choke points and littorals is necessary for most favorable use of at-sea battle groups.

In 1984, to satisfy this operational requirement, the Navy began full-scale development of an active surveillance sensor known as the Relocatable Over-the-Horizon Radar (ROTHR) **(Fig. 3-9)**. This sensor is capable of long-range detection and tracking and works alongside other surveillance assets. No other event has extended the “eyes of the fleet” more since the Navy’s carrier-based E-1 surveillance aircraft began operations in the early 1960s.

Fig. 3-9. ROTHR Receiver

The Fleet Surveillance Support Command (FSSC) was commissioned on 1 July 1987 to operate and maintain Navy ROTHR systems. Their task is to train qualified operators and other support personnel for the entire ROTHR system. Although the command is headquartered at the Naval Security Group Activity Northwest in Chesapeake, Virginia, they report administratively to Naval Space Command. Operational FSSC detachments are the assets of the Fleet Commanders-in-Chief. The detachments are operationally tasked by, and report target data directly to, Fleet Ocean Surveillance Information Centers (FOSICs). The FOSICs integrate ROTHR data with other sensor data and disseminate it to task forces, as required.

The first prototype ROTHR system comprised a transmitter site located at Whitehouse, Virginia and an operational center and receiver site collocated with FSSC headquarters at Chesapeake. Following operational test and evaluation in 1989, the prototype system was dismantled and relocated to Amchitka Island in the Aleutian Island chain. With the dissolution of the Soviet Union, the mission on the island was deemed no longer necessary. The Amchitka site was dismantled in late 1993 and moved back to Virginia, where it currently supports drug interdiction operations.

ROTHR Operations

ROTHR is a land-based, high frequency (HF) radar that can cover a 64-degree wedge-shaped area at ranges of 500 to 1,600 nautical miles. The system can detect, track and estimate the composition of groups of ships and aircraft. This extended range occurs when transmitted HF energy is refracted and reflected by the ionosphere onto distant targets. The radar receive antenna detects the faint energy reflected back from these targets (backscatter) after returning along the same path.

Each deployed ROTHR system consists of three distinct elements including a transmitter site, a receiver site and an Operations Control Center (OCC). The transmitter radiates 200 kW of power through a 16-element phased array with over 1,000 feet of antenna. The receiver array has 372 pairs of 19-foot monopoles, spaced 23 feet apart and stretching 8,500 feet. The OCC contains the ROTHR operator’s consoles **(Fig. 3-10)**, automated data processing equipment and communications equipment to receive tasking and report tracks and status.

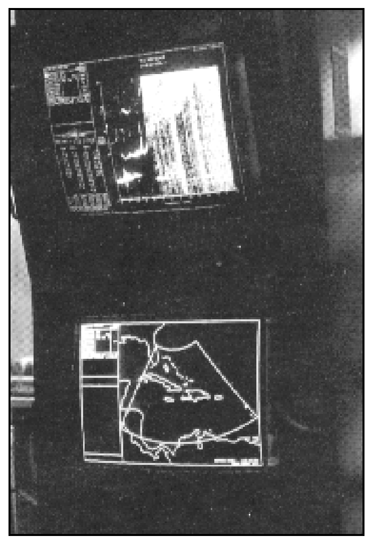

Fig. 3-10. ROTHR Console

The transmitter site will usually be located 50 to 100 nautical miles from the receiver site. The OCC will be located at or near the receiver site. All three elements of the radar, except the antennas, will be installed in transportable shelters. This will provide for relocation of the system to support rapid deployment forces in critical areas of the world and to respond to changing threats.

Tasking for ROTHR comes from the Fleet Commander-in-Chief. Radar tracks are reported to the tactical users through the FSSC. A backup capability also allows direct communication with the fleet. ROTHR is tasked with three types of surveillance:

- establishing and monitoring a single point, such as a strait, airfield or port;
- establishing and monitoring an aircraft or ship barrier;
- conducting air or ship searches in a general area.

ROTHR sites are planned worldwide and will be located to support tactical forces in geographical areas of national interest. Deployed ROTHR systems will provide battle force commanders with a new capability to extend their surveillance horizons. Previous wide-area surveillance systems were designed to warn of threats beyond horizon, but are passive sensors that depend on intentional or unintentional emissions from the target. Limitations of shipboard radars do not allow adequate time for a battle group to respond before missiles are launched. Carrier-based early warning aircraft are too limited in range and numbers to provide the coverage of the entire threatened area.

Training

Another of Naval Space Command's primary responsibilities is to develop and support space-related educational efforts. The CNO delegated this responsibility to the command to help assure that naval forces are fully aware of the present and future contribution of space systems to naval operations. It also works to guarantee that there will be sufficient numbers of qualified and trained personnel to fill the ever-expanding space specialty mission areas. NAVSPACECOM sponsors the space research chair in the Aerospace Engineering Department of the U.S. Naval Academy. The goal is to develop early interest in the expanding naval space arena. The command also supports the Naval Postgraduate School's space engineering and space operations courses with advice and consultation on the Navy's current and future technical and educational requirements.

Naval Space Support Teams

The Naval Space Support Teams' (NSST) focus is on taking the mystery out of space, and putting space-related capabilities into the hands of the warfighter.

Through direct on-site contact with naval and Marine forces, NSST members provide a wide variety of products and services ranging from technical systems assistance to pre-deployment briefings tailored for specific areas of operation. Additionally, as a component of the United States Space Command (USSPACECOM), they act as advocates for naval requirements, provide inputs to joint space doctrine, and serve as augmentees to Joint Space Support Teams during joint exercises and operations.

The NSSTs form a cadre of highly trained space-smart personnel providing expertise on space systems capabilities to deployed users. After receiving formal education in a wide variety of related topics, Navy team members are assigned to either an East Coast or West Coast team. Each team focuses chiefly on its own geographic area to remain cognizant of specific issues of concern and responsive to the needs of its customers. In addition, a Marine contingent supports Marine Corps operating forces.

Remote Sensing

Naval Space Command also supports projects to exploit the multispectral imagery capabilities of existing satellites.

A wealth of detailed information on earth resources is available from space. Shoals and anchorage areas, vegetation, trafficability and lines of communication, for example, are among the earth's features that can be analyzed and charted using satellites. The command works directly with Fleet Marine Force personnel to enhance our amphibious warfare capabilities using this satellite data.

The command provides multi-spectral imagery from LANDSAT and SPOT earth resources spacecraft to assist naval forces with exercise and strike planning, provide updated maps and charts, and enhance intelligence and surveillance capabilities. The command has provided MSI products to U.S. warfighters in support of recent operations in Southwest Asia, Somalia, Yugoslavia, Korea and Haiti.

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TOC

Chapter 4

SPACE OPERATIONS AND TACTICAL APPLICATION - U.S. ARMY

Fig. 4-1. SMDC

On Oct. 1, 1997, the Department of the Army created its newest major command, the U.S. Army Space and Missile Defense Command (SMDC) (**Fig. 4-1**). Composed of five primary components, the SMDC is a global organization. These components are the SMDC Headquarters and the Force Development Integration Center in Arlington, Va.; the U.S. Army Space Command (Forward) located in Colorado Springs, Colo.; and, the Space and Missile Defense Technical Center (SMDTC), the Space and Missile Defense Battle Lab (SMDBL) and the Space and Missile Defense Acquisition Center (SMDAC) based in Huntsville, Ala. Included in the SMDAC are the High Energy Laser Systems Test Facility (HELSTF), at White Sands Missile Range, N.M., the U.S. Army Kwajalein Atoll/Kwajalein Missile Range (USAKA/KMR), in the Republic of the Marshall Islands, the Army Space Program Office (ASPO) in Alexandria, Va., and the Joint Land Attack Cruise Missile Defense Elevated Netted Sensors Project Office (JLENS) and the Ballistic Missile Targets Joint Project Office (BMTJPO) which are both in Huntsville.

BACKGROUND

The SMDC commander is a dual-hatted leader. In addition to the duties of SMDC commander, he also serves as the commander of the U.S. Army Space Command (ARSPACE). The creation of the new major command and its organization are designed to align the command to reflect the importance of space and missile defense to the Army and the joint warfighter. The basic missions of the command are twofold. The SMDC ensures that the soldier in the field has access to space assets and their products. The command also seeks to provide effective missile defense for the nation and deployed forces.

Although a new organization, the SMDC is building on more than 40 years of achievement and progress in the space and missile defense arena. The command began in 1957, when the Army created the first program office for ballistic missile defense. With the Nike-Zeus, the Army explored the feasibility of nuclear intercepts of inter-continental missiles. On July 19, 1962, the command made history with the first successful intercept of an intercontinental ballistic missile. This feat was repeated at the next level in 1984, when the Homing Overly Experiment performed the first non-nuclear, kinetic-kill intercept of a reentry vehicle, proving it was possible to hit a "bullet with a bullet." In 1967, having proved the interceptor's capabilities, the command moved toward the next phase – deployment – with the Sentinel defense system. Redirected in 1969, the program was assigned to defend of the U.S. land-based ICBM's. On Oct. 1, 1975, the Safeguard Complex in North Dakota became operational. Congress inactivated the site almost immediately, because of concerns over the budget and the influence of the Anti-Ballistic Missile Treaty. President Ronald Reagan announced a new approach to strategic planning, the Strategic Defense Initiative, in March 1983. This concept urged an active defense rather than the traditional offensive deterrence. To address this change, elements of the Ballistic Missile Defense Organization were merged in July 1985, creating the U.S. Army Strategic Defense Command (USASDC). At the same time, efforts by the command expanded to incorporate new avenues of research. In addition to radars and interceptors, the USASDC expanded its exploration of anti-satellite systems, lasers, neutral particle beams and innovative sensors. With the new decade, the command began to move in new directions. In October 1990, as part of an effort to centralize laser research, the HELSTF transferred to the command from the Army Materiel Command. The USASDC mission was further enhanced in January 1991, when the command was assigned all Theater Missile Defense functions and again in June 1994, the USASSDC commanding general was made the Theater Missile Defense advocate.

In 1992, the Army reorganized the USASDC to focus elements upon specific needs and missions. As part of this decision, several missile and radar projects were transferred from the USASDC to the newly created Program Executive Office for Global Protection Against Limited Strikes (subsequently renamed Air and Missile Defense). Among the projects leaving the command were the Ground Based Interceptor, the High Endoatmospheric Defense Interceptor, the Theater High Altitude Area Defense, the Extended Range Interceptor (which became the Patriot Advanced Capability-3 interceptor), the ARROW, and the Ground Based Radar. The Program Executive Office was assigned the mission to develop and deploy viable national missile defense and theater missile defense systems.

The Army's renewed interest in space technology was reflected in Department of the Army's decision to create the U.S. Army Space and Strategic Defense Command (USASSDC), on Aug. 24, 1992. Under this directive, the Army Space Command became a subordinate command to the USASSDC. Other Army space interests were incorporated into the new organization in later years. The Army Space Technology Research Office transferred to the command in 1993, followed by the Army Space Program Office in 1994. Based on these changes and the years of experience, the USASSDC was named the Army's advocate for Space, Theater Missile Defense and National Missile Defense. As outlined in the General Order, dated July 1, 1993, the USASSDC was to serve as the "focal point for space and strategic defense matters, … responsible for [the] exploitation of space and strategic assets for use by warfighting [Commanders in Chief]."

With this consolidated approach, the Army had teamed all of its space-related organizations. Since 1973, the Army Space Program Office has overseen the tactical exploitation of national capabilities program, or TENCAP. The TENCAP program seeks to assess the tactical potential of current abilities and integrate them into the Army system. The Army Space Technology Research Office, established in 1988, managed near and possible far-term space R&D programs. It became the core of the new Space Applications Technology Program.

The Army Space Command, created in 1986, serves as the Army component of the U.S. Space Command and is responsible for operational space planning. This command also oversees the Defense Satellite Communications System Operations Centers and the Army Space Demonstration Program, which explores the feasibility of off-the-shelf technology in the space program. One successful example of this effort is the Small Lightweight Global Positioning System (SLGR) (**Fig. 4-2**) receiver (commonly called the "slugger") used during Operation Desert Shield/Desert Storm.

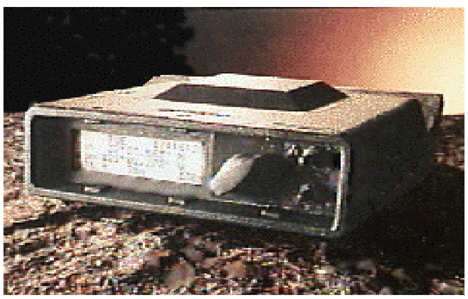

Fig. 4-2. SLGR

It is with this substantial background that the SMDC advances the Army's space and missile defense efforts towards the 21st century.

OVERVIEW

The U.S. Army Space and Missile Defense Command, a MACOM, serves as the Army's proponent for Space and National Missile Defense, and as the Army integrator for Theater Missile Defense. The command ensures that Army warfighters have access to space assets and products to win decisively with minimum casualties and effective missile defense to protect our nation as well as our deployed forces and those of our friends and allies. From its headquarters in Arlington, Va., U.S. Army SMDC oversees a number of Army elements around the globe to accomplish its challenging and diverse mission:

The U.S. Army Space Command, or ARSPACE, in Colorado Springs, Colo., serves as the Army component to the U.S. Space Command, and supports the warfighter through the 1st Satellite Control Battalion and the 1st Space Battalion. The former provides worldwide long-haul satellite communications to the warfighter through the defense satellite communications system, while the 1st Space Battalion's Army Space Support Company provides units deploying on exercises and contingency, and humanitarian operations with intelligence, planning, and operational expertise and products.

The 1st Space Battalion's Theater Missile Warning Company uses the Joint Tactical Ground Stations to provide theater CINCs with the only in-theater tactical ballistic missile warning capability on the battlefield. The ARSPACE also manages the Army's astronaut detachment at the Johnson Space Center, Houston, Texas.

The Space and Missile Defense Technical Center, or SMDTC, located in Huntsville, Ala., is the research and development element of the command. The center executes space and missile defense and directed energy research and development programs. As executive agent for DOD's Ballistic Missile Defense Organization, the center provides cost, schedule, and technical oversight for national and theater missile defense technology, and provides technical matrix support to PEO Air and Missile Defense and the National Missile Defense Joint Program Office.

The Space and Missile Defense Battle Lab, or SMDBL, in Huntsville, Ala., and Colorado Springs, Colo., links the technologist and the warfighter through experiments simulating modern "battlefield" conditions, often using sophisticated computer simulations, interfaces, and networks.

The National Missile Defense TRADOC System Manager, or TSM, in

Arlington, Va., performs the function of integrating and managing NMD user activities within the Army. It serves as a single Army user representative and advocate in the development of the land-based NMD system.

The command's Force Development and Integration Center, or FDIC, in Arlington, Va., develops the Army's space and missile defense concepts, validates requirements, and ensures Army-wide solution integration.

The Space and Missile Defense Acquisition Center in Huntsville, Ala., centralizes the command's materiel development, targets, and test facility management into one overarching organization that includes the following facilities and program offices:

- The Army Space Program Office, or ASPO, at Fort Belvoir, Va., is responsible for the Army Tactical Exploitation of National Capabilities Program – TENCAP. The program focuses on exploiting current and future tactical potential of national systems and integrating the capabilities into the Army's tactical decision-making process. The ASPO has successfully fielded more than 60 systems and currently supports 41 systems at 23 sites around the world.
- The High Energy Laser Systems Test Facility, or HELSTF, at White Sands Missile Range, N.M., serves as a national center for high-energy laser research, development, testing, and evaluation. It is the only laser facility capable of placing continuous wave megawatt laser light on a variety of targets.
- The Kwajalein Missile Range's unit geographical location in the central Pacific Ocean and unmatched suite of radars, instrumentation, and test support facilities offer extensive flexibility for ballistic missile testing and space-object tracking.
- The Ballistic Missile Targets Joint Program Office in Huntsville, Ala., provides the BMDO community with both strategic and theater missile targets for BMD weapon system developmental testing.
- The Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System Project Office, or JLENS, Project Office in Huntsville, Ala., is developing advanced radar sensors that will provide over-the-horizon coverage from cost-effective aerostat platforms. The sensors are crucial for providing early warning, surveillance, and precision track/elimination of threat cruise missiles.

SPECIFIC ELEMENTS PROVIDING SPACE SUPPORT TO ARMY OPERATIONS

ARMY SPACE COMMAND (ARSPACE*)*

Fig. 4-3. ARSPACE

The mission of the Army Space Command, or ARSPACE (**Fig. 4-3**), is to support Army, Joint, and Coalition warfighters with space-based expertise, advice, capabilities, and products. ARSPACE is also involved in the development of technological solutions to warfighter requirements through its Technical Support Office.

Missions

- *Support the Commander-in-Chief, U.S. Space Command*. The Commander of the Army Space Command is the Army component to the unified U.S. Space Command. ARSPACE ensures that the Army's requirements are met at the joint level, while bringing the CINC's views and concerns to the Army staff. ARSPACE supports CINCSPACE in the development of Joint space doctrine, as well as the development of plans, policies, and requirements for space support to Army operations.

- *Operate and Manage the Defense Satellite Communications System (DSCS)*. This system spans the globe to provide super-high-frequency communications to all U.S. warfighting forces — anywhere, anytime. Management, planning, and control of the payloads on DSCS satellites is ARSPACE's largest mission. ARSPACE operates and maintains five DSCS control facilities located around the world, one Ground Mobile Forces Control Center (AN-MSQ-114), and the DSCS Certification Facility, or DCF, at Schriever Air Force Base in Colorado. These facilities control the satellite links for tactical warfighter communications and strategic communications networks. They also provide payload control to the satellite and technical training and troubleshooting assistance required to ensure maximum support to the user. In addition, the DCF provides platform control, monitoring the health and welfare of the payloads for selected satellites in the DSCS constellation. Three Regional Space Support Centers perform DSCS planning and authorize warfighter use of DSCS capabilities.
- *Current Operations*. ARSPACE support of the Army, Joint, and Coalition warfighter spans the globe. Army Space Support Teams, or ARSST, provide expertise and advice and operate equipment which provides the warfighter support in the planning and conduct of the complete spectrum of today's military operations. Each of the five teams is aligned with a Corps and provides communications, weather, terrain analysis and 3-D visualization, mapping, and satellite coverage analysis capabilities to the Corps commander. ARSST are deployable to exercises and contingency operations and have supported every contingency operation since Operation Desert Storm. They are capable of sustained operation of the equipment, or they can train designated soldiers to operate the equipment.
- *Joint Tactical Ground Stations (JTAGS)*. The JTAGS capability supports forward deployed CINCs with direct downlink, from satellite to theater, of early warning of ballistic missile launches. The five JTAGS systems are a key part of CINCSPACE's Tactical Event System, are operated by joint Army-Navy crews, and provide continuous, all-weather threat monitoring. The design, development, and fielding of the JTAGS systems is an example of the Army's capability to fast track vital equipment procurement to support soldiers with the best equipment for mission accomplishment.
- *Missile Defense*. Working through USSPACECOM, the Ballistic Missile Defense Organization Joint Project Office, and the Army National Guard, ARSPACE is the operator representative on the team developing a system of defense for the homeland from a proliferating missile threat. As the eventual user and operator of the ground based portion of a National Missile Defense system, ARSPACE is playing a key role in planning and designing the requirements, Concept of Operations, and support required for such a system. ARSPACE and the Program Manager for Air Defense Command and Control Systems recently developed the overarching pro-

totype Theater Missile Defense, or TMD capability, the Army Theater Missile Defense Element, which ARSPACE fielded. This system synchronizes the four pillars of TMD: Passive Defense, Active Defense, Attack Operations, and Battle Management/Command, Control, Communications, and Intelligence. After three years of exercising and development, it was passed to the Army Air and Missile Defense Command, the system's user, at Ft. Bliss, Texas.

- *Human Exploration and Development of Space*. The Army Astronaut Detachment at the Johnson Space Center in Houston, Texas supports NASA's Space Shuttle and International Space Station Programs.

KEY ARSPACE SUPPORT ELEMENTS

ARMY SPACE SUPPORT TEAM (ARSST)

Such fundamental requirements as force projection, space intelligence analysis, communications, command and control are today dependent upon our capabilities in space. The ARSST is an element of ARSPACE task organized and resourced to support the commanders and staffs of land forces to orchestrate the employment of a complex array of dynamic battlefield resources. An ARSST complements the operational space based capabilities accessed by corps or divisions, such as TENCAP, SATRAN, topographic products, etc, used to obtain a relevant common picture of the battlefield. The team supports the commander and staff in the planning and integration of space assets into their training or military decision making process; obtains, processes and delivers space products to the supported unit; and assesses the operational impact of friendly and adversary space based capabilities. The ARSST manages these complex tasks from staff planning and the estimate process through contingency or operations execution, assisting the command and staff to integrate and focus space support on mission accomplishment. The team typically supports at the corps, and when resources are available, at the division level. Each team consists of 4-6 officers and NCOs, is equipped with a suite of unique hardware and software, possesses expertise in space applications and operational planning, and remains ready to deploy, when necessary, to the warfighter's location.

Support to the Corps staff and or Division staff is available at all times, by virtue of the habitual relationship that is maintained between each of the four ARSST and the four US Army corps. Requests for assistance from other organizations will also be met by ARSPACE as on-going missions permit. By employing state-of-the-art sensor and terrain modeling, as well as access to various web sites, ARSST can assist the staff in answering the commander's critical information requirements as well as providing input to assist in the preparation of staff estimates and OPLANs. The teams rely on the supported unit for logistical support.

ARSST Support Functions:

- *Satellite Advance Notice.* The team can aid staffs in making optimal use of Satellite Reconnaissance Advance Notice (SATRAN) data, which provides information on potential threat satellites and their capabilities to monitor friendly operations.

- *Position/Navigation.* The Global Positioning System is an essential combat multiplier, whether in the form of a PLGR in the hands of an infantryman or as a component in a weapon system. ARSST obtains and provides data on the fluctuating degree of GPS accuracy at specific locations for a designated time that will be available to friendly forces during planned operations (**Fig. 4-4**). The team can also provide advice on counter measures to enemy efforts to jam or spoof GPS.

Fig. 4-4. GPS Assistance

- *Space Weather.* There are a number of phenomena that occur on the surface of the Sun, which can have a dramatic effect on UHF and SATCOM communications, GPS signal reception and radars. The ARSST complements the efforts of the SWO by obtaining advance forecasts of these events and assessing which friendly systems will be degraded, the degree of degradation and when.
- *Imagery.* The ARSST deploys with a state-of-the-art automated data processing package to provide commanders and staffs imagery products beyond those provided by internal topographic units.

These products include: fly-throughs, 3-D images, perspective views and image maps (**Fig. 4-5**), all in various levels of resolution. Image maps provide staffs and soldiers up-to-date maps of areas where no maps exist or are out of date.

Fig. 4-5. Image Map

The ARSST can reach back to its Multi-spectral Imagery (MSI) Lab in Colorado Springs, which can fulfill shortfalls in additional imagery requirements, scene rectification and hard and soft copy production. These enhanced products from the lab can be shipped to the team by multiple means, such as SIPRNET, GBS, and overnight mail.

- *Intelligence Support.* ARSPACE DCSINT members provide space intelligence analysis to the ARSST. The DCSINT focus is to conduct Space Intelligence Preparation of the Battlefield, respond to space related RFI, provide assessments of how the enemy will use it's space systems, and to provide expertise on friendly force space-based intelligence capabilities. The DCSINT has a SIPRNET home page with detailed listings of threat space capabilities. Finally, the intelligence element assists the supported staff's planning effort by providing expertise on enemy and friendly availability to employ commercial satellites, enemy/friendly space vulnerabilities, and recommendations to support the targeting process.
- *SATCOM.* The team provides a limited supplement (**Fig. 4-6**) to the unit's early entry communications

connectivity using non-secure Iridium handsets, and International Maritime Satellite (INMARSAT) hand-carried terminals providing secure fax, data, telex, and voice.

Fig. 4-6. SATCOM Commercial Supplements

JOINT TACTICAL GROUND STATION (JTAGS)

JTAGS is the transportable in-theater element (**Fig. 4-7**) of the U.S. Space Command's Theater Event System and provides Theater Commander's a continuous 24-hour capability to receive and process in-theater, direct down-linked data from space-based sensors. JTAGS ties directly to worldwide and theater communications system to immediately disseminate critical information. JTAGS supports all Theater Missile Defense pillars and provides worldwide warning and alerting as well as in-theater voice warning and cueing information on tactical ballistic missiles and other tactical events of interest.

The JTAGS processes data from up to three DSP satellites to determine launch points and time, azimuth of flight, predicted ground impact point and time for TBMs. JTAGS supports passive defense by providing in-theater early warning of enemy ballistic missile launch events, and provides alert notification to command level staffs, who disseminate the alert message to units in the threatened area. JTAGS also supports active defense by cueing air defense assets to the missile track. Data is also provided on launch location to deep attack assets to aid in attack operation.

The key in JTAGS theater support is its relatively direct connectivity and distribution architecture, via a variety of voice and dam networks. By its in-theater location, JTAGS provides timely, assured early warning. ARSPACE operates two JTAGS sections indefinitely forward deployed by CINCSPACE to Korea and Germany, and maintains deployable sections in CONUS for contingencies, training and exercise support.

Fig. 4-7. JTAGS

1ST SATELLITE CONTROL BATTALION

The Defense Satellite Communications System (DSCS) provides reliable, robust, worldwide, continuous communications support to US warfighting forces, strategic military users, the US intelligence community and the National Command Authority. Customers can communicate via the DSCS using large, fixed earth terminal ground stations, transportable ground stations, and highly mobile, tactical ground stations.

The 1st SATCON Battalion is responsible for the daily C2 of the DSCS satellite and communications networks supported by these satellites (**Fig. 4-8**). The battalion operates the DSCS Operations Centers (OC), at five SATCOM locations around the world to oversee all use of the DSCS, ensuring that users receive the optimal SATCOM support authorized.

On a typical day, the DSCS OCs control nearly 1,000 links providing vital communications support to deployed warfighters, strategic users, and the intelligence community around the world.

Fig. 4-8. DSCS Comms

REGIONAL SATCOM SUPPORT CENTERS (RSSC)

RSSCs provide the joint warfighter with a single focal point for select satellite communications use within a region. RSSCs coordinate and ensure that ground mobile forces obtain necessary access to DSCS SHF-band, MILSTAR EHF, and limited commercial satellite resources. Additionally, they provide tactical communications satellite network planning and management support for CINCs and DOD agencies. The RSSCs are located at Wheeler Army Air Field, Hawaii; Patch Barracks, Germany; Arlington, Virginia; and Tampa, Florida for focused support to CINCs. In the future, the RSSCs will be one-stop-shops for all CINC and DOD SATCOM requirements-EHF, SHF, UHF, GBS and commercial.

SPACE AND MISSILE DEFENSE BATTLE LAB (SMDBL)

Fig. 4-9. SMDBL

The U.S. Army Space and Missile Defense Battle Lab (SMDBL) (**Fig. 4-9**) was activated on October 1, 1997. The SMDBL is the result of the Army's commitment to provide space and missile defense capabilities to the warfighter as rapidly as possible. The SMDBL joins the other Army, Navy, Air Force, and Joint Battle Labs that focus on quick delivery of innovations and future technologies to today's warfighter. It was formed from elements of the former Missile Defense Battle Integration Center and the Army Space Command (Forward).

Core Competencies

- *Concepts and Initiatives.* The Battle Lab identifies and examines candidate concepts, initiatives, and technologies for near-term infusion into Army space and missile defense programs or for experimentation on approved future operational capabilities. To focus military science and technology research, the SMDBL will also coordinate with Missile Defense and Space Technology Center and other materiel development activities. Additionally, this area will provide forward-looking wargaming activities to the command, including participating in the Army After Next series of long-range Army wargames.

- *Experiments, Exercises, and Training*. The SMDBL coordinates, conducts, and participates in efforts focused on bringing space and missile defense capabilities to the warfighter, including support to joint and service Commander-in-Chief exercises, Advanced Warfighting Experiments, Army Experiments, and unit training activities. Products generated by the Battle Lab through experimentation include insights, impacts, validated requirements, concepts, and leave-behind solutions, as well as changes to doctrine, training, and materiel.
- *Simulation*. Leveraging the growth and maturation of computer-based models and simulations, the Battle Lab is expanding the use of its models and simulations beyond the materiel development and analysis domain to provide sophisticated capabilities to the warfighter. Through innovative techniques, the Battle Lab has developed an interface capability to link existing simulations directly to Army Tactical Command and Control systems, so the warfighter can be directly simulated at the actual workstations in realistic environments.
- *Analysis*. The Battle Lab supports experimentation, conducts analyses in support of materiel development activities and requirements determination, performs science and technology reviews, assesses advanced concepts, and analytically supports the definition of future space and missile defense architectures.

Current Capabilities/Products

- *Synthetic Battlefield Environment*, or SBE, has been developed to provide computer simulation technologies to the warfighter in realistic formats. The SBE consists of computer-based models and simulations, simulation to tactical system interface units, and communications and network technologies, linked in a modular environment. The SBE provides the ability to stimulate Army and joint tactical command and control systems with simulations, allowing the warfighter to train on go-to-war equipment. The SBE is also suited for use by the analysis and materiel development communities, lending an operational validation to off-line simulations. The Battle Lab has successfully used the SBE in various war-fighting experiments, CINC exercises, and training events, including Roving Sands, Ulchi Focus Lens, and Coherent Defense.
- The *Extended Air Defense Testbed*, or EADTB, and *Extended Air Defense Simulation*, or EADSIM, form the core of the SBE computer simulations. The user friendly, flexible EADTB offers a high-fidelity modeling capability to operational commanders and combat and materiel developers. EADSIM, used in Desert Storm operations to plan air and air defense campaigns, is a low-to-medium fidelity comprehensive air and missile defense simulation that has widespread acceptance throughout the DOD, all three services, and most allied countries.
- The *Synthetic Battlefield Center*, or SBC, and *Hardware/Software Integration Center*, or HSIC, are laboratory environments for the Battle Lab to conduct experiments and support exercise and training activities. The SBC and HSIC combine the SBE with operational command and control workstations to allow the Battle Lab to provide interactive stimulation

to the warfighter through tactical workstations and equipment.

ARMY SPACE EXPLOITATION DEMONSTRATION PROGRAM (ASEDP)

The genesis of the ASEDP was an Army Space Council meeting in April 1987. During this meeting the Vice Chief of Staff of the Army, LTG Maxwell Thurmond, gave guidance from which the goal, philosophy, and objectives of the ASEDP are derived: "Enhance Air-land Battle execution by demonstrating how space based assets could support tactical commanders." This quote was historically significant, because it gave the Army Space Agency, and then the US Army Space Command, the command guidance needed to initiate the program which would eventually become the ASEDP. Responsibility for the Army Space Exploitation Demonstration Program (ASEDP) was assigned to the SMDBL Directorate located in Colorado Springs, Colorado.

The SMDBL continues to investigate and demonstrate space-related technologies and support space requirements documentation to maintain the US Army's preeminence on the battlefield through the ASEDP.

ASEDP Goal

Demonstrate to the field commander the latest relevant space technology from the commercial and government research and development communities.

ASEDP Philosophy

- Space-based capabilities are critical to rapid force projection operations and smaller scale contingencies.
- Use of space-based capabilities enables the force to dominate the battlefield.
- Space capabilities significantly increase combat effectiveness.
-

ASEDP Objectives

- Educate commanders on the use of space-based assets for Army operations.
- Assist in defining requirements for Army development.
- Demonstrate new technology for possible future development.
- Influence the design and use of future space systems.
- Conduct rapid prototyping in support of contingency operations.
- Assist the integration of mature space enhancements into Army Battle Command Systems

ASEDP FY00

All of SMDBL's ASEDP experiments for FY 00 are planned for integration into the Joint Contingency Force Advanced Warfighting Experiment (JCF AWE). The focus of the JCF AWE is to incorporate new warfighting concepts and information age technologies with the Army's light forces. They will continue to be expected to operate in Military Operations in Urban Terrain (MOUT) and restricted terrain environments. JCF AWE is the light force early entry portion of the Force XXI series of experiments. By utilizing JCF AWE, a cost effective venue became available for the SMDBL to exercise ASEDP experiments. The SMDBL JCF AWE- related initiatives are:

- Force Warning

- Mobile Satellite Service (MSS) and Hand-held Command and Control Wireless Communications
- Enroute Planning and Rehearsal System (EMPRS)
- Tactical Weather
- Precision SIGINT Targeting System (PSTS)
- Eagle Vision II (EVII)

Force Warning. The space-based Force Warning initiative provides a robust force warning and force protection architecture that supports Light and Strike Forces with the dissemination of time-sensitive battlefield intelligence. Force Warning devices (**Fig. 4-10**) receive critical messages such as incoming missile notification, minefield locations, chemical hazards, and guerrilla activity, and provides early entry forces with situational awareness in a handheld device. The space-based Force Warning initiative combines the use of a joint Common Operational Picture (COP) and processed intelligence data to determine battlefield hazards and send rapid notification directly to the affected or threatened forces.

Fig. 4-10. Force Warning Pager

Up to 25 Iridium pagers will be fielded during the JCF AWE. Elements of the 10th Mountain Division, 82nd Airborne Division, Special Operations Forces, and Rangers will be equipped with the Force Warning pager. Additionally, pagers will be located with the Joint Task Force (JTF) Headquarters and with the Air Force, Navy, and Marine Corps. The pagers will provide added value during many phases of the operation. The goal is for the pagers to be employed from the enroute mission planning and rehearsal phase through the heavy follow-on phase, providing forces with time-sensitive situational awareness and battlefield hazard notification.

Mobile Satellite Service (MSS) and Hand-held Command and Control Wireless Communications. (HC2WC)

This demonstration leverages current and emerging commercial Mobile Satellite Service (MSS) technologies to provide the Army commanders the ability to obtain a near-real time Common Operational Picture and to pass this COP to higher headquarters using Beyond Line of Sight (BLOS) communications. The demonstration allows the soldier in the field to pass current positional and situational information to higher headquarters and to receive regional COP from the Division Tactical Operations Center (DTOC). It can use low earth orbit (LEO), medium earth orbit (MEO), or geostationary earth orbit (GEO) satellites to provide the BLOS communications. This demonstration was initiated as part of the Joint Warrior Interoperability Demonstration (JWID) 1999, and demonstrated as the Joint Space-Based Common Operational Picture Enhancement (JSCOPE). The objectives of MSS/HC2WC are:

- Two-way messaging in common military
- Position Reports
- Call for Fire Messages

- Battlefield Situation Messages
- Self-contained device

Enroute Planning and Rehearsal System (EMPRS). The Enroute Mission Planning and Rehearsal System (EMPRS) (**Fig. 4-11**) provides commanders the capability to receive operations and intelligence updates while in flight, conduct collaborative planning with headquarters and forward elements, and disseminate and rehearse mission changes among the combat forces enroute to the objective area.

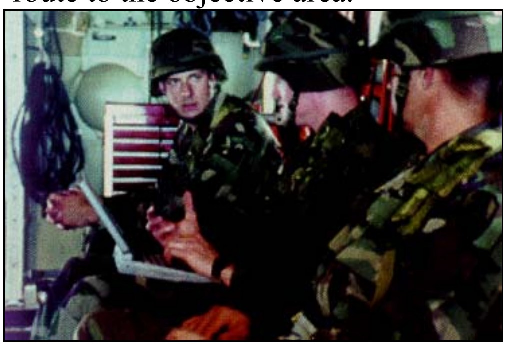

Fig. 4-11. EMPRS

EMPRS is a collaborative effort with SMDBL, the Dismounted Battlespace Battle Lab, ASEDP, and Team Monmouth to provide the aeronautical satellite communications connectivity for EMPRS. This communications segment exploits the growing commercial market in MSS. Through the use of SMDBL's Advanced Research Center Telecommunications Interface Console (ARCTIC), several satellite channels can be combined to give an overall data throughput sufficient to support collaborative planning functions such as chat, file transfer, whiteboarding, and teleconferencing.

Tactical Weather. For years, Army Commanders have been forced to cope with or avoid the weather. The Tactical Weather capability gives the Army Commander weather products that can change "cope or avoid" to "anticipate and exploit." This is accomplished through mission-focused weather products embedded in common Army Battle Command Systems (ABCS) applications. SMDBL is currently experimenting with two weather systems that will greatly enhance the commander's focus on the battlefield: the Deployable Weather Satellite Workstation (DWSW) and the Meteorological Automated Sensor and Transceiver (MAST). DSWS provides timely and accurate weather data that is critical to the battle plan. As a tactical terminal located in a tactical operations center (TOC), the DWSW will acquire, process, and distribute real-time high, resolution weather imagery and tailored products to users. This capability allows Staff Weather Officers (SWOs) to build a more complete weather database tailored to the commander's needs. DWSW is a commercial "off-the-shelf' system consisting of two 18-inch diameter flat-tracking antenna, a modular geostationary antenna seven feet in diameter, a computer workstation with color monitor, and a software package that provides zoom, imagery animation, and color enhancement. This entire package is transportable in the Army's High Mobility Multipurpose Wheeled Vehicle (HMMWV), or it can be palletized for air transport. DWSW served as the weather satellite receiver DWSW provides timely and accurate weather data during Task Force XXI and Division XXI AWEs. With SMDBL as the initiative proponent, DWSW will again be linked with the Army's Integrated Meteorological System to participate in the JCF AWE.

Utilizing satellite visual, infrared, and microwave sensors, the DWSW system provides weather data for the battlefield, day or night:

- Cloud imagery with resolution to 0.55 km for overlay on the ABCS.
- Cloud imagery for situational awareness and precipitation for mobility assessment.
- Three-dimensional atmospheric wind, temperature, and moisture fields.
- Surface temperature, soil moisture, snow and ice areas, and land classification.

Fig. 4-12. MAST

MAST (**Fig. 4-12**) integrates surface weather sensors (visibility, wind, temperature, barometric pressure, and humidity) with a LEO satellite transceiver relaying the information instantaneously. The man-portable MAST can be programmed to transmit surface weather observations hourly, or as often as needed, to the Division SWO. The MAST observations can become another digital layer of weather information for the ABCS.

Precision SIGINT Targeting System (PSTS). In a hostile environment, commanders need timely and accurate information about specific enemy targets. The Precision Signal Intelligence (SIGINT) Targeting System (PSTS) (**Fig. 4-13**) exploits an existing sensor-to-shooter architecture, providing information and supporting the timely destruction of time-critical and high payoff targets. The PSTS architecture capitalizes on the capabilities of the Guardrail Common Sensor (GRCS) and National Technical Means (NTM) to provide the warfighter with the location of enemy non-communication emitters (such as the radar used by the SA-6 air defense system depicted). The Army's organic Tactical Exploitation of National Capabilities (TENCAP) systems, together with the tactical SIGINT targeting architecture, support the timely and accurate delivery of priority target coordinates to commanders.

Fig. 4-13. PSTS Architecture

Eagle Vision II (EVII). Eagle Vision 11 (**Fig. 4-14**) is a mobile satellite ground station that receives a direct downlink of unclassified data from commercial imaging satellites. The data is processed and provided to deployed theater and corps tactical and operational commanders in usable digital image formats for command and control, mission planning, intelligence, and geographic information systems. EVII provides timely receipt of data for military operations and humanitarian assistance missions.

EVI I supports the development of situational awareness by providing the capability to collect, extract, and exploit information about the physical characteristics of the earth's surface, to include natural and man-made features, in order to build a basic foundation for the common knowledge of the battlespace. Terrain data may be generated or enriched by detailed analysis of raw images avail able from this theater asset. Terrain analysts will use the newly acquired data to enrich the digital topographic database with dynamic environment data, higher resolution feature data, and higher resolution elevation data.

Fig. 4-14. EV II

ARMY SPACE PROGRAM OFFICE (ASPO)

The Army Space Program Office, or ASPO, is responsible for the Army's tactical exploitation of national capabilities - TENCAP. The program focuses on exploiting current and future tactical potential of national systems and integrating the capabilities into the Army's tactical decision-making process. Army TENCAP systems enable the tactical commander to see and hear deep in today's battlefield and then assess the impact of shooting deep. The ASPO has successfully fielded more than 60 systems and is continually exploring ways to integrate advanced technologies into its inventory.

Primary ASPO Missions

Support appropriate organizations to develop/implement streamlined concepts of operation and requirements.

Design, develop, test, field, and sustain systems that provide national and theater products to tactical commanders.

Provide the responsible Program Executive Officers with the appropriate technologies and acquisition activities.

Provide technical support to the Army staff with respect to TENCAP activities.

Act as the focal point for technical, fiscal, and operational interactions with the national community to include:

- Identifying technologies to enhance the Army mission
- Coordinating training and exercise support for national systems
- Acting as point of contact for all tactical activities between major commands/users and the national community
- Serving as technical adviser and technical expert to TRADOC and battle labs.

TENCAP Systems

- The *Advanced Electronic Processing and Dissemination System* replaces the Enhanced Tactical User Terminal and Electronic Processing and Dissemination System. The system receives and processes raw data from selected national sensors, stores processed data, and produces intelligence reports, and has the dual function of situation awareness and projection.
- *Mobile Integrated Tactical Terminal, or MITT*, is a division- and corps-

level truck-mounted system capable of providing multiple source intelligence and secondary imagery to the tactical commander. It provides ETUT functionality in a smaller and more mobile configuration which receives, processes, and disseminates multi-disciplined information.

- *Forward Area Support Terminal* was developed to provide a downsized functional equivalent of the MITT, offering the same capabilities in a modular, portable system. This single position unit, weighing 1,200 pounds, is easily transportable.
- The *Tactical Exploitation System*, or TES, is the next generation TENCAP system. It combines total TENCAP functionality in an integrated, downsized, scalable system designed for split-base operations and can receive, process, exploit, and disseminate data. As a replacement for the Advanced Electronic Processing and Dissemination System, Modernized Imagery Exploitation System, and Enhanced Tactical Radar Correlator, the TES will be smaller, lighter, and more powerful than current systems. Enhanced Tactical Radar Correlator, or ETRAC, is the latest generation TENCAP system. It provides real-time radar imagery data to the corps commander and has the capability to receive direct downlinks from the U-2. The ETRAC is a highly mobile system that can drive on and off a C-130 aircraft, making it easy to provide direct support to early entry operations. The ETRAC is an enhanced version of the TRAC van used in Desert Storm to downlink U-2 imagery.
- *Modernized Imagery Exploitation System*, or MIES, was developed to support imagery operational areas, intelligence development for indication and warning, situation assessment, order of battle, targeting, and tactical operations. The MIES is a modernized version of the system deployed to Saudi Arabia to provide imagery support to CENTCOM during Desert Storm. MIES provides for the receipt, processing, exploitation, storage, and dissemination of imagery intelligence from national and selected theater collectors. Planned upgrades include interfaces to planned national capabilities and migration to Common Imagery Ground/Surface System standards.

CONCLUSIONS

The Army's dedication to maintaining a tactically relevant presence in the space community was demonstrated by General Gordon R. Sullivan (Retired), then Chief of Staff of the Army, when he stated:

"Aggressive exploitation of space capabilities and products normalized in concepts, doctrine, training, operations, and modernization will ensure that the Army is able to maintain land force domination well into the 21st century. The Army's future is inextricably tied to space."

Success on the future battlefield requires exploitation of the Army's five doctrinal tenets:

- *initiative,*
- *agility,*
- *depth,*
- *synchronization,*
- *and versatility.*

The extension of that battlefield into space provides commanders with an enhanced capability to exploit and advance these tenets across all Army operations. Combining near-continuous, global coverage, real-time and near-real-time capabilities for communications, positioning/

navigation, surveillance, environmental monitoring, warning and target acquisition allows commanders to anticipate enemy actions; strike at vulnerable points faster than the enemy can react; and win the land battle. Likewise, these same capabilities allow the commanders to have success in operations other than war.

As the Army moves into the 21st century, it's imperative that it remains involved in space and fully exploit space capabilities. The Army will continue to define its role, identify requirements and plan strategies for involvement. It will also participate more in the joint, combined, civil and commercial enviroments to optimize its use of this fourth medium of warfare.

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TOC

Chapter 5

SPACE LAW, POLICY AND DOCTRINE

Space policy and doctrine define the overarching goals and principles of the US space program. International and domestic laws and regulations, national interests and security objectives shape the US space program. Furthermore, fiscal considerations both shape and constrain space policy. Space policy formulation is a critical element of the US national planning process, as it provides the framework for future system requirements. This chapter outlines the basic tenets of US space policy and examines the international and domestic legal parameters within which the US conducts its space programs. The chapter details Department of Defense (DOD) and Air Force space policies, derived from The National Space Policy. It concludes with an analysis of the doctrinal principles that guide the conduct of military space activities.

INTERNATIONAL SPACE LAW

The term *space law* refers to a body of law drawn from a variety of sources and consisting of two basic types of law: international and domestic. The former refers to rights and obligations the US has agreed to through multilateral or bilateral international treaties and agreements. The latter refers to domestic legislation by Congress and regulations promulgated by executive agencies of the US government.

Table 5-1 (pp. 5-27 to 5-29) summarizes key international treaties and agreements that affect the scope and character of US military space activities. Listed below are some of the more important basic principles and rules.

International law applies to outer space. Such law includes the United Nations (UN) Charter, which requires all UN members to settle disputes by peaceful means, prohibits the threat to use or actual use of force against the territorial integrity or political independence of another state. The charter also recognizes a state's inherent right to act in individual or collective self-defense.

Outer space, the Moon, and other celestial bodies are not subject to appropriation by claim of sovereignty, use or occupation, or any other means. In 1976, eight equatorial countries claimed sovereignty over the geostationary orbital arc above their territory. Most other countries, including all major space powers, rejected the claim.

Outer space is free for use by all countries. This principle relates to the non-appropriation principle and is analogous to the right of innocent passage on the high seas.

Outer space will be used for peaceful purposes only. Most western nations, including the US, equate peaceful purposes with non-aggressive ones. Consequently, all non-aggressive military use of space is permissible, except for specific prohibitions of certain activities noted elsewhere in this section.

Astronauts are "peaceful envoys of mankind." If forced to make an emergency landing, they should not be harmed or held hostage and they must be returned to the launching country as soon as possible. Upon request, the spacecraft also should be returned if possible and the launching country will pay the costs involved.

Objects launched into space must be registered with the UN. Basic orbital parameters, launch origin, launch date and a brief explanation of the purpose of the satellite are required although the

UN set no time limit for providing this information.

A country retains jurisdiction and control over its registered space objects. This rule applies regardless of the condition of the objects.

A country is responsible for regulating, and is ultimately liable for, the outer space activities of its citizens. *In outer space, liability for damage is based on fault; therefore, assessing blame for objects colliding would be extremely difficult. The launching country is absolutely liable for damage caused on earth.*

Nuclear weapons tests and other nuclear explosions in outer space are prohibited. Before this prohibition in 1958, the US exploded three small nuclear devices in outer space in Project Argus. This occurred over a period of two weeks; such an experiment would not be permissible today.

Nuclear weapons and other weapons of mass destruction (such as chemical and biological weapons) may not be placed into orbit, installed on celestial bodies, or stationed in space in any other manner.

A country may not test any kind of weapon; establish military bases, installations, or fortifications, nor conduct military maneuvers on celestial bodies. The use of military personnel for scientific research or other peaceful purposes is permissible.

The development, testing, or deployment of space-based antiballistic missile (ABM) systems or components are prohibited. This prohibition does not apply to research and development of space-based ABMs preceding field testing.

Interfering with national technical means of verification is prohibited provided such systems are operating in accordance with generally recognized principles of international law and are in fact being used to verify provisions of specific treaties.

The US adheres to the premise in international law that any act not specifically prohibited is permissible. Thus, even though the list (see **Table 5-1**) of prohibited acts is sizable, there are few legal restrictions on the use of space for non-aggressive military purposes. As a result, international law implicitly permits the performance of such traditional military functions as surveillance, reconnaissance, navigation, meteorology and communications. It permits the deployment of military space stations along with testing and deployment in earth orbit of non-nuclear (and, until 2002, non-ABM) weapon systems. This includes anti-satellite weapons, space-to-ground conventional weapons, the use of space for individual and collective self-defense, and any conceivable activity not specifically prohibited or otherwise constrained.

Another widely accepted premise is that treaties usually regulate activities between signatories only during peacetime. This rule holds true unless a treaty expressly states that its provisions apply or become operative during hostilities, or the signatories can deduce this from the nature of the treaty itself. In other words, countries presume that armed conflict will result in the suspension or termination of a treaty's provisions. Good examples are treaties whose purpose is to disarm or limit quantities of arms maintained by the signatories. Therefore, during hostilities, the scope of permissible military space activities may broaden significantly.

Finally, it is important to understand that the former Soviet Union (FSU) has been the most important space power next to the US. The Soviet Union signed most of the peace-related treaties to which the US has agreed upon, some of which are bilateral agreements exclusively with that nation. As the USSR dissolved, the US adopted a policy of continuing to observe the requirements of all treaties and to apply their provisions to the independent states that have emerged. Nevertheless, a degree of legal uncertainty is likely to exist for a period of years until precedent establishes policy more firmly, or until formal agreements conclude with the new states. Although uncertainty applies on both sides, the obligations of the US under the new conditions are clear because the state of US sovereignty has not changed and the spirit of the original agreements still exists.

Regardless of US policy, the US cannot unilaterally hold any of the FSU states to any agreements. Most of the FSU states have agreed to continue to discharge the obligations arising out of international agreements signed by the USSR; however, not all have been formally ratified or acceded to.

A prime example of this is the ABM Treaty which was the subject of much debate both in Congress and with the Russians. The US wanted to press ahead with a limited form of national missile defense against the emerging missile technology in rogue nations, while the Russians remained vehemently opposed to any such system. The President rendered his decision in 2001.

DOMESTIC SPACE LAW

Domestic law has always shaped military space activities through the spending authorization and budget appropriation process. For example, when Congress deleted funding for further testing of the USAF's direct ascent Anti-Satellite (ASAT) weapon in the mid- 1980s, it effectively canceled the program. In addition, a number of laws not designed solely to address space have a space aspect. For instance, under the Communications Act of 1934, the president has the authority to gain control of private communications assets owned by US corporations during times of crisis. Since the 1960s, this authority has included both the ground and space segments of domestically owned communications satellites. Space-specific legislation (beyond the annual National Aeronautics and Space Administration (NASA) authorization) is a relatively recent activity.

The Reagan administration placed emphasis on the creation of a third sector of space activity, that of commercial space, in addition to the traditional military and civil sectors. For example, Congress passed the Commercial Space Launch Act of 1984 to facilitate the development of a commercial launch industry in the US. From a DOD perspective, the importance of this legislation lies in its authorization for commercial customers to use DOD launch facilities on a reimbursable basis. Thus, DOD is now in the overseeing commercial operations from its facilities and placing commercial payloads in the launch queue. Although a recent development, there is a trend towards intertwining the commercial space industry and DOD space programs, whenever possible.

The Commercial Space Act of 1998 furthered this policy of getting the government out of the launch business and requires a DOD study of the projected launch services through 2007. It also calls on the DOD to identify the "technical, structural and legal impediments associated with making launch sites or test ranges in the US viable and competitive." It also requires the government to purchase space transportation services instead of building and operating its own vehicles, calls for NASA to privatize the space shuttle and allows for excess ICBMs to be used as low-cost space boosters.

NATIONAL SPACE POLICY

A nation's space policy is extremely important, especially as it relates to space law and space doctrine. In order to understand present US space policy and attempt to predict its future, an examination of its evolution is necessary. Keep in mind, that while policy provides space goals and a national framework, national interests and national security objectives actually shape the policy. This framework will lead towards building and meeting future US requirements and subsequent national space strategies.

Early Policy

The launch of Sputnik I on 4 October 1957 had an immediate and dramatic impact on the formulation of US space policy. Although the military had expressed an interest in space technology as early as the mid 1940s, a viable program failed to emerge for several reasons. These include: intense interservice rivalry; military preoccupation with the development of ballistic missiles that prevented a sufficiently high funding priority from being assigned to proposed space systems; and national leadership that did not initially appreciate the strategic and international implications of emerging satellite technology. Once national leadership gained this appreciation, it became committed to an open and a purely scientific space program.

The emergence of Sputnik I transposed this line of thought: besides clearly demonstrating the Soviets had the missile technology to deliver payloads at global ranges, Sputnik led to much wider appreciation of orbital possibilities. The result was the first official US government statement that space indeed, was of military significance. This statement, issued on 26 March 1958 by President Dwight D. Eisenhower's science advisory committee, stated that the development of space technology and the maintenance of national prestige were important for the defense of the United States. Congress also quickly recognized that space activities were potentially vital to national security.

The first official national space policy was the National Aeronautics and Space Act of 1958. This act stated the policy of the United States was to devote space activities to peaceful purposes for the benefit of all humankind. It mandated separate civilian and national security space programs and created a new agency, the National Aeronautics and Space Administration to direct and control all US space activities, except those "peculiar to or primarily associated with the development of weapons systems, military operations, or the defense of the United States." The Department of Defense was to be responsible for these latter activities.

A legislative basis for DOD responsibilities in space was thereby provided early in the space age. The act established a mechanism for coordinating and integrating military and civilian research and development. It also encouraged significant international cooperation in space and called for preserving the role of the US as a leader in space technology and its application. Thus, the policy framework for a viable space program was in place. The principles enunciated by NASA have become basic tenets of the US space program. These tenets included: peaceful focus on the use of space, separation of civilian and military space activities, emphasis on international cooperation and preservation of a space role. All presidential space directives issued since 1958 have reaffirmed these basic tenets.

However, a space program of substance still did not exist. The Eisenhower administration's approach to implementing the new space policy was conservative, cautious and constrained. The government consistently disapproved of the early DOD and NASA plans for manned space flight programs. Instead the administration preferred to concentrate on unmanned, largely scientific missions and to proceed with those missions at a measured pace. It was left to subsequent administrations to give the policy substance.

Intervening Years

Two presidential announcements, one by John F. Kennedy on 25 March 1961 and the second by Richard M. Nixon on 7 March 1970, were instrumental in providing the focus for the US space program. The Kennedy statement came during a period of intense national introspection. The Soviet Union launched and successfully recovered the world's first cosmonaut. Although Yuri Gagarin spent just 89 minutes in orbit, his accomplishment electrified the world. This caused the US to question its scientific and engineering skills as well as its entire educational system. The American response articulated by President Kennedy as a national challenge to land a man on the Moon and return him safely to Earth defined US space goals for the remainder of the decade.

Prestige and international leadership were clearly the main objectives of the Kennedy space program. However, the generous funding that accompanied the Apollo program had important collateral benefits as well. It permitted the buildup of US space technology and the establishment of an across-the-board space capability that included planetary exploration, scientific endeavors, commercial applications and military support systems.

President Johnson's years in office saw the commencement of work on nuclear ASATs and the cancellation of the DynaSoar (Dynamic Ascent and Soaring) Flight program. This program, which began in 1958, was a 35 foot glider with a small delta wing and was to be boosted into orbit by a Titan III rocket. The program was determined to be unnecessary in light of NASA's manned spacecraft program.

As the 1960s drew to a close, a combination of factors including domestic unrest, an unpopular foreign war and inflationary pressures forced the nation to reassess the importance of the space program. Against this backdrop, President Nixon made his long-awaited space policy announcement in March 1970. His announcement was a carefully considered and worded statement that was clearly aware of political realities and the mood of Congress and the public. In part, it stated:

"Space expenditures must take their proper place within a rigorous system of national priorities....Operations in space from here on in must become a normal and regular part of national life. Therefore, they must be planned in conjunction with all of the other undertakings important to us."

Although spectacular lunar and planetary voyages continued until 1975 as a result of budgetary decisions made during the 1960s, the Nixon administration considered the space program of intermediate priority and could not justify increased investment or the initiation of large new projects. It viewed space as a medium for exploiting and extending the previously realized technological and scientific gains. The emphasis was on practical space applications to benefit American society in a variety of ways.

During the Nixon years, the space world saw three notable events:

- On 5 January 1972, Nixon approved the development of the space shuttle.
- The National Aeronautics and Space Council (started by the Space Act of 1958) was inactivated.
- The Gemini B/Manned Orbiting Laboratory (MOL) was shelved due to lack of urgency and funding.

Within the DOD, this accentuation on practicality translated into reduced emphasis on manned spaceflight, but led to the initial operating capability for many of the space missions performed today. For example, initial versions of the systems were all developed and fielded during this period. These versions are now known as: the Defense Satellite Communications System, the Defense Support Program, the Defense Meteorological Satellite Program and the Navy's Transit Navigation Satellite Program (later to evolve as the Global Positioning System).

One major new space initiative undertaken during the l970s eventually had far greater impact on the national space program than planners had originally envisioned: the space transportation system (STS), or space shuttle. The shuttle's goal was routine and low-cost access to orbit for both civil and military sectors. However, as development progressed, the program experienced large cost and schedule overruns. These problems caused the US space program to lose much of its early momentum, as the high costs would adversely affect other space development efforts, both civil and military. In addition, schedule slippage meant a complete absence of American astronauts in space for the remainder of the decade.

Carter Administration Space Policy

President Jimmy Carter's administration conducted a series of interdepartmental studies to address the malaise that had befallen the nation's space effort. The studies addressed apparent fragmentation and possible redundancy among civil and national security sectors of the US space program. It also sought to develop a coherent recommendation for a new national space policy. These efforts resulted in two 1978 Presidential Directives (PD): PD-37, National Space Policy and PD-42, Civil Space Policy.

PD-37 reaffirmed the basic policy principles contained in the National Aeronautics and Space Act of 1958. It identified the broad objectives of the US space program, including the specific guidelines governing civil and national security space activities.

PD-37 was important from a military perspective because it contained the initial, tentative indications that a shift was occurring in the national security establishment's view on space. Traditionally, the military had seen space as a force enhancer, or an environment in which to deploy systems to increase the effectiveness of land, sea and air forces. Although the focus of the Carter policy was clearly on restricting the use of weapons in space, PD-37 reflected an appreciation of the importance of space systems to national survival; a recognition of the Soviet threat to those systems; and a willingness to push ahead with development of an anti-satellite capability in the absence of verifiable and comprehensive international agreements restricting such systems. In other words, the administration was beginning to view space as a potential war-fighting medium.

PD-42 was directed exclusively at the civil space sector to guide US efforts over the next decade. However, it was devoid of any long-term space goals, expecting the nation to pursue a balanced evolutionary strategy of space applications, space science, and exploration activities. The absence of a more visionary policy reflected the continuing developmental problems with the shuttle and the resulting commitment of larger than expected resources.

Reagan Administration Space Policy

President Ronald Reagan's administration published comprehensive space policy statements in 1982 and 1988. The first policy statement, pronounced on 4 July 1982 and embodied in National Security Decision Directive 42 (NSDD-42), reaffirmed the basic tenets of previous (Carter) US Space Policy. It also placed considerable emphasis on the STS as the primary space launch system for both national security and civil government missions. In addition, it introduced the basic goals of promoting and expanding the investment and involvement of the private sector in space. Space-related activities comprise a third element of US space operations, which complemented national security and the civil sectors.

The single statement of national policy from this period that most influenced military space activities and illuminated the transition to a potential space war-fighting framework is NSDD-85, dated 25 March 1983. Within this document, President Reagan stated his long term objective to eliminate the threat of nuclear armed ballistic missiles through the creation of strategic defensive forces. This NSDD coincided with the establishment of the Strategic Defense Initiative Organization (SDIO) and represented a significant step in the evolution of US space policy. Since 1958, the US had, for a variety of reasons, refrained from crossing an imaginary line from space systems designed to operate as force enhancers to establishing a warfighting capability in space. The anti-satellite (ASAT) initiative of the Carter administration was a narrow response to a specific Soviet threat. However, the SDI program represented a significant expansion in the DOD's assigned role in the space arena.

The second comprehensive national space policy incorporated the results of a number of developments that had occurred since 1982, notably the US commitment in 1984 to build a space station and the space shuttle Challenger.

For the first time, the national space program viewed commercial space equal to the traditional national security and civil space sectors. Moreover, the new policy dramatically retreated from its previous dependence on the STS and injected new life into expendable launch vehicle programs. In the national security sector, this program was the first to address space control and force application at length, further developing the transition to warfighting capabilities in space.

In 1988, the last year of the Reagan presidency, Congress passed a law allowing creation of a National Space Council (NSPC), a cabinet-level organization designed to coordinate national policy among the three space sectors. The incoming administration would officially establish and very effectively use the National Space Council.

Bush Administration Space Policy

Released in November 1989 as National Security Directive 30 (NSD-30), and updated in a 5 September 1990 supplement, the Bush administration's national space policy retained the goals and emphasis of the final Reagan administration policy. The Bush policy resulted from an NSPC review to clarify, strengthen and streamline space policy, and has been further enhanced by a series of National Space Policy directives (NSPD) on various topics. Areas most affected by the body of Bush policy documentation included:

- US Commercial Space Policy Guidelines
- Provision of a framework for the National Space Launch Strategy
- Landsat Remote Sensing Strategy
- Space exploration initiative
- Concern for the Space-based Global Change Observation, a key component to the nation's overall approach to global stewardship and one of the nation's highest priority science programs

The policy reaffirmed the organization of US space activities into three complementary sectors: civil, national security and commercial. The three sectors coordinate their activities to ensure maximum information exchange and minimum duplication of effort.

The Bush policy proceeds to detail specific policy, implementing guidelines and actions for each of the three space sectors and inter-sector activities. The civil sector will engage in all manners of space-related scientific research, will develop space-related technologies for government and commercial applications, and establish a permanent manned presence in space. NASA is the lead civil space agency.

NASA and the Departments of Defense, Commerce and Transportation work cooperatively with the commercial sector to make government facilities and hardware available on a reimbursable basis.

The US will conduct those activities in space that are necessary to national defense. Such activities contribute to security objectives by: (1) deterring or, if necessary, defending against enemy attack; (2) assuring that enemy forces cannot prevent our use of space; (3) negating, if necessary, hostile space systems; and (4) enhancing operations of US and allied forces. In order to accomplish these objectives, DOD develops, operates and maintains a robust space force structure capable of satisfying the mission requirements of space support, force enhancement, space control and force application.

Primarily directed at the civil and national security sectors, several policy requirements apply across sector divisions. These include such things as continuing the technology development and operational capabilities of remote-sensing systems, space transportation systems, space-based communications systems and the need to minimize space debris.

Clinton Administration Space Policy

A repositioning of priorities in the Clinton Administration was reflected by the decision in August 1993, to merge various White House science and technology councils into one National Science and Technology Council (NSTC), which would do most of the day-to-day work through permanent or ad hoc interagency working groups. The National Space Council was absorbed into the new "NSTC" along with the National Critical Materials Council and the Federal Coordinating Council for Science, Engineering and Technology.

The White House structure for articulating national policy for science and technology was put in place by the Presidential Review Directive (PRD)/NSTC series and the Presidential Decision Directive (PDD)/NSTC series as established by PDD/NSTC 1. Within four months during the summer of 1994, three additional policies were established articulating Clinton's space policy.

PDD/NSTC 2 - US POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEMS (May 94)

PDD/NSTC 2 calls for the Department of Commerce and Defense "to integrate their programs into a single, converged, national polar-orbiting operational environmental weather satellite system." This began occurring in 1997. The DMSP satellite program merged with the National Oceanic Atmospheric Administration (NOAA) satellite program in May 1998. The new system formed by the merger of the two programs will be known as the Polar Orbiting Environmental Satellite (POES) System.

PDD/NSTC 3 - LANDSAT REMOTE SENSING STRATEGY (May 94)

PDD/NSTC 3 replacing Bush's NSPD 5 assures "the continuity of LANDSAT-type and quality of data," and reduces the "risk of data gap," that is, loss of earth sensing data due to a lack of LANDSAT."

PDD/NSTC 4 - National Space Transportation Policy (Aug 94)

PDD/NSTC 4 superseded all previous policies for US space transportation and "establishes national policy, guidelines, and implementation actions for the conduct of national space transportation programs." It also provides allocated space transportation responsibilities among Federal civil and military agencies.

In May 1996, President Clinton set forth his National Space Policy.

Current National Space Policy

PDD/NSTC 8 - National Space Policy (May 96)

In September 1996, the Clinton administration released its National Space Policy which had five goals:

- Knowledge by exploration (1989)
- Maintain national security (1989)
- Enhance competitiveness and capabilities(new)
- Private sector investment (1989)
- Promote international cooperation (1989)

These goals are very similar to those established in 1978 by President Carter and their heritage goes back as far as the 1958 National Aeronautics and Space Act under Eisenhower.

For each major area covered in the 1996 National Space Policy (Civil space, Defense space, Intelligence space, Commercial space and Intersector space), a set of guidelines similar to the ones in the 1989 National Space Policy was established.

Department of Defense Sector Guide-Lines

The most current National Space Policy is largely classified and supersedes the 1989 policy. Unclassified prominent aspects of the new policy dealing with DOD include:

- Renewed direction that the US will maintain its leadership role by supporting a strong, stable and balanced national space program that serves our goals in national security and other areas.
- Renewed direction that the goals of the US space program include:
  - Strengthening and maintaining the national security of the US
  - Promoting international cooperation to further US national security and foreign policies.
- Renewed direction that the US will conduct those space activities necessary for national security.
- Direction that key priorities for national security space activities are to improve our ability to support military operations worldwide, monitor and respond to strategic military threats, and monitor arms control and nonproliferation agreements and activities.
- Direction that the Secretary of Defense and the Director of Central Intelligence shall ensure that defense and intelligence space activities are closely coordinated; that space architectures are integrated to the maximum extent feasible; and will continue to modernize and improve their respective activities to collect against, and respond to, changing threats, environments and adversaries.
- Renewed direction that national security space activities shall contribute to US national security by:
  - Providing support for the US's inherent right of self defense and our defense commitments to allies and friends;
  - Deterring, warning and, if necessary, defending against enemy attack;
  - Assuring that hostile forces cannot prevent our own use of space;
  - Countering, if necessary, space systems and services used for hostile purposes;
  - Enhancing operations of US and allied forces;
  - Ensuring our ability to conduct military and intelligence space-related activities;
  - Satisfying military and intelligence requirements during peace and crisis as well as through all levels of conflict; and;

* Supporting the activities of national policy makers, the intelligence community, the National Command Authorities, combatant commanders and the military services, other federal officials and continuity of government operations.

- Direction that critical capabilities necessary for executing space missions must be assured.
- Renewed direction that DOD shall maintain the capability to execute the mission areas of space support, force enhancement, space control and force application.
- Renewed direction that DOD, as launch agent for both the defense and intelligence sectors, will maintain the capability to evolve and support those space transportation systems, infrastructure and support activities necessary to meet national security requirements.
- Direction that DOD will be the lead agency for improvement and evolution of the current expendable launch vehicle fleet, including appropriate technology development.
- Direction that DOD will pursue integrated satellite control, continue to enhance the robustness of its satellite control capability and coordinate with other departments and agencies, as appropriate, to foster the integration and interoperability of satellite control for all governmental space activities.
- Renewed direction that, consistent with treaty obligations, the US will develop, operate and maintain space control capabilities to ensure freedom of action in space and, if directed, deny such freedom of action to adversaries.
- Direction that the US will pursue a ballistic missile defense program to provide for: enhanced theater missile defense capability later this decade; a national missile defense deployment readiness program as a hedge against the emergence of a long-range ballistic missile threat to the US; and an advanced technology program to provide options for improvements to planned and deployed defenses.

In general, this first post-Cold War statement of National Space Policy provides a coherent vision and direction for the conduct of space activities in response to the major changes which have occurred since 1989.

The significance of the policy is the degree to which the Department of Defense has recognized the utility of space in accomplishing national security objectives.

Department of Defense Space Policy

On July 9, 1999 the Secretary of Defense released the new revision to the DOD Space Policy, the previous one being dated 1987. This DOD Space Policy incorporates new policies and guidance promulgated since 1987 and includes the new National Space Policy issued by President Clinton in October 1998. It sets the freedom of space as a vital area, establishes definitions of the four mission areas using terms space combat, combat support, service support and space as a medium just like air, sea and land.

Major changes address the transformation of the international security environment; the promulgation of new national security and national military strategies; changes in the resources allocated to national defense; changes in force structure; lessons learned from the operational employment of space forces; the global spread of space systems, technology, and information; advances in military and information technologies; the growth of commercial space activities; enhanced inter-sector cooperation; and increased international cooperation.

In addition, the DOD Space Policy establishes a comprehensive policy framework for the conduct of space and space-related activities. US SPACE

COMMAND is listed as the POC for DOD military space. The DOD policy also calls for integrating space into military operations doctrine.

The DOD Space Policy is published as DOD Directive 3100.10 and is dated July 9, 1999. Because of its importance, the entire document is included at Appendix D of this SRG.

Air Force Space Policy

The earliest recorded statement of Air Force policy regarding space occurred on 15 January 1948, when Gen Hoyt S. Vandenberg stated: "The USAF, as the service dealing primarily with air weapons especially strategic has logical responsibility for the satellite." As reflected in General Vandenberg's statement, Air Force leaders have traditionally viewed space as an atmosphere in which the Air Force would have principle mission responsibilities. This view was perhaps best articulated by former Air Force Chief of Staff Gen Thomas D. White, when he coined the term *aerospace* during testimony before the House Committee on Science and Astronautics in February 1959:

"Since there is no dividing line, no natural barrier separating these two areas (air and space), there can be no operational boundary between them. Thus, air and space comprise a single continuous operational field in which the Air Force must continue to function. The area is aerospace."

As a result of this early positioning, the Air Force assumed the predominate space role within DOD. The Air Force Space Policy evolved as that role expanded. However, the policy was not formally documented until 1988. In late 1987 and early 1988, the Air Force convened the Blue Ribbon Panel on the future of the Air Force in space. A senior-level working group composed of both space and aviation professionals considered whether the service should continue to seek the leadership role for DOD space activities, and if so, how best to proceed.

The panel strongly affirmed the desirability of operating in space to accomplish Air Force missions and achieve wider national security objectives. It also developed a list of recommendations for making most effective use of the space arena in future Air Force operations. On 2 December 1988, the Air Force formally adopted the Blue Ribbon Panel's fundamental assumptions and codified them in a new space policy document. With only a few minor modifications to accommodate organizational change within the service, this document remains the current statement of comprehensive Air Force space policy. The tenets of that policy are:

Space power will be as decisive in future combat as air power is today. This long-term vision recognizes the inherent advantages that space operations bring to military endeavors and looks forward to a time when technology, experience and widespread acceptance allow the US to make full use of those advantages.

The US must be prepared for the evolution of space power from combat support to the full spectrum of military capabilities. The Air Force believes that space is a military operating arena just as are land, sea and air. Expansion of the space control and force application mission areas is necessary and desirable to take full advantage of space for effective accomplishment of national security objectives.

The Air Force will make a solid corporate commitment to integrate space throughout the Air Force. To use space effectively, the Air Force must fully institutionalize space operations. There can be no separation of a "space Air Force" and an "aviation Air Force." Combat power is greatest and most effective when operations in the two mediums are closely integrated. In an effort to accomplish this integration, the Air

Force became devoted to: incorporate space into its doctrine; normalize space responsibilities within the Air Staff; institute personnel cross-flow measures to expand space expertise throughout the service; encourage space-related mission solutions and expertise at all major commands and air component commands; and consolidate space system requirements, advocacy and operations (exclusive of developmental systems) in Air Force Space Command.

The US, DOD, and Air Force all have a policy for the military space mission areas of space control, force application, force enhancement and space support, possessing implementation guidelines for each area. An updated AF Space Policy is expected shortly in light of the new National and DOD Space Policies.

In summary, US national space policy has, for the most part, kept pace with the growth of its US space program and is now one of the most well-documented areas of government policy. It clearly articulates goals that are both challenging and within the realm of possibility.

SPACE DOCTRINE

Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms,* defines doctrine as "fundamental principles by which the military forces or elements thereof guide their actions in support of national objectives. It is authoritative but requires judgment in application." A shorter and perhaps more workable definition espoused by Professor I. B. Holley, Jr., of Duke University is: "military doctrine is what is officially believed and taught about the best way to conduct military affairs."

Accordingly, military space doctrine articulates what is officially believed and taught about the best way to conduct military space affairs. This section examines joint space doctrine and Air Force space doctrine.

Doctrine drives the strategy that allows you to accomplish the mission. Doctrine provides a knowledge base for making strategy decisions. Without doctrine, military strategists would have to make decisions without points of reference and continually be faced with reinventing the wheel and risk repeating past mistakes. Doctrine and strategy are linked in that doctrine offers an analysis of lessons learned to devise and carry out strategy.

Strategy originates in policy and is an implementation of doctrine. Strategy addresses broad objectives and the plans for achieving them. While doctrine describes how a job should be done to achieve an objective, strategy defines how a job will be accomplished to achieve national political objectives. Thus, strategy, as defined by Webster, is the science or art of military command as applied to overall planning and conduct of large-scale combat operations, designed to support national policy and political objectives.

NATIONAL SECURITY STRATEGY

National security strategy changes with the world's political and economic environments. What was strategy during the Cold War changed dramatically during the post-Cold War era of the 1990s.

In the post-Cold War era, national security strategy focused initially on "engagement and enlargement" which placed the US at the forefront of driving international relations. This new strategy called for the US to be engaged around the world with the objective of enlarging the family of democratic nations.

In October 1998, the White House issued its *"A National Security Strategy for a New Century."*

This latest strategy states that the nation's challenge and responsibility are to sustain the US's role as the most powerful force for peace, prosperity and the universal values of democracy and freedom. To accomplish that goal, the US must harness the forces of global integration for the benefit of our own people and people around the world. The national security strategy is pursuing a tional security strategy is pursuing a forward-looking strategy attuned to the realities of the new era (21st century).

The new national security strategy has three core objectives:

- To enhance our security;
- To bolster America's economic prosperity; and
- To promote democracy abroad.

During the last five years, the US has been putting this strategy in place through a network of institutions and arrangements with distinct missions but with a common purpose— to secure and strengthen the gains of democracy and free markets while turning back their enemies. These institutions and arrangements are laying a foundation for security and prosperity in the 21st century.

This new national security strategy encompasses a wide range of initiatives known as the *"imperative of engagement"* – shaping the international environment in appropriate ways to bring about a more peaceful and stable world. These initiatives include expanded military alliances like NATO, its Partnership for Peace program, and its partnerships with Russia and the Ukraine; promoting free trade through the World Trade Organization and the move toward free trade zones in the Americas and elsewhere around the world; strong arms control regimes like the Chemical Weapons Convention and the Comprehensive Nuclear Test Ban Treaty; multinational coalitions combating terrorism, corruption, crime and drug trafficking; and binding international commitments to protect the environment and safeguard human rights.

This strategic approach requires that the US must lead abroad if we are to be secure at home, but we cannot lead abroad unless we are strong at home. Today's complex security environment demands that all of our instruments of national power be effectively integrated to achieve our security objectives.

These global leadership efforts will be guided by President Clinton's strategic priorities:

- To foster regional efforts led by the community of democratic nations to promote peace and prosperity in key regions of the world;
- To increase cooperation in confronting new security threats that defy borders and unilateral solutions;
- To strengthen the military, diplomatic and law enforcement tools necessary to meet these challenges; and
- To create more jobs and opportunities for Americans through a more open and competitive economic system that also benefits others around the world.

This strategy is tempered by the recognition that there are limits to America's involvement in the world. The US must be selective in the use of its capabilities and the choices made in advancing these objectives.

Quadrennial Defense Review

The Quadrennial Defense Review (QDR) looks at the National Security Strategy to determine where we were, where we are now, and where we are going. The QDR (1999) takes a fresh look at the world today and beyond to identify threats, risks, and opportunities for the US national security. From this, an overarching *defense strategy* is developed to deal with the world today and tomorrow, identify military capabilities, and the policies and programs needed to support them.

The QDR then focused on the fundamentals of military power today and in the future: quality people, ready forces, and superior organization, doctrine and technology needed to meet national objectives and strategy.

The template for seizing the technologies of the future and ensuring military dominance is *Joint Vision 2010,* the plan set forth by the Chairman of the JCS for military operations in the future.

The QDR then defined a *shape-respond-prepare strategy* to build on the strategic foundation of the past and our experiences since the end of the Cold War. This strategy determines that the US must be capable of fighting and winning two major theater wars nearly simultaneously.

This requires the continuing need to maintain a continuous overseas presence in order to *shape* the international environment and to be better able to *respond* to a variety of smaller scale contingencies and asymmetric threats. The QDR also placed great emphasis on the need to *prepare now* for the future in which hostile and potentially hostile states will acquire new capabilities.

The QDR then discusses how JV2010 will describe the future of US military forces and the four operational concepts. Finally, the QDR discusses how defense forces are rebalanced to preserve combat capability and readiness.

National Military Strategy

The military has an important role in this "imperative of engagement" outlined by the President. The objective – to defend and protect US national interests – requires the US Armed Forces to advance national security by applying military power to help *Shape* the international environment and *Respond* to the full spectrum of crises, while they *Prepare Now* for an uncertain future.

Elements of Strategy

Shaping the International Environment. The US Armed Forces help shape the international environment through deterrence, peacetime engagement activities, and active participation and leadership in alliances. By increasing understanding and reducing uncertainty, engagement builds constructive security relationships, helps to promote the development of democratic institutions, and helps keep some countries from becoming adversaries tomorrow.

Responding to the Full Spectrum of Crises. The US military will be called upon to respond to crises across the full range of military operations. Our demonstrated ability to rapidly respond and to decisively resolve crises provides the most effective deterrent and sets the stage for future operations.

Preparing Now for an Uncertain Future. As we move into the next century, it is imperative that the US maintain the military superiority essential to our global leadership.

Strategic Concepts

The National Military Strategy describes four strategic concepts that govern the use of our forces to meet the demands of the strategic environment.

- *Strategic Agility* is the timely concentration, employment and sustainment of US military power anywhere, at our own initiative, and at a speed and tempo that our adversaries cannot match. Strategic agility allows us to conduct multiple missions, across the full range of military operations, in geographically separated regions of the world.
- *Overseas presence* is the visible posture of US forces and infrastructure strategically positioned forward, in and near key regions. Forces present overseas promote stability, help prevent conflict, and ensure the protection of US interests. Our overseas presence demonstrates our determination to defend US, allied, and friendly interests while ensuring our ability to rapidly concentrate combat power in the event of a crisis.
- *Power Projection* is the ability to rapidly and effectively deploy and sustain US military power in and from multiple, dispersed locations

until conflict resolution. Power projection provides the flexibility to respond swiftly to crises, with force packages that can be adapted rapidly to the environment in which they must operate, and if necessary, fight their way into a denied theater.

- *Decisive Force* is the commitment of sufficient military power to overwhelm an adversary, establish new military conditions, and achieve a political resolution favorable to US national interests.

THE JOINT FORCE

Joint Vision 2010

Joint Vision 2010, published by the Chairman of the JCS, is a conceptual template for how the Armed Forces will work in the future to achieve new levels of effectiveness in joint warfighting. JV2010 embodies the improved intelligence and command and control available in the information age and envisions four operational concepts:

- *Dominant Maneuver* refers to the multidimensional application of information, engagement and mobility capabilities to position and employ widely dispersed joint land, sea, air and space forces to accomplish the mission.
- *Precision Engagement* consists of a system of systems that enables our forces to locate an object or target, provide responsive C2, generate the desired effect, assess the level of success and retain the flexibility to re-engage with precision when required.
- *Full Dimensional Protection* will be control of the battlespace to ensure our forces can maintain freedom of action while providing multi-layered defense for forces and facilities at all levels.
- *Focused Logistics* is the fusion of information, logistics and transportation technologies that provide rapid crisis response, to track and shift assets while enroute, and to deliver tailored logistics packages where needed.

General Henry Shelton, the new Chairman of the JCS, in his Posture Statement before the 106th Congress in February 1999 stated his support for the new National Security Strategy and the "imperative of engagement." He restated the concept of Joint Vision 2010 and said that "to ensure that tomorrow's Joint Force remains the world's best, we are moving forward to "operationalize" Joint Vision 2010, (which is) our conceptual framework for future joint operations.

One of the concepts for future joint operations is to organize the Unified Commands under the Unified Command Plan (UCP). One of his objectives is to establish a Joint Forces Command, a Space and Information Command, and a joint command for homeland defense. The Joint Forces Command is in the UCP for establishment in 1999.

Joint Vision 2020

The new Joint Vision 2020 has recently been released by the JCS. This vision focuses on full spectrum dominance as the major point for future warfare.

Joint Vision 2020 builds upon and extends the conceptual template established by *Joint Vision 2010* to guide the continuing transformation of America's Armed Forces. The primary purpose of those forces has been and will be to fight and win the Nation's wars. The overall goal of the transformation described in this document is the creation of a force that is dominant across the full spectrum of military operations – persuasive in peace, decisive in war, preeminent in any form of conflict.

In 2020, the nation will face a wide range of interests, opportunities, and challenges and will require a military that can both win wars and contribute to peace. The global interests and responsibilities of the United States will endure, and there is no indication that threats to those interests and responsibilities, or to our allies, will disappear. The strategic concepts of decisive force, power projection, overseas presence, and strategic agility will continue to govern our efforts to fulfill those responsibilities and meet the challenges of the future. This document describes the operational concepts necessary to do so.

If our Armed Forces are to be faster, more lethal, and more precise in 2020 than they are today, we must continue to invest in and develop new military capabilities. This vision describes the ongoing transformation to those new capabilities. As first explained in *JV 2010*, and dependent upon realizing the potential of the information revolution, today's capabilities for maneuver, strike, logistics, and protection will become dominant maneuver, precision engagement, focused logistics, and full dimensional protection.

The joint force, because of its flexibility and responsiveness, will remain the key to operational success in the future. The integration of core competencies provided by the individual Services is essential to the joint team, and the employment of the capabilities of the Total Force (active, reserve, guard, and civilian members) increases the options for the commander and complicates the choices of our opponents. To build the most effective force for 2020, we must be fully joint: intellectually, operationally, organizationally, doctrinally, and technically.

The overarching focus of this vision is full spectrum dominance – achieved through the interdependent application of dominant maneuver, precision engagement, focused logistics, and full dimensional protection. Attaining that goal requires the steady infusion of new technology and modernization and replacement of equipment. However, material superiority alone is not sufficient. Of greater importance is the development of doctrine, organizations, training and education, leaders, and people that effectively take advantage of the technology.

The evolution of these elements over the next two decades will be strongly influenced by two factors. First, the continued development and proliferation of information technologies will substantially change the conduct of military operations. These changes in the information environment make information superiority a key enabler of the transformation of the operational capabilities of the joint force and the evolution of joint command and control. Second, the US Armed Forces will continue to rely on a capacity for intellectual and technical innovation. The pace of technological change, especially as it fuels changes in the strategic environment, will place a premium on our ability to foster innovation in our people and organizations across the entire range of joint operations. The overall vision of the capabilities we will require in 2020, as introduced above, rests on our assessment of the strategic context in which our forces will operate.

USSPACECOM Vision for 2020

Today, the United States is the preeminent military power in space. USSPACECOM's Vision for 2020, when attained, will ensure that preeminence-providing a solid foundation for securing our future national security in space.

To move towards attaining the USSPACECOM Vision for 2020, we developed four operational concepts from an examination of the Unified Command Plan's assigned missions, the *Joint Vision 2010* operational concepts and the anticipated strategic environment.

Control of Space (CoS) is the ability to ensure uninterrupted access to space for US forces and our allies, freedom of operations within the space medium and an ability to deny others the use of space, if required. The ability to gain and maintain space superiority will become critical to the joint campaign plan. With uninterrupted access to space, the United

States can launch and reconstitute satellite constellations as required without impediment from our adversaries. Just as dominant battlefield awareness (DBA) is critical to the success of land, sea, and air forces, space surveillance will help us achieve DBA of space. As the US military relies more on space, our vulnerability also increases, so we must protect our space assets and be able to deny other nations from gaining an advantage through their space systems.

Global Engagement (GE) is the combination of global surveillance of the Earth, worldwide missile defense, and the potential ability to apply force from space. GE addresses increasing ballistic and cruise missile threats, the need for force application, and the need for effective forward presence with reduced forward basing. By 2020, a second generation system for National Missile Defense is expected to be in place-with many of the weapons and sensors potentially moving into space. Surveillance and strike missions for land, sea, and air will improve using space systems. For example, a force application system based in space could be available for strategic attack, and space-based surveillance may augment systems on land and in the air. At present, the notion of weapons in space is not consistent with US national policy. Planning for the possibility is a purpose of this plan should our civilian leadership decide that the application of force from space is in our national interest.

Full Force Integration (FFI) seamlessly joins space-derived information and space forces with information and forces from the land, sea, and air. Space power will be instrumental in getting the right military capability to the right forces, at the right time. Space forces must integrate with all our fighting forces-from the Joint Task Force's headquarters down to warfighters in the land, sea, and air components. Innovative organizations and operational concepts, tailored flows of information, and trained, dedicated professionals are all keys to FFI.

Global Partnerships (GP) augment the military's space capabilities by leveraging civil, commercial, and international space systems. This operational concept results from the explosive growth of commercial and international space capabilities. The United States can use these systems to bolster-and decrease the cost of-military capabilities; they will also increase battlespace awareness and information connectivity. GP can improve stability, offer mutual advantages to all partners and increase flexibility for the United States. Partnerships make possible shared costs, shared risks, and increased opportunities.

As we move onto the 21st Century, space forces will continue to provide support from space, but will also begin to conduct space operations. The emerging synergy of space superiority-equal to land sea, and air superiority-will enable us to achieve Full Spectrum Dominance.

Air Force Support of JV 2010

The Air Force is already developing many of the systems required to support Joint Vision 2010. The new joint strategy for the future is entitled: “Global Engagement.” (***Note:*** The Air Force has now updated its "Global Engagement" strategy based on the new JV 2020 - *see next section - "AF Vision 2020"*.)

Core Competencies, as defined by the Chief of Staff of the Air Force in AF Vision 2025, represent the combination of professional knowledge, airpower expertise and technological know-how that, when applied, produces superior military capabilities. Within the Air Force, core competencies provide a bridge between doctrine and the acquisition/programming process. Defining future core competencies provides strategic focus for the vision.

The six core competencies needed to maintain the Air Force of the future are:

- *Air and Space Superiority*. Provides US forces freedom from attack and freedom to attack. The idea is that if air dominance is achieved, US and allied forces can operate with impunity throughout the battle area, which in turn will lead to quick victory. For this ability to be complete, the Air Force must be able to aggressively counter cruise and ballistic missiles.

- *Global Attack.* The ability of the Air Force to attack rapidly, anywhere on the globe and anytime, is unique. To maintain this ability, the Air force will keep its current level of overseas presence (80,000 troops permanently deployed and 12,000 to 14,000 on temporary duty). It will also increase the use of the air expeditionary force concept, in which the planes and troops deployed are tailored to a specific mission, rather than prepackaged.

- *Rapid Global Mobility.* Air mobility assets are a "combat force multiplier" and essential to the nation's ability to respond quickly and decisively to unexpected challenges. These are critical to all missions, including combat, peacekeeping and humanitarian efforts.
- *Precision Engagement* Apply selective air power against specific targets and achieve discrete and discriminant effects. By the 21st century, it will be possible to find, fix, track and target anything that moves on the surface of the Earth. But the Air force must develop new operations concepts for applying air and space power to a wide range of objectives.
- *Information Superiority.* Provide the strategic perspective and flexibility of air and space to information operations. This means using Air Force assets to provide any joint force with pictures of the entire battle space. To do this, the Air Force must expand its defensive information-warfare capabilities and continue to develop offensive information-warfare abilities.
- *Agile Combat Support.* Improve combat commanders' responsiveness, deployability and sustainability through effective combat-support operations. This will mean relying more on quick response than on pre-deploying inventories of supplies overseas, especially in the case of expeditionary forces whose destinations are less predictable.

Air Force Vision 2020

On 21 June 2000, F. Whitten Peters, Secretary of the Air Force, and Gen. Michael E. Ryan, AF Chief of Staff, announced the new Air Force Vision for the 21st century in line with the new Joint Vision 2020.

The new Air Force vision is called **"America's Air Force: Global Vigilance, Reach and Power"** and captures where the Air Force is going as a service and outlines the diverse challenges expected in the 21st century. This new document builds upon and extends ideas in the previous AF 2010 vision and reflects organizational and conceptual improvements since the publication of the last vision. It also supports the principles laid out in the recently released Joint Vision 2020.

According to the SECAF, the new AF Vision for 2020 is short and concise and does not talk about specific weapon systems or details of defense budgets. Instead, it represents our thinking about the aerospace domain and our role in it -- how we'll exploit the full aerospace continuum to meet the nation's needs.

Global Vigilance, Reach and Power are the overarching aerospace capabilities described in this new vision, according to General Ryan. It includes vigilance to anticipate and deter threats, reach to curb crises, and power to prevail in conflicts and win wars.

Key to this new concept is the Expeditionary Aerospace Force (AEF) which will provide both increased capabilities to meet the nation's security requirements and greater predictability and stability for Air Force personnel.

Air Force Vision 2020 can be found on the web at www.af.mil/vision.

Doctrine

Doctrine is not a hard set of rules to follow, but rather a guide to exercise judgment in using forces and weapons. Doctrine serves as a starting point for how to attack a problem and then is used as a standard to measure success or failure, which helps to determine how to alter doctrine. Its worth is that it draws upon hard learned lessons of past battles, incorporates new concepts and ideas and presents us with the results to help in decision making. The real key is the accurate analysis and interpretation of history and the experiences it provides. In order to win battles in the future, doctrine must grow and evolve to meet changing needs, experiences, technological changes and other aspects of the future which impact the way we fight.

Doctrine does not stand alone, without impact from outside sources. Several factors can influence doctrine:

- Government and politics, as well as public opinion, play a major role in how forces are employed and how doctrine is used (i.e., Vietnam War).
- Cultural change impacts doctrine.
- New threats can impact doctrine.
- New experiences can impact doctrine.
- Old experiences can be reinterpreted and impact doctrine.
- New technology can impact doctrine.

These factors not only influence doctrine; they sometimes impact on the application of doctrine and strategy in specific situations.

The Doctrine, Strategy, Policy Triangle

Try to visualize how doctrine, strategy and policy fit together within a national vision. Vision drives strategy and policy. Vision begins at the highest national level as a view of how our nation will impact and be impacted by the world of the future. It drives policy and action decisions which in turn drive the strategic planning for accomplishing that vision.

Policy is a statement of important, high-level direction that guides decisions and actions throughout the Air Force. Policy translates the ideas, goals and principles contained in mission, vision and strategic plans into actionable directives.

Strategy originates in policy and addresses broad objectives and the plans for achieving them. To allow the US to meet the varied challenges of the post-Cold War world, the national security strategy of Engagement and Enlargement was defined, which called for the US to be actively engaged around the world with the objective of enlarging the family of democratic nations. This was replaced by the new national security strategy for the 21st century (Shape, Respond, Prepare Now) discussed earlier.

The new military strategy was developed to support this national vision and strategy. Strategy represents an implementation of doctrine; it is a guide to winning in combat. Doctrine provides a foundation from which to address and assess courses of action.

Doctrinal Beginnings

Doctrine was originally developed from a set of beliefs about how wars should be conducted. As experiences developed using different strategies and tactics, doctrine changed with it. Experience is one of the major keys that led to statements of doctrine.

General Curtis LeMay, former CINCSAC, said:

"*At the very heart of war lies doctrine. It represents the central beliefs for waging war in order to achieve victory. Doctrine is of the mind, a network of faith and knowledge reinforced by experience which lays the pattern for utilization of men, equipment, and tactics. It is fundamental to sound judgment*."

Although the US had used two atomic weapons in the war against Japan, doctrine on exactly how to use this new weapon had not been fully developed. The doctrine of massive nuclear retaliation, symbol of the Cold War, had not been "tested", so doctrine in this regard was a *belief* about how nuclear weapons should be used.

Following World War II, the Cold War provided the US with its initial foray into international politics as the leader of the Free World. The "Truman Doctrine" was dictated by the threat from the communist World and focused on surviving as a nation while containing and, if necessary, defeating communism worldwide. This fostered National Military Strategy, a straightforward policy designed to preserve the US and its allies. The strategy was simple: prevent and deter an attack against the US and, if necessary, defeat an adversary using the strongest military power on earth. This particular policy served the US well for 50 years. The doctrine during this period was also straightforward: massive nuclear retaliation, if necessary, against an adversary committed to doing the same.

At the height of the cold war, space systems came into existence, allowing the US and the Soviet Union to collect intelligence data on each other from the realm of space. Space systems were initially developed to support the Cold War nuclear deterrence strategy. National space policy was developed as part of National Security Strategy with basically the same aims of self-preservation, assured warning of enemy attack and monitoring of nuclear arms treaties. Space systems proliferated to include communications, navigation, warning and reconnaissance.

In the 1980s, space became incorporated into doctrine and strategy. Many military thinkers knew that space was at a similar stage to the first use of airpower and that doctrine must be developed rapidly in order to take advantage of this new dimension of warfare.

General O'Malley, USAF Operations and Planning during that time, stated:

"*I believe the use of space by military forces is at a point paralleling the positions of air power after WW I…we must apply the same considerations to space systems as we do for other operations…and we must be prepared to protect our vital interests in space as well as those in land, sea, and air.*"

National space policy added a new dimension to national military strategy. For the first time, space became a standard tool in the hands of military strategist; however, one in which no one had any experience in applying its capabilities.

Many schools of thought therefore arose on how to apply space systems to military doctrine and strategy. At Air University, students formed study groups on the use of space systems and various schools of thought emerged on the value of space systems and how they could be utilized. These various schools of thought provided an intellectual framework in the 1980s as a way to study the new space doctrine. It was meant to take a hard look at the beliefs that had been formulated initially, using air doctrine as a guide.

The four basic schools of thought that emerged were:

- *Sanctuary*. Viewed space systems as being able to provide information to the nation from the relative safety of space.
- *Survivability*. Determined space systems were not inherently safe and survivable and thus provided only limited safety. This view as-

sumed that if an adversary attacked our space systems, that we should retaliate in kind.

- *Control*. Felt that space provided extensive control over terrestrial operations, by providing a view that no other systems could provide and that space systems could be used to control both space and earth wars.
- *High Ground.* Believed that future wars would be won or lost in space because space systems could overcome any advantages that ground offensive systems possessed.

The end of the Cold War brought enormous changes to national security strategy and national military strategy, as noted earlier. Under the national security strategy at that time outlined by the President as "Engagement and Enlargement," the US would maintain a strong defense capability, promote cooperative security measures, work to open foreign markets, spur economic growth and promote democracy abroad.

Air Force leadership responded by focusing on how to support the nation in this new environment. The result was the Air Force's strategic architecture for the 1990s entitled: "Global Reach - Global Power." This strategy identified what Air Force organization and modernization priorities would be and provided the template for restructuring the Air Force in terms of sustaining readiness concurrent with force downsizing and new missions, including humanitarian ones.

While Global Reach - Global Power was the Air Force strategy for identifying the capabilities that provided security for the nation in the early 1990s and supported the national security strategy, a further vision was needed which planned for well into the future. This began with Joint Vision 2010, the JCS Chairman's vision for joint warfighting in the 21st century. The Air Force then developed its AF Vision 2025 to support the JV 2010 concepts. (The Army, Navy, and Marine Corps have developed similar concepts to support JV 2010.)

The Gulf War not only saw the first integrated use of air and space systems, but for the first time, the warfighter recognized the contribution of space systems. Gen Thomas Moorman, former commander of AF Space Command, said that the Gulf War was the "first space war." Space systems helped the warfighter maintain air supremacy, attack strategic and tactical targets, keep up with enemy positions and movements and guide our forces across the trackless desert.

The doctrine of how we fight and integrate with other services and for the first time, other allies, some of whom had never before been in our coalition, brought forth some new doctrinal concepts during the war. The result is that Air Force and Joint Doctrine has been forever changed by the Gulf War and must be redeveloped for future conflicts. We are on the ground floor of this change.

AFDD-1, *Basic Aerospace Doctrine for the USAF*, is a starting point to learn about doctrine and lists the basic tenets for air and space power.

Along with the evolution of doctrine comes the evolution of manuals and regulations. In addition to AFDD-1, the AF has published AFDD 2-2, *Space Operations*, which provides guidance for the use of space systems.

The mission of the Air Force has always been control of the air or air superiority. The newest mission statement now shows that air and space are indivisible:

"The mission of the Air Force is to defend the US through the control and exploitation of air and space."

Space must be controlled the same way that air is controlled to ensure freedom of action throughout the entire airspace realm. These new concepts are incorporated into AFDD-1.

Joint Space Doctrine

The integration of air and space power, not only for Air Forces, but for joint/allied forces in the Gulf War, led to the beginning of Joint Space Doctrine and thinking on how to employ these new support assets.

Recent experiences in operations like JUST CAUSE, DESERT SHIELD/ DESERT STORM in Iraq and ALLIED FORCE in Kosovo have demonstrated the need for *joint* space doctrine. Developing joint space doctrine has now taken on a high priority. Space offers several roles in supporting joint operations:

- First, space is more than global in its environment. It is an "area" in which military power can be projected through terrestrial forces.
- Second, these capabilities result from technological advances which improve global command, control and communications.
- Third, we need the ability to monitor and respond to events worldwide. Space forces provide a continuous global presence in that regard.
- Fourth, the contribution of space forces to joint operations depends on people; both space and terrestrial warfighters.
- Lastly, space forces can decrease the fog of war to provide the warfighter with a clearer picture of the battle space. Information superiority mentioned earlier as part of Joint Vision 2010 does just that.

Space is the fourth operating medium, a region where, according to General Estes, former USCINCSPACE, unique capabilities offer a tremendous force multiplier and potential for independent force applications. Joint space doctrine can provide both the principles and a common framework for comprehending and integrating space capabilities.

Joint space doctrine will allow joint commanders and their planners to understand space as an aggregate of capabilities rather than as a single asset. Joint Publication 3-14 defines the use of space systems in joint operations but is still in final draft and coordination.

Space operations offers continuous global support, 24 hours a day. Space components can function across the full spectrum of conflict, from peace to war and can be quickly retasked to specific joint operations. Commanders can select those capabilities which best support their missions.

In developing joint space doctrine, planners must understand the capabilities of US Space Command to support their operations. *(See Chapter 18 for a full discussion of US Space organizations, their missions, and their capabilities.)*

You are already familiar with many of the systems under Space Force Enhancement as they serve you directly (i.e., communications, navigation, weather, etc.). The other areas provide important benefits for the warfighter also. For example, space control ensures that our satellite systems are protected from enemy attack and that we can negate any attempt to destroy our systems.

The joint operations planner must be aware of these capabilities and limitations. As another example, space forces may furnish the warfighter with missile warning information. However, the terrestrial commander must have the proper equipment to receive it, integrate it with other data from other assets and use it in theater missile defense operations. Joint operation planning for the use of space assets is at an infant stage. Additionally, there are several issues which impact on how space assets may be used, primarily from the political realm.

Several integrated wargames have been (and continue to be) conducted to focus on developing joint doctrine for space operations. The following two issues are the major themes that dominated the wargames under the important area of space control:

- Political constraints pervade the conduct of counterspace operations.

- Protecting space assets is a difficult problem.

The wargames determined that national command authorities have been directly involved in a great many decisions in space control and operations that terrestrial commanders often have control over in ground battle situations. Protection of space assets and negation of enemy assets are prime considerations which give high-level decision makers concern over escalating wartime operations. Coupled with this issue is the general fact that most political leaders have a lack of knowledge and experience with space systems and capabilities involved.

The second major issue is that of protecting our space assets. Often when space systems fail, it cannot be readily determined if it was a design failure, a cosmic event or a deliberate attack by a terrestrial enemy. Again political leaders are often unwilling to make any decision which may escalate the situation nor are they willing to attack an adversary's space assets as a starting point.

The wargames also showed that a determined adversary could develop very damaging offensive capabilities against satellite systems in less time than we could develop effective defenses.

These issues have a definite impact on development of joint and service doctrine on the use of space systems and must be taken into consideration.

Air Force Space Doctrine

The Air Force did not have a space doctrine until October 1982, when it published Air Force Manual (AFM) 1-6, *Military Space Doctrine.* AFM 1-6 clearly reflected the changing emphasis on the military use of space: it recognized the inherent benefits to be gained by any nation choosing to exploit the military advantages of space and chartered the Air Force "to provide forces for controlling space operations and gaining and maintaining space superiority." The manual also sought to establish the Air Force as the premier service with regard to space. It stated:

The Air Force was responsible for developing space forces, operational concepts, and employment tactics for the unified and specified commands (this was three years before the establishment of a separate unified command for space, US Space Command), for the management of space operations including launch, command and control, and on-orbit sustainment of military space assets for the DOD, NASA, and other government agencies and branches, and for promoting advanced technologies in order to develop the space force structure of the future.

AFM 1-6 never gained the wide acceptance necessary to institutionalize space doctrine, primarily because it failed to incorporate the historical experience gained in other military environments which might be relevant to space. The resultant doctrine was highly constrained by the policy of the time, rather than a clear articulation of "the best way to conduct military affairs" in space. The manual was rescinded in September 1990, in conjunction with a complete update of the hierarchy and content of all Air Force doctrine. However, it was successful in increasing the awareness of space operations and the potential of space throughout the Air Force during the eight years of its existence.

Current Air Force practice is to fully incorporate space into a single basic doctrinal manual for both air and space, AF Doctrine Document 1, *Basic Aerospace Doctrine of the United States Air Force,* and to promote detailed space doctrine through AFDD 2-2, *Space Operations.* The purpose is to recognize space forces as an immature but ultimately equal partner with air forces in the efficient employment of aerospace power. Together, these two manuals articulate space doctrine at the strategic and operational levels of war. (AFDD 1 and AFDD 2-2 were published in *August 1998*.)

Air Force space doctrine rests on four fundamental premises:

- *The focus of armed conflict will remain on the earth's surface for the foreseeable future*. Although the capabilities of space forces to influence the terrestrial battlefield are growing and actual conflict will probably occur in space someday, the terrestrial-based governments or other entities that command these forces are the ultimate focus of the conflict. Military force is used (in space or elsewhere) to cause these governments or entities to alter their policies and actions.
- *Space doctrine must be minimally constrained by current policy*. Instead, it articulates what is believed to be long-lasting principles about the best way to conduct military affairs. The doctrine and policy are used together to derive the military strategies and rules of engagement employed during combat.
- *Space doctrine must anticipate the future*. This is true of all military doctrine but is particularly necessary for space for at least three reasons. First, US military experience in space is very limited, and there is little choice but to anticipate future operations. Second, the rate of space technology development is extremely rapid, and publishing doctrine strictly for today's systems and operational concepts would quickly leave an obsolete doctrine. Third, one of the fundamental purposes of doctrine is to guide the development of future forces. If the US fails to anticipate the future, the risk will be fielding the same unimproved space systems indefinitely.
- *The principles of war: mass, objective, surprise, maneuver, the offensive, simplicity, unity of command, economy of force, and security apply fully and completely to space operations*. During this progression into space, no reasons have been found to question these principles, nor have any further principles been discovered.

The Air Force space doctrine builds on these premises along with the characteristics of space forces and the space environment. The general mission areas are; space control, force application, force enhancement and space support to develop operational-level employment principles for those forces. It also recognizes and articulates both the similarities and the differences between air and space forces. As the Air Force moves towards the concept of integrated aerospace power, a clear grasp of the differences between the two becomes more important. Some of the employment principles for space forces are similar to those for air forces, but others are quite different. Among the employment principles for space forces are:

- *Gain and maintain control of space*. With control of space, friendly space forces, acting either as a force enhancer or force applier, can help put enemy forces on the defensive, disrupt operations and even cause enemy forces to suffer significant losses. Control of space enhances and, in the future, may even secure freedom of action for friendly forces in all geographical environments and preserve for them the advantage of tactical surprise.
- *Centralize control, decentralize execution.* Space forces must be organized to achieve the concentration, direction and focus required to achieve decisive results. This is best accomplished through a single commander for space forces with responsibility and authority to prosecute the space campaign. Opportunities for decentralized mission execution are somewhat limited today but, in the future, will more fully allow

subordinate commanders to draw on their own ingenuity and initiative to accomplish campaign objectives.

- *Attack the enemy's centers of gravity*. A military center of gravity is a characteristic, capability, or locality from which a force derives its freedom of action, physical strength, or will to fight. For the present, space forces assist terrestrial forces who attack traditional centers of gravity in the future, space forces will have more direct space control and force application combat roles.
- *Seize the initiative*. Initiative allows commanders to dictate the timing and tempo of operations and exploit the capabilities of space forces to the maximum extent possible. By controlling timing and tempo, the space forces commander can dominate the action, remain unpredictable, create uncertainty in the enemy commander's mind, and operate beyond the enemy's ability to react effectively.
- *Maintain sufficient reserves*. Space forces commanders, in particular, should consider carefully what level of reserve capability is appropriate. They must consider ongoing and continuous space operations, as well as unanticipated future requirements. Moreover, forces held in reserve can have a dramatic effect when committed at times and places such that they produce significant changes in the space or terrestrial battle.

Space doctrine is concerned with the preparation and employment of space forces. Proper training and equipping of forces is a subject of both AFDD 1 and AFDD 2-2. AFDD 2-2 provides space doctrine down to the level of the space campaign, giving guidance for each of the space mission areas, in turn, from the perspective of the operational space forces commander. The overall effect of the two manuals together is to describe in some detail how the Air Force can use space systems and the space environment effectively to perform or support all of its missions and tasks.

Air Force doctrine is currently being revised to include space, because there are operational gaps in existing doctrine concerning space employment. Additionally, the vision for the future sees new and emerging missions for which we must rely on space systems to sustain us. Lessons learned from recent crises and new technologies all contribute to the development of Air Force space doctrine and the integration of that doctrine into the joint process.

We have already seen that the Air Force of the future will depend on six Core Competencies that will enable us to fulfill the mission and how those Core Competencies fit into the Chairman's Joint Vision. The Core Competencies will meld with the basic aerospace tenets (found in AFDD 1) to form future vision and doctrine. It is therefore important that you understand doctrine and these future concepts.

General Howard Estes, former USCINCSPACE, stated:

"We are the world's most successful space-faring nation. We are also the world's most space-dependent nation, thereby making us vulnerable to hostile groups or powers seeking to disrupt our access to, and use of space. In purely military terms, the national dependence on space based systems equates to a vulnerability. History shows that vulnerabilities are eventually exploited by adversaries, so the US must be prepared to defend those systems."

The responsibilities of the Air Force in space include a large and growing number of functions that contribute to the defense of the United States. Space operations are important elements of a credible deterrent to armed conflict. They have proven their value in helping to resolve conflicts on terms acceptable to the United States by providing various kinds of information and support to military forces and national decision makers. In the future, space systems will provide the decisive edge in countering threats to US national interests.

The Air Force regards military operations in space as being among its prime national security responsibilities and conducts these operations according to the letter and spirit of existing treaties and international law. In response to national direction, the Air Force ensures freedom of access to space for peaceful pursuits and uses space systems to perform unique, economical, and effective functions to enhance the nation's land, sea and air forces. As the Air Force space program has matured over a period of nearly four decades, Air Force policy and doctrine have reflected ever increasing roles and responsibilities and have particularly expanded their emphasis on space as a warfighting medium wherein the full spectrum of military conflict may, and eventually will, take place.

Table 5-1

International Treaties[1], Agreements and Conventions that Limit Military Activities in Space

Agreement	*Principle/Constraint*
United Nations Charter (1947)	Made applicable to space by the Outer Space Treaty of 1967. Prohibits states from threatening to use, or actually using, force against the territorial integrity or political independence of another state (Article 2(4)). Recognizes a state's inherent right to act in individual or collective self-defense when attacked. Customary international law recognizes a broader right to self-defense, one that does not require a state to wait until it is actually attacked before responding. This right to act preemptively is known as the right of anticipatory self-defense (Article 51).
Limited Test Ban Treaty (1963)	Bans nuclear weapons tests in the atmosphere, in outer space, and underwater. States may not conduct nuclear weapon tests or other nuclear explosions (i.e., peaceful nuclear explosions) in outer space or assist or encourage others to conduct such tests or explosions Article I).
Outer Space Treaty (l967)	Outer space, including the Moon and other celestial bodies, is free for use by all states (Article I). Outer space and celestial bodies are not subject to national appropriation by claim of sovereignty, use, occupation, or other means (Article II). Space activities shall be conducted in accordance with international law, including the UN Charter (Article III). The Moon and other celestial bodies are to be used exclusively for peaceful purposes (Article IV). Nuclear weapons and other weapons of mass destruction (such as chemical and biological weapons) may not be placed in orbit, installed on celestial bodies, or stationed in space in any other manner (Article IV). A state may not conduct military maneuvers, establish military bases, fortifications or installations: or test any type of weapon on celestial bodies. Use of military personnel for scientific research or other peaceful purpose is permitted (Article IV).

Table 5-1 – (Continued)

Agreement	*Principle/Constraint*
Outer Space Treaty (l967)	States are responsible for governmental and private space activities, and must supervise and regulate private activities (Article VI).
	States are internationally liable for damage to another state (and its citizens) caused by its space objects (including privately owned ones) (Article VII).
	States retain jurisdiction and control over space objects while they are in space or on celestial bodies (Article VIII).
	States must conduct international consultations before proceeding with activities that would cause potentially harmful interference with activities of other parties (Article IX).
	States must carry out their use and exploration of space in such a way as to avoid harmful contamination of outer space, the Moon, and other celestial bodies, as well as to avoid the introduction of extraterrestrial matter that could adversely affect the environment of the Earth (Article IX).
	Stations, installations, equipment, and space vehicles on the Moon and other celestial bodies are open to inspection by other countries on a basis of reciprocity (Article XII).
Agreement on the Rescue and Return of Astronauts and Objects launched into Outer Space (1968)	
	Expands on the language of Article V of the Outer Space Treaty which declares astronauts are to be regarded as "Envoys of Mankind" and be rendered "all possible assistance."
	It calls for a state in which a spacecraft crashes or a state operating in space that is in a position to assist astronauts in distress to conduct rescue operations (if it is a manned craft) and to speedily return astronauts to the launching state. Hardware need only be returned to the launching state upon request, and need not be returned promptly.
Antiballistic Missile (ABM) Treaty between the US and USSR (1972)	
	Prohibits development, testing, or deployment of space-based ABM systems or components (Article V).
	Prohibits deployment of ABM systems or components except as authorized in the treaty (Article I).
	Prohibits interference with the national technical means a party uses to verify compliance with the treaty (Article XII).

Table 5-1 – (Continued)

Agreement	*Principle/Constraint*
Liability Convention (1972)	A launching state is absolutely liable for damage by its space object to people or property on the Earth or in its atmosphere (Article II). Liability for damage caused elsewhere than on Earth to another state's space object, or to persons or property on board such a space object, is determined by fault (Article III).
Convention on Registration (1974)	Requires a party to maintain a registry of objects it launches into Earth orbit or beyond (Article II). Information of each registered object must be furnished to the UN as soon as practical, including basic orbital parameters and general function of the object (Article IV).
Environmental Modification Convention (1980)	Prohibits military or other hostile use of environmental modification techniques as a means of destruction, damage, or injury to any other state if such use has widespread, long-lasting, or severe effects (Article I).

Notes:
[1] **Text and information on these treaties and agreements can be found at** www.un.org. **See the section on International Law , Treaties at** http://untreaty.un.org/English/treaty.asp. **Another great reference is the Archimedes Space Law and Policy Library at** http://www.permanent.com/archimedes/LawLibrary.html.

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JUL 0 9 1999

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
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UNDER SECRETARIES OF DEFENSE
DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
ASSISTANT SECRETARIES OF DEFENSE
GENERAL COUNSEL OF THE DEPARMENT OF DEFENSE
INSPECTOR GENERAL OF THE DEPARTMENT OF DEFENSE
ASSISTANTS TO THE SECRETARY OF DEFENSE
DIRECTORS OF DEFENSE AGENCIES

SUBJECT: Department of Defense Space Policy

Introduction

For over forty years, the United States has led the world in the national security uses of outer space. The last major revision of DoD Space Policy, however, was in 1987 during the Cold War. Major changes have taken place since that time which warrant a significant update to reflect new priorities and the nation's evolving space policies and guidance. The increasing importance of space activities to the security and defense of the United States requires a comprehensive and coherent space policy. Such a policy is necessary to maintain the nation's leadership role in space into the next century and achieve U.S. national security objectives. Accordingly, DoD Space Policy is updated by this memorandum and the issuance of DoD Directive 3100.aa, "Space Policy."

Objectives of this Update

This update accomplishes several important objectives. Specifically, it does the following:

1. Incorporates new policies and guidance promulgated since the last update. This includes the National Space Policy issued by the President in 1996.

2. Addresses the major changes that have taken place since the last update. This includes: the transformation of the international security environment; the promulgation of new national security and national military strategies; changes in the resources allocated to national defense; changes in force structure; lessons learned from the operational employment of space forces; the global spread of space systems, technology, and information; advances in military and information technologies; the growth of commercial space activities; enhanced intersector cooperation; and increased international cooperation.

3. Establishes a comprehensive policy framework for the conduct of space and space-related activities. This framework will help to articulate the need for capabilities, guide the allocation of resources, and direct programmatic activities.

Themes of this Update

National Interest. Space is a medium like the land, sea, and air within which military activities will be conducted to achieve U.S. national security objectives. The ability to access and utilize space is a vital national interest because many of the activities conducted in the medium are critical to U.S. national security and economic well-being. The globally interdependent information- and knowledge-based economy as well as information-based military operations make the information lines of communication to, in, through, and from space essential to the exercise of U.S. power.

Strategic Enabler. Space power is as important to the nation as land, sea, and air power. It is a strategic enabler of the National Military Strategy and Joint Vision 2010. Space forces support the execution of strategy and the realization of doctrine by enabling information superiority through domination of the collection, generation, and dissemination of information. The command, control, communications, intelligence, surveillance, and reconnaissance (C3ISR) capabilities provided by space forces are necessary to maintain military readiness, enable implementation of the operational concepts of dominant maneuver, precision engagement, focused logistics, and full dimensional protection, and support the planning and conduct of military operations.

Information Superiority. Space forces provide significant capabilities to help integrate and deliver C3ISR support to U.S. military forces and, if directed, deny such support to an adversary. They help enable Combatant Commanders and operational forces to synthesize information and dictate the timing and tempo of operations. Achieving space and information superiority will help to counter an adversary's ability to command and control its forces. Access to and use of space will help enable the United States to establish and sustain the battlespace dominance and information superiority necessary to achieve success in military operations.

Deterrence. Space forces are integral to the deterrent posture of the U.S. armed forces. They help to ensure that preparations for and initiation of hostile actions will be discovered in a timely manner. Effective use of space forces will support the credible threat of force and its application in response to aggression. Space forces thus may introduce an element of uncertainty into the minds of potential adversaries about whether they can achieve their aims. Space forces are critical to the ability of the United States to ensure the costs of the threat or use of force against our interests are unacceptable to potential aggressors. The deterrence of aggression and the defense of the United States and its allies will be strengthened by ensuring that an adversary can not obtain an asymmetric advantage by countering our space capabilities or using space systems or services for hostile purposes.

Defense. Space forces contribute to the overall effectiveness of U.S. military forces in the event deterrence fails. The high technology force multipliers provided by space systems enhance the combat power of military forces. The capability to control space, if directed, will contribute to achieving the full dimensional protection, battlespace dominance, and information superiority necessary for success in military operations. Similarly, the ability to perform space force application in the future could add a new dimension to U.S. military power. Space forces thus will enable the United States to compel an adversary to cease and desist from the pursuit of its aims through the use of necessary and proportional force.

Freedom of Space. Ensuring the freedom of space and protecting U.S. national security interests in the medium are priorities for space and space-related activities. U.S. space systems are national property afforded the right of passage through and operations in space without interference. In this regard, space is much like the high seas and international airspace. The political, military, and economic value of the nation's activities in space, however, may provide a motive for an adversary to counter U.S. space assets. Purposeful interference with U.S. space systems will be viewed as an infringement on our sovereign rights. The U.S. may take all appropriate self-defense measures, including, if directed by the National Command Authorities, the use of force, to respond to such an infringement on our rights.

Integration. Space capabilities and applications will be integrated into the strategy, doctrines, concepts of operations, education, training, exercises, and operations and contingency plans of U.S. military forces. Space force structure, missions, capabilities, and applications will be incorporated into Professional Military Education as well as Joint and Service training and exercises to ensure appropriately educated and trained personnel are provided to all levels of military staffs and forces. A space-literate military with the necessary understanding of space operations and the ability to exploit fully space applications is critical to achieve national security objectives.

Defense-Intelligence Cooperation. Management of national security space activities will focus on improving the coordination and, as appropriate, integration of defense and Intelligence Community space activities. An integrated national security space architecture will minimize unnecessary duplication, achieve efficiencies in acquisition and future operations, and thereby improve support to military operations.

Intersector Cooperation. The establishment of partnerships between the defense space sector and the intelligence, civil, and commercial space sectors will enable the leveraging of scarce resources and reduce the cost of acquiring, operating, and supporting operational space force capabilities. Such partnerships will help to free scarce resources to focus defense investments on areas where there are limited incentives for the U.S. intelligence, civil, or commercial space sectors to pursue as well as sustain a robust U.S. space industrial base.

International Cooperation. Space forces provide a national advantage to the United States and are an important element within coalition strategy where America can contribute unique capabilities for international security. Although the U.S. will maintain the ability to act independently, coalition military operations are increasingly the norm. Deploying forces in cooperation with those of other countries increases the importance of interoperability. Space systems are capable of performing missions that place a premium on interoperability by providing access to common user systems, processes, and information. They enable military forces to operate in a combined environment in a more efficient and effective manner. Space forces enhance forward presence by providing the means to support commitments while minimizing risk to U.S. personnel. Integrating space capabilities into combined operations through cooperative activities will strengthen the defense relationships and alliance structures that help to underpin U.S. national security.

Purposes of the Document

DoD Directive 3100.aa, "Space Policy," establishes policy and assigns responsibilities for space and space-related activities. It implements PDD-NSC-49/NSTC-8, "National Space Policy" and supersedes the February 4, 1987, Secretary of Defense Memorandum, "Department of Defense Space Policy," and DoD Directive 3500.1, "Defense Space Council."

Attachments:
a/s

cc: Director of Central Intelligence

Department of Defense
DIRECTIVE

NUMBER 3100.10
July 9, 1999

ASD(C3I)

SUBJECT: Space Policy

References: (a) PDD-NSC-49/NSTC-8, "National Space Policy (U)," September 14, 1996
(b) Secretary of Defense Memorandum, "Department of Defense Space Policy" (U), February 4, 1987 (hereby canceled)
(c) DoD Directive 3500.1, "Defense Space Council," December 29, 1988 (hereby canceled)
(d) The White House, "A National Security Strategy for a New Century," October 1998
(e) through (nn), see enclosure 1

1. PURPOSE

This Directive:

1.1. Establishes policy and assigns responsibilities for space and space-related matters within the Department of Defense.

1.2. Implements reference (a), supersedes references (b) and (c), and supports and amplifies references (a) and (d) through (nn).

1.3. Authorizes publication of additional DoD issuances consistent with this Directive and references (a) and (d) through (nn).

2. APPLICABILITY AND SCOPE

2.1. This Directive applies to the Office of the Secretary of Defense, the Military Departments (including the Coast Guard when it is operating as a Military Service in the Department of the Navy), the Chairman of the Joint Chiefs of Staff, the Combatant Commands, the Inspector General of the Department of Defense, the Defense Agencies, and the DoD Field Activities (hereafter referred to collectively as "the DoD Components"). The term "Military Services," as used herein, refers to the Army, the Navy, the Air Force, and the Marine Corps.

2.2. The scope of this Directive includes the policy, requirements generation, planning, financial management, research, development, testing, evaluation, acquisition, education, training, doctrine, exercise, operation, employment, and oversight of space and space-related activities within the Department of Defense.

3. DEFINITIONS

Terms used in this Directive are defined in enclosure 2.

4. POLICY

It is DoD policy that:

4.1. Space is a medium like the land, sea, and air within which military activities shall be conducted to achieve U.S. national security objectives. The ability to access and utilize space is a vital national interest because many of the activities conducted in the medium are critical to U.S. national security and economic well-being.

4.2. Ensuring the freedom of space and protecting U.S. national security interests in the medium are priorities for space and space-related activities. U.S. space systems are national property afforded the right of passage through and operations in space without interference, in accordance with reference (a).

4.2.1. Purposeful interference with U.S. space systems will be viewed as an infringement on our sovereign rights. The U.S. may take all appropriate self-defense measures, including, if directed by the National Command Authorities (NCA), the use of force, to respond to such an infringement on U.S. rights.

4.3. The primary DoD goal for space and space-related activities is to provide operational space force capabilities to ensure that the United States has the space power to achieve its national security objectives, in accordance with reference (d). Contributing goals include sustaining a robust U.S. space industry and a strong, forward-looking technology base.

4.3.1. Space activities shall contribute to the achievement of U.S. national security objectives, in accordance with reference (a), by:

4.3.1.1. Providing support for the United States' inherent right of self-defense and defense commitments to allies and friends.

4.3.1.2. Assuring mission capability and access to space.

4.3.1.3. Deterring, warning, and, if necessary, defending against enemy attack.

4.3.1.4. Ensuring that hostile forces cannot prevent the United States' use of space.

4.3.1.5. Ensuring the United States' ability to conduct military and intelligence space and space-related activities.

4.3.1.6. Enhancing the operational effectiveness of U.S. and allied forces.

4.3.1.7. Countering, if necessary, space systems and services used for hostile purposes.

4.3.1.8. Satisfying military and intelligence requirements during peace and crisis as well as through all levels of conflict.

4.3.1.9. Supporting the activities of national policy-makers, the Intelligence Community, the NCA, Combatant Commanders and the Military Services, other Federal officials, and continuity of Government operations.

4.4. Mission Areas. Capabilities necessary to conduct the space support, force enhancement, space control, and force application mission areas shall be assured and integrated into an operational space force structure that is sufficiently robust, ready, secure, survivable, resilient, and interoperable to meet the needs of the NCA, Combatant Commanders, Military Services, and intelligence users across the conflict spectrum.

4.5. Assured Mission Support. The availability of critical space capabilities necessary for executing national security missions shall be assured, in accordance with references (a) and (e) through (h). Such support shall be considered and implemented at all stages of requirements generation, system planning, development, acquisition, operation, and support. Assured mission capability shall be assessed and taken into account in determining tradeoffs among cost, performance, resilience, lifetime, protection, survivability, and related factors. Access to space, robust satellite control, effective surveillance of space, timely constellation replenishment/reconstitution, space system protection, and related information assurance, access to critical electromagnetic frequencies, critical asset protection, critical infrastructure protection, force protection, and continuity of operations shall be ensured to satisfy the needs of the NCA, Combatant Commanders, Military Services, and the intelligence users across the conflict spectrum.

4.6. Planning. Planning for space and space-related activities shall focus on improving the conduct of national security space operations, assuring mission support, and enhancing support to military operations and other national security objectives. Such planning shall also identify missions, functions, and tasks that could be performed more efficiently and effectively by space forces than terrestrial alternatives.

4.6.1. Long-range planning objectives for space capabilities are to:

4.6.1.1. Ensure U.S. leadership through revolutionary technological approaches in critical areas.

4.6.1.2. Develop a responsive, customer-focused architecture that simplifies operations and use.

4.6.1.3. Ensure civil and commercial capabilities are used to the maximum extent feasible and practical (including the use of allied and friendly capabilities, as appropriate), consistent with national security requirements.

4.6.1.4. Provide assured, cost-effective, responsive access to space.

4.6.1.5. Contribute to a comprehensive command, control, communications, intelligence, surveillance, and reconnaissance architecture that integrates space, airborne, land, and maritime assets.

4.6.1.6. Ensure space systems are seamlessly integrated within a globally accessible and secure information infrastructure.

4.6.1.7. Provide appropriate national security space services and information to the intelligence, civil, commercial, scientific, and international communities.

4.6.1.8. Provide space control capabilities consistent with Presidential policy as well as U.S. and applicable international law.

4.6.1.9. Protect national security space systems to ensure mission execution.

4.6.1.10. Explore force application concepts, doctrine, and technologies consistent with Presidential policy as well as U.S. and applicable international law.

4.6.1.11. Promote a trained, space-literate national security workforce able to utilize fully space capabilities for the full spectrum of national security operations.

4.6.2. Architectures. An integrated national security space architecture, including space, ground, and communications link segments, as well as user interfaces and equipment, shall be developed to the maximum extent feasible. Such an integrated architecture shall address defense and intelligence missions and activities to eliminate unnecessary vertical stove-piping of programs, minimize unnecessary duplication of missions and functions, achieve efficiencies in acquisition and future operations, provide strategies for transitioning from existing architectures, and thereby improve support to military operations and other national security objectives.

4.6.2.1. Space architectures shall be structured to take full advantage, as appropriate, of defense, intelligence, civil, commercial, allied, and friendly space capabilities. Such architectures shall also include, as appropriate, system, operational, and technical architecture descriptions. Joint technical standards drawn from widely accepted commercial standards, consistent with national security requirements, shall provide the basis for new system integration where appropriate. Appropriate interoperability and standards mandates shall be observed to enable the interoperability of space services.

4.6.2.2. Space architectures should be designed for appropriate levels of mission optimization, availability, and survivability in all aspects of on-orbit configurations and associated infrastructure. Planning shall emphasize the need for responsiveness and the elimination of vulnerabilities that could prevent mission accomplishment.

4.7. Augmentation. Requirements, arrangements, and procedures, including cost sharing and reciprocity arrangements, for augmentation of the space force structure by civil, commercial, allied, and friendly space systems shall be identified in coordination with the Director of Central Intelligence, as appropriate, and shall be planned and implemented in accordance with reference (a).

4.8. Mobilization and Preparedness. Space forces and their supporting industrial base shall be integrated into the defense mobilization planning process. Specific programs, facilities, and personnel shall be identified and incorporated into relevant critical assets and items lists, in accordance with references (e), (g), (i) and (j).

4.9. Support to Commercial Space Activities. Stable and predictable U.S. private sector access to appropriate DoD space-related hardware, facilities, and data shall be facilitated consistent with national security requirements, in accordance with references (a) and (k). The U.S. Government's right to use such hardware, facilities, and data on a priority basis to meet national security and critical civil sector requirements shall be preserved.

4.10. Translating Operational Needs into Programs. Space programs and activities shall be responsive to mission area shortfalls, validated operational needs, and operational requirements. Requirements, resources, and acquisition activities, where applicable, shall be documented in the requirements generation system, the acquisition management system, and the planning, programming, and budgeting system. Space shall be considered as a medium for conducting any operation where mission success and effectiveness would be enhanced relative to other media.

4.10.1. Cost as an Independent Variable. Cost, as an independent variable, shall be applied in all architecture development processes to ensure requiring organizations understand cost drivers and weigh all requirements against their associated costs.

4.10.2. Acquisition. Acquisition strategies shall usually include: an overview of the system's capabilities and concept of operations desired for the full system; a flexible overall architecture, which includes a process for change; an emphasis on open systems design, flexible technology insertion, and rigorous technology demonstrations; rapid achievement of incremental capability in response to time-phased statements of operational requirements; and close and frequent communications with users. At program initiation, the acquisition strategy submitted for the cognizant acquisition authority's approval shall describe whether an evolutionary approach is appropriate, and, if so, how the program manager will implement the approach. Progression to an additional level of capability beyond the first increment requires the cognizant acquisition authority's approval and shall be based on a review of evolving requirements and technology development.

4.10.3. Preference for Commercial Acquisition. Lengthy mission specifications shall be balanced against opportunities for technology insertion, taking into consideration commercial-off-the-shelf solutions for national security items, non-developmental items, and national security adaptations of commercial items. Acquisition of national security-unique systems shall not be authorized, in general, unless suitable and adaptable commercial alternatives are not available. Such cooperation should be based on the principles of reciprocity and tangible mutual benefits and should be pursued in a manner that reasonably protects and balances U.S. national security and economic interests.

4.10.4. Science and Technology. Leading-edge technologies that address identified mission area deficiencies shall be investigated. Investments for such technology shall feature a suitable mix of theoretical research and scientific exploration and applications which support the joint vision for military operations and other national security objectives.

4.10.5. Demonstration and Experimentation. Technology applications that address mission area deficiencies shall be demonstrated. Such demonstrations shall involve both the developmental and operational elements of the DoD Components and shall be pursued to identify the value of emerging technology to the warfighter and the national security community.

4.10.6. Research and Development. Commercial systems and technologies shall be leveraged and exploited whenever possible. Research and development investments shall focus on unique national security requirements which have no known potential, or insufficient potential, for civil or commercial sector exploitation or which require protection from disclosure. Forecasts of long-term needs shall guide investments using sound business criteria to ensure they have reasonable internal rates of return compared with alternatives.

4.10.7. Test and Evaluation. Test and evaluation programs shall be structured to provide essential information to decision-makers, assess attainment of technical performance parameters, and determine whether systems are operationally effective, suitable, and survivable for intended use. Operational test and evaluation activities shall plan and conduct operational tests, report results, and provide evaluations of effectiveness and suitability.

4.10.8. Modeling and Simulation. Models and simulations shall be used to reduce the time, resources, and risks of the acquisition process and increase the quality of the systems being acquired. Space capabilities and applications shall be integrated into campaign-level and other models and simulations. Models and simulations shall focus on demonstrating the military worth and other value of both friendly and adversary space capabilities and applications to mission accomplishment.

4.10.9. Sustainment. Production procurement decisions for space systems shall be based on careful analysis of the advantages of multi-year procurements and high order quantity buys against the disadvantage of technology obsolescence, threat changes, and cost to store and maintain launch readiness of satellites. For a given satellite program, such sustainment acquisitions shall store no more than the number of satellites authorized for the particular constellation plus adequate attrition reserves. Production rate decisions shall be based on retention of critical industrial base and space system readiness maintenance.

4.10.10. Partnerships with Industry. Partnerships with industry shall be pursued to research, develop, acquire, and sustain space systems and associated infrastructure.

4.10.11. Outsourcing and Privatization. Opportunities to outsource or privatize space and space-related functions and tasks, which could be performed more efficiently and effectively by the private sector, shall be investigated aggressively, consistent with the need to protect national security and public safety. Clear lines of accountability to Combatant Commanders shall be demonstrated and documented in the employment of such resources.

4.10.12. Electromagnetic Spectrum Management. Assured access to the electromagnetic spectrum is a critical factor in spacecraft system design, acquisition, and operations and shall be an important consideration in the development and procurement of a space system. Electromagnetic spectrum for space systems, once chosen, shall be legally authorized for use in accordance with references (l) and (m) as well as national and applicable international policies.

4.11. Operations. Space capabilities shall be operated and employed to: assure access to and use of space; deter and, if necessary, defend against hostile actions; ensure that hostile forces cannot prevent U.S. use of space; ensure the United States' ability to conduct military and intelligence space and space-related activities; enhance the operational effectiveness of U.S., allied, and friendly forces; and counter, when directed, space systems and services used for hostile purposes.

4.11.1. Integration. Space capabilities and applications shall be integrated into the strategy, doctrine, concepts of operations, education, training, exercises, and operations and contingency plans of U.S. military forces. Space support to the lowest appropriate level, including the lowest tactical level, shall be emphasized and optimized to ensure that all echelons of command understand and exploit fully the operational advantages which space systems provide, understand their operational limitations, and effectively use space capabilities for joint and combined operations.

4.11.2. Education, Training, and Exercises. Information about space force structure, missions, capabilities, and applications shall be incorporated into Professional Military Education as well as Joint and Service training and exercises to provide appropriately educated and trained personnel to all levels of joint and component military staffs and forces. Space missions and capabilities, the ability to operate under foreign surveillance or against an adversary enhanced by space capabilities, and the ability to compensate for capability loss shall be integrated into appropriate Joint and Service exercises.

4.11.3. National Guard and Reserve Forces. A total force approach shall be used in structuring and resourcing space force capabilities and ensuring interoperability among active, National Guard, and Reserve forces.

4.11.4. Military Personnel-in-Space. The unique capabilities that can be derived from the presence of humans in space may be utilized to the extent feasible and practical to perform in-space research, development, testing, and evaluation as well as enhance existing and future national security space missions. This may include exploration of military roles for humans in space focusing on unique or cost-effective contributions to operational missions.

4.11.5. Space Debris. The creation of space debris shall be minimized, in accordance with reference (a). Design and operation of space tests, experiments, and systems shall strive to minimize or reduce the accumulation of such debris consistent with mission requirements and cost effectiveness.

4.11.6. Spacecraft End-of-Life. Spacecraft disposal at the end of mission life shall be planned for programs involving on-orbit operations. Spacecraft disposal shall be accomplished by atmospheric reentry, direct retrieval, or maneuver to a storage orbit to minimize or reduce the impact on future space operations.

4.11.7. Spaceflight Safety. All DoD activities to, in, through, or from space, or aimed above the horizon with the potential to inadvertently and adversely affect satellites or humans in space, shall be conducted in a safe and responsible manner that protects space systems, their mission effectiveness, and humans in space, consistent with national security requirements. Such activities shall be coordinated with U.S. Space Command, as appropriate, for predictive avoidance or deconfliction with U.S., friendly, and other space operations.

4.11.8. Nuclear Power Sources in Space. Space nuclear reactors shall not be used in Earth orbit without the approval of the President or his designee, in accordance with references (a) and (n). Requests for such approval shall take into account public safety, economic considerations, treaty obligations, and U.S. national security and foreign policy interests.

4.12. Intersector Cooperation. Enhanced cooperation with the intelligence, civil, and commercial space sectors shall be pursued to ensure that all U.S. space sectors benefit from the space technologies, facilities, and support services available to the nation. Such cooperation shall share or reduce costs, minimize redundant capabilities, minimize duplication of missions and functions, achieve efficiencies in acquisition and future operations, improve support to military operations, and sustain a robust U.S. space industry and a strong, forward-looking space technology base. Improvement of the coordination and, as appropriate, integration of defense and intelligence space activities shall be a priority. Procedures shall be established for the timely transfer of DoD-developed space technology to the private sector consistent with the need to protect national security, in accordance with reference (a).

4.13. International Cooperation. International cooperation and partnerships in space activities shall be pursued with the United States' allies and friends to the maximum extent feasible, in accordance with reference (a), Section 104(e) of reference (o) and references (p) through (s). Such cooperation shall forge closer security ties with U.S. allies and friends, enhance mutual and collective defense capabilities, and strengthen U.S. economic security. It shall also strengthen alliance structures, improve interoperability between U.S. and allied forces, and enable them to operate in a combined environment in a more efficient and effective manner. Such cooperation shall be based on the principles of reciprocity and tangible, mutual benefit and shall take into consideration U.S. equities from a broad foreign policy perspective. Such cooperation shall be pursued in a manner, which protects both U.S. national security and economic security and is consistent with U.S. arms control, nonproliferation, export control, and foreign policies.

4.14. Intelligence Support. A high priority shall be placed on the collection, analysis, and timely dissemination of intelligence information to support space and space-related policy-making, requirements generation, research, development, testing, evaluation, acquisition, operations, and employment. Requirements for such intelligence support shall be identified, prioritized, and submitted through established processes to produce timely, useful intelligence products, in accordance with reference (t).

4.15. Arms Control and Related Activities. Space and space-related activities shall comply with applicable presidential policies as well as applicable domestic and international law. Space forces planning shall include the provision of appropriate responses to possible breakouts from existing arms control treaties and agreements. The President shall be advised on the military significance of potential space arms control agreements and other related measures being considered for international implementation. Positions and policies regarding arms control and related activities shall preserve the rights of the United States to conduct research, development, testing, and operations in space for military, intelligence, civil, and commercial purposes, in accordance with reference (a).

4.16. Nonproliferation and Export Controls. The Missile Technology Control Regime is the primary tool of U.S. missile nonproliferation policy, in accordance with references (a) and (u). Space systems, technology, and information that could be used in a manner detrimental to U.S. national security interests shall be protected. Measures shall be taken to protect technologies, methodologies, information, and overall system capabilities and vulnerabilities, which sustain advantages in space capabilities and continued technological advancements. Measures shall also be taken to maintain appropriate controls over those technologies, methodologies, information, and capabilities, which could be sold or transferred to foreign recipients. Other countries' practices, U.S. foreign policy objectives, and encouragement of free and fair trade in commercial space activities shall be taken into account when considering whether to enter into space-related agreements.

4.17. Trade in Space Goods and Services. The national security implications of decisions related to the trade of U.S.-manufactured space goods and services, as well as frequency spectrum and landing rights, shall be identified and assessed. Such decisions shall seek to balance concerns about the proliferation of critical technologies and information with national security space applications and the interests of the U.S. space industry and U.S. foreign policy.

4.17.1. The commercial value of intellectual property developed with U.S. Government support shall be protected. Technology transfers resulting from international cooperation shall not undermine national security or industrial competitiveness, in accordance with reference (a).

4.17.2. Foreign military sales of U.S. space hardware, software, and related technologies may be used to enhance security relationships with strategically important countries subject to overall U.S. Government policy guidelines.

4.18. Security. Security measures shall be implemented to protect all classified aspects of space and space-related activities, in accordance with references (a) and (v) through (x) and other applicable security directives. Space missions shall be conducted in a manner intended to prevent unauthorized knowledge of and use of capabilities for countering specific missions or systems. The status and capabilities of on-orbit and terrestrial elements of the space force structure, deployment and replenishment strategies, planned, programmed, and operational objectives, and launch dates shall be classified, as appropriate, taking into account the value of needed protection for national security interests as compared with the public interests that would be served by release of such information. Technology transfer, including the direct or indirect sharing of information and resources with foreign governments or foreign-owned or -controlled contractors, shall be subject to reference (x) and other relevant security policies.

4.19. Public Affairs. Public affairs activities shall be conducted to provide general information to the public about space and space-related activities consistent with the need to protect national security information. Publication of unclassified information about the contributions of space forces to national security and other national interests shall be encouraged. Specific guidance for public affairs release shall be structured, as necessary, to protect the identity, mission, and associated operations of classified space and space-related activities.

5. RESPONSIBILITIES

Consistent with Section 105 of reference (o) and reference (y):

5.1. The Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD(C3I)), in accordance with reference (z), shall:

5.1.1. Serve as the principal staff assistant and advisor to the Secretary and Deputy Secretary of Defense and focal point within the Department of Defense for space and space-related activities.

5.1.2. Develop, coordinate, and oversee the implementation of policies regarding space and space-related activities and, in coordination with the Under Secretary of Defense for Policy, ensure that space policy decisions are closely integrated with overall national security policy considerations.

5.1.3. Oversee the development and execution of space and space-related architectures, acquisition, and technology programs, in coordination, as appropriate, with the Under Secretary of Defense for Acquisition and Technology.

5.1.4. Oversee the Director of the National Security Agency's compliance with this Directive in accordance with reference (aa).

5.1.5. Oversee the Director of the Defense Intelligence Agency's compliance with this Directive in accordance with references (bb) and (cc).

5.1.6. Oversee the Director of the National Reconnaissance Office's management and execution of the National Reconnaissance Program to meet the U.S. Government's needs through the research, development, acquisition, and operation of spaceborne reconnaissance systems in accordance with references (dd) and (ee).

5.1.7. Oversee the Director of the National Imagery and Mapping Agency's compliance with this Directive in accordance with reference (ff).

5.1.8. Oversee the Director of the Defense Information Systems Agency's compliance with this Directive in accordance with reference (gg).

5.1.9. Oversee the National Security Space Architect's compliance with this Directive in accordance with reference (hh).

5.2. The Under Secretary of Defense for Acquisition and Technology, in accordance with reference (ii), shall serve as the Acquisition Executive for space programs that are designated Major Defense Acquisition Programs and, in coordination with the ASD(C3I), oversee space and space-related acquisition and technology programs.

5.3. The Under Secretary of Defense for Policy, in accordance with reference (jj), shall:

5.3.1. Ensure that space policy decisions are closely integrated with overall national security policy considerations, in coordination with the ASD(C3I).

5.3.2. Review all Combatant Commander operations and contingency plans to ensure proposed employment of space forces are coordinated and consistent with DoD policy and the National Military Strategy.

5.4. The Under Secretary of Defense, Comptroller (USD(C)) shall comply with this Directive in accordance with reference (kk).

5.5. The General Counsel of the Department of Defense shall provide legal advice and assistance to the Secretary and Deputy Secretary of Defense, and, as appropriate, other DoD Components on all aspects of space and space-related activities, including the application of all applicable statutes, directives, regulations, and international agreements, in accordance with reference (ll).

5.6. The Director of Operational Test and Evaluation shall comply with this Directive in accordance with reference (mm).

5.7. The Secretaries of the Military Departments shall comply with this Directive in accordance with reference (y) as well as integrate space capabilities and applications into all facets of their Department's strategy, doctrine, education, training, exercises, and operations of U.S. military forces.

5.8. The Chairman of the Joint Chiefs of Staff (CJCS), in accordance with reference (y), shall:

5.8.1. Establish a uniform system for evaluating the readiness of each Combatant Command and Combat Support Agency to carry out assigned missions by employing space forces.

5.8.2. Develop joint doctrine for the operation and employment of space systems of the Armed Forces and formulate policies for the joint space training of the Armed Forces and for coordinating the space military education and training of the members of the Armed Forces.

5.8.3. Integrate space forces and their supporting industrial base into the Joint Strategic Capabilities Plan mobilization annex and formulate policies for the integration of National Guard and Reserve forces into joint space activities.

5.8.4. Provide guidance to Combatant Commanders for planning and employment of space capabilities through the joint planning process.

5.9. The Combatant Commanders shall:

5.9.1. Consider space in the analysis of alternatives for satisfying mission needs as well as develop and articulate military requirements for space and space-related capabilities.

5.9.2. Integrate space capabilities and applications into contingency and operations plans as well as plan for the employment of space capabilities within their Area of Responsibility.

5.9.3. Provide input for evaluations of the preparedness of their Combatant Command to carry out assigned missions by employing space capabilities.

5.9.4. Coordinate on Commander in Chief of U.S. Space Command campaign plans and provide supporting plans as directed by the CJCS.

5.9.5. Plan for and provide force protection, in coordination with the Commander in Chief of U.S. Space Command, for space forces assigned, deployed, and operating in their Area of Responsibility.

5.9.6. The Commander in Chief of U.S. Space Command, in accordance with reference (nn), shall:

5.9.6.1. Serve as the single point of contact for military space operational matters, except as otherwise directed by the Secretary of Defense.

5.9.6.2. Conduct space operations, including support of strategic ballistic missile defense for the United States.

5.9.6.3. Coordinate and conduct space campaign planning through the joint planning process in support of the National Military Strategy.

5.9.6.4. Advocate space (including force enhancement, space control, space support, and force application) and missile warning requirements of other Combatant Commanders.

6. EFFECTIVE DATE

This Directive is effective immediately.

Secretary of Defense

Enclosures - 2
E1. References, continued
E2. Definitions

E1. ENCLOSURE 1

REFERENCES, continued

(e) PDD-NSC-63, "Critical Infrastructure Protection," May 22, 1998
(f) PDD-NSC-67, "Enduring Constitutional Government and Continuity of Government Operations (U)," October 21, 1998
(g) DoD Directive 5160.54, "Critical Asset Assurance Program (CAAP)," January 20, 1998
(h) DoD Directive 3020.26, "Continuity of Operations Policy and Planning," May 26, 1995
(i) E.O. 12919, "National Defense Industrial Resources Preparedness," June 6, 1994
(j) E.O. 12656, "Assignment of Emergency Preparedness Responsibilities," November 18, 1988
(k) DoD Directive 3230.3, "DoD Support for Commercial Space Launch Activities," October 14, 1986
(l) DoD Directive 4650.1, "Management and Use of the Radio Frequency Spectrum," June 24, 1987
(m) DoD Directive 3222.3, "Department of Defense Electromagnetic Compatibility Program," August 20, 1990
(n) National Security Council Memorandum, "Revision to NSC/PD-25, dated December 14, 1977, entitled Scientific or Technological Experiments with Possible Large Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space," May 17, 1995
(o) National Security Act of 1947, as amended
(p) DoD Directive 2000.9, "International Co-Production Projects and Agreements Between the United States and Other Countries or International Organizations," January 23, 1974
(q) PDD-NSC-23, "U.S. Policy on Foreign Access to Remote Sensing Space Capabilities (U)," March 9, 1994
(r) PDD-NSTC-2, "Convergence of U.S. Polar-Orbiting Operational Environmental Satellite Systems," May 5, 1994
(s) PDD-NSTC-6, "U.S. Global Positioning System Policy," March 28, 1886
(t) DoD Directive 5240.1, "Intelligence Activities," April 25, 1988
(u) PDD-NSC-13, "Nonproliferation and Export Controls (U)," September 27, 1993
(v) E.O. 12958, "Classified National Security Information," April 12, 1995
(w) E.O. 12951, "Release of Imagery Acquired by Space-Based National Intelligence Reconnaissance Systems," February 22, 1995
(x) E.O. 12829, "National Industrial Security Program," January 6, 1993

(y) Title 10, United States Code
(z) DoD Directive 5137.1, "Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD(C3I))," February 12, 1992
(aa) DoD Directive 5100.20, "National Security Agency and the Central Security Service," December 23, 1971
(bb) DoD Directive 5105.21, "Defense Intelligence Agency (DIA)," February 18, 1997
(cc) DoD Instruction 5105.58, "Management of Measurement and Signature Intelligence (MASINT)," February 9, 1993
(dd) DoD Directive TS-5105.23, "National Reconnaissance Office (U)," March 27, 1964
(ee) Secretary of Defense and Director of Central Intelligence, "Agreement for the Reorganization of the National Reconnaissance Program (U)," August 11, 1965
(ff) DoD Directive 5105.60, "National Imagery and Mapping Agency," October 11, 1996
(gg) DoD Directive 5105.19, "Defense Information Systems Agency (DISA)," June 25, 1991
(hh) Secretary of Defense and Director of Central Intelligence, "Memorandum of Understanding for National Security Space Management," July 1998
(ii) DoD Directive 5134.1, "Under Secretary of Defense for Acquisition and Technology (USD(A&T))," June 8, 1994
(jj) DoD Directive 5111.1, "Under Secretary of Defense for Policy," March 22, 1995
(kk) DoD 7000.14-R, "Department of Defense Financial Regulations, Volume 1: General Financial Management Information, Systems, and Requirements," January 1999
(ll) DoD Directive 5145.1, "General Counsel of the Department of Defense," December 15, 1989
(mm) DoD Directive 5141.2, "Director of Operational Test and Evaluation," April 2, 1984
(nn) Unified Command Plan (U)

E2. ENCLOSURE 2

DEFINITIONS

E2.1.1. Force Application. Combat operations in, through, and from space to influence the course and outcome of conflict. The force application mission area includes: ballistic missile defense and force projection.

E2.1.2. Force Enhancement. Combat support operations to improve the effectiveness of military forces as well as support other intelligence, civil, and commercial users. The force enhancement mission area includes: intelligence, surveillance, and reconnaissance; tactical warning and attack assessment; command, control, and communications; position, velocity, time, and navigation; and environmental monitoring.

E2.1.3. Space Control. Combat and combat support operations to ensure freedom of action in space for the United States and its allies and, when directed, deny an adversary freedom of action in space. The space control mission area includes: surveillance of space; protection of U.S. and friendly space systems; prevention of an adversary's ability to use space systems and services for purposes hostile to U.S. national security interests; negation of space systems and services used for purposes hostile to U.S. national security interests; and directly supporting battle management, command, control, communications, and intelligence.

E2.1.4. Space Forces. The space and terrestrial systems, equipment, facilities, organizations, and personnel necessary to access, use, and, if directed, control space for national security.

E2.1.5. Space Power. The total strength of a nation's capabilities to conduct and influence activities to, in, through, and from the space medium to achieve its objectives.

E2.1.6. Space Superiority. The degree of dominance in space of one force over another, which permits the conduct of operations by the former and its related land, sea, air, and space forces at a given time and place without prohibitive interference by the opposing force.

E2.1.7. Space Support. Combat service support operations to deploy and sustain military and intelligence systems in space. The space support mission area includes launching and deploying space vehicles, maintaining and sustaining spacecraft on-orbit, and deorbiting and recovering space vehicles, if required.

E2.1.8. Space Systems. All of the devices and organizations forming the space network. These consist of: spacecraft; mission package(s); ground stations; data links among spacecraft, ground stations, mission or user terminals, which may include initial reception, processing, and exploitation; launch systems; and directly related supporting infrastructure, including space surveillance and battle management/command, control, communications, and computers.

Chapter 6

SPACE ENVIRONMENT

Why is knowing the space environment important? Our increased dependence on space-based systems to meet warfighter objectives and needs, coupled with the increasing use of microelectronics and a move to non-military specifications for satellites, increases our vulnerability to loss of critical satellite functions or entire systems (see **Fig. 6-1**). The space environment is a hostile environment for satellites.

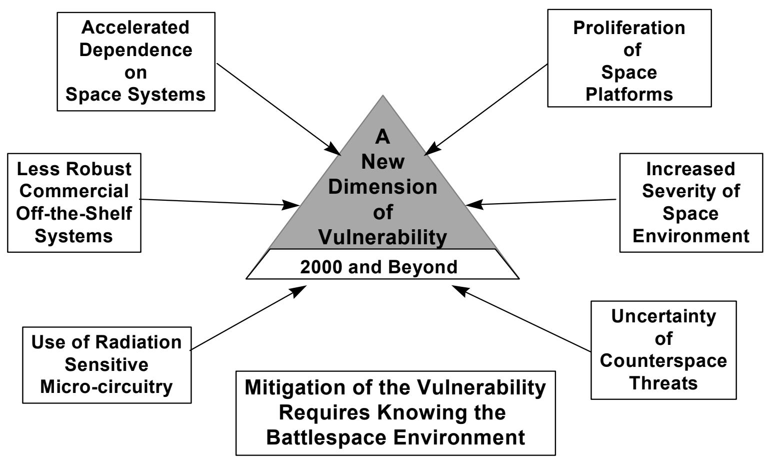


Fig. 6-1. Dimension of Vulnerability

SPACE ENVIRONMENT IMPACTS ON SYSTEMS

The origin of space environmental impacts on radar, communications and space systems lies primarily with the sun. The sun is continuously emitting electromagnetic energy and electrically charged particles. Superimposed on these emissions are enhancements in the electromagnetic radiation (particularly at X-ray, Extreme Ultra Violet (EUV) and Radio wavelengths) and in the energetic charged particle streams emitted by the sun. These solar radiation enhancements have a significant potential to influence DOD operations.

Each solar-geophysical phenomena or event has the potential to adversely impact radar, communications and space systems. This section will discuss those impacts in general, then individually.

DOD System Impacts

Generally the stronger a solar flare, the denser/faster/more energetic a particle stream, or the sharper a solar wind discontinuity or enhancement, the more severe will be the event's impacts on the near-Earth environment and on DOD systems operating in that environment. Unfortunately, the DOD system impacts discussed in this section do not occur one at a time, but will most likely occur in combinations of more than one thing. The stronger the causative solar-geophysical activity, the more in number of simultaneous effects a system may experience. Each of the three general categories of solar radiation (**Fig. 6-2**) has its own characteristics and types of immediate or delayed DOD system impacts.

simply miss hitting the Earth. For those events that do affect the near-Earth environment, effects can be both immediate and delayed, depending on the exact type of enhanced radiation emitted.

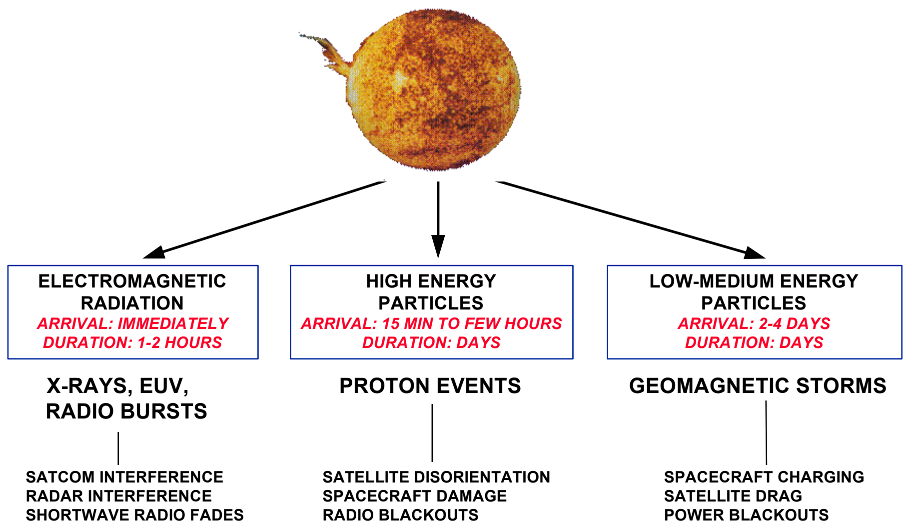


Fig. 6-2. Solar Radiation Particle Types and Effects

Non-DOD System Impacts

DOD systems are not the only ones affected by solar-geophysical activity. Some of these "non-DOD" impacts can indirectly affect military operations. For example, system impacts from a geomagnetic storm can include: (1) induced electrical currents in power lines which can cause transformer failures and power outages and (2), magnetic field variations, which can lead to compass errors and interfere with geological surveys.

ELECTROMAGNETIC (IMMEDIATE) VS PARTICLE (DELAYED) EFFECTS

Every solar event is unique in its exact nature and the enhanced emissions it produces. Some solar events cause little or no impact on the near-Earth environment because their enhanced particle and/or electromagnetic (X-ray, EUV and/or Radio wave) emissions are too feeble or their particle streams may

The following paragraphs summarize the three general categories of solar radiation and the immediate or delayed DOD system impacts they produce.

Electromagnetic Radiation

We detect flares by the enhanced X-ray, ultraviolet, optical and/or radio waves they emit. All of these wavelengths travel to the Earth at the speed of light (in about 8 minutes); so by the time we first observe a flare, it is already causing immediate environmental effects and DOD system impacts. These impacts are almost entirely limited to the Earth's sunlit hemisphere, as the radiation does not penetrate or bend around the earth. Since enhanced electromagnetic emissions cease when the flare ends, the effects tend to subside as well. As a result, these effects tend to last only a few tens of minutes to an hour or two. Sample system effects include; satellite communications (SATCOM) and radar interference (specifically, enhanced background noise), LORAN navigation errors and absorption of HF (6-30 mHz) radio communications.

High Energy Particles

These particles (primarily protons, but occasionally cosmic rays) can reach the Earth within 15 minutes to a few hours after the occurrence of a strong solar flare. Not all flares produce these high energy particles (plus the Earth is a rather small target 93 million miles from the sun) so predicting solar proton and cosmic ray events is a difficult forecast challenge. The major impact of these protons is felt over the polar caps, where the protons have ready access to low altitudes through funnel-like cusps (earth's magnetic field lines that terminate into the earth's North and South poles) in the Earth's magnetosphere. The impact of a proton event can last for a few hours to several days after the flare ends. Sample impacts include satellite disorientation, physical damage to satellites and spacecraft, false sensor readings, LORAN navigation errors and absorption of HF radio signals. Proton events are probably the most hazardous of space weather events (**Fig. 6-3**). Proton events occur when solar flares eject high energy particles (mainly protons) that arrive at the earth in 30 minutes.

Low to Medium Energy Particles

Particle streams (composed of both protons and electrons) may arrive at the Earth about two to three days after a flare. Such particle streams can also occur at any time due to other non-flare solar activity. These particles cause geomagnetic and ionospheric storms, which can last from hours to several days. Typical problems include: spacecraft electrical charging, drag on low orbiting satellites, radar interference, space tracking errors and radio wave propagation anomalies. These impacts are most frequently experienced in the nightside sector of the Earth.

ELECTROMAGNETIC (IMMEDIATE) EFFECTS

The first of the specific DOD system impacts to be discussed will be the Short Wave Fade (SWF), which is caused by solar flare X-rays. The second impact covered will be SATCOM and radar interference caused by solar flare radio bursts. These electromagnetic impacts are almost entirely limited to the Earth's sunlit hemisphere and occur simultaneously (immediate to eight minutes) with the solar flare that caused them.

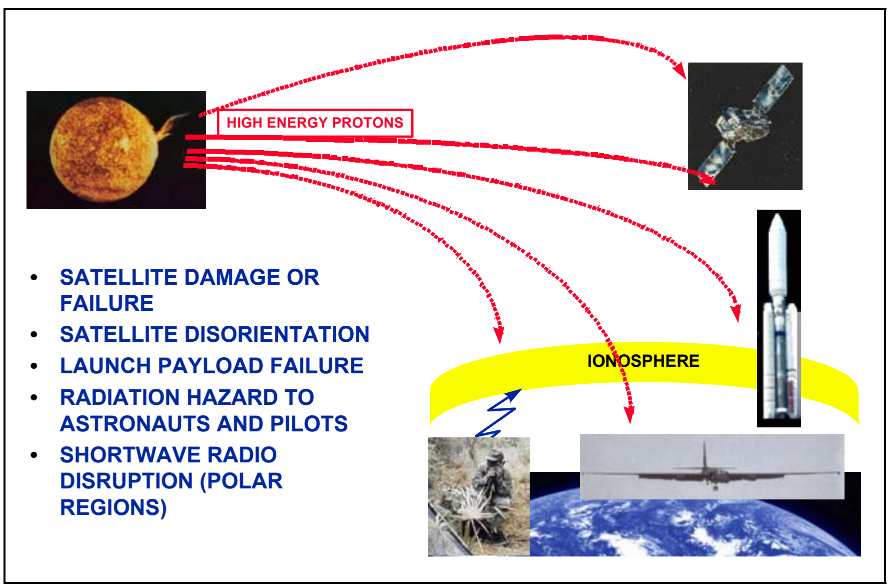


Fig. 6-3. High Energy Particle Impacts

Short Wave Fade (SWF) Events

The High Frequency (HF, 6-30 mHz) radio band is also known as the short wave band. Thus, a SWF refers to an abnormally high fading (or absorption) of a HF radio signal.

HF Radio Communications

The normal mode of radio wave propagation in the HF range is by refraction using the ionosphere's strongest (or F) layer for single hops and by a combination of reflection and refraction between the ground and the F-layer for multiple hops (**Fig. 6-4**). It should be noted that the "ionosphere" is defined as that portion of the Earth's atmosphere above 45 miles where ions and electrons are present in quantities sufficient to affect the propagation of radio waves. HF radio waves are refracted by the ionosphere's F-layer. However, each passage through the ionosphere's D-layer causes signal absorption, which is additive.

Maximum Useable Frequency (MUF)

The portion of the ionosphere with the greatest degree of ionization is the F-layer (normally between about 155 and 250 miles altitude). The presence of free electrons in the F-layer causes radio waves to be refracted (or bent), but the higher the frequency, the less the degree of bending. As a result, surface-to-surface radio operators use Medium or High Frequencies (300 kHz to 30 mHz), while SATCOM operators use Very High to Extremely High Frequencies (VHF/EHF 30 mHz to 300 gHz). The MUF is that frequency above which radio signals encounter too little ionospheric refraction (for a given take-off angle) to be bent back toward the Earth's surface (i.e., they become trans-ionospheric). Normally the MUF lies in the upper portion of the HF band.

Lowest Useable Frequency (LUF)

The lowest layer of the ionosphere is the D layer (normally between 45 and 55 mile altitude). At these altitudes there is still a large number of neutral air atoms and molecules coexisting with the ionized particles. As a passing radio wave causes the ions and free electrons to oscillate, they will collide with the neutral air particles and the oscillatory motion will be damped out and converted to heat. Thus, the D-layer acts to absorb passing radio wave signals. The lower the frequency, the greater the degree of signal absorption. The LUF is that frequency below which radio signals

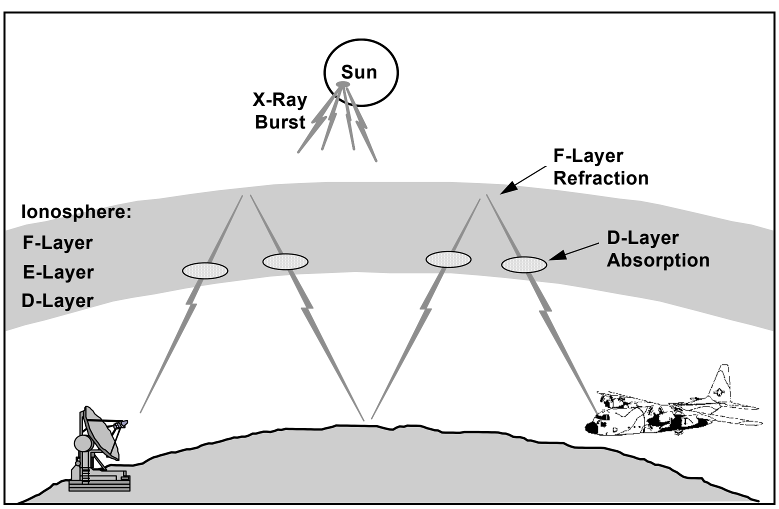


Fig. 6-4. High Frequency (HF) Communications

encounter too much ionospheric absorption to permit them to pass through the D-layer. Normally the LUF lies in the lower portion of the HF band.

HF Propagation Window

The HF radio propagation window is the range of frequencies between a LUF (complete D-layer signal absorption) and a MUF (insufficient F-layer refraction to bend back the signal). This window varies by location, time of day, season and with the level of solar and/or geomagnetic activity. HF operators choose propagation frequencies within this window so their signals will pass through the ionosphere's D-layer and subsequently refract from the F-layer. Typical LUF/MUF curves show a normal, daily variation. During early afternoon, incoming photo-ionizing solar radiation (X-rays, but mostly Ultraviolet) is at a maximum, so the D and F-layers are strong and the LUF and MUF are elevated. During the night, the removal of ionizing sunlight causes all ionospheric layers to weaken (the D and E-layers disappear altogether), and the LUF and MUF become depressed.

HF radio waves above the MUF encounter insufficient refraction and pass through the ionosphere into space. Those below the LUF suffer total absorption in the ionosphere's lowest layer. The result is a useable frequency window.

The Short Wave Fade (SWF) Event

X-ray radiation emitted during a solar flare can significantly enhance D-layer ionization and absorption (thereby elevating the LUF) over the entire sunlit hemisphere of the Earth. This enhanced absorption is known as a SWF and may, at times, be strong enough to close the HF propagation window completely (called a Short Wave Blackout) (see **Fig. 6-5**). The amount of signal loss depends on a flare's X-ray intensity, location of the HF path relative to the sun and design characteristics of the system. A SWF is an "immediate" effect, experienced simultaneously with observation of the causative solar flare. As a result, it is not possible to forecast a specific SWF event. Rather, forecasters can only predict the likelihood of a SWF event based on the probability of flare occurrence determined by an overall analysis of solar features and past activity. However, once a flare is observed, forecasters can quickly (within seven minutes of event onset) issue a SWF warning, which contains a prediction of the frequencies to

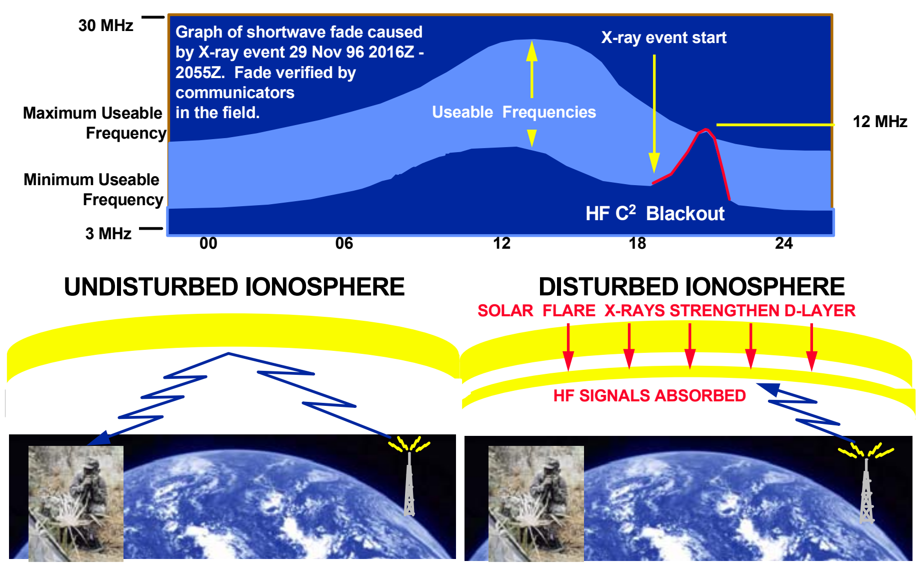


Fig. 6-5. High Frequency (HF) Propagation Windows

be affected and the duration of signal absorption. Normally SWFs persist only for a few minutes past the end of the causative flare, i.e., for a few tens of minutes to an hour or two.

Other Sudden Ionospheric Disturbances (SIDs)

A SWF is only the most common and troublesome of a whole family of SIDs caused by the influence of solar flare X-rays on the ionosphere. Other SIDs describe additional impacts. For example, flare X-rays can also cause the altitude of the D-layer's base to lower slightly. This phenomena (called a Sudden Phase Anomaly) will affect Very-Low Frequency (VLF, 6-30 kHz) and Low Frequency (LF, 30-300 kHz) transmissions and can cause LORAN navigation errors.

Radio bursts from solar flares can cause the background level of solar noise to increase by tens-of-thousands. This can lead to direct Radio Frequency Interference (RFI) of SATCOM and ground or spaced-based radars.

SATCOM and Radar Interference

Solar flares can cause the amount of radio wave energy emitted by the sun to increase by a factor of tens of thousands over certain frequency bands in the VHF to SHF range (30 mHz to 30 gHz). If the sun is in the field of view of the receiver and if the burst is at the right frequency and intense enough, these radio bursts can produce direct Radio Frequency Interference (RFI) on a SATCOM link or missile detection/ space tracking radar. (**Fig. 6-6**). Knowledge of a solar radio burst can allow a SATCOM or radar operator to isolate the RFI cause and avoid time consuming investigation of possible equipment malfunction or jamming.

Solar Radio Bursts

Radio bursts are another "immediate" effect, experienced simultaneously with observation of the causative solar flare.

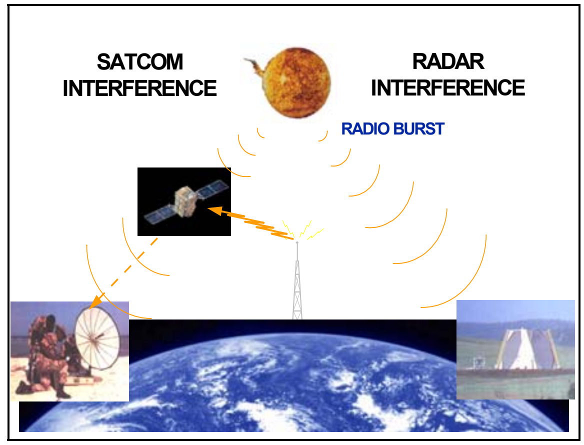


Fig. 6-6. Radio Burst Effects

Consequently, it is not possible to forecast the occurrence of radio bursts, let alone what frequencies they will occur on and at what intensities. Rather, forecasters can only issue rapid warnings (within seven minutes of event onset) that identify the observed burst frequencies and intensities. Radio burst impacts are limited to the sunlit hemisphere of the Earth. They will persist only for a few minutes to tens of minutes, but usually not for the full duration of the causative flare.

Solar Conjunction

There is a similar geometry-induced affect called "solar conjunction", which is when the ground antenna, satellite and the sun are in line. This accounts for why geosynchronous communication satellites will experience interference or blackouts (e.g., static or "snow" on TV signals) during brief periods on either side of the spring and autumn equinoxes. This problem does not require a solar flare to be in progress, but its effects are definitely greatest during Solar Max when the sun is a strong background radio emitter.

Solar Radio Noise Storms

Sometimes a large sunspot group will produce slightly elevated radio noise levels, primarily on frequencies below 400 mHz. This noise may persist for days, occasionally interfering with communications or radar systems using an affected frequency.

PARTICLE (DELAYED) EFFECTS

The discussion of specific DOD system impacts will continue with the major "delayed" (or charged particle induced) system impacts. These impacts tend to occur hours to several days after the solar activity that caused them. They persist for up to several days and are mostly felt in the nighttime sector (as the particles that cause them usually come from the magnetosphere's tail), although they are not strictly limited to that time/geographic sector.

Particle Events

The sources of the charged particles (mostly protons and electrons) include: solar flares, Coronal Mass Ejections (CMEs), disappearing filaments, eruptive prominences and Solar Sector Boundaries (SSBs) or High Speed Streams (HSSs) in the solar wind. Except for the most energetic particle events, the charged particles tend to be guided by the interplanetary magnetic field (IMF) which lies between the sun and the Earth's magnetosphere. The intensity of a particle-induced event generally depends on the size of the solar flare, filament or prominence, its position on the sun and the structure of the intervening IMF. Alternately, the sharpness of a SSB or density/speed of a HSS will determine the intensity of a particle-induced event caused by these phenomena.

Recurrence

One important factor in forecasting particle events is that some of the causative phenomena (like SSBs and coronal holes, the source region for HSSs) persist for months, while the sun rotates once every 27 days. As a result, there is a tendency for these long-lasting phenomena to show a 27-day recurrence in producing geomagnetic and ionospheric disturbances.

High Frequency Absorption Events

High Frequency SWFs over the sunlit hemisphere (caused by solar flare X-rays enhancing D-layer absorption) were already discussed. There are similar HF absorption events at high geomagnetic latitudes (above 55 degrees). However, at high latitudes, the enhanced ionization of D-layer atoms and molecules (which produce signal absorption) is caused by particle bombardment from space. Another difference is that these high latitude absorption events can last for hours to several days, and usually occur simultaneously with other radio transmission problems.

Polar Cap Absorption (PCA) Events

For a PCA event, the enhanced ionization is caused by solar flare or CME protons that gain direct access to low altitudes (as low as 35 km) by entering through the funnel-like cusps in the magnetosphere above the Earth's polar caps.

Auroral Zone Absorption (AZA) Events

For an AZA event, the enhanced ionization is caused by particles (primarily electrons) from the magnetosphere's tail, which are accelerated toward the Earth during a geomagnetic storm and are guided by magnetic field lines into the auroral zone latitudes. These are the same ionizing particles that cause the aurora or Northern/ Southern Lights.

Ionospheric Scintillation

The intense ionospheric irregularities found in the auroral zones and at +/- 20 degrees of the geomagnetic equator are the primary causes of ionospheric "scintillation". Scintillation of radio wave signals is the rapid, random variation in signal amplitude, phase and/or polarization caused by small-scale irregularities in the electron density along a signal's path (**Fig. 6-7**). Ionospheric radio wave scintillation is very similar to the visual twinkling of starlight or heat shimmer over a hot road caused by atmospheric turbulence. The result is signal fading and data dropouts on satellite command uplinks, data downlinks or on communications signals.

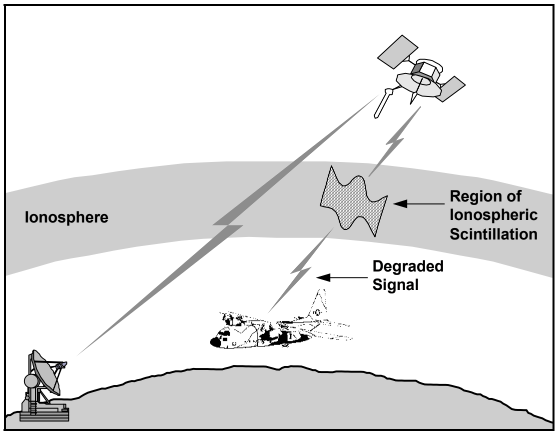


Fig. 6-7. Ionospheric Scintillation

Scintillation tends to be a highly localized effect. Only if the signal path penetrates an ionospheric region where these small-scale electron density irregularities are occurring will an impact be felt. Low latitude, nighttime links with geo-synchronous communications satellites are particularly vulnerable to intermittent signal loss due to scintillation. In fact, during the Persian Gulf war, allied forces relied heavily on SATCOM links, and scintillation posed an unanticipated, but very real operational problem.

GPS and Scintillation

GPS satellites, which are located at semi-synchronous altitude, are also vulnerable to ionospheric scintillation. Signal strength enhancements and fades as well as phase changes due to scintillation, can cause a GPS receiver to lose signal lock with a particular satellite.

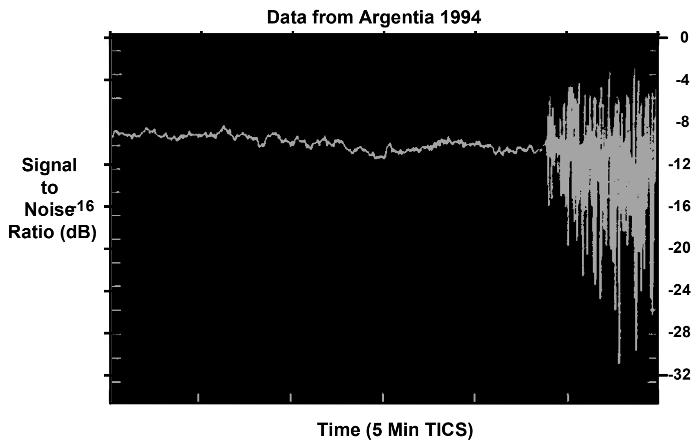
The reduction in the number of simultaneously useable GPS satellites may result in a potentially less accurate position fix. Since scintillation occurrence is positively correlated with solar activity and the GPS network has received wide-spread use only recently during a quiet portion of the 11-year solar cycle, the true environmental vulnerability of the GPS constellation is yet to be observed. But even during low solar activity levels, it has been shown, under strong scintillation, that the GPS signals cannot be seen through the background noise due to the rapid changes in the ionosphere, even with the use of dual frequency receivers (**Fig. 6-8**).

GPS and Total Electron Content (TEC)

The TEC along the path of a GPS signal can introduce a positioning error. Just as the presence of free electrons in the ionosphere caused HF radio waves to be bent (or refracted), the higher frequencies used by GPS satellites will suffer some bending (although to a much lesser extent than with HF radio waves). This signal bending increases the signal path length. In addition, passage through an ionized medium causes radio waves to be slowed (or retarded) somewhat from the speed of light. Both the longer path length and slower speed can introduce up to 300 nanoseconds (equivalent to about 100 meters) of error into a GPS location fix--unless some compensation is made for the effect. The solution is relatively simple for two-frequency GPS receivers, since signals of different frequency travel at different speeds through the same medium. Measuring the difference in signal phases for the two frequencies allows computation of the local phase delay for a particular receiver and elimination of 99 percent of the error introduced in a location fix. Unfortunately, this approach will not work for single-frequency receivers. For them, a software algorithm is used to model ionospheric effects based on the day of the year and the average solar UV flux for the previous few days. This method produces a gross correction for the entire ionosphere. But, as has already been stated, the ionosphere varies rapidly and significantly over geographical area and time. Consequently, the algorithm can eliminate, at best, about 50 percent of the error and a far smaller percentage of the error in regions where an enhanced degree of ionization is found (such as in the auroral latitudes and near the geomagnetic equator during evening hours).

environmental forecasters are heavily dependent on its known association with other environmental phenomena (such as aurora) and scintillation climatology.

Scintillation is also frequency dependent; the higher the radio frequency (all other factors held constant), the lesser the impact of scintillation.



This is a plot of the actual signal to noise ratio graph measured during a moderate scintillation event. A warfighter may lose total GPS signal lock during such events. This includes dual frequency systems.

Fig. 6-8. Scintillation Effect on GPS Signal

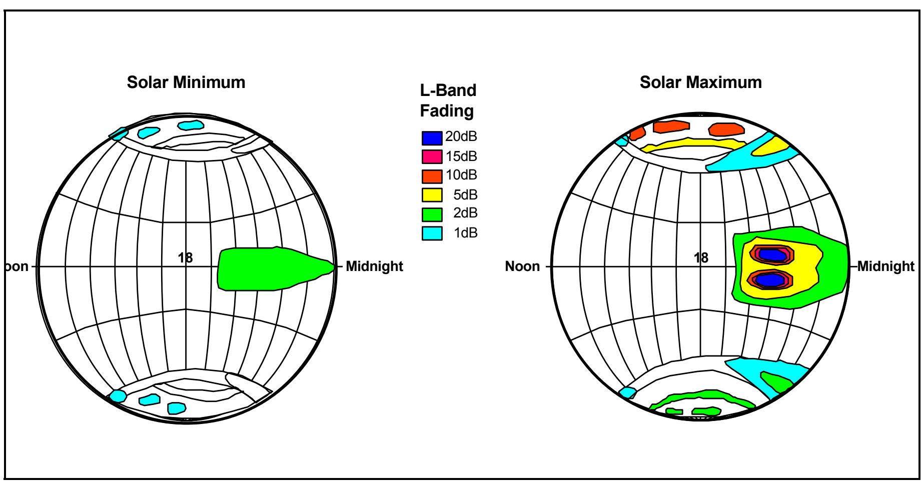


Fig. 6-9. Scintillation Occurrence

Scintillation Occurrence

There is no fielded network of ionospheric sensors capable of detecting real-time scintillation occurrence or distribution (**Fig. 6-9**). Presently space

Statistically, scintillation tends to be most severe at lower latitudes (within $\pm$ 20 degrees of the geomagnetic equator) due to ionospheric anomalies in that region. It is also strongest from local sunset until just after midnight, and during periods of high solar activity. At

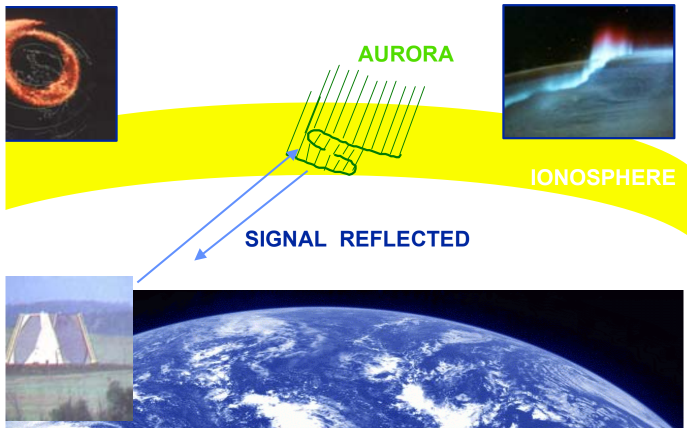


Fig. 6-10. Radar Aurora

higher geomagnetic latitudes (the auroral and polar regions), scintillation is strong, especially at night, and its influence increases with higher levels of geomagnetic activity. Knowledge of those time periods and portions of the ionosphere where conditions are conducive to scintillation permits operators to reschedule activities or to switch to less susceptible radio frequencies.

Radar Aurora Clutter and Interference

As previously discussed, a geomagnetic and ionospheric storm will cause both enhanced ionization and rapid variations (over time and space) in the degree of ionization throughout the auroral oval. Visually, this phenomena is observed as the Aurora or Northern /Southern Lights. This enhanced, irregular ionization can also produce abnormal radar signal back-scatter on poleward looking radars, a phenomena known as "radar aurora" (**Fig. 6-10**). The strength of radar aurora signal returns and the amount of Doppler frequency shifting, are aspect dependent.

Impacts can include increased clutter and target masking, inaccurate target locations and even false target or missile launch detection. While improved software screening programs have greatly reduced the frequency of false aircraft or missile launch detection, they've not been eliminated totally. (*NOTE*: Radar aurora is a separate phenomena from the weak radio wave emission produced by the recombination/de-excitation of atmospheric atoms and molecules in the auroral oval, a process which also produces the much stronger infrared, visible and ultraviolet auroral emissions.)

Surveillance Radar Errors

The presence of free electrons in the ionosphere causes radiowaves to be bent (or refracted) as well as slowed (or retarded) somewhat from the speed of light. Missile detection and spacetrack radars operate at Ultra High Frequencies (UHF, 300-3,000 mHz) and Super High Frequencies (SHF, 3,000-30,000 mHz) to escape most of the effects of ionospheric refraction so useful to HF surface-to-surface radio operators. However, even radars operating at these much higher frequencies are still susceptible to enough signal refraction and retardation to produce unacceptable errors in target bearing and range.

Bearing and Range Errors

A bearing (or direction) error is caused by signal bending, while a range (or distance) error is caused by both the longer path length for the refracted signal and the slower signal speed (**Fig. 6-11**). For range errors, the effect of longer path length dominates in UHF signals, while slower signal speed dominates for SHF signals.

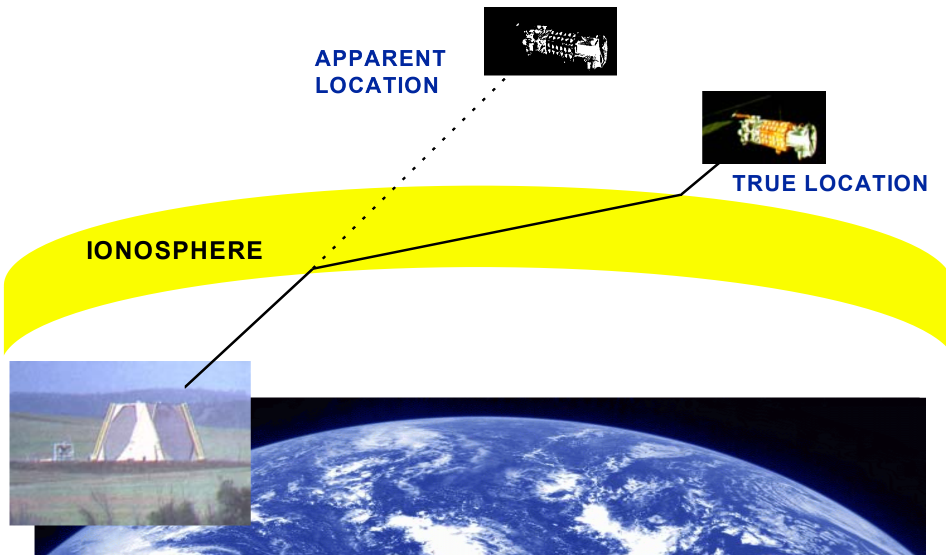


Fig. 6-11. Surveillance Radar Errors

Correction Factors

Radar operators routinely attempt to compensate for these bearing and range errors by applying correction factors that are based on the expected ionospheric "total electron content (TEC)" along a radar beam's path. These predicted TEC values/correction values are based on time of day, season and the overall level of solar activity. Unfortunately, individual solar and geophysical events will cause unanticipated, short-term variations from the predicted TEC values and correction factors. These variations (which can be either higher or lower than the anticipated values) will lead to inaccurate position determinations or difficulty in acquiring targets. Real-time warnings when significant TEC variations are occurring, help radar operators minimize the impacts of their radar's degraded accuracy.

Space-Based Surveillance

The bearing and range errors introduced by ionospheric refraction and signal retardation (as described above) also apply to space-based surveillance systems. For example, a space-based sensor attempting to lock on to a ground radio emitter may experience a geolocation error.

Over-the-Horizon Backscatter (OTH-B) Surveillance Radars

OTH-B radars use HF refraction through the ionosphere to detect targets beyond the horizon. OTH-B operators need to be aware of existing and expected ionospheric conditions (in great detail) over a wide geographical area. Otherwise, improper frequency selection will reduce target detection performance; or incorrect estimation of ionospheric layer heights will give unacceptable range errors.

Atmospheric Drag

Another source for space object positioning errors is that of either more *or less* atmospheric drag than expected on low orbiting objects (generally at less than about 1,000 km altitude). Energy deposited in the Earth's upper atmosphere by EUV, X-ray and charged particle bombardment heats the atmosphere, causing it to expand outward. Low earth-orbiting satellites and other space objects then experience denser air and more frictional drag than expected. This drag decreases an object's altitude and increases its orbital speed. The result is the object will be some distance below and ahead of its expected position when a ground radar or optical telescope attempts to locate it (see **Fig. 6-12**). Conversely, exceptionally calm solar and/or geomagnetic conditions will cause *less* atmospheric drag than predicted and an object could be higher and behind where it was expected to be found.

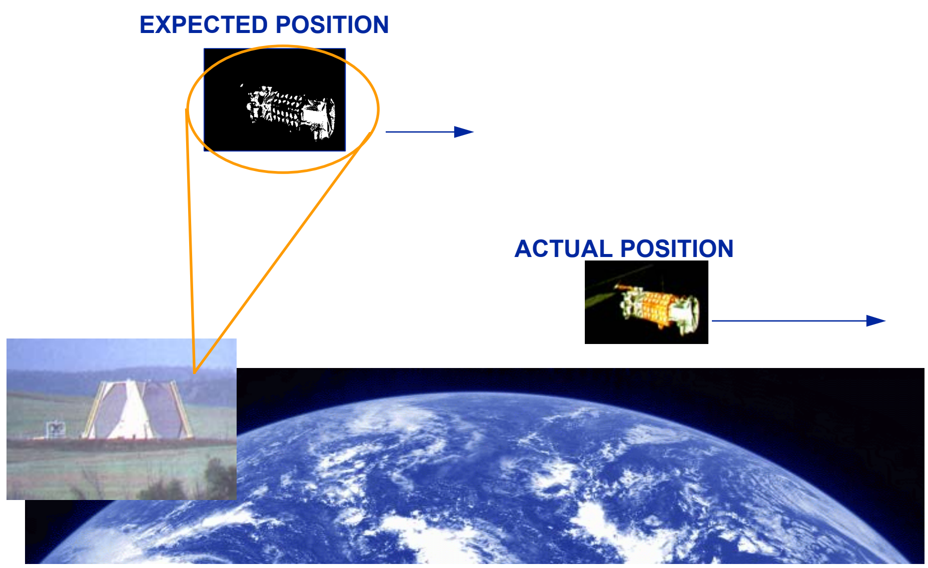


Fig. 6-12. Atmospheric Drag

Impacts of Atmospheric Drag

The consequences of atmospheric drag include: (1) inaccurate satellite locations which can hinder rapid acquisition of SATCOM links for commanding or data transmission; (2) costly orbit maintenance maneuvers may become necessary; and (3) de-orbit predictions may become unreliable. A classic case of the latter was Skylab. Geomagnetic activity was so severe, for such an extended period, that the expanded atmosphere caused Skylab to de-orbit and burn-in before a planned Space Shuttle rescue mission was ready to launch.

Contributions to Drag

There are two space environmental parameters used by current models to predict the orbits of space objects. The first is the solar "F10 index". Although the F10 index is a measure of solar radio output at 10.7 centimeters (or 2,800 mHz), it is a very good indicator of the amount of EUV and X-ray energy emitted by the sun and deposited in the Earth's upper atmosphere. In **Fig. 6-13** the Solar Flux (F10) graph shows a clear, 27-day periodicity caused by the sun's 27-day period of rotation and the fact that hot, active regions are not uniformly distributed on the sun's surface. The second parameter is the geomagnetic "Ap index", which is a measure of the energy deposited in the Earth's upper atmosphere by charged particle bombardment. This index shows strong spikes corresponding

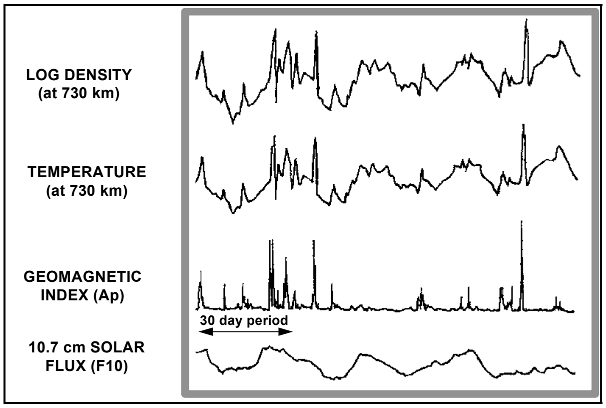


Fig. 6-13. Factors Contributing to Atmospheric Drag

to individual geomagnetic storms. The upper two graphs, which show upper atmospheric temperature and density (observed by a satellite at 730 km altitude), clearly reflect the influence of these two indices. Since it takes time for the atmosphere to react to a change in the amount of energy being deposited in it, drag impacts first tend to be noticeable about six hours after a geomagnetic storm starts and may persist for about 12 hours after the storm ends.

The Impact of Geomagnetic Storms on Orbit Changes

Two impacts of geomagnetic storms on space tracking radar's have now been discussed. The first was bearing and range errors induced by inadequate compensation for TEC changes, which caused *apparent* location errors. The second was atmospheric drag, which caused *real* position errors. These effects can occur simultaneously. During a severe geomagnetic storm in March 1989, over 1,300 space objects were temporarily misplaced (**Fig. 6-14**). It took almost a week to re-acquire all the objects and update their orbital elements. This incident led to a revision in operating procedures. Normally drag models do not include detailed forecasts of the F10 and Ap indices. However, when severe conditions are forecast, more comprehensive model runs are made, even though they're also more time consuming.

Space Launch and Payload Deployment Problems

Atmospheric Drag

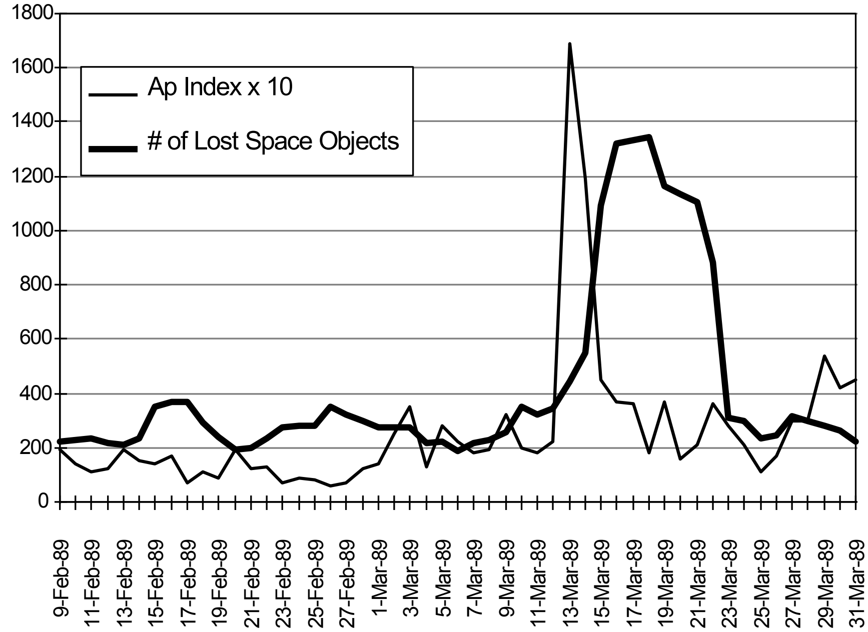
Excessively high *or* low geomagnetic conditions can produce atmospheric density variations along a proposed launch trajectory. The ability of a launch vehicle to compensate for these variations may be exceeded. In addition, the atmospheric density profile based on changes in altitude will determine how early the protective shielding around a payload can be jettisoned. If the protective shielding is jettisoned too early the payload is exposed to excessive frictional heating.

Particle Bombardment

Charged particle bombardment during a geomagnetic storm or proton event can produce direct physical damage on a launch vehicle or its payload, or it can deposit an electrical charge on *or* inside the spacecraft. The electrostatic charge deposited may be discharged (lead to arcing) by on-board electrical activity such as vehicle commanding. In the past, payloads have been damaged by attempted deployment during geomagnetic storms or proton events.

Radiation Hazards

Despite all engineering efforts, satellites are still quite susceptible to the charged particle environment. In fact, with newer microelectronics and their lower operating voltages, it will actually be easier to cause electrical upsets than on older, simpler vehicles. Furthermore, with the perceived lessening of the man-made nuclear threat, there has been a trend to build new satellites with less nuclear radiation hardening. This previous hardening also protected the satellites from space environmental radiation hazards.



This Fig. demonstrates how a geomagnetic storm can change the orbits of space objects unexpectedly, causing difficulty for those who maintain orbital data.

Fig. 6-14. Geomagnetic Storms and Orbit Changes

Both low and high earth-orbiting spacecraft and satellites are subject to a number of environmental radiation hazards, such as direct physical damage and/or electrical upsets caused by charged particles. These charged particles may be: (1) trapped in the "Van Allen Radiation Belts," (2) in directed motion during a geomagnetic storm or (3) protons/cosmic rays of direct solar or galactic origin.

Van Allen Radiation Belts

The Outer and Inner Van Allen Radiation Belts are two concentric, toroid (or donut-shaped) regions of stable, trapped charged particles that exist because the geomagnetic field near the Earth is strong and field lines are closed (**Fig. 6-15**). The Inner Belt has a maximum proton density approximately 5,000 km above the Earth's surface and contains mostly high-energy protons produced by cosmic ray collisions with the Earth's upper atmosphere. The Outer Belt has a maximum proton density at an altitude ranging from 16,000 to 20,000 km and contains low to medium energy electrons and protons whose source is the influx of particles from the magneto-tail during geomagnetic storms.

Geosynchronous Orbit

"Geosynchronous" orbit (35,782 km or 22,235 statute miles altitude) is commonly used for communication satellites. Unfortunately, it lies near the outer boundary of the Outer Belt, and suffers whenever that boundary moves inward or outward. Semi-synchronous orbit (which is used for GPS satellites) lies near the middle of the Outer Belt (in a region called the "ring current") and suffers from a variable, high density particle environment. Both orbits are particularly vulnerable to the directed motion of charged particles that occurs during geomagnetic storms. Particle densities observed by satellite sensors can increase by a factor of 10 to 1,000 over a time period as short as a few tens of minutes.

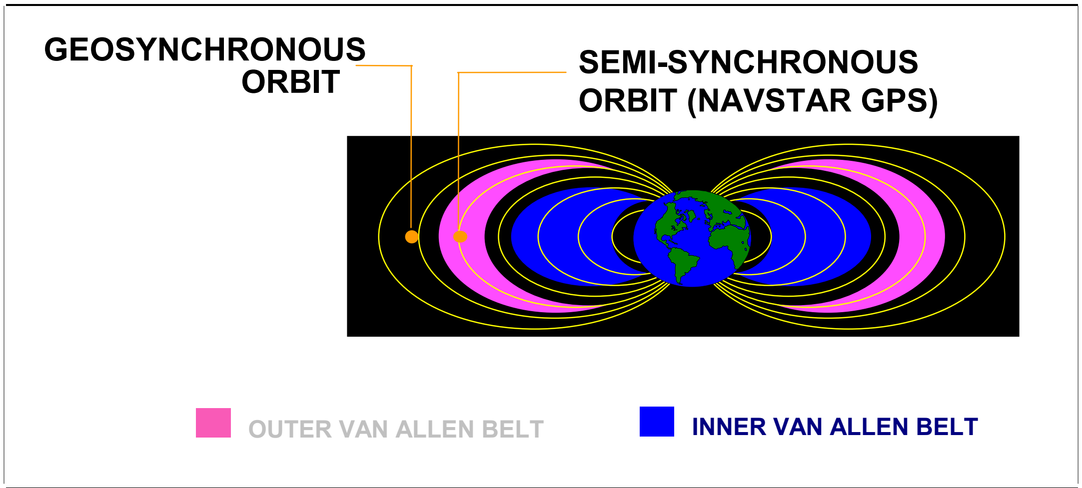


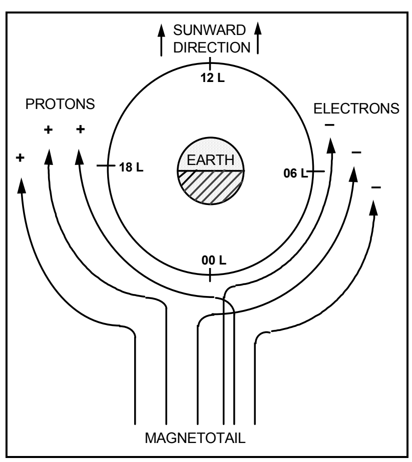
Fig. 6-15. Van Allen Radiation Belts

Geomagnetic Storms

As mentioned earlier, charged particles emitted by the sun cause problems primarily on the *night* side of the Earth. Their arrival causes a shock wave to ripple through the magnetosphere, causing magnetic field lines out in the magnetosphere's tail to recombine, and previously stored particles are then shot toward the Earth's night side hemisphere. Some of these particles stay near the plane of the equator and feed the ring current in the Outer Van Allen Radiation Belt, while other particles follow magnetic field lines up (and down) toward auroral latitudes.

Radiation Belt Particle Injections

The particles from the night side magnetosphere (or magneto-tail) which stayed near the plane of the equator will feed the ring current in the Outer Van Allen belt. The electrons and protons, since they are oppositely charged, tend to move in opposite directions when they reach the ring current (**Fig. 6-16**).



Cross-section of the magnetosphere taken in the plane of the Earth's geomagnetic equator.

Fig. 6-16. Geomagnetic Storms - Radiation Belt Particle Injections

Furthermore, the protons and electrons have about the same amount of energy, but the electrons (since they are 1,800 times lighter) move 40 times faster. Finally, the electrons are about 10 to 100 times more numerous than the protons.

The result of all these factors is that electrons are much more effective at causing physical damage due to collision and electrical charging than the protons. This fact explains why the preponderance of satellite problems occur in the midnight to dawn (0001 to 0600 Local) sector, while the evening (1800 to 2359 Local) sector is the second most common location for problems. This explanation is well supported by the rather large number of satellite anomalies which actually can be observed in the midnight to dawn sector.

Auroral Particle Injections

Some of the particles from the night side magnetosphere follow geomagnetic field lines up (and down) toward the northern and Southern Hemisphere auroral latitudes. These particles will penetrate to very low altitudes (as low as 35 km), and can cause physical damage and electrical charging on high-inclination, low-altitude satellites or Space Shuttle missions (**Fig. 6-17**).

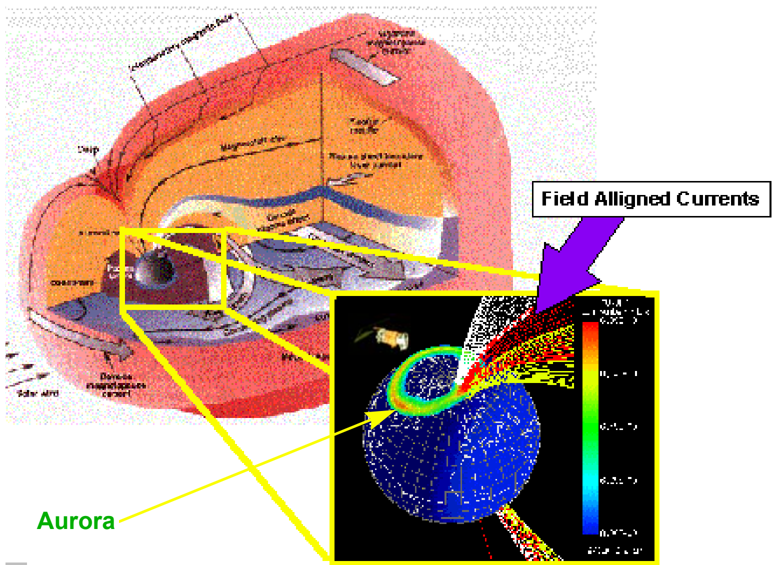


Fig. 6-17 Geomagnetic Storms Auroral Particle Ejections

Electrical Charging

One of the most common anomalies caused by the radiation hazards discussed above is spacecraft or satellite electrical charging. Many things can produce charging. (1) an object's motion through a medium containing charged particles (called "wake charging"), which is a significant problem for large objects like the Space Shuttle or a space station, (2) direct particle bombardment, as occurs during geomagnetic storms and proton events, or (3) solar illumination, which causes electrons to escape from an object's surface (called the "photoelectric effect"). The impact of each phenomenon is strongly influenced by variations in an object's shape and the materials used in its construction (**Fig. 6-18**).

Surface versus Deep Charging

An electrical charge can be deposited either on the surface or deep within an object. Solar illumination and wake charging are surface charging phenomena. For direct particle bombardment, the higher the energy of the bombarding particles, the deeper the charge can be placed. Normally electrical charging will not (in itself) cause an electrical upset or damage.

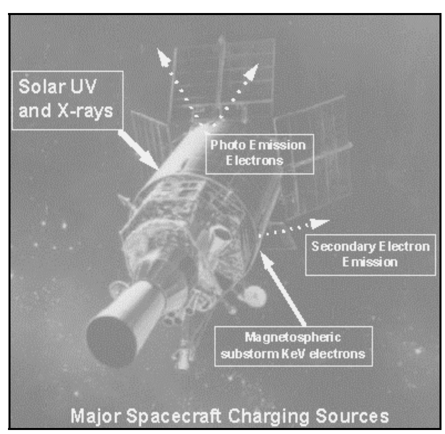


Fig. 6-18. Spacecraft Charging

It will deposit an electrostatic charge which will stay on the vehicle (for perhaps many hours) until some triggering mechanism causes a discharge or arcing. Such mechanisms include: (1) a change in particle environment, (2) a change in solar illumination (like moving from eclipse to sunlit) or (3) on-board vehicle activity or commanding.

Charging Impacts

Generally, an electrostatic discharge can produce; (1) spurious circuit switching, (2) degradation or failure of electronic components, thermal coatings and solar cells or (3) false sensor readings. In extreme cases, a satellite's life span can be significantly reduced, necessitating an unplanned launch of a replacement satellite. Warnings of environmental conditions conducive to spacecraft charging allow operators to reschedule vehicle commanding, reduce on-board activity, delay satellite launches and deployments or re-orient a spacecraft to protect it from particle bombardment. Should an anomaly occur, an environmental post-analysis can help operators determine whether the environment contributed to it and the satellite function can be safely re-activated or re-set, or whether engineers need to be called out to investigate the incident. An accurate assessment can reduce down-time by several days. Charging occurs primarily when solar and geomagnetic activity are high and on geosynchronous or polar-orbiting satellites.

Single Event Upsets (SEUs)

Very high-energy protons or ions (either from solar flares or the Inner Van Allen Belt) or cosmic rays (either from the very largest solar flares or from galactic sources outside our Solar System) are capable of penetrating completely through a satellite. As they pass through, they will ionize particles deep inside the satellite. In fact, a *single* proton or cosmic ray can (by itself) deposit enough charge to cause an electrical upset (circuit switch, spurious command or memory change or loss) or serious physical damage to on-board computers or other components. Hence these occurrences are called "*single* event upsets". SEUs are very random, almost unpredictable events. They can occur at any time during the 11-year Solar Cycle. In fact, SEUs are actually most common near Solar *Minimum*, when the Interplanetary Magnetic Field emanating from the sun is weak and unable to provide the Earth much shielding from cosmic rays originating outside the Solar System.

Satellite Disorientation

Many satellites rely on Electro-optical sensors to maintain their orientation in space. These sensors lock onto certain patterns in the background stars and use them to achieve precise pointing accuracy. These star sensors are vulnerable to cosmic rays and high-energy protons, which can produce flashes of light as they impact a sensor. The bright spot produced on the sensor may be falsely interpreted as a star. When computer software fails to find this false star in its star catalogue or incorrectly identifies it, the satellite can lose attitude lock with respect to the Earth. Directional communications antenna, sensors and solar cell panels would then fail to see their intended targets. The result may be loss of communications with the satellite, loss of satellite power and, in extreme cases, loss of the satellite due to drained batteries (gradual star sensor degradation can also occur under constant radiation exposure). Disorientation occurs primarily when solar activity is high and on geosynchronous or polar-orbiting satellites.

Geomagnetic Storm Surface Impacts

Geomagnetic storms cause rapid fluctuations in the Earth's magnetic field and increase the amount of precipitating energetic particles impinging on the Earth's ionosphere. The rapid fluctuations can lead to induced currents in power grids that may lead to failure of that grid (**Fig. 6-19**). This can and has happened, predominately in the higher latitudes. (In March of 1989, the Canadian Province of Quebec suffered a power grid failure of this type.) Such fluctuations can also

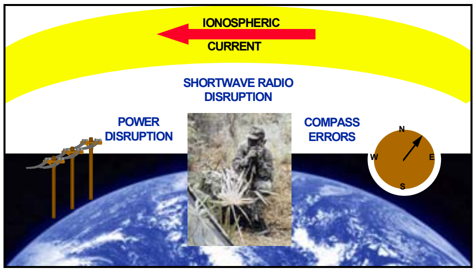


Fig. 6-19. Geomagnetic Storm Surface Impacts

cause orientation errors for those relying on magnetic compasses for navigation. In addition to the ionospheric disturbances discussed earlier, localized rapidly changing ionospheric activity can occur. This activity may not be picked up by space environment sensors, but can cause HF communication users to suffer sporadic interference or total localized blackouts.

SPACE ENVIRONMENTAL SUPPORT

The 55th Space Weather Squadron (55SWXS).

55SWXS is DOD's only space environmental analysis and forecasting facility. It is a subordinate unit of the Air Force Weather Agency (AFWA), Offutt AFB, NE. At the time of this writing the plan is to move the 55SWXS to Offutt's AFWA facilities effective 1 Oct 2001. At that time the 55SWXS will cease operations at Schriever AFB, CO and the mission will be conducted from AFWA.

The squadron is a 24-hour support operation providing tailored space environmental products and services to DOD and national program customers.

The 55SWXS headquarters is at Schriever AFB, Colorado and operates several Geographically Separated Units (GSUs) to monitor the Sun. Known as the Solar Electro-Optical Network (SEON), it is the only network in the world dedicated to observing the Sun at optical and radio wavelengths in real time.

Mission

55SWXS provides space environmental support for worldwide operations (**Fig. 6-20**). The squadron gathers and processes space environmental data from ground and space-based sensor networks, analyzes and models the space environment, forecasts solar and space environmental phenomena and provides alerts, warnings and assessments for operational impacts to Air Force and other DOD agencies. Support to customers can be provided at the unclassified, collateral and Sensitive Compartmented Information (SCI) levels. Systems supported include satellite vehicle and payload operations, ground and satellite-based communications, navigation, surveillance and weapon system radar, as well as high-altitude reconnaissance aircraft and the Space Shuttle.

Products

55SWXS products fall into one of four categories:

<u>Parameter Observations</u>. The 55SWXS monitors solar activity through the data received from SEON, other ground-based ionospheric sounder networks and satellite-based sensors. Critical parameters from this data are used to optimize tailored environmental models used in specifying satellite locations and enhancing HF and satellite communications links, as well as radar and satellite tracking correction and calibration.

<u>Analysis</u>. Near-Real Time and Post Analysis. This category gives system

operators, engineers and decision-makers expert analyses of the role the space environment plays in system anomalies. This provides quicker resolution of anomalies reducing system downtime and saving time searching for other causes.

anomaly resolution in support of radar, satellite vehicle and payload operations.

Access to 55SWXS Products

The 55SWXS uses a number of common user systems as well as dedicated point-to-point communication circuits to support the dissemination of data. Products are available over the Automated Weather Network (AWN) and both unclassified and classified AUTODIN. See your local weather support officer to gain access to products disseminated over the AWN and learn how to get them. To receive products via AUTODIN, contact 55SWXS and your address will be added to the product distribution lists.

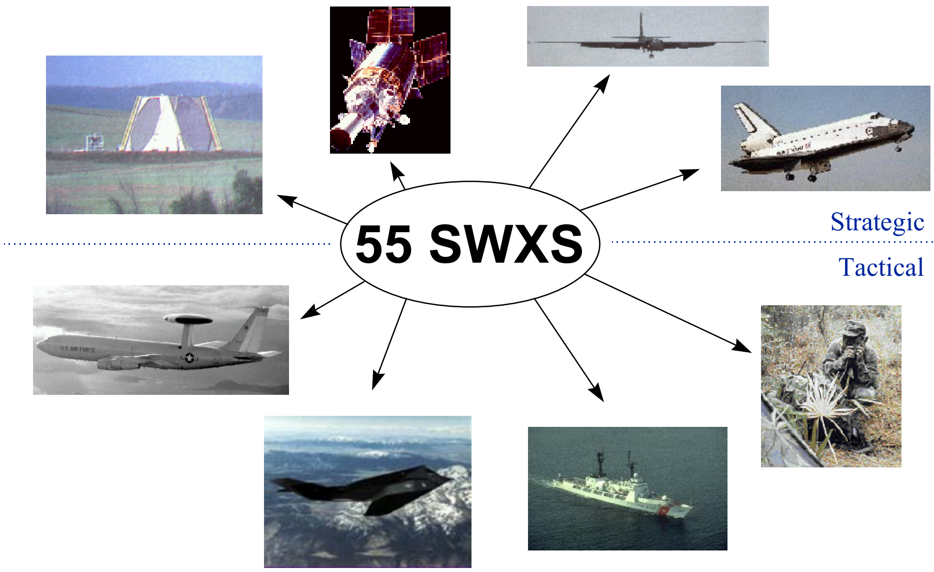


Fig. 6-20. 55SWXS Mission Support

Forecasts. 24-Hours/days, 7 days per week. All portions of the radio spectrum are subject to variability in the ionosphere. The 55SWXS provides predictions of critical parameters for optimizing HF and satellite communications operations and planning, satellite drag prediction and radar and satellite signal correction.

Warnings. Navigation systems are influenced by energetic proton flux into the polar caps as well as geomagnetic activity. Also, energetic protons pose a significant health hazard to high-altitude reconnaissance aircraft pilots and astronauts operating in the space environment. Satellite systems in certain orbits can perform anomalously or be damaged during solar flare induced particle storms. The squadron provides situational awareness products, potential systems effects and aids in system

Web Page

The 55th Space Weather Squadron has a comprehensive web page. This web page is available on Intelink and the Global Command and Control System (GCCS) as well as unclassified, non-DOD Internet systems. The address is: http://www.schriever.af.mil/55swxs/index.htm.

Product Catalog

The 55SWXS maintains AFCAT 15-152, Volume 5, *Space Environmental Products*. This publication describes the space environmental analysis, forecast and warning services provided by 55SWXS and defines terms used in space environmental products. However, most of the publication is devoted to a detailed description of each standard product available from the forecast center, plus some samples of customer tailored products.

Requests for Support

Eligible organizations may request space environmental support or products. Several ways of dissemination are available, (restrictions based on the product or support may apply) including AWN, AUTODIN, FAX and mail.

AFI 15-118 Support Assistance Request (SAR)

To request continuing, a-periodic or one-time support (i.e., contingency, exercise or customized support), submit an AFI 15-118, Support Assistance Request (SAR) to 55SWXS/DOO (Operations) or DOUX (Payload Management). The format of a SAR is described in AFI 15-118 (available from most USAF base weather units, including Army support units). For additional details or assistance in determining support requirements, contact 55SWXS/DOUX (Payload Management).

Special Support

The 55SWXS/DOO (Operations) personnel can provide immediate support 24 hours a day. They prefer to coordinate requirements beforehand to ensure support is optimum, but short-notice responses may be requested.

Points of Contact:

- **55SWXS Internet Address:**
55swxs@schriever.af.mil

- **55SWXS/DOO (Operations):**
  24 hours a day
  DSN: 560-6313/6312/6311/2404/6322
  Commercial: (719) 567-xxxx
  FAX extensions: 6407/2100/6219

- **55SWXS/DOUX (Requirements):**
  0730 - 1630 MST
  DSN: 560-2420/2422/6331/6332
  Commercial: (719) 567-xxxx
  FAX extensions: 2287/2288

- **55th Space Weather Squadron's mailing address is:**
  55SWXS
  715 Kepler Ave., Ste 60
  Schriever AFB, Colorado 80912-7160

The 614th Aerospace Weather Team (AWT)

The 614/AWT is a unit of 14th Air Force and operates around the clock at Vandenberg AFB, CA in the Commanders Space Air Forces (COMSPACEAF) Aerospace Operations Center (AOC). The AWT receives its space environment strategic products from the AFWA and extracts information directly applicable to space operations. The information is put into reports and forwarded to 14th Air Force units, USSPACECOM and other components such as ARSPACE and NAVSPACE. The 614/AWT also performs a reachback function for units such as Aerospace Expeditionary Forces (AEF) requiring short duration support.

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Jacchia, L., "Atmospheric Structure and Its Variations At Heights Above 200 KM", *CIRA (Cospar International Reference Atmosphere)*. North-Holland Publishing Company, Amsterdam. 1965.

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http://www.sec.noaa.gov/index.html
Home page of the National Oceanic and Atmospheric Administration. Provides space weather alerts, warnings, and forecasts, and related space weather information.

http://www.sec.noaa.gov/info/Cycle23.html
Overview of NOAA's panel discussion and conclusion on predictions of how Solar Cycle 23 would affect space weather.

http://sohowww.nascom.nasa.gov/
Home page for the Solar and Heliospheric Observatory; capabilities, images, and related information.

http://www.srl.caltech.edu/ACE/
Home page for the Advanced Composition Explorer spacecraft; educational and other information related to capabilities, projects, and goals.

http://www.sel.noaa.gov/today.html
NOAA's Space Environment Center reviews today's space environment and provides links to related space weather information.

http://solar.sec.noaa.gov/primer/primer.html
NOAA tutorial on space weather environment.

http://www.ips.gov.au/papers/
Australian government website providing comprehensive information about the sun and space weather.

http://www.ips.gov.au/papers/richard/calc_inter.html
Provides predictions of solar interference to satellite based on satellite location information entered by user.

TOC

Chapter 7

TERRESTRIAL-SOLAR ENVIRONMENT AND EFFECTS ON MANNED SPACEFLIGHT

The space environment is hostile. This hostility is fueled primarily by the sun and extends into the terrestrial environment. This chapter examines the construction of the terrestrial environment, acting as a precursor to the following chapter, which details the space environment. As solar effects and activity fluctuate, the boundary between the terrestrial and space environment becomes decreasingly defined.

TERRESTRIAL ENVIRONMENT

Although there are many varied definitions of space, for this discussion, an altitude of 150 km/93 miles is sufficient. This is the minimum altitude for maintaining a circular orbit around earth and equates to an 87.5 minute period. Now that the approximate parameters for satellite operation have been identified, the different layers of the Earth's atmosphere should be addressed.

Troposphere

The *troposphere* is the lowest region of the atmosphere and extends up to an altitude of about seven miles (see **Fig. 7-1**). The troposphere contains about three-fourths of the Earth's atmosphere by weight. It is in this layer of air that almost all cloud and weather phenomenon occur. The upper boundary of the troposphere is known as the tropopause. Instrumental aircraft and balloons have observed a steady decrease in temperature as altitude increases. This temperature decrease continues until the tropopause, at which point it stabilizes at -70° F.

At an altitude of 10,000 feet, the oxygen pressure of the atmosphere is not great enough to allow people to work efficiently over a long period of time. Although many people eventually become acclimated to altitudes of 10,000 feet and higher, for someone who lives at or near sea level, the oxygen pressure above 10,000 feet is insufficient to sustain active and efficient performance. Thus, the Air Force requires the use of supplemental oxygen for flight crew members at altitudes above 10,000 feet.

Stratosphere

The layer above the troposphere is called the *stratosphere*. This region is characterized by the near absence of water vapor and clouds. The average altitude of this layer is seven miles at the base and 22 miles at the top. Approximately 99 percent of the atmosphere lies below the top of the stratosphere. The temperature is a constant -70° F from the troposphere to about 12 miles (20 kilometers), whereupon it inclines to about 30° F at the top of the stratosphere.

At an altitude of about nine miles (15 km), supplemental oxygen fails as a sufficient aid to sustain life. Here the combined pressure of carbon dioxide and water vapor in the lungs equals the outside atmospheric pressure, and therefore, breathing (more precisely, the absorption of oxygen by the red blood cells) cannot take place without supplemental pressure. Hence, at this altitude, pressurized cabins or pressure suits are a necessity. The vapor pressure of human body fluids is about 47 mm of mercury. As soon as the atmospheric pressure drops to this level, bubbles of water vapor and other gases (notably nitrogen) appear in the body fluids. This means the blood literally starts to boil as these bubbles continue to expand. The gas bubbles first appear on the mucus membranes of the mouth and eyes and later in the veins and arteries. This would happen to an unprotected person at an altitude of about 12 miles (20 km).

Wearing a pressure suit or being contained in a pressurized cabin will prevent this problem.

At 15 miles (25 km), compressing the outside air to pressurize a cabin is no longer feasible. The air density is about 1/27 of the sea level value at this altitude.

Compressing this thin air is not an

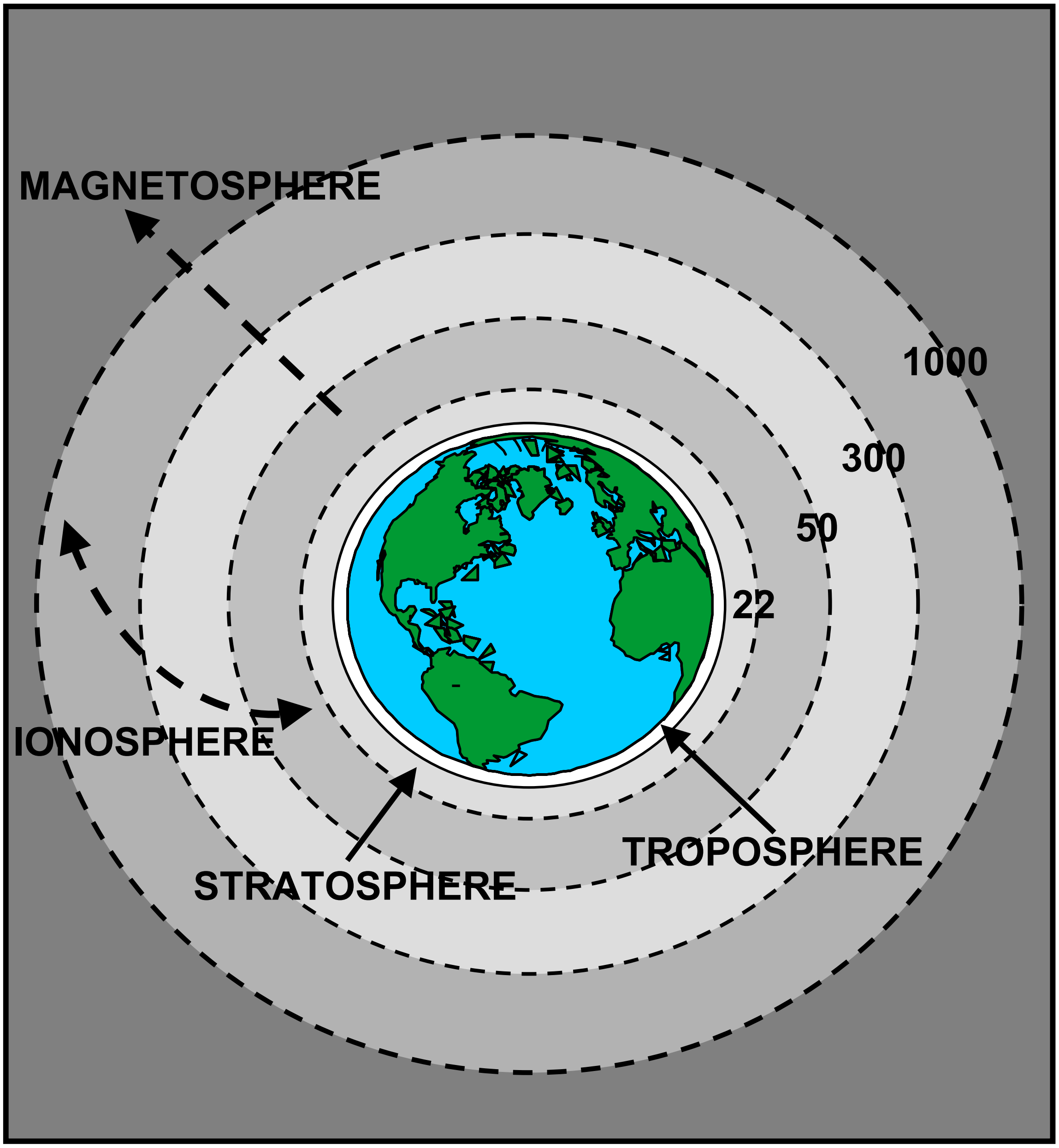

Fig. 7-1. Space Regions
NOTE: All altitudes (given in miles) are approximate. Latitudes, seasons and solar activities cause significant deviations.

impossible task, but is certainly not an economical one. Furthermore, the process of air compression would involve undesirable heat transfer to the air. Finally, the atmosphere at this altitude contains a significant percentage of ozone, which if compressed, would poison the cabin atmosphere. Above 15 miles (25 km), the cabin or space suit must have a supply of both oxygen and pressure independent of the outside atmosphere, thus adding significantly to the weight and degree of sophistication of a vehicle. As far as a man is concerned, this altitude could be considered the beginning of space. Above this altitude, man must take everything he needs for survival, as this environment will supply him no food, water or air.

The upper boundary of the stratosphere contains the greatest concentration of ozone, which is a vital part of the Earth's atmosphere. It absorbs a large part of the Sun's ultraviolet radiation, shielding the fragile process we call life from its harmful effects. This absorption process heats up the thin atmosphere at this altitude to a temperature of 30° F.

Mesosphere

The region of the atmosphere called the *mesosphere* extends from the top of the stratosphere at 22 miles (35 km) to about 50 miles (80 km). All but one-millionth of the atmosphere lies below the top of the mesosphere, where the atmosphere is so thin that no sound can be transmitted.

The operating limit for turbojet engines is reached at 26 miles. However, there is not enough oxygen in the atmosphere to operate even a ramjet engine once it reaches 28 miles. Engines must be supplied with both a fuel and an oxidizer above this altitude. Thus, to a propulsion engineer, space commences at 28 miles (45 km) because rockets must be used for propulsion above this height.

On the administrative side, space starts at the top of the mesosphere at 50 miles (80 km). A pilot flying at or above this altitude earns astronaut wings.

Thermosphere

The *thermosphere* extends up to somewhere between 200-300 miles (320-480 km) beginning at about 50 miles (81 km) (experts do not agree on an exact division). From the low temperature of -135° F at the top of the mesosphere, the temperature curve increases again, reaching as high as 2,200° F.

The atoms and molecules in this layer are bombarded by powerful electromagnetic waves from the Sun and become charged or ionized, causing extreme temperatures. The thermosphere is also the region where the Aurora Borealis or the aurora occurs, although it has been observed as high as 1,000 km. The solar wind plays an important role in the aurora by either supplying the necessary charged particles or by perturbing the magnetosphere so that the particles are "dumped" into the atmosphere near the magnetic poles. As these particles collide with the sparse gas molecules in the upper atmosphere, light energy released causes auroral displays.

In 1964, a New York law firm asked the Air Force Office of Aerospace Research to define the beginning of space. This scientific organization based their answer on aerodynamic forces, probably because the majority of the staff were associated with flying. These forces, acting on ballistic reentry vehicles, lifting reentry vehicles and boost-glide orbital vehicles, can usually be neglected at altitudes above 62 miles (100 km). Therefore, if an aeronautical engineer is concerned with lift and drag, space begins above this altitude.

About 100 miles (161 km) above the Earth is a region of darkness and complete silence. This is called the Black Sky region. The stars appear as brilliant points of light and the area between them is jet black because there is not enough air to scatter or reflect the light rays.

Also part of the thermosphere is the ionosphere. When we discuss communications, both ground and via satellite, the ionosphere plays a significant role in the success or failure of the communications. The ionosphere begins in the upper part of the mesosphere and extends upward through the thermosphere and ends just short of the exosphere in the upper region of the thermosphere. The Sun's rays, including X-rays and ultraviolet radiation, pass into the thermosphere and break the layer's molecules into positive ions and negative electrons. These ions and electrons refract radio transmissions from earth back toward the surface, facilitating the reception of long-range radio broadcast in the High Frequency (HF) frequency range. The ionosphere will be discussed in more detail in this publication's Chapter 6.

Exosphere

The exosphere is the most distant atmospheric region from the Earth's surface. The upper boundary of the layer extends to heights of perhaps 960 to 1000 miles and is relatively undefined. The exosphere is a transitional zone between Earth's atmosphere and interplanetary space. It is only from the exosphere that atmospheric gases can, to any appreciable extent, escape into outer space. There are so few molecules in this outer stretch of the atmosphere that even temperatures are hard to define.

THE SOLAR ENVIRONMENT

The Sun

The Sun is a typical star - a great sphere of luminous gas (see **Fig. 7-2**). It is composed of the same chemical elements that compose the Earth and other objects of the universe, but in the Sun (and other similar stars) these elements are heated to a gaseous state. Tremendous pressure is produced by the great weight of the Sun's layers. The high temperature of its interior and the consequent thermonuclear reactions keep the Sun gaseous. These nuclear reactions are the source of the energy continuously radiated to space, which drives solar activity. A relatively small core contains most of the mass and is almost entirely responsible for the Sun's luminosity. The core is defined as the central sphere within one fourth the radius of the Sun.

The Sun's *core temperature* is 15 million degrees Kelvin (K). Its pressure is approximately 250 billion atmospheres and its specific gravity is slightly less than 160. The energy released in the core

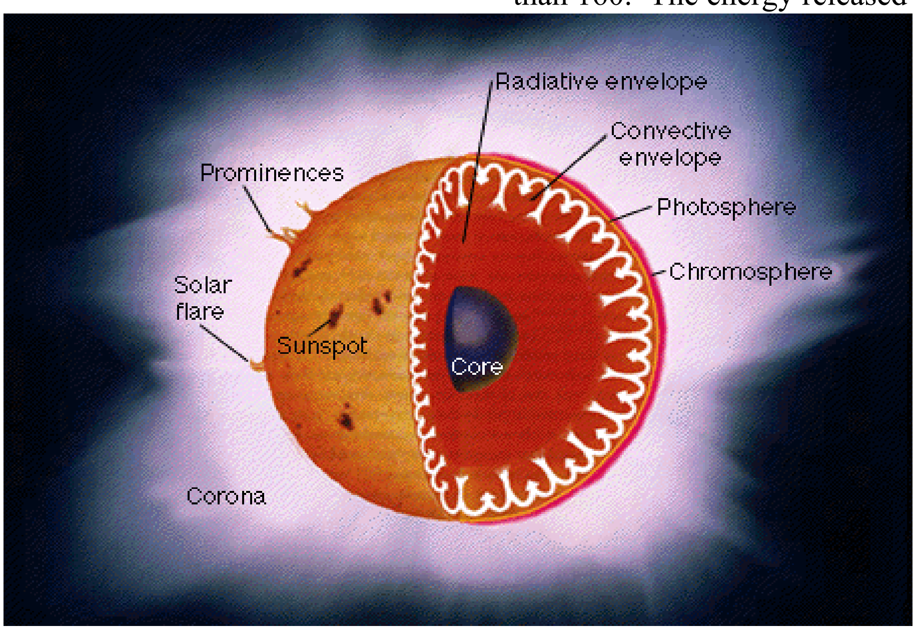

Fig. 7-2. The Sun

results from the fusion of hydrogen nuclei to form helium nuclei. The core also contains almost all of the products or "ashes" of the nuclear burning.

The next region out from the core is called the *radiative envelope* because the energy generated in the Sun's core is transferred toward the surface by radiation. Outward from the core, the temperature, pressure and density decrease rapidly, as does the energy of an average photon. Photons are absorbed and re-emitted many times as they diffuse toward the surface. In this way, the energy flowing from the core in the form of high-energy gamma rays is changed to x-rays, to extreme ultraviolet (EUV) rays, to ultraviolet (UV) rays and finally to the lower energy visible light which is most characteristic of the solar energy freely radiated to space. Temperature is the gas property that is primarily responsible for the establishment of a turbulent layer beneath the Sun's surface. In the radiation zone, the temperature has reached a value which is low relative to that in the core (1 million degrees K).

The final layer of the solar interior is the *convection envelope* zone. As the name implies, the primary mode of energy transfer through this zone is direct transport, rather than radiation. Each element of rising gas carries its own parcel of energy directly to the surface. In addition to this mode of transfer, the powerful turbulence generates noise or "mechanical energy," which as low-frequency sound waves, propagates through the photosphere and into the Sun's outer layers. Although the amount of energy transported in this way is relatively small, it plays a major role in establishing the character of the outer layers of the Sun.

The only parts of the Sun that can be observed directly are its outer layers, collectively known as the Sun's atmosphere. The solar atmosphere is not stratified into physically distinct layers with sharp boundaries. Yet there are three general regions each having substantially different properties, gradually transitioning from one region to the next. These are the *photosphere*, the *chromosphere* and the *corona*.

Photosphere

The solar *photosphere* is what one sees when looking at the sun. It is not a discrete surface but instead covers a range of depths from which the solar radiation escapes. The energy radiated by the photosphere constitutes almost all of the energy emitted by the Sun. Direct telescopic observation and photography show that the photosphere is not perfectly smooth, but has a mottled appearance resembling rice grains. This structure of the photosphere is now generally called granulation. Typically, granules are about 1,000 km in diameter (the smallest observed are about 300 km across). They appear as bright spots surrounded by narrow darker regions. The granules themselves are columns of hotter gases rising from below the photosphere and as the rising gas reaches the photosphere it spreads out and sinks down again. The darker intergranular regions are the cooler gases sinking back, while the centers of the granules are hotter than the intergranular regions by 50 to 100 degrees K. The vertical motions of gases in the granules have speeds of about 2 or 3 km/s. Individual granules persist for about 8 minutes and are the pinnacles of convection currents of gases seen through the photosphere.

The most conspicuous features of the photosphere are the Sunspots. Occasionally, spots on the sun are large enough to be visible to the naked eye and such spots have been observed for many centuries. Galileo was the first to show Sunspots to be on the surface of the sun, rather than opaque patches in the Earth's atmosphere or the silhouettes of planets between the sun and earth. In 1774, Alexander Wilson suggested the spots were "holes" through which one could see past the photosphere into a cooler interior of the sun. However, the spots are not holes in the photosphere, but rather regions where the gases are cooler than those of the surrounding regions. Sunspots are still hotter than the surfaces of many stars and if they could be removed from the sun, they would be seen to shine brightly; they appear dark only by contrast with the hotter, brighter surrounding photosphere. Individual Sunspots have lifetimes that range from a few hours to a few months. Most of them disappear within a day but a few persist for a week or occasionally much longer.

Chromosphere

The region of the Sun's atmosphere immediately above the photosphere is the *chromosphere*. Until this century the chromosphere was best observed when the Moon, during a total solar eclipse covered the photosphere. Today it is possible to photograph both the chromosphere and its spectrum outside of an eclipse. The chromosphere is about 2,000 to 3,000 km thick, but in its upper region it breaks up into a forest of jets (called spicules). So the position of the upper boundary of the chromosphere is somewhat arbitrary. The temperature increases through the chromosphere from 4,500° K at the photosphere to 100,000° K or so at the upper chromospheric levels. Ultraviolet observations of the chromosphere, such as those made from Skylab, have been especially helpful in revealing information about its structures.

Corona

The final layer of the solar atmosphere is the *corona*, which extends from the top of the chromosphere out millions of miles into space. The corona is normally invisible except during an eclipse or when using a coronagraph. The average temperature of the corona is 1.5 million degrees K. The corona exists in a fully ionized state, within which ionized gas occasionally condenses and streams down the localized magnetic field lines. As seen against the background of space, these are called prominences. Filaments are the same phenomena, but are seen against the solar disk and consequently appear darker than the hotter solar background.

The space environment is determined to a very large extent by the Sun. Many phenomena on or near the Earth are closely related to solar activity, although sometimes the exact nature of the relationship is not well understood. The Sun is constantly radiating energy even under quiet conditions. This "steady-state" phenomenon is called the solar wind. Because of the high temperature of the Sun's corona, protons and electrons beyond a certain distance from the Sun acquire velocities in excess of the escape velocity from the Sun. Thus, there is a continuous outward flow of charged particles in all directions from the Sun.

This quiet is interrupted at irregular intervals by "transient" solar flares of varying intensity, which appear suddenly over small areas of the Sun. The high speed of solar protons emitted by a solar flare are probably the most potent of the radiation hazards to space flight. Flares themselves are probably the most spectacular disturbances seen on the Sun. They are observed optically as a sudden large increase in light from a portion of the Sun's atmosphere. A flare may spread in area during its lifetime, which may be from several minutes to a few hours. There is a relationship between the number of Sunspots and the frequency of flare formation, but the most important flares do not necessarily occur at solar cycle maximum.

There are many events that may occur on Earth following a solar flare. In addition to the increase in visible light minutes after the start of a flare, there is a Sudden Ionospheric Disturbance (SID) in the Earth's ionosphere. This, in turn, causes short wave fadeout, resulting in the loss of long range communications for 15 minutes to an hour. X-rays emitted by the flare probably cause the SIDs. During the first few minutes of a flare, there may be a radio noise storm consisting of bursts of noise over a wide range of frequencies. There may also be disturbances in the Earth's magnetic field, changes in the auroras and decreases in solar cosmic ray intensity. However, from the point of view of a space traveler, the most important effect is the marked increase in solar protons. The energy of these protons ranges from about 10 Million Electron Volts (mev) to about 500 mev. Consequently, the dose of radiation accumulated during exposure to the solar protons may vary from negligible to well above a lethal dose.

These flares may be weak and last only 5 to l0 minutes, or strong and last up to several hours. Flares are sporadic emissions of electromagnetic energy (UV, x-ray and IR) and high-energy charged particles (mostly protons and electrons). Particles are actually spiraled into interplanetary space at average velocities between 300 km/s to 550 km/s (186-342 mi/s).

EFFECTS ON MANNED SPACEFLIGHT

It is one thing to put a satellite in orbit, but quite another to put a man in orbit and keep him there. In addition to command, control, health and welfare of a satellite, there is the need for a breathable atmosphere, waste management, heat and humidity regulation along with the possibility of contaminants and radiation. What about limiting acceleration during lift-off/re-entry, vibration, noise and lighting? How about the physiological change of weightlessness, the concern of muscle deconditioning, the loss of calcium within the bones and the psychological stress of isolation from planet Earth? Manned space-flight is a true challenge. However, past experience has demonstrated that it can be accomplished without loss of life by staying flexible and adaptable to a new environment.

Radiation Concerns

The first thing for mission planners to realize is that there is no region of space free from radiation. Therefore, the U.S. is forced to accept some risk for each space journey. The primary concern lies in the ionizing radiation from high-energy particles (protons and electrons). If a particle possesses enough energy, it can pass through the protective equipment and impact the crewmember's body. An extremely high-energy particle will pass through the body with no serious effects. The body upon impact will stop particles of slightly less energy. As these particles decelerate, their energy is converted into a pulse of EM radiation.

This EM radiation will ionize atoms within a crewmember's body and the biological result of radiation can be monitored to determine the impact. The unit of measurement for this is the REM, which relates the biological damage to the type of radiation (1 REM = dose RAD x relative biological effectiveness (RBE)). Radiation damages the body by altering the chemical makeup of individual cells. If the dose is high enough, the cell can be destroyed. This can lead to the failure of systems within the body. The more sensitive organ systems and tissues within the body are the blood, digestive, central nervous, skin, eyes and reproductive. The dose received will determine whether the impact is immediate or delayed. The health of the individual will also have an impact on the severity of the effects.

There are several methods that can be used to protect astronauts from radiation or minimize their exposure. These methods are mission timing, orbital planning and shielding. The first area to consider should be mission timing. To minimize the effects of solar activity, missions should be planned during solar minimum. Unfortunately, this approach is usually not feasible due to time constraints. Mission timing may involve scheduling the construction of a space station for the least hazardous period of the solar cycle, or making minor changes to an existing mission such as termination of an extravehicular activity (EVA) during very energetic solar flare activity.

Orbital planning can be a viable means of reducing radiation exposure. In general, equatorial orbits and low altitude/low inclination orbits are the least hazardous, while geosynchronous orbits (GEO), especially during solar particle events, expose the crewmember to the greatest levels of ionizing radiation. The one exception to this is in the South Atlantic Anomaly, where weak magnetic fields allow charged particles to reach a lower altitude.

The most common protection used is shielding. This can be in the form of a spacesuit or designed within the walls of the spacecraft. Material used for shielding must be dense yet lightweight. Aluminum (Al) is usually the choice for most applications. Heavier metals would be more effective, but add additional weight. The thickness of the aluminum can vary from 0.8 mm to several millimeters, depending on the orbit and duration of the mission. A large manned space structure would typically have about 5-8 g/cm^2 (Al) shielding surrounding the habitat or work area. For most orbits, 5 g/cm^2 (Al) represents a safe compromise between a worker's health and weight limitations.

Future manned space missions will expose astronauts to radiation hazards more severe than those dealt with today. Missions requiring high inclination or high altitude will have to be closely monitored to determine the effect of radiation on the crew. Planners will have to consider both the short-term impact of solar flare events and the problem of total dosage to crewmembers in orbits with a high density of charged particles. Future designers will have to determine the amount of shielding that can economically be sent into orbit. If the shielding is not enough, scenarios will have to be developed to enable the retrieval of astronauts to low-Earth orbits until the danger is past. All of these areas will have to be examined in order to design the optimal mission.

Life Support

There are numerous necessities/ requirements for keeping a person alive and functioning in space. Whether at extreme altitudes or in space, people require a sealed cabin or spacesuit that provides an adequate partial pressure of oxygen (O_2) for tissue oxygenation. The cabin may contain nitrogen, which makes up 80% of the Earth's atmosphere.

The early U.S. space vehicles (Mercury, Gemini and Apollo) contained 100% oxygen at five pounds per square inch (psi). The advantages of this atmosphere were:

- Lower pressure allowed for reduced strength of storage containers, therefore reduced weight in the spacecraft
- Allowed for simplified gas control (only one gas)
- Absence of nitrogen eliminated the possibility of space sickness (short term missions)

The disadvantages of this atmosphere were:

- Increased fire hazards (Apollo I: Grissom, White and Chaffee killed on the pad)
- Tendency to produce anemia (lack of red blood cells)
- Extended duration may prove to be toxic

Due to these disadvantages, the Skylab used an atmosphere composed of 70% oxygen and 30% nitrogen, which is the opposite of the Earth's mixture. This change decreased the hazard of fire and the susceptibility of anemia (decrease in red blood cells), but increased that of space sickness.

Currently, the space shuttle uses 80% nitrogen and 20% oxygen mixture at 14.7 psi (same as Earth at sea level). As with Skylab, this mixture makes the crew more susceptible to space sickness. The increase in space sickness is believed to be caused by the absence of gravity, combined with the presence of nitrogen, leading to a lack of equilibrium for the astronauts. Also, the normal pressure makes it necessary for stronger and heavier structures for cabin composition.

Thus far, the types of atmosphere an astronaut can breathe in space have been discussed. However, in addition to oxygen, astronauts also need food and water. A person has a requirement for approximately 22.7 pounds of oxygen, 4.7 pounds of water and 1.3 pounds of food per day. At the same time, one can see an equivalent weight of waste products being produced. Presently, it is impossible to carry these stored materials on space missions because of the weight involved. Therefore, the food currently consists of dehydrated foods, which are rehydrated by hot/cold water on board. However, this is impractical for spaceflights of several months or years. Therefore, for future long-term missions, scientists must design a system of regeneration (growing food) from the materials on board the spacecraft. This system consists of recycling all waste products, such that they can be used again. For example, carbon dioxide (CO_2) and water (H_2O) wastes would be recycled into foods high in protein and carbohydrates. Also, scientists believe that algae could be used to absorb CO_2 and produce O_2, and then be eaten. Another possibility is that algae could use urine and fecal material (like we do here on Earth) to form a nutrient broth. Even if a closed-loop or regeneration system is finally developed and employed, some food must be taken along to break-up the monotony of the diet. Supplemental vitamins should also be included in convenient form. This food would also act as a back up should the regeneration system malfunction or fail.

Waste management is the process of effectively controlling waste products within the confines of a spacecraft. Waste management is not as critical for an open-loop system as it is for a closed-loop system. The primary types of waste encountered are exhaled waste products, standard trash and of course, biological waste products. All of these types of wastes must be collected and stored. In an open-loop system, a person's largest waste product is oxygen (O). We breath in 22.7 lbs. of O and only use 9% of it, exhaling 20.7 lbs. of O. A possible solution would be to remove CO_2 and H_2O vapor from the exhaled waste gases and return the O to the astronauts. Today's systems filter out these byproducts, and provide supplemental O from cylinders carried on board the spacecraft.

In addition to the cabin environmental control systems, the astronauts must have environmental suits to protect them in the event of loss of cabin pressure and for extravehicular activity (EVA). These suits must provide the same protection, as the cabin provides the following:

- Atmosphere
- Water
- Waste Collection
- Heating/Cooling
- Communications
- Guidance/Control
- Shielding/Protection from radiation and micrometeoroids

Physiological Stresses

Normally, human internal heat regulatory mechanisms tend to keep the body temperature at a constant 98.6° F. This is done via heat loss by respiration and through the skin. If the body needs to cool off, the blood vessels near the skin dilate and result in perspiration. Usually, a nude body can maintain thermal balance in an environment between 70-80° F with a relative humidity of 45%. In spacecraft, it is difficult to maintain this type of environment due to the electronic gear on board, friction caused by leaving/re-entering the Earth's atmosphere and sunlight/shadow on the spacecraft's outer hull. Therefore, special suits are worn under the pressure suit to provide circulating water to help dissipate the heat along with air-conditioning in the cabin. Current technology has allowed the shuttle crews to exist in a "T-shirt" environment, except during EVA.

The problems associated with the mechanical environment include all those stresses placed on an astronaut as a result of the vehicle and its operations in the space environment: acceleration, vibration, noise, lighting and weightlessness. These stresses occur during lift-off and velocity changes associated with re-entry. Due to the effects of these increased forces on the cardiovascular and muscular systems, an astronaut must have some protection. The circulatory system tolerance varies, depending on the manner in which the "G" (unit of gravity forces) force is applied. Therefore, astronauts use the supine (lying down, facing upward) position with the head and feet slightly raised to enable the astronaut to withstand up to 20 Gs for short periods of time. The maximum G force for the shuttle is three Gs, similar to flying a heavy glider.

Man is most sensitive to the vibration frequency range of 4-10 cycles/second, because the major internal organs' natural resonance frequency is in this range. When the organs become resonant with the vibrations, one may suffer severe pain, nausea, headaches and dizziness. The organs begin tearing away from the mesentery holding them in place. Current power and control procedures have minimized this problem.

Noise has been a problem for people for a long time, but never before has the intensity been so great as the noise produced by space boosters. The maximum tolerance of noise for people is about 140-150 decibels (dB), at which level permanent damage to the hearing mechanism will occur if exposure continues for approximately one minute. Space boosters generate 145-175 dB during lift-off. Materials in the vehicle structure and on-board equipment help to alleviate the noise problem.

Manned spacecraft are able to receive light from the Sun either continuously, if in free space, or for a majority of time if the vehicle is in orbit around the planet. The light can be brought into the spacecraft, but the UV light must be filtered and the Sun's intensity must be diffused. We can also provide artificial illumination to the spacecraft. Regardless of the method of lighting, it must be controlled to allow for the concept of passage of time to assist in maintaining regular sleeping habits.

There are many physiological changes that occur once in orbit. The first to show up are shifts in the body fluids and changes in the elastic properties of the blood vessels. The former can lead to a "fullness of head" condition which can upset the body's equilibrium. This condition refers to body fluids pooling in the upper chest and head region. The sensation is similar to hanging upside down for long periods of time. The body usually adapts quickly to these changes.

Areas of greater concern include muscle de-conditioning, which is currently controlled by physical conditioning while in orbit. This appears to work for current programs, but will have to be closely monitored to determine if this approach is adequate for long duration missions.

The problem of mineral imbalance is also of great concern. Current research has not shown that this condition can be controlled. One of the main areas where this shows up is in the loss of calcium within the bones.

NASA has many ongoing studies to simulate the effects of weightlessness and to determine the health impacts. The CIS has also collected valuable data in this area, in conjunction with their cosmonauts reaching more than one year on orbit. The bottom line will again be trade-off between crew health, design considerations and mission requirements. The effects of working in a zero-G environment have been well studied and documented. In question are the effects that will be seen when the length of space missions extends beyond one year. Planners will have to consider the long and short-term health problems. Some risks may have to be taken if a particular mission is long in duration and leaves the near-Earth environment. An example of this would be a manned mission to Mars. Ground controllers would be unable to retrieve an astronaut if health problems occurred. Also any rescue attempt would probably arrive too late.

Psychological Stresses

Of concern will be the long periods of isolation required in future manned spaceflights. Current missions involve relatively short time periods in low-Earth orbits, where the astronauts know they can be retrieved if necessary. As we extend the time on orbit the psychological stresses increase. Space stations and interplanetary vehicles will have to meet the psychological requirements of the crew. Earlier missions attempted to do this by keeping the crew busy with an increased workload. However this will not be practical on prolonged flights. Possible ways to minimize this problem are through proper design of the spacecraft and intensive crew screening.

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TOC

Chapter 8

ORBITAL MECHANICS

Knowledge of orbital motion is essential for a full understanding of space operations. The vantage point of space can be visualized through the motion Kepler described and by comprehending the reasons for that motion as described by Newton. Thus, the objectives here are to gain a conceptual understanding of orbital motion and become familiar with common terms describing that motion.

A HISTORY OF THE LAWS OF MOTION[1]

Early Cosmology

This generation is far too knowledgeable to perceive the universe as early man saw it. Each generation uses the knowledge of the previous generation as a foundation to build upon in the ever-continuing search for comprehension. When the foundation is faulty, the tower of understanding eventually crumbles and a new building proceeds in a different direction. Such was the case during the dark ages in medieval Europe and the Renaissance.

The Babylonians, Egyptians and Hebrews each had various ingenious explanations for the movements of the heavenly bodies. According to the Babylonians, the Sun, Moon and stars danced across the heavenly dome entering through doors in the East and vanishing through doors in the West. The Egyptians explained heavenly movement with rivers in a suspended gallery upon which the Sun, Moon and planets sailed, entering through stage doors in the East and exiting through stage doors in the West.

Though one may view these ancient cosmologies with a certain arrogance and marvel at the incredible creativity by which they devised such a picture of the universe, their observations were amazingly precise. They computed the length of the year with a deviation of less than 0.001% from the correct value, and their observations were accurate, enabling them to precisely predict astronomical events. Although based on mythological assumptions, these cosmological theories "worked."

Greece took over from Babylon and Egypt, creating a more colorful universe. However, the 6th century BC (the century of Buddha, Confucius and Lâo Tse, the Ionian philosophers and Pythagoras) was a turning point for the human species. In the Ionian school of philosophy, rational thought was emerging from the mythological dream world. It was the beginning of the great adventure in which the Promethean quest for natural explanations and rational causes would transform humanity more radically than in the previous two hundred thousand years.

Astronomy

Many early civilizations recognized the pattern and regularity of the stars' and planets' motion and made efforts to track and predict celestial events. The invention and upkeep of a calendar required at least some knowledge of astronomy. The Chinese had a working calendar at least by the 13th or 14th century BC. They also kept accurate records for things such as comets, meteor showers, fallen meteorites and other heavenly phenomena. The Egyptians were able to roughly predict the flooding of the Nile every year: near the time when the star Sirius could be seen in the dawn

[1]Much of this information comes from Arthur Koestler's *The Sleepwalkers.*

sky, rising just before the Sun. The Bronze Age peoples in northwestern Europe left many monuments indicating their ability to understand the movement of celestial bodies. The best known is Stonehenge, which was used as a crude calendar.

The early Greeks initiated the orbital theories, postulating the Earth was fixed with the planets and other celestial bodies moving around it; a *geocentric* universe. About 300 BC, Aristarchus of Samos suggested that the Sun was fixed and the planets, including the Earth, were in circular orbits around the Sun; a *heliocentric* universe. Although Aristarchus was more correct (at least about a heliocentric solar system), his ideas were too revolutionary for the time. Other prominent astronomers/philosophers were held in higher esteem and, since they favored the geocentric theory, Aristarchus' heliocentric theory was rejected and the geocentric theory continued to be predominately accepted.

Aristotle, one of the more famous Greek philosophers, wrote encyclopedic treatises on nearly every field of human endeavor. Aristotle was accepted as the ultimate authority during the medieval period and his views were upheld by the Roman Catholic Church, even to the time of Galileo. However, his expositions in the physical sciences in general, and astronomy in particular, were less sound than some of his other works. Nevertheless, his writings indicate the Greeks understood such phenomena as phases of the Moon and eclipses at least in the 4th century BC. Other early Greek astronomers, such as Eratosthenes and Hipparchus, studied the problems confronting astronomers, such as: How far away are the heavenly bodies? How large is the Earth? What kind of geometry best explains the observations of the planets' motions and their relationships?

The Greeks were under the influence of Plato's metaphysical understanding of the universe, which stated:

"*The shape of the world must be a perfect sphere, and that all motion must be in perfect circles at uniform speed.*"

This circular motion was so aesthetically appealing that Aristotle promoted this circular motion into a dogma of astronomy. The mathematicians' task was now to design a system reducing the apparent irregularities of planetary motion to regular motions in perfectly fixed circles. This task would keep them busy for the next two thousand years.

Perhaps the most elaborate and fanciful system was one Aristotle constructed using fifty-four spheres to account for the motions of the seven planets.[2] Despite Aristotle's enormous prestige, this system was so contrived that it was quickly forgotten. In the 2nd century AD, Ptolemy modified and amplified the geocentric theory explaining the apparent motion of the planets by replacing the "sphere inside a sphere" concept with a "wheel inside a wheel" arrangement. According to his theory, the planets revolve about imaginary planets, which in turn revolve around the Earth. Thus, this theory employed forty wheels: thirty-nine to represent the seven planets and one for the fixed stars.

Even though Ptolemy's system was geocentric, this complex system more or less described the observable universe and successfully accounted for celestial observations. With some later modifications, his theory was accepted with absolute authority throughout the Middle Ages until it finally gave way to the heliocentric theory in the 17th century.

Modern Astronomy

Copernicus

In the year 1543, some 1,800 years after Aristarchus proposed a heliocentric system, a Polish monk named Nicolas

[2] In this instance the seven "planets" include the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn.

Koppernias (better known by his Latin name, Copernicus) revived the heliocentric theory when he published De Revolutionibus Orbium Coelestium (*On the Revolutions of the Celestial Spheres*). This work represented an advance, but there were still some inaccuracies. For example, Copernicus thought that the orbital paths of all planets were circles with their centers displaced from the center of the sun.

Copernicus did not prove that the Earth revolves about the sun; the Ptolemic system, with some adjustments, could have accounted just as well for the observed planetary motion. However, the Copernican system had more ascetic value. Unlike the Ptolemic system, it was elegant and simple without having to resort to artful wheel upon wheel structures. Although it upset the church and other ruling authorities, Copernicus made the Earth an astronomical body, which brought unity to the universe.

Tycho De Brahe

Three years after the publication of *De Revolutionibus*, Tyge De Brahe was born to a family of Danish nobility. Tycho, as he came to be known, developed an early interest in astronomy and made significant astronomical observations as a young man. His reputation gained him royal patronage and he was able to establish an astronomical observatory on the island of Hveen in 1576. For 20 years, he and his assistants carried out the most complete and accurate astronomical observations yet made.

Tycho was a despotic ruler of Hveen, which the king could not sanction. Thus, Tycho fell from favor, leaving Hveen in 1597 free to travel. He ended his travels in Prague in 1599 and became Emperor Rudolph II's Imperial Mathematicus. It was during this time that a young mathematician, who would also become an exile from his native land, began correspondence with Tycho. Johannes Kepler joined Tycho in 1600 and, with no means of self-support, relied on Tycho for material well being.

Tycho and Kepler's relationship was far from a great friendship. It was short (eighteen months) and fraught with controversy. This brief relationship ended when Tycho De Brahe, the meticulous observer who introduced precision into astronomical measurement and transformed the science, became terminally ill and died in 1601.

Kepler

Johannes Kepler was born in Wurttemberg, Germany, in 1571. He experienced an unstable childhood that, by his own accounts, was unhappy and ridden with sickness. However, Kepler's genius propelled him through school and guaranteed his continued education.

Kepler studied theology and learned the principles of the Copernican system. He became an early convert to the heliocentric hypothesis, defending it in arguments with fellow students.

In 1594, Kepler was offered a position teaching mathematics and astronomy at the high school in Gratz. One of his duties included preparing almanacs providing astronomical and astrological data. Although he thought astrology, as practiced, was essentially quackery, he believed the stars affected earthly events.

During a lecture having no relation to astronomy, Kepler had a flash of insight; he felt with certainty that it was to guide his thoughts throughout his cosmic journey. Kepler had wondered why there were only six planets and what determined their separation. This flash of insight provided the basis for his revolutionary discoveries. Kepler believed that each orbit was inscribed within a sphere that enclosed a perfect solid[3] within which existed the next orbital sphere and so on for all the planets.

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[3]A perfect solid is a three dimensional geometric figure whose faces are identical and are regular polygons. These solids are: (1) tetrahedron bounded by four equilateral triangles, (2) cube, (3) octahedron (eight equilateral triangles), (4) dodecahedron (twelve pentagons), and (5) icosahedron (twenty equilateral triangles).

He did not believe these solids actually existed, but rather, God created the planetary orbits in relation to these perfect solids. However, Kepler made the errant connection that this was the basis of the divine plan, because there are only five regular solids and there were only six known planets.

Kepler explained his pseudo-discoveries in his first book, the Mysterium Cosmographicum (*Cosmic Mystery*). Although based on faulty reasoning, this book became the basis for Kepler's later great discoveries. The scientific and metaphysical communities at the time were divided as to the worth of this first work. Kepler continued working toward proving his theory and in doing so, found fault with his enthusiastic first book. In his attempts at validation, he came to realize he could only continue with Tycho's data—but he did not have the means to travel and begin their relationship. Fortunately for the advancement of astronomy, the power of the Catholic Church in Gratz grew to a point where Kepler, a Protestant, was forced to quit his post. He then traveled to Prague where his short tumultuous relationship with Tycho began. On 4 February 1600, Kepler finally met Tycho De Brahe and became his assistant.

Tycho originally set Kepler to work on the motion of Mars, while he kept the majority of his astronomical data secret. This task was particularly difficult because Mars' orbit is the second most eccentric (of the then known planets) and defied the circular explanation. After many months and several violent outbursts, Tycho sent Kepler on a mission to find a satisfactory theory of planetary motion (the study of Mars continued to be dominant in this quest); one compatible with the long series of observations made at Hveen.

After Tycho's death in 1601, Kepler became Emperor Rudolph's Imperial Mathematicus. He finally obtained possession of the majority of Tycho's records, which he studied for the next twenty-five years of his life.

Kepler's Laws

Kepler's earth-shaking discoveries came in anything but a straightforward manner. He struggled through tedious calculations for years just to find that they led to false conclusions. Kepler stumbled upon his second law (which is actually the one he discovered first) through a succession of canceling errors. He was aware of these errors and in his explanation of why they canceled he got hopelessly lost. In the struggle for the first law (discovered second), Kepler seemed determined not to see the solution. He wrote several times telling friends that if the orbits were just an ellipse, then all would be solved, but it wasn't until much later that he actually tried an ellipse. In his frustrating machinations, he derived an equation for an ellipse in a form he did not recognize[4]. He threw out his formula (which described an ellipse) because he wanted to try an entirely new orbit: an ellipse[5].

Kepler's 1st Law
(Law of Ellipses)

The orbits of the planets are ellipses with the Sun at one focus.

[4]In modern denotation, the formula is:

$$\mathbf{R} = \mathbf{1} + e\cos(\beta)$$

where **R** is the distance from the Sun, β the longitude referred to the center of the orbit, and ***e*** the eccentricity.

[5]After accepting the truth of his elliptical hypothesis, Kepler eventually realized his first equation was also an ellipse.

Later Sir Isaac Newton found that certain refinements had to be made to Kepler's first law to account for perturbing influences. Neglecting such influences (e.g., atmospheric drag, mass asymmetry and third body effects), the law applies accurately to all orbiting bodies.

Figure 8-1 shows an ellipse where $\mathbf{F_1}$ is one focus and $\mathbf{F_2}$ is the other. This depiction illustrates that, by definition, an ellipse is constructed by joining all points that have the same combined distance (**D**) between the foci.

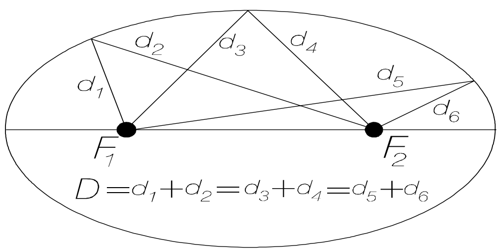

Fig. 8-1. Ellipse with axis

The maximum diameter of an ellipse is called its *major axis*; the minimum diameter is the *minor axis*. The size of an ellipse depends in part upon the length of its major axis. The shape of an ellipse is denoted by *eccentricity* (***e***) which is the ratio of the distance between the foci to the length of the major axis (see Orbit Geometry section).

The path of ballistic missiles (not

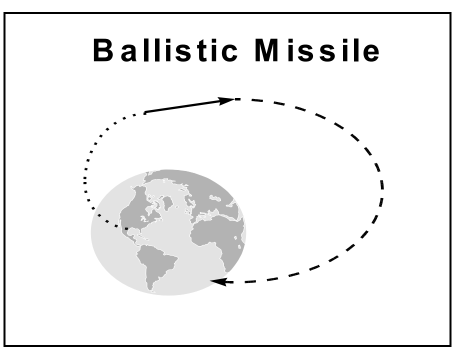

Fig. 8-2. Ballistic Missile Path

including the powered and reentry portion) are also ellipses; however, they happen to intersect the Earth's surface (**Fig. 8-2**).

With Kepler's second law, he was on the trail of Newton's Law of Universal Gravitation. He was also hinting at calculus, which was not yet invented.

Kepler's 2nd Law
(Law of Equal Areas)

The line joining the planet to the Sun sweeps out equal areas in equal times.

Based on his observation, Kepler reasoned that a planet's speed depended on its distance to the Sun. He drew the connection that the Sun must be the source of a planet's motive force.

With circular orbits, Kepler's second law is easy to visualize (**Fig. 8-3**). In a circular orbit an object's speed and radius both remain constant, and therefore, in a given interval of time it travels the same

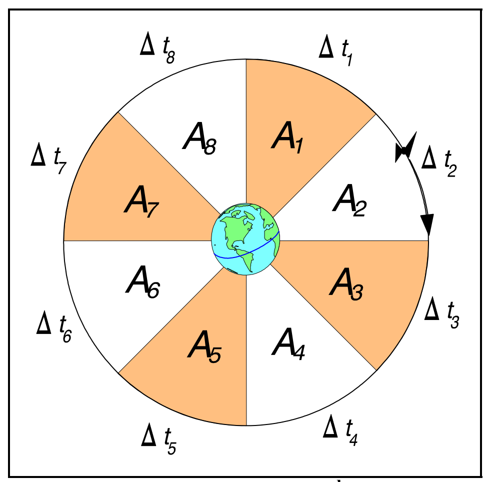

Fig. 8-3. Kepler's 2nd Law

distance along the circumference of the circle. The areas swept out over these intervals are equal.

However, closed orbits in general are not circular but instead elliptical with.non-zero eccentricity (An ellipse with zero eccentricity is a circle[6] see pg. 8-11).

[6]That is, naturally occurring orbits have some non-zero eccentricity. A circle is a special form of an ellipse where the eccentricity is zero. Most artifi-

Kepler's second law isn't quite as obvious when applied to an ellipse. **Figure 8-4** depicts an elliptical orbit where two equal areas are swept out in equal intervals of time but are not symmetric. It is also apparent from **Fig 8-4** the closer a planet is to the Sun (also, any satellite to its prime mover, like the Earth) the faster it

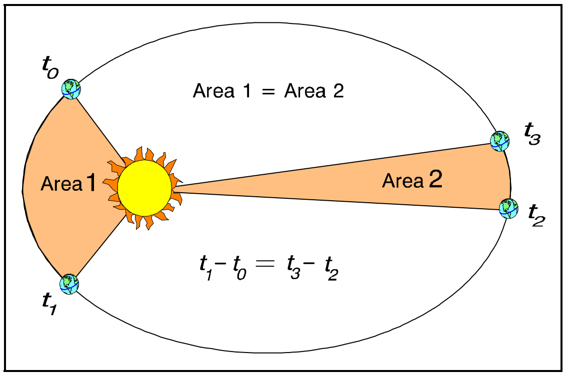

Fig. 8-4. An Elliptical Orbit

travels[7].

Kepler discovered his third law ten years after he published the first two in <u>Astronomia Nova</u> (*New Astronomy*). He had been searching for a relationship between a planet's *period* and its *distance* from the Sun since his youth. Kepler was looking at harmonic relationships in an attempt to explain the relative planetary spacing. After many false steps and with dogged persistence, he discovered his famous relationship:

Kepler's 3rd Law
(Law of Harmonics)

The squares of the periods of revolution for any two planets are to each other as the cubes of their mean distances from the Sun.[8]

Kepler's 3rd Law directly relates the square of the period to the cube of the mean distance for orbiting objects. He believed in an underlying harmony in nature. It was a great personal triumph when he found a simple algebraic relationship, which he believed to be related to musical harmonics.

Isaac Newton

On Christmas Day 1642, the year Galileo died, there was born a male infant tiny and frail, Isaac Newton—who would alter the thought and habit of the world.

Newton stood upon the shoulders of those who preceded him; he was able to piece together Kepler's laws of planetary motion with Galileo's ideas of inertia and physical causes, synthesizing his laws of motion and gravitation. These principles are general and powerful, and are responsible for much of our technology today.

Newton took a circuitous route in formulating his hypotheses. In 1665, an outbreak of the plague forced the University of Cambridge to close for two years. During those two years, the 23-year-old genius conceived the law of gravitation, the laws of motion and the fundamental concepts of differential calculus. Due to some small discrepancies in his explanation of the Moon's motion, he tossed his papers aside; it would be 20 years before the world would learn of his momentous discoveries.

Edmund Halley asked the question that brought Newton's discoveries before the world. Halley was visiting Newton at Cambridge and posed the question: "If the Sun pulled on the planets with a force inversely proportional to the square of the

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cial satellites are predominately in orbits that are as close to circular as we can achieve.

7Kepler's second law is basically stating that angular momentum remains constant, but the concept of angular momentum wasn't invented when he formulated his laws.

8In mathematical terms: $\frac{\boldsymbol{P}^2}{\boldsymbol{a}^3} = \boldsymbol{k}$, where $\boldsymbol{P}$ is the orbital period, $\boldsymbol{a}$ is the semi-major axis, which is the average orbital distance, and $\boldsymbol{k}$ is a constant.

distances, in what paths ought they to go?" To Halley's astonishment, Newton replied without hesitation: "Why in ellipses, of course. I have already calculated it and have the proof among my papers somewhere." Newton was referring to his work during the plague outbreak 20 years earlier and in this casual way, his great discovery was made known to the world.

Halley encouraged his friend to completely develop and publish his explanation of planetary motion. The result appeared in 1687 as *The Mathematical Principles of Natural Philosophy*, or simply the Principia.

Newton's Laws

As we've seen, many great thinkers were on the edge of discovery, but it was Newton that took the pieces and formulated a grand view that was consistent and capable of describing and unifying the mundane motion of a "falling apple" and the motion of the planets:[9]

Newton's 1st Law
(Inertia)

Every body continues in a state of uniform motion in a straight line, unless it is compelled to change that state by a force imposed upon it.

This concise statement encapsulates the general relationship between objects and causality. Newton combined Galileo's idea of inertia with Descartes' uniform motion (motion in a straight line) to create his first law. If an object deviates from rest or motion in a straight line with constant speed, then some force is being applied.

Newton's first law describes undisturbed motion; inertia, accordingly, is the resistance of mass to changes in its motion. His second law describes how motion changes. It is important to define momentum before describing the second law. Momentum is a measure of an object's motion. Momentum ($\vec{p}$) is a vector quantity defined as the product of an object's mass (m) and its relative velocity ($\vec{v}$)[10].

Newton's second law describes the relationship between the applied force, the mass of the object and the resulting motion:

$$\boxed{\vec{p} = m\,\vec{v}}$$

Newton's 2nd Law
(Momentum)

When a force is applied to a body, the time rate of change of momentum is proportional to, and in the direction of, the applied force.

When we take the *time rate of change* of an object's momentum (essentially differentiate momentum with respect to time, $d\vec{p}/dt$), this second law becomes Newton's famous equation:[11]

$$\boxed{\vec{F} = m\vec{a}}$$

Newton continued his discoveries and with his third law, completed his grand view of motion:

[9]We still essentially see the Universe in Newtonian terms; Einstein's general relativity and quantum mechanics are a modification to Newtonian mechanics, but have yet to be unified into a single grand view.

[10]Velocity is an inertial quantity and, as such, is relative to the observer. Momentum, as measured, is also relative to the observer.

[11]The differentiation of momentum with respect to time actually gives $\vec{F} = \dot{m}\vec{v} + m\dot{\vec{v}}$ where $\dot{m}$ is the rate of change of mass and $\dot{\vec{v}}$ is the rate of change of velocity which is acceleration $\vec{a}$. In simple cases we assume that the mass doesn't change, so $\dot{m} = 0$ and the equation reduces to $\vec{F} = m\dot{\vec{v}} \Rightarrow \vec{F} = m\vec{a}$. For an accelerating booster the $\dot{m}$ term is not zero.

Newton's 3rd Law
(Action-Reaction)

For every action there is a reaction that is equal in magnitude but opposite in direction to the action.

This law hints at conservation of momentum; if forces are always balanced, then the objects experiencing the opposed forces will change their momentum in opposite directions and equal amounts.

Newton combined ideas from various sources in synthesizing his laws. Kepler's laws of planetary motion were among his sources and provided large scale examples. Newton synthesized his concept of gravity, but thought that one must be mad to believe in a force that operated across a vacuum with no material means of transport.

Newton theorized gravity, which he believed to be responsible for the "falling apples" and the planetary motion, even though he could not explain gravity or how it was transmitted. In essence, Newton developed a system that described man's experience with his environment.

Universal Gravitation

Every particle in the universe attracts every other particle with a force that is proportional to the product of the masses and inversely proportional to the square of the distance between the particles.

$$\boxed{F_g = G\left(\frac{M_1 m_2}{D^2}\right)}$$

Where F_g is the force due to gravity, G is the proportionality constant, M_1 and m_2 the masses of the central and orbiting bodies, and D the distance between the two bodies.

Kepler's laws of planetary motion are empirical (found by comparing vast amounts of data in order to find the algebraic relationship between them); and describe the way the planets are observed to behave. Newton proposed his laws as a basis for all mechanics. Thus Newton should have been able to derive Kepler's laws from his own, and he did:

***Kepler's First Law:** If two bodies interact gravitationally, each will describe an orbit that can be represented by a conic section about the common center of mass of the pair. In particular, if the bodies are permanently associated, their orbits will be ellipses. If they are not permanently associated, their orbits will be hyperbolas.*

***Kepler's Second Law:** If two bodies revolve about each other under the influence of a central force (whether they are in a closed orbit or not), a line joining them sweeps out equal areas in the orbit plane in equal intervals of time.*

***Kepler's Third Law:** If two bodies revolve mutually about each other, the sum of their masses times the square of their period of mutual revolution is in proportion to the cube of their semi-major axis of the relative orbit of one about the other.*

ORBITAL MOTION

Newton's laws of motion apply to all bodies, whether they are scurrying across the face of the Earth or out in the vastness of space. By applying Newton's laws one can predict macroscopic events with great accuracy.

Motion

According to Newton's first law, bodies remain in uniform motion unless acted upon by an external force; that uniform motion is in a straight line. This motion is known as inertial motion, referring to the property of *inertia*, which the first law describes.

Velocity is a relative measure of motion. While standing on the surface of the Earth, it seems as though the buildings, rocks, mountains and trees are all motionless; however, all of these objects are moving with respect to many other objects (Sun, Moon, stars, planets, etc.). Objects at the equator are traveling around the Earth's axis at approximately 1,000 mph; the Earth and Moon system is traveling around the Sun at 66,000 mph; the solar system is traveling around the galactic center at approximately 250,000 mph, and so on and so forth.

The only way motion can be experienced is by seeing objects change position with respect to one's location. Change in motion may be experienced by feeling the compression or tension within the body due to acceleration (sinking in the seat or being held by seat belts). In some cases, acceleration cannot be felt, as in free-fall. Acceleration is felt when the forces do not operate equally on every particle in the body; the compression or tension is sensed in the body's tissues. With this feeling and other visual clues, any change in motion that has occurred may be detected. Gravity is felt as opposing forces and the resulting compression of bodily tissues. In free-fall, acceleration is not felt because every particle in the body is experiencing the same force and so there is no tissue compression or tension; thus, no physical sensation. What is felt is the sudden change from tissue compression to a state of no compression.

According to Newton's second law, for a body to change its motion there must be a force imposed upon it. Everyone has experience with changing objects' motion or compensating for forces that change their motion. An example is playing catch—when throwing or catching a ball, its motion is altered; thus, gravity is compensated for by throwing the ball upward by some angle allowing gravity to pull it down, resulting in an arc. When the ball leaves the hand it starts accelerating toward the ground according to Newton's laws (at sea level on the Earth the acceleration is approximately 9.81 m/s or 32.2 ft/s). If the ball is initially motionless, it will fall straight down. However, if the ball has some horizontal motion, it will continue in that motion while accelerating toward the ground. **Figure 8-5** shows a ball released with varying lateral (or horizontal) velocities.

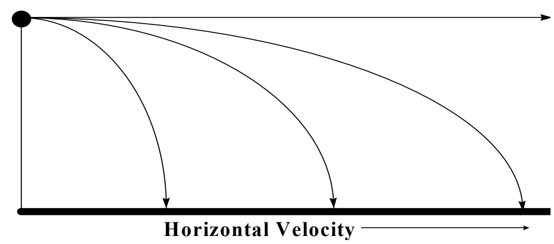

Fig. 8-5. Newton's 2nd Law

In **Figure 8-5**, if the initial height of the ball is approximately 4.9 meters (16.1 ft) above the ground, then at sea level, it would take 1 second for the ball to hit the ground. How far the ball travels along the ground in that one second depends on its horizontal velocity (see **Table 8-1**).

Table 8-1. Gravitational Effects

Horizontal Velocity	Distance (@ 1 sec) Vertical	Horizontal
1	4.9	1
2	4.9	2
4	4.9	4
8	4.9	8
16	4.9	16

All values are in meters and meters/second.

Eventually one would come to the point where the Earth's surface drops away as fast as the ball drops toward it. As **Fig. 8-6** depicts, the Earth's surface curves down about 5 meters for every 8 km.

At the Earth's surface (without contending for the atmosphere, mountains or other structures), a satellite would have to travel at approximately 8 km/sec (or about 17,900 mph) to fall around the Earth without hitting the surface; in other words, to orbit.[12]

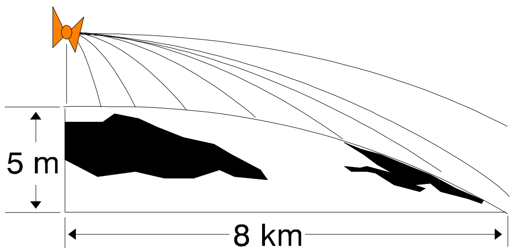

Fig. 8-6. Earth's Curvature

Figure 8-7 shows how differing velocity affects a satellite's trajectory or orbital path. The Figure depicts a satellite at an altitude of one Earth radius (6378 km above the Earth's surface). At this distance, a satellite would have to travel at

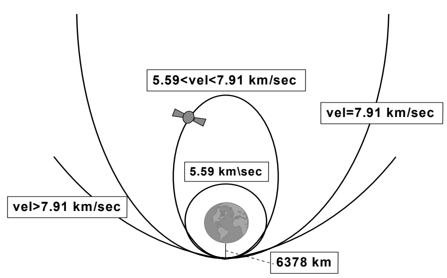

Fig. 8-7. Velocity versus Trajectory

5.59 km/sec to maintain a circular orbit and this speed is known as its *circular speed* for this altitude. As the satellite's speed increases, it falls farther and farther away from the Earth and its trajectory becomes an elongating ellipse until the speed reaches 7.91 km/sec. At this speed and altitude the satellite has enough energy to leave the Earth's gravity and never return; its trajectory has now become a parabola, and this speed is known as its *escape speed* for this altitude. As the satellite's speed continues to increase beyond escape speed its trajectory becomes a flattened hyperbola. From a low Earth orbit of about 100 miles, the escape velocity becomes 11.2 km/sec. In the above description, the two specific speeds (5.59 km/sec and 7.91 km/sec) correspond to the circular and escape speeds for the specific altitude of one Earth radius.

The satellite's motion is described by Newton's three laws and his Law of Universal Gravitation. The Law of Universal Gravitation describes how the force between objects decreases with the square of the distance between the objects. As the altitude increases, the force of gravity rapidly decreases, and therefore the satellite can travel slower and still maintain a circular orbit. For the object to escape the Earth, it has to have enough kinetic energy (kinetic energy is proportional to the square of velocity) to overcome the gravitational potential energy of its position. Since gravitational potential energy is proportional to the distance between the objects, the farther the object is from the Earth, the less potential energy the satellite must overcome, which also means the less kinetic energy is needed.

ORBIT GEOMETRY

The two-body equation of motion describes conic sections. The conic section an object will follow depends on its velocity and the magnitude of the central force. If an object lacks the velocity (insufficient kinetic energy) to overcome the gravitational attraction (potential energy) then it will follow a closed path (circle or ellipse). However, if the object has enough velocity to

[12]Because the Earth does have an atmosphere, to stay in a "stable" orbit objects must be above the atmosphere—about 94 miles above the Earth's surface. Because the force due to gravity is inversely proportional to the square of the distance between the objects, at 94 miles an object has to travel at 7.8 km/sec (17,500 mph), while the Moon (at 249,000 miles) has to travel at only .9144 km/sec. (All these speeds are for circular orbits.)

overcome the gravitational attraction then the object will follow an open path (parabola or hyperbola) and escape from the central force.

Figure 8-8 shows the basic geometry for the various possible conic sections. The parameters that describe the size and shape of the conics are its *semi-major axis* **a** (half of the large axis) and *eccentricity* **e** (the ratio between the separation of the foci—*linear eccentricity* **c**—and the semi-major axis).

Figure 8-9 depicts a satellite orbit with additional parameters whose conic section is an ellipse.

*Semi-major Axis (**a**)*—half of the distance between perigee and apogee, a measure of the orbits size, also the average distance from the attracting body.

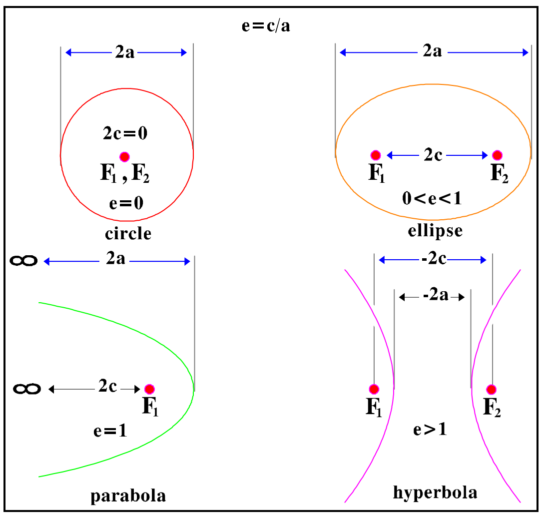

Fig. 8-8. Conic Section Geometry

Linear Eccentricity (c)—half of the distance between the foci.

Eccentricity (e)—ratio of the distance between the foci (**c**) to the size of the ellipse (**a**); describes the orbit's shape.

Perigee—the closest point in an orbit to the attracting body.

Apogee—the farthest point in an orbit to the attracting body.

These parameters apply to all trajectories. A circular orbit is a special case of the elliptical orbit where the foci coincide (c = 0). A parabolic path is a transition between an elliptical and a hyperbolic trajectory. The parabolic path represents the minimum energy escape trajectory. The hyperbolic is also an escape trajectory; and represents a trajectory with excess escape velocity.

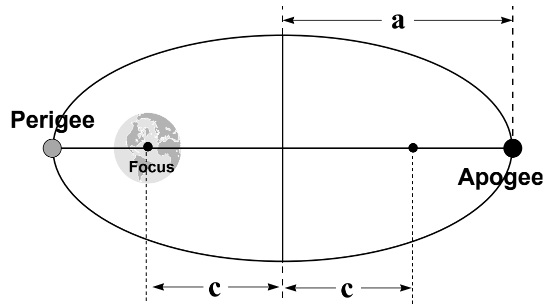

Fig. 8-9. Elliptical Geometry

Table 8-2 shows the values for the eccentricity (discussed later) for the various types of orbits. Eccentricity is associated with the shape of the orbit. Energy is associated with the orbit's size (for closed orbits).

Table 8-2. Eccentricity Values

Conic Section	Eccentricity *(e)*
circle	$e = 0$
ellipse	$0 < e < 1$
parabola	$e = 1$
hyperbola	$e > 1$

CONSTANTS OF ORBITAL MOTION: MOMENTUM AND ENERGY

For some systems, there are basic properties which remain constant or fixed. Energy and momentum are two such properties required for a conservative system.

Momentum

Momentum is the product of mass times velocity ($\bar{p} = m\bar{v}$). This is the term for linear momentum and remains constant internal to the system in every direction. In some instances it is more advantageous to describe motion in angular terms. For example, when dealing with spinning or rotating objects, it is simpler to describe them in angular terms An important angular property in orbital mechanics is *angular momentum.* Angular momentum is the product of linear momentum times the radius of revolution.[13] This property, like linear momentum, remains constant internal to the system for such things as orbiting objects.

A simple experiment can be performed illustrating conservation of angular momentum. Starting with some object on the end of a string, the object may be spun to impart angular momentum to the system. The amount of angular momentum depends on the object's mass and velocity, and the length of the string (radius): $\vec{h} = m(\vec{r} \times \vec{v})$. Now, if the string is shortened, the object will speed up (spin faster). From the above equation, mass (m) remains constant; angular momentum ($\vec{h}$) must remain constant as the radius ($\vec{r}$) decreases, so the object's velocity ($\vec{v}$) increases. This same principle holds true for orbiting systems. In an elliptical orbit, the radius is constantly varying and so is the orbital speed, but the angular momentum remains constant. Hence, there is greater velocity at perigee than at apogee.

Energy

A system's mechanical energy can also be conserved. Mechanical energy (denoted by E) is the sum of kinetic energy (KE) and potential energy (PE): $E = KE + PE$. Kinetic energy is the energy associated with an object's motion and potential energy is the energy associated with an object's position. Every orbit has a certain amount of mechanical energy. A circular orbit's radius and speed remain constant, so both potential and kinetic energy remain constant. In all other orbits (elliptical, parabolic and hyperbolic) the "radius" and speed both change, and therefore, so do both the potential and kinetic energy in such a way that the total mechanical energy of the system remains constant. Again, for an elliptical orbit, this results in greater velocity at perigee than apogee. If a satellite's position and velocity is known, a satellite's orbit may be ascertained. Position determines potential energy while velocity determines kinetic energy.

COORDINATE REFERENCE SYSTEMS AND ORBITAL ELEMENTS

Reference systems are used everyday. Once an agreed upon reference has been determined, spatial information can be traded. The same must be done when considering orbits and satellite positions The reference system used depends on the situation, or the nature of the knowledge to be retrieved.

How does one know where satellites are, were or will be? Coordinate reference systems allow measurements to be defined, resulting in specific parameters which describe orbits. A set of these parameters is a satellite's *orbital element set*. Two elements are needed to define an orbit: a satellite's position and velocity. Given these two parameters, a satellite's past and future position and velocity may be predicted.

In three-dimensional spaces, it takes three parameters each to describe position and velocity. Therefore, any element set defining a satellite's orbital motion requires at least six parameters to fully describe that motion. There are different types of element sets, depending on the use. The Keplerian, or classical, element set is useful for space operations andtells us four parameters about orbits, namely:

- Orbit size
- Orbit shape
- Orientation
  - orbit plane in space
  - orbit within plane

[13] Angular momentum is actually the vector cross product of linear momentum and the radius of revolution: $\vec{h} = \vec{r} \times \vec{p} \Rightarrow m(\vec{r} \times \vec{v})$.

- Location of the satellite

Semi-Major Axis (a)

. The *semi-major axis* (a) describes an orbit's size and is half of the distance between apogee and perigee on the ellipse. This is a significant measurement since it also equals the average radius, and thus is a measure of the mechanical energy of the orbiting object.

Eccentricity (e)

Eccentricity ($\boldsymbol{e}$) measures the shape of an orbit and determines the positional relationship to the central body which occupies one of the foci. Recall from the orbit geometry section that eccentricity is a ratio of the foci separation (linear eccentricity, $\boldsymbol{c}$) to the size (semi-major axis, $\boldsymbol{a}$) of the orbit:

$$\boxed{e = c/a}$$

Size and shape relate to orbit geometry, and tell what the orbit looks like. The other orbital elements deal with orientation of the orbit relative to a fixed point in space.

Inclination (i)

The first angle used to orient the orbital plane is *inclination* ($\boldsymbol{i}$): a measurement of the orbital plane's tilt. This is an angular measurement from the equatorial plane to the orbital plane ($0° \le \boldsymbol{i} \le 180°$), measured counter-clockwise at the ascending node while looking toward Earth (**Fig. 8-10**).

Inclination is utilized to define several general classes of orbits. Orbits with inclinations equal to 0° or 180° are *equatorial orbits,* because the orbital plane is contained within the equatorial plane. If an orbit has an inclination of 90°, it is a *polar orbit,* because it travels over the poles. If $0° \le \boldsymbol{i} < 90°$, the satellite orbits in the same general direction as the Earth (orbiting eastward around the Earth)

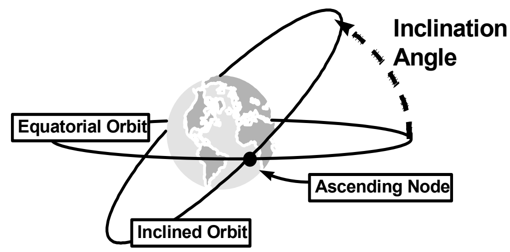

Fig. 8-10. Inclination Tilt

and is in a *prograde orbit*. If $90° < \boldsymbol{i} \le 180°$, the satellite orbits in the opposite direction of the Earth's rotation (orbiting westward about the Earth) and is in a *retrograde orbit*. Inclination orients the orbital plane with respect to the equatorial plane (fundamental plane).

Right Ascension of the Ascending Node (Ω)

Right Ascension of the Ascending Node, **Ω** (upper case Greek letter omega), is a measurement of the orbital plane's rotation around the Earth. It is an angular measurement within the equatorial plane from the First point of Aries eastward to the ascending node ($0° \le \boldsymbol{\Omega} \le 360°$) (**Fig. 8-11**).

The First Point of Aries is simply a fixed point in space. The Vernal Equinox is the first day of spring (in the northern hemisphere). However, for the astronomer, it has added importance because it is a convenient way of fixing this principle direction. The Earth's

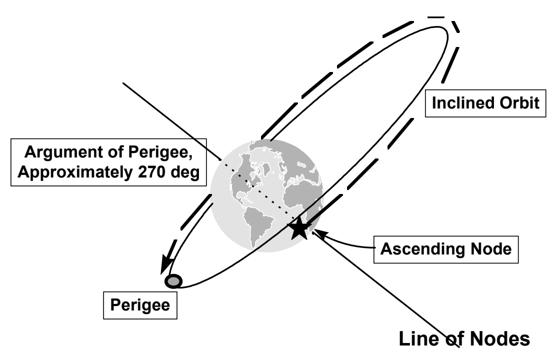

Fig. 8-13. Argument of Perigee

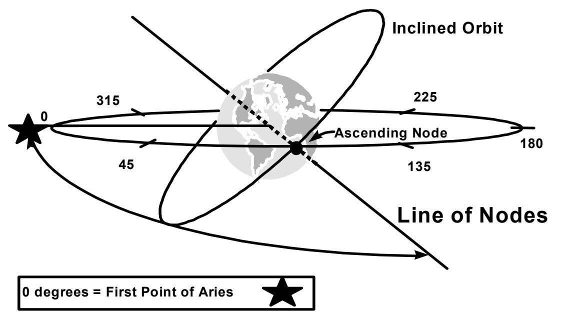

Fig. 8-11. Right Ascension of the Ascending Node

equatorial plane and its orbit about the Sun provide the principle direction. The Earth orbits about the Sun in the ecliptic plane, and this plane passes through the centers of both the Sun and Earth; the Earth's equatorial plane passes through the center of the Earth, which is tilted at approximately 23° to the ecliptic. The intersection of these two planes forms a line that passes though Earth's center and passes through the Sun's center twice a year: at the Vernal and Autumnal

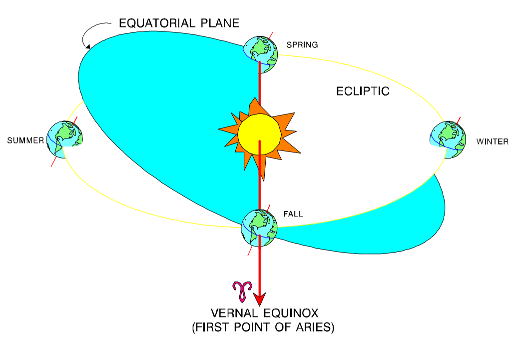

Fig. 8-12. Vernal Equinox

Equinoxes. The ancient astronomers picked the principle direction as that from the Sun's center through the Earth's center on the first day of Spring, the Vernal Equinox (**Fig. 8-12**).

The ancient astronomers called this the First Point of Aries because, at the time, this line pointed at the constellation Aries. The Earth is spinning like a top, and like a top, it wobbles on its axis. It takes approximately 25,800 years for the axis to complete one revolution. With the axis changing over time, so does the equatorial plane's orientation. The intersection between the ecliptic and the equatorial plane is rotating westward around the ecliptic. With this rotation, the principle direction points to different constellations. Presently, it is pointing towards Pisces. The orbital elements for Earth satellites are referenced to inertial space (a non-rotating principle direction) so the orbital elements must be referenced to where the principle direction was pointing at a specific time. The orbital analyst does this by reporting the orbital elements as referenced to the mean of 1950 (a popular *epoch year* reference). Most analysts have updated their systems and are now reporting the elements with respect to the mean of 2000.

Argument of Perigee (ω)

Inclination and Right Ascension fix the orbital plane in inertial space. The orbit must now be fixed within the orbital plane. For elliptical orbits, the perigee is described with respect to inertial space.

The *Argument of Perigee,* ω (lower case Greek letter omega), orients the orbit within the orbital plane. It is an angular measurement within the orbital plane from the ascending node to perigee in the direction of satellite motion ($0° \leq \omega \leq 360°$) (see **Fig. 8-13)**.

Table 8-3. Classical Orbital Elements

Element	Name	Description	Definition	Remarks
a	semi-major axis	orbit *size*	half of the long axis of the ellipse	orbital period and energy depend on orbit size
e	eccentricity	orbit *shape*	ratio of half the foci separation (*c*) to the semi-major axis	closed orbits: $0 \le e < 1$ open orbits: $1 \le e$
i	inclination	orbital plane's *tilt*	angle between the orbital plane and equatorial plane, measured counterclockwise at the ascending node	equatorial: i = 0° or 180° prograde: $0° \le i < 90°$ polar: i = 90° retrograde: $90° < i \le 180°$
Ω	right ascension of the ascending node	orbital plane's *rotation* about the Earth	angle, measured eastward, from the vernal equinox to the ascending node	$0° \le \Omega < 360°$ undefined when i = 0° or 180° (equatorial orbit)
ω	argument of perigee	orbit's *orientation* in the orbital plane	angle, measured in the direction of satellite motion, from the ascending node to perigee	$0° \le \omega < 360°$ undefined when i = 0° or 180°, or e = 0 (circular orbit)
ν	true anomaly	satellite's *location* in its orbit	angle, measured in the direction of satellite motion, from perigee to the satellite's location	$0° \le \nu < 360°$ undefined when e = 0 (circular orbit)

True Anomaly (ν)

At this point all the orbital parameters needed to visualize the orbit in inertial space have been specified. The final step is to locate the satellite within its orbit. *True Anomaly*, ν (lower case Greek letter nu), is an angular measurement that describes where the satellite is in its orbit at a specified time, or Epoch. It is measured within the orbital plane from perigee to the satellite's position in the direction of motion (0°≤ν≤360°).

True Anomaly locates the satellite with respect to time and is the only orbital element that changes with time. There are various conventions for describing True Anomaly and Epoch. By fixing one, the other is also fixed. Sometimes they will choose True Anomaly to be 0° and give the Epoch as the *time of perigee passage*; or they will choose the Epoch as the moment when the satellite passes through the ascending node and provide the value for True Anomaly.

There are different types of element sets. However, usually only orbital analysts deal with these sets. The Keplerian, or classical element, is the only element relevant to a majority of space operations. **Table 8-3** summarizes the Keplarian orbital element set, and orbit geometry and its relationship to the Earth.

ORBIT CHARACTERISTICS

Inclination (***i***) alone determines the four general orbit classes:

Prograde — $0° \le \boldsymbol{i} < 90°$
Retrograde — $90° < \boldsymbol{i} \le 180°$
Equatorial — $\boldsymbol{i}$ = 0°, 180°
Polar — $\boldsymbol{i}$ = 90°

Other common orbits include those used for communication, weather and navigation:

Geostationary —Period =23hrs56min
$\boldsymbol{i}$ = 0°
$\boldsymbol{e}$ = 0
Geosynchronous—Period =23hrs56min
Molniya —Period =11hrs58min
$\boldsymbol{i}$ = 63.4°
$\boldsymbol{e}$ = .72
Sun-synchronous—Period=1hr41min
$\boldsymbol{i}$ = 98°
Semi-synchronous-Period =11hr58min

GROUND TRACKS

The physics of two-body motion dictates the motions of the bodies will lie within a plane (two-dimensional motion). The orbital plane intersects the Earth's

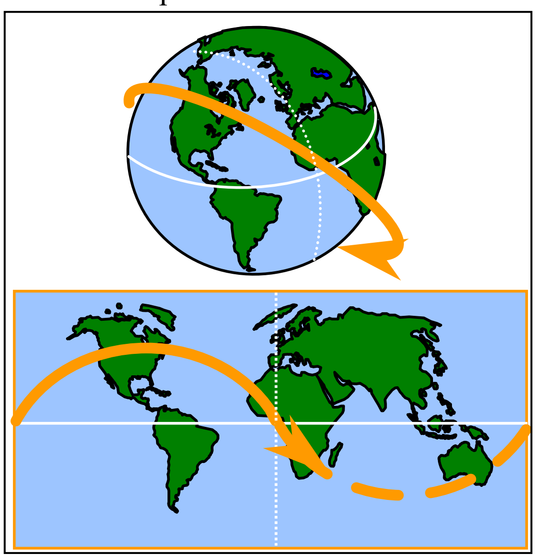

Fig. 8-14. Ground Track

surface forming a *great circle*. A satellite's ground track is the intersection of the line between the Earth's center and the satellite, and the Earth's surface; the point on the line at the surface of the Earth is called the *satellite subpoint*. The ground track, then, is the path the satellite subpoint traces on the Earth's surface over time (**Fig. 8-14**). However, the Earth does rotate on its axis at the rate of one revolution per 24 hours. With the Earth rotating under the satellite, the intersection of the orbital plane,[14] and the Earth's surface is continually changing.

The ground track is the expression of the relative motion of the satellite in its orbit to the Earth's surface rotating beneath it. Because of this relative motion, ground tracks come in almost any form and shape imaginable. Ground track shape depends on many factors:

Inclination	$\boldsymbol{i}$
Period	$\boldsymbol{P}$
Eccentricity	$\boldsymbol{e}$
Argument of Perigee	$\boldsymbol{\omega}$

Inclination defines the tilt of the orbital plane and therefore, defines the maximum latitude, both North and South of the ground track.

The period defines the ground track's *westward regression*. With a non-rotating Earth, the ground track would be a great circle. Because the Earth does rotate, by the time the satellite returns to the same place in its orbit after one revolution, the Earth has rotated eastward by some amount, and the ground track looks like it has moved westward on the Earth's surface (*westward regression)*. The orientation of the satellite's orbital plane does not change in inertial space, the Earth has just rotated beneath it. The time it takes for the satellite to orbit (its orbital period) determines the amount the Earth rotates eastward and hence its westward regression.

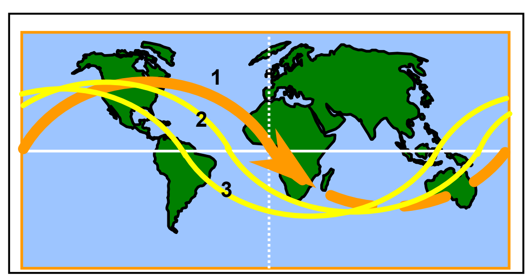

Fig. 8-15. Earth's Rotation Effects

Figure 8-15 shows the effect of the Earth's rotation on the ground track. The

[14]Except for equatorial orbits, whose orbital plane is contained within the equatorial plane.

Earth rotates through 360° in 24 hours, giving a rotation rate of 15°/hr.[15] With a period of 90 min., a satellite's ground trace regresses 22.5° westward per revolution (15°/hr × 1.5 hrs= 22.5°). Westward regression is the angle through which the Earth has rotated underneath the satellite during the time it takes the satellite to complete one orbit.

Eccentricity affects the ground track because the satellite spends different amounts of time in different parts of its orbit (it's moving faster or slower). This means it will spend more time over certain parts of the Earth than others. This has the effect of creating an unsymmetrical ground track. It is difficult to determine how long the satellite spends in each hemisphere by simply looking at the ground trace. The time depends on both the length of the trace and the speed of the satellite.

Argument of perigee skews the ground track. For a prograde orbit, at perigee the satellite will be moving faster eastward than at apogee; in effect, tilting the ground track.

A general rule of thumb is that if the ground track has any portion in the eastward direction, the satellite is in a prograde orbit. If the ground trace does not have a portion in the eastward direction, it is either a retrograde orbit or it could be a super-synchronous prograde orbit.

Relative Motions

Because the Earth is a rotating the velocity of points on the surface is different depending on their distance from the Earth's axis of rotation. In other words, points on the equator have a greater eastward velocity than points north and south of the equator.

Figure 8-16 conceptualizes a geo-stationary orbit and its ground track. A

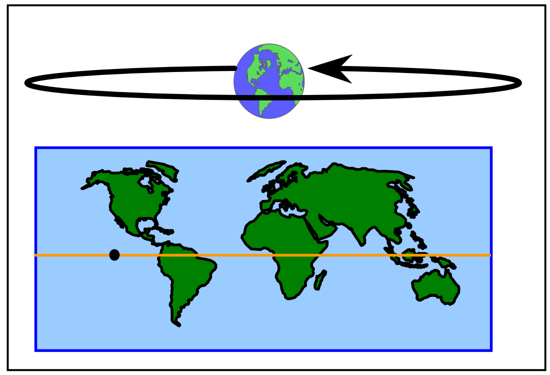

Fig. 8-16. Geostationary Orbit/Ground Track

satellite in a ideal geostationary orbit has the same orbital period as the Earth's rotational period, its inclination is 0° and its eccentricity is 0. The ground track will remain in the equatorial plane, the westward regression will be 360° and the satellite's speed never changes. Therefore, from the earth, the ground track will be a point on the equator.

Now take the same orbit and give it an inclination of 45°**)**.

The period and eccentricity remain the same. The westward regression will be

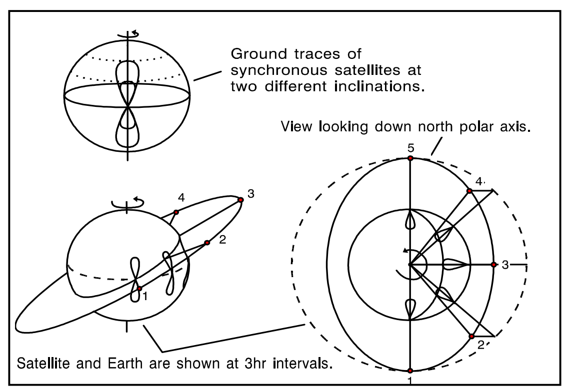

Fig. 8-17. Ground Traces of Inclined, Circular, Synchronous Satellites

360° so the ground trace will retrace itself with every orbit. The ground trace will also vary between 45° North and 45° South. The apparent ground trace looks like a figure eight(**Fig. 8-17** for the simplest case. If the orbital parameters are varied (such as eccentricity and argument of perigee), the relative motions of the satellite and the

[15]In reality, the 28-hour rotation rate is with respect to the Sun and is called the *solar day*. The rotation rate with respect to inertial space (the fixed stars, or background stars) is actually 23 hrs 56 min and is called the *sidereal day*.

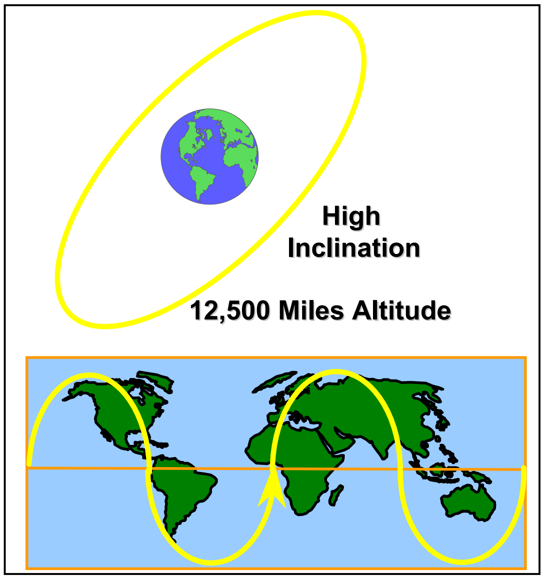

Fig. 8-18. Semi-synchronous Orbit

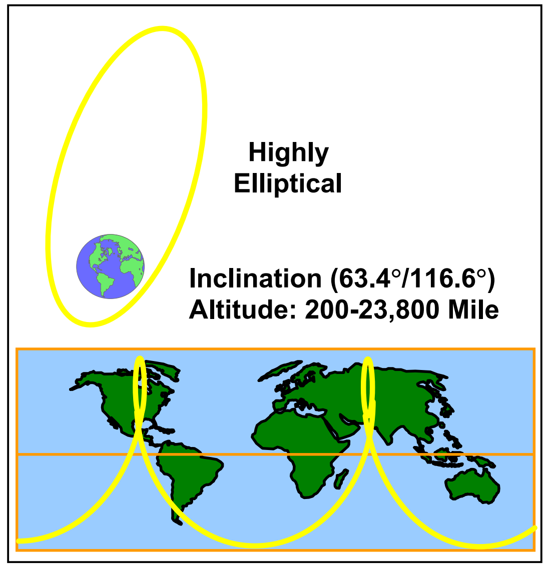

Fig. 8-19. Molniya Orbit

Earth's surface can become quite complicated. For orbits with small inclinations, the eccentricity and argument of perigee dominate the effect of the Earth's surface speed at different latitudes and can cause the ground track to vary significantly from a symmetric figure eight. These parameters can be combined in various ways to produce practically any ground track.

The semi-synchronous orbit (used by the Global Positioning System) also provides a unique ground track. This orbit, with its approximate 12-hour period, repeats twice a day. Since the Earth turns half way on its axis during each complete orbit, the points where the sinusoidal ground tracks cross the equator coincide pass after pass and the ground tracks repeat each day (**Fig. 8-18**).

Figure 8-19 shows a typical Molniya orbit that might be used for northern hemispheric communications. The Russians are credited with the discovery of this ingenious orbit. With the high degree of eccentricity the satellite travels slowly at apogee and can hang over the Northern Hemisphere for about two thirds of its period. Since the period is 12 hours, the ground track retraces itself every day, much the same as the semi-synchronous orbit

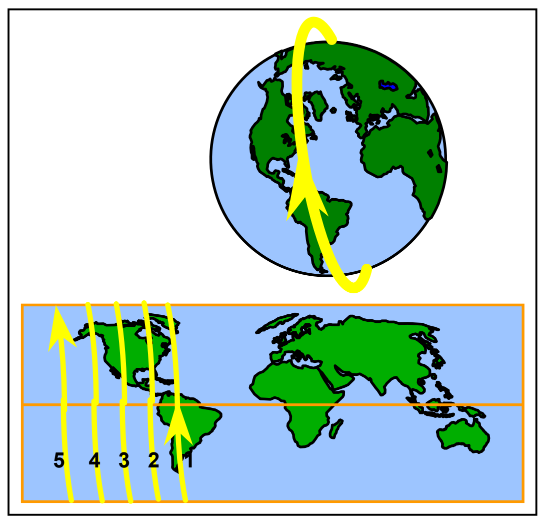

Fig. 8-20. Sun-synchronous Orbit

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Figure 8-20 shows a representative sun-synchronous orbit. In this case, the orbital elements represent a DMSP (Defense Meteorological Satellite Program) satellite. The satellite is in a slightly retrograde orbit; therefore, the satellite travels east to west along the track..

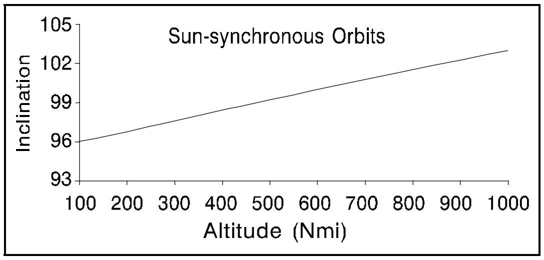

Fig. 8-21. Inclination versus Altitude

A sun-synchronous orbit is one in which the orbital plane rotates eastward around the Earth at the same rate that the Earth orbits the Sun. So, the orbit must rotate eastward around the Earth at a little less than 1°/day {(360°/year)/(365.25 days/ year) = .986°/day}. This phenomenon occurs naturally due to the oblateness of the Earth (see the section on perturbations).

Sun-synchronous orbits can be achieved at different altitudes and inclinations. However, all the inclinations for sun-synchronous satellites are greater than 90° (retrograde orbits). **Figure 8-21** plots inclination versus altitude for sun-synchronous orbits.

LAUNCH CONSIDERATIONS

The problem of launching satellites comes down to geometry and energy. If there were enough energy, satellites could be launched from anywhere at any time into any orbit. However, energy is limited and so is cost.

When a satellite is launched, it is intended to end up in a specific orbit, not only with respect to the Earth, but often with respect to an existing constellation. Also, the geometry of the planets must be taken into consideration when launching an interplanetary probe. Meeting operational constraints determines the launch window. The launch system is designed to accomplish the mission with the minimum amount of energy required because it is usually less expensive.[16]Keeping energy to a minimum restricts the launch trajectories and the launch location.

Launch site latitude and orbit inclination are two important factors affecting how much energy boosters have to supply. Orbit inclination depends on the satellite's mission, while launch site latitude is, for the most part, fixed (to our existing launch facilities).[17] Only minimum energy launches (direct launch) will be addressed. A minimum energy is one in which a satellite is launched directly into the orbital plane (i.e., no plane change or inclination maneuver).By looking at the geometry, the launch site must pass through the orbital plane to be capable of directly launching into that plane. Imagine a line drawn from the center of the Earth through the launch site and out into space. After a day, this line produces a conical configuration due to the rotation of the Earth. A satellite can be launched into any orbital plane that is tangent to, or passes through, this cone. As a result of this geometry, the lowest inclination that can be achieved by directly launching is equal to the latitude of the launch site.

If the orbital plane inclination is greater than the launch site latitude, the launch site will pass through the orbital plane twice a day, producing two launch windows per day. If the inclination of the orbital plane is equal to the launch site latitude, the launch site will be coincident with the orbital plane once a day, producing one launch window a day. If the inclination is less than the launch site latitude, the launch site will not pass through, or be coincident with the orbital plane at any time, and so there will not be any launch windows for a direct launch.

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[16]There are some situations when it is less expensive to use an existing system with extra energy because a lower class booster will not meet the mission needs. In this case, there is an extra margin and the launch windows are larger.

[17]There are various schemes to get around the problem of fixed launch sites: air launch, sea launch, and portable launch facilities, for instance.

A simplified model for determining inclination from launch site latitude and launch azimuth is:[18]

$$\cos(i) = \cos(L) \bullet \sin(Az)$$

i = inclination
L = launch site latitude
Az = launch azimuth

The cosine of the latitude reduces the range of possible inclinations and the sine of the azimuth varies the inclination within the reduced range. When viewing the Earth and a launch site, it is possible to launch a satellite in any direction (launch azimuth). The orbital plane must pass through the launch site and the center of the Earth.

For launches due east (no matter what the launch site latitude) the inclination will equal the launch site latitude. For launches on any other azimuth, the inclination will always be greater than the launch site latitude.

Just as the launch site latitude determines the minimum inclination (launching due east), it also determines the maximum inclination by launching due west. The maximum inclination is 180 minus the latitude.

The actual launch azimuths allowed (in most countries) are limited due to the safety considerations of not launching over populated areas, which further limits the possible inclinations from any launch site. However, the inclination can change after launch by performing an out of plane maneuver (see next section).

Launch Velocity

When a satellite is launched, energy is imparted to it. The two tasks of increasing the satellite's potential and kinetic energies must be accomplished. Potential energy is increased by raising the satellite above the Earth (increasing its altitude by at least 90-100 miles). In order to maintain a minimum circular orbit at that altitude, the satellite has to travel about 17,500 mph. Due to the Earth's rotation, additional kinetic energy may need to be supplied depending on launch azimuth to achieve this orbital velocity (17,500 mph). The starting velocity at the launch sites vary with latitude. It ranges from zero mph at the poles to 1,037 mph at the equator.

If a satellite is launched from the equator prograde (in the same direction as the earth's rotation) starting with 1,037 mph, only 16,463 mph must be supplied (17,500 mph- 1,037 mph). If launched from the equator retrograde (against the rotation of the earth), 18,537 mph must be supplied. Launching with the earth's rotation saves fuel and allows for larger payloads for any given booster.

There are substantial energy savings when locating launch sites close to the equator and launching in a prograde direction.

ORBITAL MANEUVERS

It is a rare case indeed to launch directly into the final orbit. In general, a satellite's orbit must change at least once to place it in its final mission orbit. Once a satellite is in its mission orbit, perturbations must be counteracted, or perhaps the satellite must be moved into another orbit.

As was previously mentioned, a satellite's velocity and position determine its orbit.[19] Thus, one of these parameters must be changed in order to change its orbit. The only option is to change the velocity, since position is relatively constant. By changing the velocity, the satellite is now in a different orbit. Since gravity is conservative, the satellite will always return to the point where it performed the maneuver (provided it doesn't perform another maneuver before returning).

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[18]This is a simplified model because it ignores the Earth's rotation, which has a small effect.

[19]The position and velocity correspond to the force of gravity and the satellite's momentum. Knowing the forces on the satellite and its momentum, we can apply Newton's second law and predict its future positions (in other words, we know its orbit).

Mission Considerations

Since both position and velocity determine a satellite's orbit, and many different orbits can pass through the same point, the velocity vectors must differ[20] to result in a different orbit while passing through the same point.

When an orbit is changed through its velocity vector, a *delta-v* ($\Delta \boldsymbol{v}$) is performed. For any single $\Delta \boldsymbol{v}$ orbital change, the desired orbit must intersect the current orbit, otherwise it will take at least two $\Delta \boldsymbol{v}$s to achieve the final orbit.

When the present and desired orbits intersect, a $\Delta \boldsymbol{v}$ is employed to change the satellite's velocity vector. The $\Delta \boldsymbol{v}$ vector can be determined by subtracting the present vector from the desired vector. The resultant velocity vector is the $\Delta \boldsymbol{v}$ required to get from one point to another.

PERTURBATIONS

Perturbations are forces which change the motion (orbit) of the satellite. These forces have a variety of causes/origins and effects. These forces are named and categorized in an attempt to model their effects. The major perturbations are:

- Earth's oblateness;
- Atmospheric drag;
- Third-body effects;
- Solar wind/radiation pressure;
- Electromagnetic drag.

Earth's Oblateness

The Earth is not a perfect sphere. It is somewhat misshapen at the poles and bulges at the equator. This squashed shape is referred to as *oblateness*. The North polar region is more pointed than the flatter South polar region, producing a slight "pear" shape. The equator is not a perfect circle; it is slightly elliptical. The effects of Earth's oblateness are gravitational variations or perturbations, which have a greater influence the closer a satellite is to the Earth. This bulge is often modeled with complex mathematics and is frequently referred to as the *J2 effect*.[21] For low to medium orbits, these influences are significant.

One effect of Earth's oblateness is *nodal regression.* Westward regression due to Earth's rotation under the satellite was discussed in the ground tracks section. Nodal regression is an actual rotation of the orbital plane, relative to the First Point of Aries, about the Earth (the right ascension changes). If the orbit is prograde, the orbital plane rotates westward around the Earth (right ascension decreases); if the orbit is retrograde, the orbital plane rotates eastward around the Earth (right ascension increases).

In most cases, perturbations must be counteracted. However, in the case of sun-synchronous orbits, perturbations can be advantageous. In the slightly retrograde sun-synchronous orbit, the angle between the orbital plane and a line between the Earth and the Sun needs to remain constant. As the Earth orbits eastward around the Sun, the orbital plane must rotate eastward around the Earth at the same rate. Since it takes 365 days for the Earth to orbit the Sun, the sun-synchronous orbit must rotate about the Earth at just under one degree per day. The oblateness of the Earth perturbs the orbital plane by nearly this amount.

A sun-synchronous orbit is beneficial because it allows a satellite to view the same place on Earth with the same sun angle (or shadow pattern). This is very valuable for remote sensing missions because they use shadows to measure object height.[22]

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[20] Remember that velocity is a vector — it has both a magnitude and a direction.

[21] J2 is a constant describing the size of the bulge in the mathematical formulas used to model the oblate Earth.

[22] With a constant sun angle, the shadow lengths give away any changes in height, or any shadow changes give clues to exterior configuration changes.

Another significant effect of Earth's asymmetry is *apsidal line rotation*. Only elliptical orbits have a line of apsides and so this effect only affects elliptical orbits. This effect appears as a rotation of the orbit within the orbital plane; the argument of perigee changes. At an inclination of 63.4° (and its retrograde compliment, 116.6°), this rotation is zero. The Molniya orbit was specifically designed with an inclination of 63.4° to take advantage of this perturbation. With the zero effect at 63.4° inclination, the stability of the Molniya orbit improves limiting the need for considerable on-board fuel to counteract this rotation. At a smaller inclination (but larger than 116.6°), the argument of perigee rotates eastward in the orbital plane; at inclinations between 63.4° and 116.6°, the argument of perigee rotates westward in the orbital plane. This could present a problem for non-Molniya communications satellites providing polar coverage. If the apogee point rotated away from the desired communications (rotated from the Northern to Southern Hemisphere), the satellite would be useless.

The ellipticity of the equator has an effect that shows up most notably in geostationary satellites (also in inclined geosynchronous satellites). Because the equator is elliptical, most satellites are closer to one of the lobes and experience a slight gravitational misalignment. This misalignment affects geostationary satellites more because they view the same part of the earth's surface all the time, resulting in a cumulative effect.

The elliptical force causes the subpoint of the geostationary satellite to move east or west with the direction depends on its location. There are two stable points at 75 East and 105 West, and two unstable stable points 90° out (165 East and 5 West).[23]

[23]A stable point is like a marble in the bottom of a bowl; an unstable stable point is like a marble perfectly balanced on the top of a hill.

Atmospheric Drag

The Earth's atmosphere does not suddenly cease; rather it trails off into space. However, after about 1,000 km (620 miles), its effects become minuscule. Generally speaking, atmospheric drag can be modeled in predictions of satellite position. The current atmospheric model is not perfect because of the many factors affecting the upper atmosphere, such as the earth's day-night cycle, seasonal tilt, variable solar distance, fluctuation in the earth's magnetic field, the suns 27-day rotation and the 11-year sun spot cycle. The drag force also depends on the satellite's coefficient of drag and frontal area, which varies widely between satellites.

The uncertainty in these variables cause predictions of satellite decay to be accurate only for the short term. An example of changing atmospheric conditions causing premature satellite decay occurred in 1978-1979, when the atmosphere received an increased amount of energy during a period of extreme solar activity. The extra solar energy expanded the atmosphere, causing several satellites to decay prematurely, most notably the U.S. space station SKYLAB.

The highest drag occurs when the satellite is closest to the earth (at perigee), and has a similar effect in performing a delta-V at perigee; it decreases the apogee height, circularizing the orbit. On every perigee pass, the satellite looses more kinetic energy (negative delta-V), circularizing the orbit more and more until the whole orbit is experiencing significant drag, and the satellite spirals in.

Third Body Effects

According to Newton's law of Universal Gravitation, every object in the universe attracts every other object in the universe. The greatest third body effects come from those bodies that are very massive and/or close such as the Sun, Jupiter and the Moon. These forces ffect satellites in orbits as well. The farther a satellite is from the Earth, the greater the third body forces are in proportion to Earth's gravitational force, and therefore, the greater the effect on the high altitude orbits.

Radiation pressure

The Sun is constantly expelling atomic matter (electrons, protons, and Helium nuclei). This ionized gas moves with high velocity through interplanetary space and is known as the solar wind. The satellites are like sails in this solar wind, alternately being speeded up and slowed down, producing orbital perturbations.

Electromagnetic Drag

Satellites are continually traveling through the Earth's magnetic field. With all their electronics, satellites produce their own localized magnetic fields which interact with the earth's, causing torque on the satellite. In some instances, this torque is advantageous for stabilization. More specifically, satellites are basically a mass of conductors. Passing a conductor through a magnetic field causes a current in the conductor, producing electrical energy. Some recent experiments used a long tether from the satellite to generate electrical power from the earth's magnetic field (the tether also provided other benefits).

The electrical energy generated by the interaction of the satellite and the earth's magnetic field comes from the satellite's kinetic energy about the earth. The satellite looses orbital energy, just as it does with atmospheric drag, which results in orbital changes. The magnetic field is strongest close to the Earth where satellites travel the fastest. Thus, this effect is largest on low orbiting satellites. However, the overall effect due to electromagnetic forces is quite small.

DEORBIT AND DECAY

So far the concern has been with placing and maintaining satellites in orbit. When no longer useful, satellites must be removed from their operational orbit. Sometimes natural perturbations such as atmospheric drag take care of disposal, but not always.

For satellites passing close to the earth (low orbit or highly elliptical orbits), satellites can be programmed to re-enter, or they may re-enter autonomously. Deliberate re-entry of a satellite with the purpose of recovering the vehicle intact is called *deorbiting*. This is usually done to recover something of value: people, experiments, film, or the vehicle itself. The natural process of spacecraft (or any debris – rocket body, payload, or piece) eventually re-entering Earth's atmosphere is called *decay*.

In some situations, the satellites are in such stable orbits that natural perturbations will not do the disposal job . In these situations, the satellite must be removed from the desirable orbit. To return a satellite to earth without destroying it takes a considerable amount of energy. Obviously, it is impractical to return old satellites to earth from a high orbit. The satellite is usually boosted into a slightly higher orbit to get it out of the way, and there it will sit for thousands of years.

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Limited information on perturbations—uses TOPEX as an example.

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Go to: Dean, Engineering Division-Astronautics, Instructional Wares, then browse.

http://www.jpl.nasa.gov/basics/
Browse.

http://www.jpl.nasa.gov/basics/bsf-toc.htm
Select topic of interest

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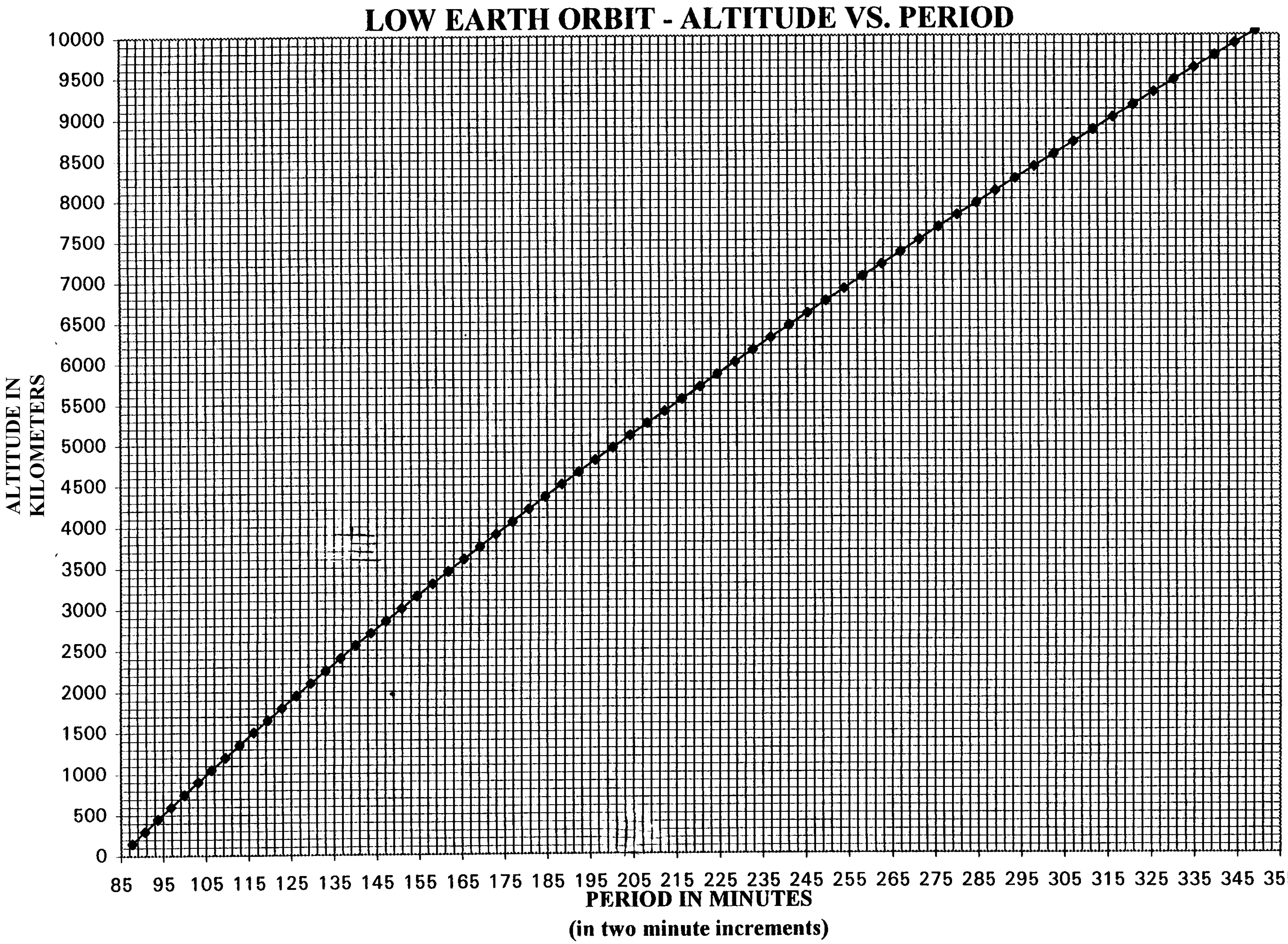
LOW EARTH ORBIT - ALTITUDE VS. PERIOD
ALTITUDE IN KILOMETERS
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
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4500
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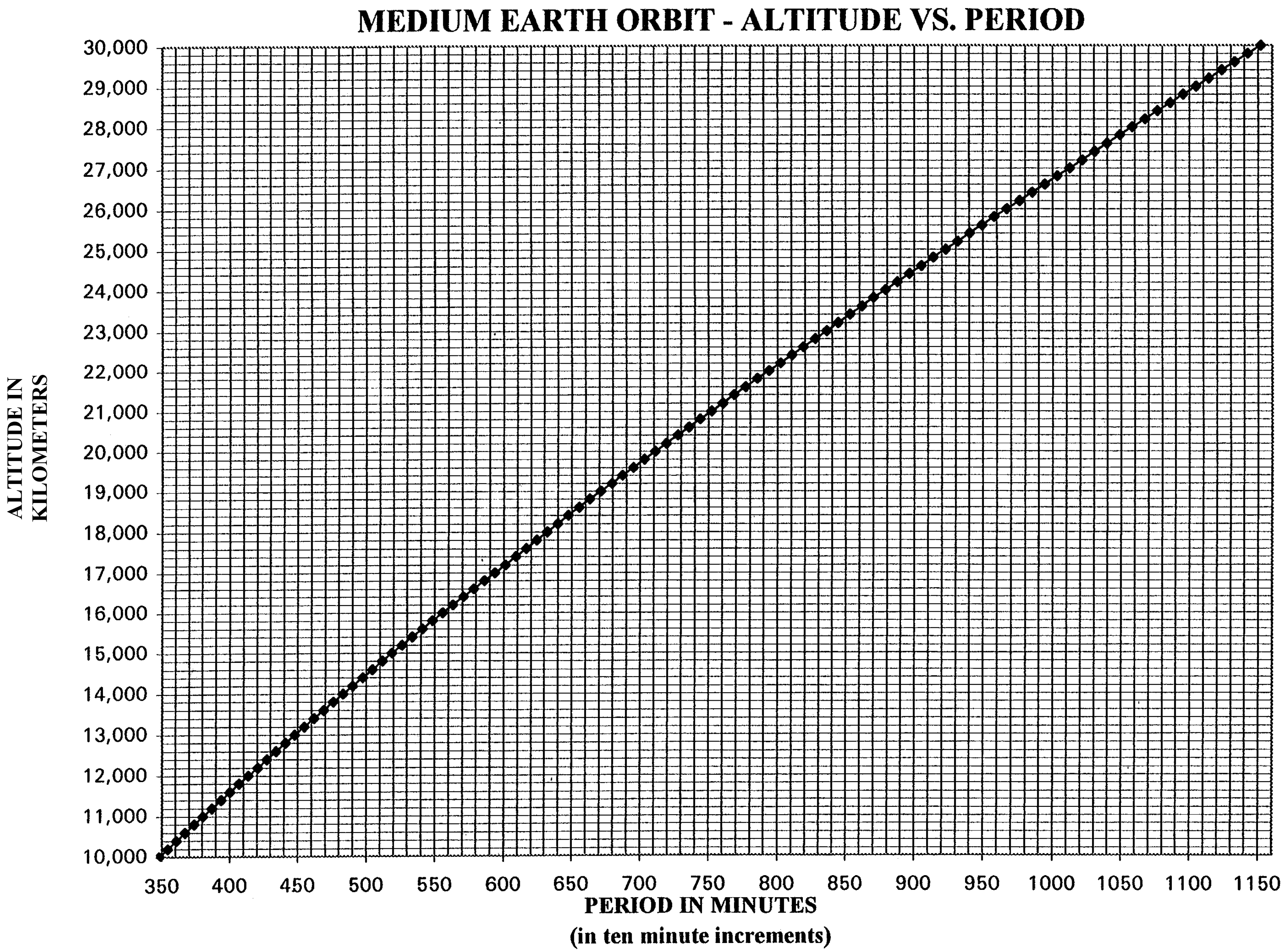
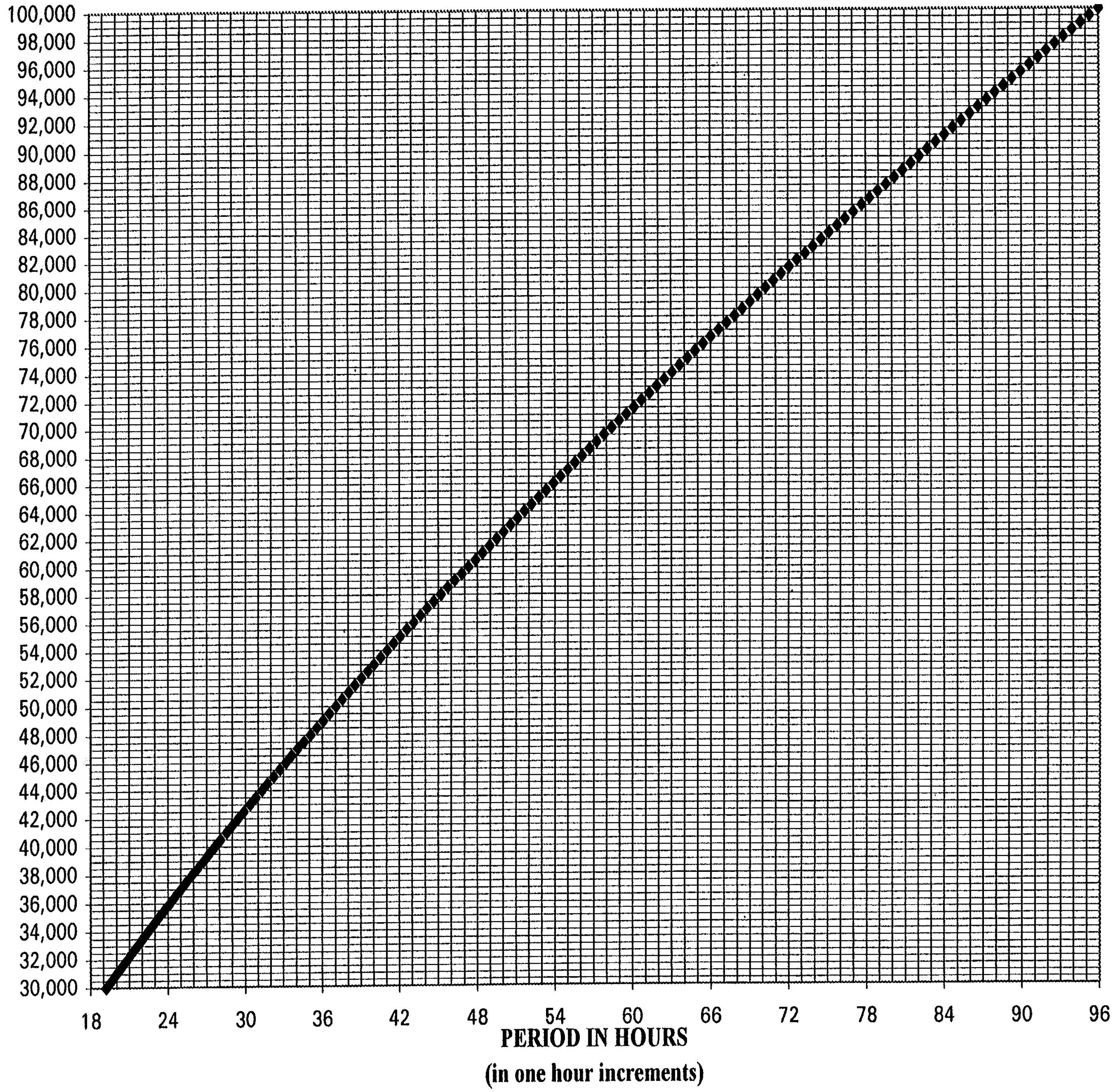
500
0
85 95 105 115 125 135 145 155 165 175 185 195 205 215 225 235 245 255 265 275 285 295 305 315 325 335 345
PERIOD IN MINUTES
(in two minute increments)



MEDIUM EARTH ORBIT - ALTITUDE VS. PERIOD
ALTITUDE IN KILOMETERS
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
PERIOD IN MINUTES
(in ten minute increments)


100,000
98,000
96,000
94,000
92,000
90,000
88,000
86,000
84,000
82,000
80,000
78,000
76,000
74,000
72,000
70,000
68,000
66,000
64,000
62,000
60,000
58,000
56,000
54,000
52,000
50,000
48,000
46,000
44,000
42,000
40,000
38,000
36,000
34,000
32,000
30,000
18
24
30
36
42
48
54
60
66
72
78
84
90
96
PERIOD IN HOURS
(in one hour increments)

DISTANCE CONVERSION FACTORS

STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS
100	86.90	160.94	260	225.93	418.43	580	504.01	933.43
105	91.24	168.98	270	234.62	434.53	600	521.39	965.62
110	95.59	177.03	280	243.31	450.62	620	538.77	997.81
115	99.93	185.08	290	252.00	466.72	640	556.14	1,029.99
120	104.28	193.12	300	260.69	482.81	660	573.52	1,062.18
125	108.62	201.17	310	269.38	498.90	680	590.90	1,094.37
130	112.97	209.22	320	278.07	515.00	700	608.28	1,126.55
135	117.31	217.26	330	286.76	531.09	720	625.66	1,158.74
140	121.66	225.31	340	295.45	547.18	740	643.04	1,190.93
145	126.00	233.36	350	304.14	563.28	760	660.42	1,223.12
150	130.35	241.40	360	312.83	579.37	780	677.80	1,255.30
155	134.69	249.45	370	321.52	595.46	800	695.18	1,287.49
160	139.04	257.50	380	330.21	611.56	820	712.56	1,319.68
165	143.38	265.54	390	338.90	627.65	840	729.94	1,351.87
170	147.73	273.59	400	347.59	643.75	860	747.32	1,384.05
175	152.07	281.64	410	356.28	659.84	880	764.70	1,416.24
180	156.42	289.69	420	364.97	675.93	900	782.08	1,448.43
185	160.76	297.73	430	373.66	692.03	920	799.46	1,480.61
190	165.11	305.78	440	382.35	708.12	940	816.84	1,512.80
195	169.45	313.83	450	391.04	724.21	960	834.22	1,544.99
200	173.80	321.87	460	399.73	740.31	980	851.60	1,577.18
205	178.14	329.92	470	408.42	756.40	1,000	868.98	1,609.36
210	182.49	337.97	480	417.11	772.49	1,020	886.36	1,641.55
215	186.83	346.01	490	425.80	788.59	1,040	903.74	1,673.74
220	191.17	354.06	500	434.49	804.68	1,060	921.11	1,705.93
225	195.52	362.11	510	443.18	820.78	1,080	938.49	1,738.11
230	199.86	370.15	520	451.87	836.87	1,100	955.87	1,770.30
235	204.21	378.20	530	460.56	852.96	1,120	973.25	1,802.49
240	208.55	386.25	540	469.25	869.06	1,140	990.63	1,834.67
245	212.90	394.29	550	477.94	885.15	1,160	1,008.01	1,866.86
250	217.24	402.34	560	486 63	901.24	1,180	1,025.39	1,899.05

DISTANCE CONVERSION FACTORS

STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS
1,200	1,042.77	1,931.24	2,800	2,433.13	4,506.22	6,000	5,213.86	9,656.18
1,250	1,086.22	2,011.70	2,900	2,520.03	4,667.15	6,200	5,387.65	9,978.05
1,300	1,129.67	2,092.17	3,000	2,606.93	4,828.09	6,400	5,561.45	10,299.93
1,350	1,173.12	2,172.64	3,100	2,693.83	4,989.03	6,600	5,735.24	10,621.80
1,400	1,216.57	2,253.11	3,200	2,780.72	5,149.96	6,800	5,909.04	10,943.67
1,450	1,260.02	2,333.58	3,300	2,867.62	5,310.90	7,000	6,082.83	11,265.54
1,500	1,303.46	2,414.05	3,400	2,954.52	5,471.84	7,200	6,256.63	11,587.42
1,550	1,346.91	2,494.51	3,500	3,041.42	5,632.77	7,400	6,430.42	11,909.29
1,600	1,390.36	2,574.98	3,600	3,128.31	5,793.71	7,600	6,604.22	12,231.16
1,650	1,433.81	2,655.45	3,700	3,215.21	5,954.65	7,800	6,778.01	12,553.04
1,700	1,477.26	2,735.92	3,800	3,302.11	6,115.58	8,000	6,951.81	12,874.91
1,750	1,520.71	2,816.39	3,900	3,389.01	6,276.52	8,200	7,125.61	13,196.78
1,800	1,564.16	2,896.85	4,000	3,475.90	6,437.45	8,400	7,299.40	13,518.65
1,850	1,607.61	2,977.32	4,100	3,562.80	6,598.39	8,600	7,473.20	13,840.53
1,900	1,651.05	3,057.79	4,200	3,649.70	6,759.33	8,800	7,646.99	14,162.40
1,950	1,694.50	3,138.26	4,300	3,736.60	6,920.26	9,000	7,820.79	14,484.27
2,000	1,737.95	3,218.73	4,400	3,823.50	7,081.20	9,200	7,994.58	14,806.14
2,050	1,781.40	3,299.20	4,500	3,910.39	7,242.14	9,400	8,168.38	15,128.02
2,100	1,824.85	3,379.66	4,600	3,997.29	7,403.07	9,600	8,342.17	15,449.89
2,150	1,868.30	3,460.13	4,700	4,084.19	7,564.01	9,800	8,515.97	15,771.76
2,200	1,911.75	3,540.60	4,800	4,171.09	7,724.95	10,000	8,689.76	16,093.64
2,250	1,955.20	3,621.07	4,900	4,257.98	7,885.88	10,200	8,863.56	16,415.51
2,300	1,998.65	3,701.54	5,000	4,344.88	8,046.82	10,400	9,037.35	16,737.38
2,350	2,042.09	3,782.00	5,100	4,431.78	8,207.75	10,600	9,211.15	17,059.25
2,400	2,085.54	3,862.47	5,200	4,518.68	8,368.69	10,800	9,384.94	17,381.13
2,450	2,128.99	3,942.94	5,300	4,605.57	8,529.63	11,000	9,558.74	17,703.00
2,500	2,172.44	4,023.41	5,400	4,692.47	8,690.56	11,200	9,732.53	18,024.87
2,550	2,215.89	4,103.88	5,500	4,779.37	8,851.50	11,400	9,906.33	18,346.74
2,600	2,259.34	4,184.35	5,600	4,866.27	9,012.44	11,600	10,080.12	18,668.62
2,650	2,302.79	4,264.81	5,700	4,953.16	9,173.37	11,800	10,253.92	18,990.49
2,700	2,346.24	4,345.28	5,800	5,040.06	9,334.31	12,000	10,427.71	19,312.36

DISTANCE CONVERSION FACTORS

STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS
12,500	10,862.20	20,117.04	28,000	24,331.33	45,062.18	60,000	52,138.57	96,561.81
13,000	11,296.69	20,921.73	29,000	25,200.31	46,671.54	62,000	53,876.53	99,780.54
13,500	11,731.18	21,726.41	30,000	26,069.29	48,280.91	64,000	55,614.48	102,999.27
14,000	12,165.67	22,531.09	31,000	26,938.26	49,890.27	66,000	57,352.43	106,218.00
14,500	12,600.16	23,335.77	32,000	27,807.24	51,499.63	68,000	59,090.38	109,436.72
15,000	13,034.64	24,140.45	33,000	28,676.22	53,109.00	70,000	60,828.34	112,655.45
15,500	13,469.13	24,945.14	34,000	29,545.19	54,718.36	72,000	62,566.29	115,874.18
16,000	13,903.62	25,749.82	35,000	30,414.17	56,327.72	74,000	64,304.24	119,092.90
16,500	14,338.11	26,554.50	36,000	31,283.14	57,937.09	76,000	66,042.19	122,311.63
17,000	14,772.60	27,359.18	37,000	32,152.12	59,546.45	78,000	67,780.15	125,530.36
17,500	15,207.08	28,163.86	38,000	33,021.10	61,155.82	80,000	69,518.10	128,749.09
18,000	15,641.57	28,968.54	39,000	33,890.07	62,765.18	82,000	71,256.05	131,967.81
18,500	16,076.06	29,773.23	40,000	34,759.05	64,374.54	84,000	72,994.00	135,186.54
19,000	16,510.55	30,577.91	41,000	35,628.03	65,983.91	86,000	74,731.96	138,405.27
19,500	16,945.04	31,382.59	42,000	36,497.00	67,593.27	88,000	76,469.91	141,623.99
20,000	17,379.52	32,187.27	43,000	37,365.98	69,202.63	90,000	78,207.86	144,842.72
20,500	17,814.01	32,991.95	44,000	38,234.95	70,812.00	92,000	79,945.81	148,061.45
21,000	18,248.50	33,796.63	45,000	39,103.93	72,421.36	94,000	81,683.77	151,280.18
21,500	18,682.99	34,601.32	46,000	39,972.91	74,030.72	96,000	83,421.72	154,498.90
22,000	19,117.48	35,406.00	47,000	40,841.88	75,640.09	98,000	85,159.67	157,717.63
22,500	19,551.97	36,210.68	48,000	41,710.86	77,249.45	100,000	86,897.62	160,936.36
23,000	19,986.45	37,015.36	49,000	42,579.84	78,858.81	102,000	88,635.58	164,155.08
23,500	20,420.94	37,820.04	50,000	43,448.81	80,468.18	104,000	90,373.53	167,373.81
24,000	20,855.43	38,624.73	51,000	44,317.79	82,077.54	106,000	92,111.48	170,592.54
24,500	21,289.92	39,429.41	52,000	45,186.76	83,686.91	108,000	93,849.43	173,811.27
25,000	21,724.41	40,234.09	53,000	46,055.74	85,296.27	110,000	95,587.39	177,029.99
25,500	22,158.89	41,038.77	54,000	46,924.72	86,905.63	112,000	97,325.34	180,248.72
26,000	22,593.38	41,843.45	55,000	47,793.69	88,515.00	114,000	99,063.29	183,467.45
26,500	23,027.87	42,648.13	56,000	48,662.67	90,124.36	116,000	100,801.24	186,686.17
27,000	23,462.36	43,452.82	57,000	49,531.65	91,733.72	118,000	102,539.20	189,904.90
27,500	23,896.85	44,257.50	58,000	50,400.62	93,343.09	120,000	104,277.15	193,123.63

Chapter 9

U.S. SPACE LAUNCH SYSTEMS

Space systems can be divided into two categories: the launch vehicle and the payload. The launch vehicle, commonly called the booster, propels the spacecraft and its associated payload into space. Typically for military missions, a specific payload is always flown on a specific booster. For example, the Global Positioning System (GPS) satellites are always launched on a Delta II launch vehicle. The same is true for most of our military payloads.

US SPACE LAUNCH SYSTEM DEVELOPMENT

Legacy Boosters

Delta

Delta rockets are a family of medium lift class vehicles by which a variety of satellites have been launched as part of U.S. and international space programs. It was originally designed as an interim launch vehicle consisting of a Thor Intermediate Range Ballistic Missile (IRBM) first stage and Vanguard second and third stages. Continued improvements allow the Delta to inject *over* 4,000 pounds into a geosynchronous transfer orbit (GTO).

The National Aeronautics and Space Administration (NASA) placed the original contract with the Douglas Aircraft Company in April 1959. The early three-stage vehicle had a length of 85.4 feet, a first stage diameter of eight feet and a lift-off weight of 113,500 pounds. The modified Thor first stage had a thrust of about 170,000 pounds. On 13 May 1960, the first Delta failed to achieve orbit, but subsequent vehicles proved to be highly reliable.

Built by McDonnell Douglas (which merged with Boeing in August 1997), The Delta II entered the Air Force inventory in February 1988. The vehicle was developed after the Air Force decided to return to a mixed fleet of expendable launch vehicles following the Challenger disaster and other launch failures.

The first Delta II was successfully launched on 14 February 1989. The Delta II 6925 carried nine GPS satellites into orbit. The Delta II model 7925, the current version of this venerable launch vehicle, boosted the remainder of the original GPS constellation and is currently used to launch the new Block 2R version of GPS.

The Delta II's first stage is 12 feet longer than previous Deltas, bringing the total vehicle height to 130.6 feet. The payload fairing (shroud covering the third stage and the satellite) was widened from eight to 9.5 feet to hold the GPS satellite. The nine solid-rocket motors (SRM) that ring the first stage contain a more powerful propellant mixture than previously used.

Delta 7925 began boosting GPS satellites in November 1990. The Delta 7925 added new solid rocket motors with cases made of a composite material called graphite-epoxy. The motor cases built by Hercules Aerospace are lighter, but as strong as the steel cases they replaced. The new motors are six feet longer and provide much greater thrust. The main-engine nozzle on the first stage was also enlarged to give a greater expansion ratio for improved performance.

The Delta program has had a history of successful domestic/foreign military and commercial launches. The Delta has accomplished many firsts over its lifetime: it was the first vehicle to launch an international satellite (Telstar I in 1962); the first geosynchronous orbiting satellite (Syncom II in 1963) and the first commercial communication satellite (COMSAT I in 1965).

Atlas

The Atlas (**Fig. 9-1**) was produced in the 1950s as the first U.S. intercontinental ballistic missile to counter the threat posed by the Soviet development of large ballistic missiles. An Atlas booster carried U.S. astronaut John Glenn into orbit under the first U.S. manned program, Project Mercury.

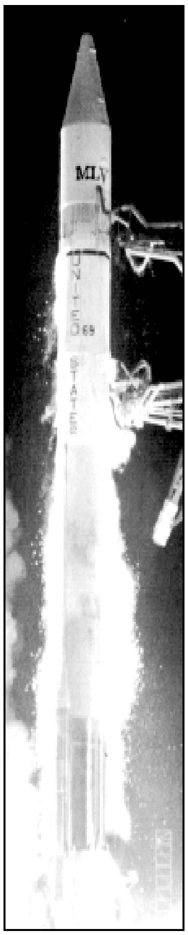


Fig. 9-1. ATLAS I

Its design profited from the thermonuclear break-through of 1954, which led to warheads of lighter weight. Atlas rockets also played a prominent role in the U.S. space program. The Atlas ICBM stood 82.5 feet high and had a diameter of 10 feet. The lift-off weight was about 266,000 pounds, with a range exceeding 9,000 miles.

Attached to the base of the Atlas structure was a gimbal-mounted Rocket-dyne LR-105 engine of 57,000 lb thrust, which operated together with two 1,000 lb thrust swiveling motors used for roll control.

Two Rocketdyne LR-89 boost engines burned at takeoff with the central sustainer. Each of these 165,000 lb-thrust engines operated for about 145 seconds before separating (half-stage). The central Atlas engine continued to burn for a total of about 270 seconds. All the engines drew their liquid oxygen-kerosene (RP-1) propellants from common tanks in the sustainer. Guidance depended on an inertial system that deflected the main engines in conjunction with the two roll jets.

The first Atlas launches were at Cape Canaveral in 1957, but only the third launch on 2 August 1958 was a complete success, traveling about 2,500 miles downrange. The operational Atlas D was flight-tested from the Pacific Test Range in California, between April and August of 1959. Improved versions, Atlas E and F, were test launched in 1960 and 1961, respectively. Some operational missiles were contained in coffin-like shelters (Atlas E) from which they were raised to a vertical position for launch. The increasing vulnerability of launch sites to Soviet ICBMs led to the construction of an underground silo in which the Atlas F was fueled, serviced and elevated to the surface for launching.

In its role as a space launch vehicle, systems are modified for specific space missions. Current Atlas II boosters, provide a medium lift capability for the Fleet Satellite Communications Systems (FLTSATCOM) and the Defense Satellite Communications System (DSCS). The booster generates approximately 340,000 pounds of thrust at liftoff and can place payloads of up to 1,750 pounds into polar orbit. Atlas space launch vehicles were used in all three unmanned lunar exploration programs. Atlas Centaur vehicles also launched Mariner and Pioneer planetary probes.

The Atlas booster has been in use for more than 30 years and remains a key part of the U.S. space program. The first space launch on an Atlas E was in 1974 and the last launch of the "E" series was in March 1995. The E series had been used to launch the military's Defense Meteorological Satellite Program (DMSP) satellites.

In May 1988, the Air Force chose General Dynamics to develop the Atlas II vehicle, primarily to launch DSCS payloads. This series uses an improved Centaur upper stage, the world's first high-energy propellant stage, to increase its payload capability. Atlas II also has lower-cost electronics, an improved flight computer and longer propellant tanks than Atlas I, which was developed for commercial payloads due to the lull of launch activity caused by several launch failures in the late 1980s. It was used throughout the 1990's primarily for commercial comsats.

Atlas II provides higher performance than the earlier Atlas I by using engines with greater thrust and longer fuel tanks for both stages. The total thrust capability of the Atlas II of approximately 490,000 pounds enables the booster to lift payloads of about 6,100 pounds into geo-synchronous orbit.

On 15 December 1993, the first Atlas IIAS was launched. The rocket can carry 8,000 pounds to a geo-synchronous transfer orbit and up to 18,000 pounds to a low earth orbit. The vehicle uses four Castor 4A solid strap-ons, is 156 feet tall and weighs 524,789 pounds at lift off. Only two of the strap-ons are used at launch. The other two are air-starts about one minute after launch. The launch of the Atlas IIAS completes the development of the original Atlas family.

The division of General Dynamics that builds the Atlas was acquired by Martin Marietta in 1994. They, in turn, merged with Lockheed in 1996 to form the Lockheed-Martin conglomerate.

As of mid-1999, the radically new Atlas III was about to make its inaugural flight. Due to numerous delays stemming from a problem with the upper stage motor, The Atlas III was finally launched on 24 May 1999, flawlessly boosting an Eutelsat communications satellite to geosynchronous orbit. The new model use a Russian designed RD-180 engine with two thrust chambers rather than the traditional one sustainer/two booster configuration of the original Atlases. Engines made by Pratt & Whitney under license will be used for US government launches (by US law) but Russian manufactured engines can be used for commercial payloads. A versatile and upgraded version of the Atlas III dubbed the Atlas V is Lockheed Martin's entry into the US Air Force Evolved Expendable Launch Vehicle (EELV) program (described later).

Titan II

Deployed as an ICBM from 1963 until 1987, the Titan II (**Fig. 9-2**) is not new to the space launch role. In 1965, modified Titan IIs began supporting NASA's manned Gemini and other unmanned space flights. Fifteen of the 50 existing Titan II ICBMs were refurbished and modified to support future launches.

The two-stage Titan II ICBM stood 103 feet tall with a diameter of 10 feet, and a lift-off weight of about 330,000 pounds. Operationally, the single reentry vehicle usually carried a thermonuclear warhead of five to 10 megatons with a top range of 9,300 miles. The Titan II was in service between 1963 and 1987, with 54 operational missiles. The force comprised three wings of 18 missiles each stored in underground silos at Davis-Mothan AFB, Arizona, McConnell AFB, Kansas and Little Rock AFB, Arkansas.

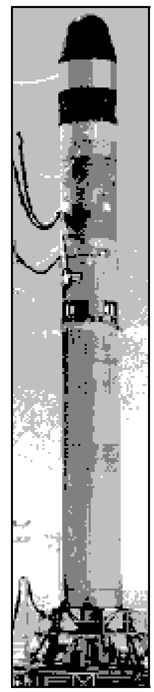


Fig. 9-2. Titan II

Each of the two first-stage Titan II engines develops a thrust of 215,000 pounds. The single second-stage engine develops 100,000 pounds of thrust. Both stages use storable nitrogen tetroxide and aerozine-50 propellants. An inertial system provides guidance commands to the engines. The engines are gimbal-mounted for thrust vector control.

Modified Titan IIs launched Gemini Program astronauts into orbit in 1965 and 1966. Other modified Titans were used to launch Earth satellites and space probes. Heavy payloads were launched by the Titan IIID, which consisted of the two Titan core stages and two strap-on solid propellant boosters. The Titan IIIC consisted of the Titan II central core, a restartable trans-stage with a thrust exceeding 16,000 pounds and two strap-on boosters. The Titan IIIE, which launched two Viking spacecraft to Mars and two

Voyager probes to Jupiter, Saturn, Uranus and Neptune, combined the technology of Titan IIIC with the high-performance Centaur stage. The process of adding larger solid rocket motors (SRMs) to the Titan eventually led to the development of the Titan IV.

Titan IV

Previously known as the Titan 34D-7, Titan IV is the newest and largest expendable booster. The first and second stages of the Titan 34D were stretched and one and one-half segments added to the SRMs. The 16.7-foot-wide payload fairing encloses both the satellite and upper stage. These improvements allow the Titan IV to carry payloads of up to 49,000 lbs to LEO, almost equivalent to the space shuttle's capacity. As the military's heavy lift class booster, it normally launches large payloads weighing up to 12,700 lbs into geo-stationary orbits or up to 38,000 lbs into low earth polar orbits.

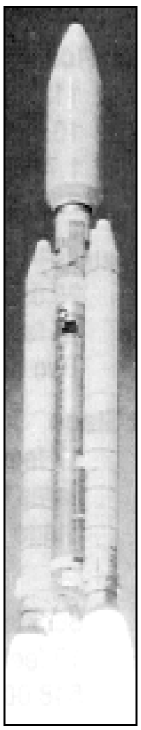


Fig. 9-3. Titan IVB

The flexible vehicle can be launched with one or two optional upper stages for greater and varied carrying capability. In addition, a solid rocket motor upgrade (SRMU) completed testing in 1994 giving the Titan IVB model 25 percent greater lift capability. The first launch using the SRMU occurred successfully in February 1997. The IVB (**Fig. 9-3**) model will the standard U.S. heavy lift vehicle into the next century.

Newer Boosters

Pegasus

Pegasus (**Fig. 9-4**) was developed privately by Orbital Sciences Corporation (OSC). It was first launched into orbit on 5 April 1990 from a B-52 aircraft over the Pacific Ocean.

The triangular-winged rocket is set free at an altitude of 40,000 feet and falls for five seconds. The first stage engine then ignites and flies like a plane during the first-stage burn. It then ascends like a missile in second and third-stage burns.

Pegasus is designed to carry light payloads weighing between 450 and 600 pounds into polar orbit or up to 900 pounds into equatorial orbit. A nominal altitude would be around 280 miles.

The vehicle has three graphite epoxy composite case Hercules motors, a fixed delta platform composite wing and an aft skirt assembly that includes three control fins, an avionics section and a payload faring. A fourth stage can be added to increase payload weight.

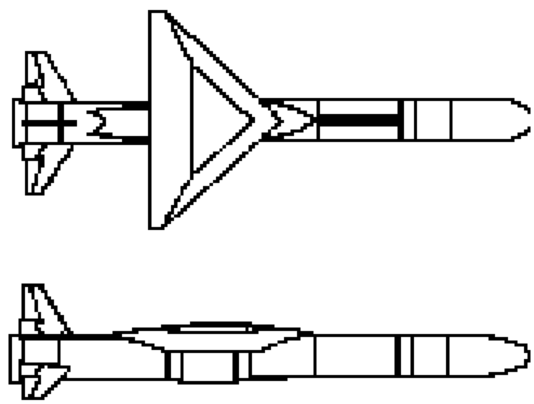


Fig. 9-4. Pegasus

Pegasus weighs about 41,000 pounds at launch. It is 50 feet long and 50 inches in diameter. The XL model uses stretched first and second stages, making it about five feet longer than the standard Pegasus. The first XL launch in July 1994 ended in failure. However, it since has flown successfully over 30 times.

Fig. 9-5. OSC's L-1011 Pegasus Launcher

A new launch platform for the Pegasus was also developed. A modified L-1011 (Fig. 9-5), purchased from Air Canada, debuted in mid-1994.

Taurus

Taurus is being developed by OSC as a four-stage, inertial-guided, solid- propellant launch vehicle. Its configuration is derived from the Pegasus and adds a Peacekeeper (now Castor 120) first stage. The Defense Advanced Research Projects Agency (DARPA) signed a contract with OSC in July 1989 for the initial development of the Taurus.

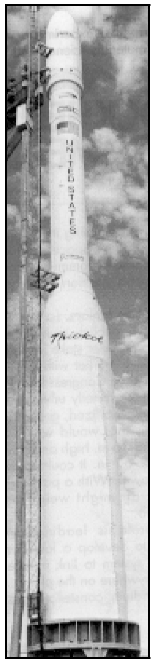


Fig. 9-6. Taurus

The overall length of Taurus is 90 feet and weighs 150,000 pounds at launch. Its maximum diameter (first stage) is 92 inches. The vehicle, shown in **Figure 9-6**, is designed to carry 3,000 pounds into a low polar orbit, up to 3,700 pounds for a due East launch, and up to 950 lbs to geosynchronous transfer orbit .

The first Taurus launch occurred at Vandenberg AFB, California on 13 March 1994. Taurus can be launched from both the Eastern and Western Ranges and has a mobile capability. It is designed to respond rapidly to launch needs and can be ready for launch within eight days. The launch site is a concrete pad with a slim gantry based on its design to be a simple "mobile" launch platform.

Athena I and II

Lockheed announced its new series of expendable launch vehicles in May 1993. First known as the Lockheed Launch Vehicle (LLV) then called the Lockheed-Martin Launch Vehicle (LMLV), this family of rockets are designed to carry light to medium sized payloads to low Earth orbit.

The LMLV has three primary configurations based on the integration of two types of solid rocket motors, Thiokol Corporation's Castor 120 and United Technologies' Orbus 21D.

Fig. 9-7. ATHENA

The smallest of the three rocket versions, Athena 1 (**Fig. 9-7)** can carry a payload of up to 1,750 pounds to LEO. The first launch of this version was from Vandenberg in August 1995 and ended in failure. A launch of NASA's Lewis scientific satellite in 1997 was successful. Launches are also possible from Cape Canaveral.

The Athena II uses Castor 120 booster for both first and second stages and stands 100 feet tall. When additional performance is needed, the rocket can be configured inot the third version by fitting it with Thiokol's Castor-4 solid rocket strap-on boosters

Originally, Lockheed-Martin planned on up to 10 launches/year, but the actual launch rate has been much lower, presumably due to a lower than expected demand for LEO satellite launch services. The advertised launch cost is $14 million, making this booster something of a bargain. The last Athena launch was in 2001 from the Kodiak launch site in Alaska.

Delta III

A new intermediate-class launcher, the Delta III was developed without government support by Boeing Corporation for a commercial Heavy-medium lift payloads. Hughes Aircraft Company (now part of Boeing), a commercial satellite builder, bought ten Delta III launches in 1995 to give Boeing a customer base for the rocket and bring down the cost of launch.

Fig. 9-8. Delta III Launch

Delta III will boost 8,400 pounds to GTO, more than twice what the Delta II can lift. The rocket (**Fig. 9-8**) will have a new cryogenic upper stage and larger fairing.

The first two launches ended in failure. The first was auto-destructed when the vehicle lost control and the second was due to a failure in the second stage. A third attempt, this time a demonstration launch with a dummy payload aboard was successfully launched on 23 August 2000. The Delta III is being phased out in favor of the Delta IV, the Boeing entry into the USAF's EELV competition.

Delta MED-LITE Services Program

Boeing-Orbital Sciences Corporation (OSC) teaming arrangement is providing with NASA for the Medium Light Expendable Launch Vehicle Services program to fill the gap between the small launch vehicle market and the medium-class market. Med-Lite's objective is to support the Mars Surveyor and Discovery programs. Under this program, NASA picked various versions of Boeing's Delta II for 5 to 14 launches of small scientific payloads beginning in 1998.

OSC's Taurus is also included in the MED-LITE program and is launching smaller payloads. A modified Delta II with only three or four strap-ons will handle the heavier payloads in this class.

Evolved Expendable Launch Vehicles

Typical launch costs hover around $10,000 per pound of payload placed in orbit. Recognizing the need for a new, less expensive generation of expendable launchers, the Air Force began its Evolved Expendable Launch Vehicle program in 1995. The goal of the program was to provide more affordable and reliable access to space, saving at least 25 percent and as much as 50 percent over the cost of the "heritage" systems of Delta, Atlas and Titan rockets. In essence, the Air Force is buying launch services, not launch vehicles.

Two competing booster designs emerged from the program, but both will be used rather than allowing a potential single point of failure. Boeing's design is called the Delta IV, and Lockheed Martin's is the Atlas V. With the new standardized launch vehicle families, a single launch pad design, design reliability of 98 percent and completely standardized set up and launch procedures and equipment, the Air Force hopes to realize significant savings over heritage systems. The projected savings through the expected end of the program in 2020 could amount to $5 to 10 billion. The launch services contracted so far cover the period from 2002 to 2006 and a total of 28 launches, with Boeing receiving a contract for 22 launches for $1.7 billion, while Lockheed Martin's contract is for six launches for $500 million. A recent dip in demand for satellite launches, however, is keeping the unit prices on the EELVs higher than originally projected since fewer are being produced.

Delta IV

Boeing's version of the EELV is the Delta IV. Its first launch was on November 20, 2002, when it lofted a European EUTELSAT commercial communications satellite into a geosynchronous transfer orbit. The Delta IV design is based on a modular common booster core (**Fig. 9-9**)-using the liquid hydrogen-liquid oxygen RS-68 engine, which produces 650,000 pounds of thrust. A single common booster core is used for medium lift applications, but can be configured with up to four strap-on solid rocket booster to lift from 9,200 to 14,500 lbs to a geosynchronous transfer orbit (GTO). The Delta IV launches from pad 37 at Cape Canaveral Air Force Station. The booster with its payload fairing stands from 200-225 feet tall. For heavy lift applications, two full-sized common booster cores can be strapped onto a center common booster core to allow up to 29,000 lbs to GTO or 45,200 lbs to LEO.

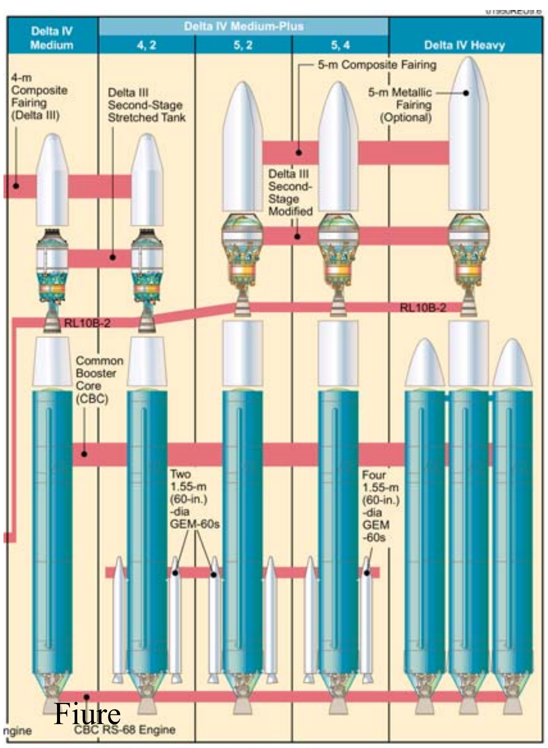


Figure 9-9
Delta IV Configurations

Atlas V

Lockheed Martin's entry into the Air Force's EELV competition is the Atlas V (Fig. 9-10). The decision by the USAF to retain two EELV lines resulted in some launches for the Atlas V but not as many as the Delta IV model. The first Atlas V launch was on August 21, 2002 when it successfully boosted a new European commercial communications satellite into GTO. It will launch medium/heavy to heavy payloads into earth orbit from pad 41 at Cape Canaveral Air Force Station. A planned pad on the west coast is on currently on hold as it may not be immediately needed.

Figure 9-10
Atlas V

Like the Atlas III, the Atlas V core uses the Russian RD-180 engine and will be augmented for heavy payloads with two strap-on boosters. The RD-180 engine is rated at 861,000 lbs of thrust at liftoff. The Atlas V can lift 20,000 lb to LEO or 10,900 lb to GTO. .The booster stands 191 feet tall and is 12.5 feet in diameter.

Manned Boosters

Space Transportation System

The Space Transportation System (STS), also known as the Space Shuttle (**Fig. 9-11**) is a reusable spacecraft designed to be launched into orbit by rockets and then to return to the Earth's surface by gliding down and landing on a runway. The Shuttle was selected in the early 1970s as the principal space launcher and carrier vehicle to be developed by NASA. It was planned as a replacement for the more expensive, expendable booster rockets used since the late 1950s for launching major commercial and governmental satellites. Together with launch facilities, mission control and supporting centers, and a tracking and data relay satellite system, it would complete NASA's new Space Transportation System.

Although the shuttle launched a few military payloads in its early days, such as the Defense Support Program satellite, the USAF abandoned it as a launch vehicle after the Challenger disaster. However, it could conceivably be used for military missions again if the decision were made to do so.

After various delays, the program commenced in the early 1980s. Despite several problems, the craft demonstrated its versatility in a series of missions until the fatal disaster during the launch of the Challenger on January 28, 1986 forced a long delay. The program resumed in late 1988 and the modifications to the shuttle affected neither the basic design of the craft nor its overall dimensions.

The three main components of the Space Shuttle are the orbiter, the external tank and the solid rocket boosters. The Shuttle weighs 4.5 million pounds at launch and stands 184.2 feet tall and can carry up to 55,000 pounds of cargo to LEO on one mission.

The orbiter, 78 feet across the wing tips and 122.2 feet long, is the portion resembling a delta-winged jet fighter. It is a rocket stage during launch, a spaceship in orbit and a hypersonic glider on reentry and landing. A three-deck crew compartment and an attitude thruster module are in the nose, the mid-body is the cargo hold or payload bay (15 ft wide and 60 ft long) and the tail holds the three main engines plus maneuvering engine pods.

Each engine, burning hydrogen and oxygen, produces up to 394,000 pounds of thrust. The external tank, actually an oxygen tank and a hydrogen tank joined by a load-bearing intertank, is the structural backbone of the Shuttle. Measuring 27.56 feet wide and 154.2 feet tall, it carries 1,520,000 pounds of liquefied propellants for the main engines. The shuttle's main engines produce over 27 million horsepower and empties the external tank in about eight and one-half minutes.

Two solid rocket boosters, each slightly over 12 feet wide and 149 feet tall, provide the Shuttle with a lift to the upper atmosphere so the main engines can work more efficiently. Each produces an average thrust of 3.3 million pounds. The propellant in the solid rocket motors consists of ammonium perchlorate, aluminum powder, iron oxide and a binding agent. Total thrust of the vehicle at liftoff (two solid motors and three liquid engines) is 7.78 million pounds.

The Shuttle's main engines are ignited, the booster rockets are ignited about six seconds before lift-off at T-6 seconds and the hold-down bolts are released at T-0. The Shuttle lifts off vertically about 2.5 seconds later with all five engines operating. As soon as it clears the gantry, it rolls and pitches to fly with the orbiter upside down, as the craft's design puts the thrust vector off-center.

At T+2 minutes 12 seconds, the boosters burn out and are jettisoned from the external tank at an altitude of approximately 26-27 statute miles. The boosters then parachute into the sea for recovery, refurbishing and reuse. Meanwhile, the Shuttle continues on under the power of the main engines. Just short of orbital velocity, the engines are shut down (T+8 min 32 sec) and the tank is jettisoned (T+8 min 50 sec). The tank burns up as it reenters the atmosphere.

Once the vehicle is in space, it maneuvers using two different systems, the Orbital Maneuvering System (OMS) and the Reaction Control System (RSC). The orbiter's own OMS engines act as the third stage that puts the craft into orbit.

The OMS uses two bipropellant, 6,000 pound thrust rocket engines mounted in pods on the aft end of the orbiter fuselage. The hypergolic propellants consist of monomethylhydrazine and nitrogen tetroxide, with about 21,600 pounds of propellant stored within the orbiter in titanium tanks. The OMS is used for orbit insertion or transfer, orbit circulation, rendezvous and deorbit.

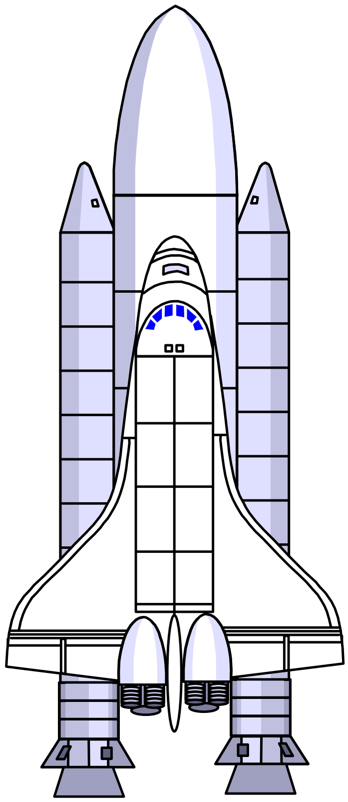


Fig. 9-11. Space Transportation System (STS)

The RCS uses 38 bi-propellant liquid rocket engines and six bipropellant liquid rocket vernier thrusters. Fourteen of the engines are on the orbiter's nose, together with two verniers. The remaining engines and verniers are split equally between the two OMS pods of the aft end of the orbiter fuselage. The RCS used the same type propellants as the OMS, but carries 2,413 pounds of fuel in separate tanks. There is a system to transfer fuel to and from the RCS to the OMS. The RCS is used to maneuver in space during rendezvous and deorbit maneuvers.

The vehicle is normally manned by a crew of four (minimum two, maximum eight except as noted): the commander, pilot, mission specialist and payload specialist. In an emergency ten people can fit in the orbiter. The interior of the orbiter is pressurized, allowing the astronauts to operate in a short-sleeve environment without spacesuits. Passengers can fly on the shuttle without extensive astronaut training because of the relatively light 3G acceleration during launch and the pressurized cabin. The self-contained crew module is supported within the fuselage by four attachment points, the entire module being welded to create the pressure tight vessel. The module has a fuselage side hatch for access, a hatch into the airlock from the mid-section and a hatch from the airlock into the payload bay. As previously mentioned, the crew module is divided into three levels. The upper flight deck has seats for the mission and payload specialists, the commander, and the pilot. There are dual flight controls and the controls for the Remote Manipulator System (RMS) which extracts payloads from the Shuttle's cargo bay. The mid-level deck has additional seating, a galley, electronics bays and crew sleeping and comfort facilities. The lowest level houses environmental equipment and storage.

At the end of the orbital mission, the orbiter is protected from the heat of reentry by heat-resistant ceramic tiles. As dynamic pressure from the air increases, control of the vehicle switches from the RCS to aerodynamic surfaces and the orbiter glides to a landing.

Proposed Boosters

Operationally Responsive Spacelift Initiative

The Air Force began the Operationally Responsive Spacelift initiative in 2003. The goal of the program is to pave the way for reusable rockets that could be launched at a low cost on short notice. As part of a one year analysis of alternatives study which began March 1, 2003, teams are investigating a variety of space planes, air-launched boosters, and fully reusable as well as expendable or partly-reusable spacelifters. The study is closely linked to NASA's Next Generation Launch Technology program, the follow-on to their recently scaled-back Space Launch Initiative. A multi-staged system could be in place by 2014, depending on funding. Also, a low-cost expendable upper stage booster and an orbital transfer vehicle capable of handling spacecraft servicing would be developed. The goal is to have a system that can launch within hours to days as opposed the weeks to months of preparation required by current boosters. Payloads could include the Common Aero Vehicle (CAV, an reentry vehicle which can deliver a variety of munitions to a ground target) or microsatellites.

Scorpius-Sprite

One possible contender for an Operationally Responsive Spacelift job is Micorcosm's Sprite Mini-Lift Launch vehicle **(Fig 9-12)**. Research for the ongoing Scorpius-Sprite program is funded by the Air Force and the Missile Defense Agency, and NASA as well as Microcosm's own research and development funds.

Scorpius, the sub-orbital research vehicle, has already flown and will be scaled up to become the fully orbital Sprite. The Sprite will be 53 feet tall and consist of six 42-inch diameter pods around a central core giving it an an overall diameter of 11.2 feet. It will be a three stage launcher with six 20,000 lb thrust engines followed by a second stage single 20,000 lb engine. The third stage will produce 2,500 lbs of thrust and place a 700 lb payload in a 100 NM low Earth orbit for $1.8 million. A primary goal is to simplify launch operations so that liftoff occurs only 8 hours after the vehicle is brought to the pad.

Figure 9-12
Sprite

RASCAL

The Responsive Access, Small Cargo, Affordable Launch (RASCAL) program will design and develop a low cost orbital insertion capability for dedicated micro-size satellite payloads. The concept is to develop a responsive, routine, small payload delivery system capable of providing flexible access to space using a combination of reusable and low cost expendable vehicle elements.

Specifically, the RASCAL system will be comprised of a reusable airplane-like first stage vehicle called the reusable launch vehicle and a second stage expendable rocket vehicle. The RASCAL demonstration objectives are to place satellites and commodity payloads, between 110 and 280 lbs (50 and 130 kilograms) in weight, into low earth orbit at any time, any inclination with launch efficiency of $9,100 per pound ($20,000 per kilogram) or less. While the cost goal is commensurate with current large payload launch systems, the operational system, through production economies of scale, will be more than a factor of three less than current capabilities for the dedicated micro payload size. This capability will enable cost effective use of on-orbit replacement and re-supply and provide a means for rapid launch of orbital assets for changing national security needs.

With recent advances in design tools and simulations, this program will prudently reduce design margins and trade-off system reliability to maximize cost effectiveness. This program will also leverage advancements in autonomous range safety, first-stage guidance and predictive vehicle health diagnosis, management and reporting to lower the recurring costs of space launch.

FALCON

The FALCON program objectives are to develop and demonstrate technologies that will enable both near-term and far-term capability to execute time-critical, global reach missions. Near-term capability will be accomplished via development of a rocket boosted, expendable munitions delivery system that delivers its payload to the target by executing unpowered boost-glide maneuvers at hypersonic speed. This concept called the Common Aero Vehicle (CAV) would be capable of delivering up to 1,000 pounds of munitions to a target 3,000 nautical miles downrange. An Operational Responsive Spacelift (ORS) booster vehicle will place CAV at the required altitude and velocity. The FALCON program will develop a low cost rocket booster to meet these requirements and demonstrate this capability in a series of flight tests culminating with the launch of an operable CAV-like payload. Far-term capability is envisioned to entail a reusable, hypersonic aircraft capable of delivering 12,000 pounds of payload to a target 9,000 nautical miles from CONUS in less than two hours. Many of the technologies required by CAV are also applicable to this vision vehicle concept such as high lift-to-drag technologies, high temperature materials, thermal protection systems, and periodic guidance, navigation, and control. Initiated under the Space Vehicle Technologies program, and leveraging technology developed under the Hypersonics program, FALCON will build on these technologies to address the implications of powered hypersonic flight and reusability required to enable this far-term capability. The FALCON program addresses many high priority mission areas and applications such as global presence, space control, and space lift.

CURRENT LAUNCH SYSTEM CHARACTERISTICS

Table 9-1. Delta II

Delta II

The Delta II is a two- or three-stage booster. Stages one and two use liquid propellant while stage three uses solid propellant. The booster is configured with nine solid rocket strap-ons surrounding the first stage. The current 7925 model uses lighter and longer strap-ons for increased impulse and greater payload capacity.

- **Delta II 7925**

Stage	Thrust (lbs)	Length (ft)
I	236,984	85.4
II (7925)	9,645	9.3
III (7925)	5,098	6.7

Total Length: 121 feet
Diameter: 8 ft
Fairing Diameters: 8, 9.5 or 10 ft
Payload: 4,120 lbs to GTO
6,985 lbs to polar
11,330 lbs to LEO

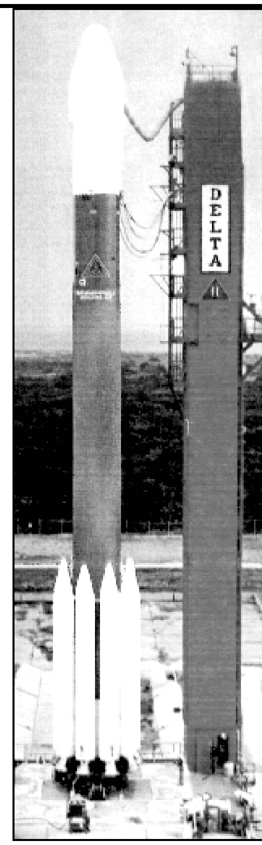
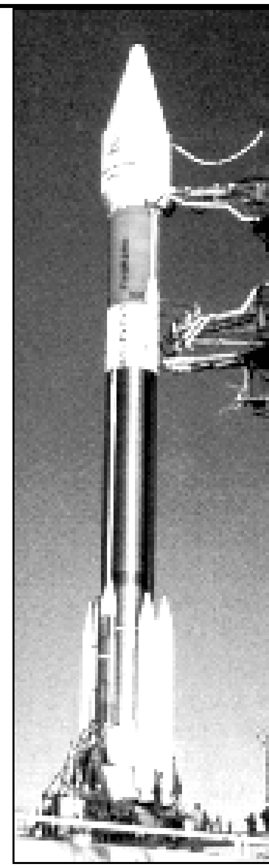


Table 9-2. Atlas II, IIAS, III

Atlas II, IIAS



The Atlas is a stage and one-half liquid propellant booster. It has continually been upgraded since its original late-1950's design as the nation's first ICBM. The Atlas is a medium/heavy lift booster used extensively by the commercial market and for USAF payloads such as the DSCS III satellites.

- **Atlas II**

Engine:	Thrust (lbs)
Booster:	206,950 each (2)
Sustainer:	60,474
Length:	149.6 ft
Diameter:	10 ft
Payload:	14,916 to LEO
	6,094 to GTO

- **Atlas IIAS**

Engine:	Thrust (lbs)
Booster:	207,110 each (2)
Sustainer:	60,525
Strap-ons:	97,500 each (4)
Length:	156 ft
Diameter:	10 ft
Payload:	18,000 to LEO
	8,000 to GTO

- **Atlas III**

Engine:	861,075 lbs thrust
Length:	173.2 ft
Diameter:	10 ft
Payload:	19,050 lb to LEO
	8,940 lb to GTO

Table 9-3. Titan II SLV

Titan II SLV

The Titan II SLV is a former ICBM modified to launch space payloads. Changes to the ICBM include payload interface modifications and the addition of an attitude control system. It is very capable of putting medium/heavy payloads into low earth orbit. It is primarily used by the USAF for launching DMSP satellites into low earth, sun synchronous orbits.

Stage	Thrust (lbs)	Length(ft)
I	430,000	70
II	100,040	40
Payload fairing:	N/A	20 - 25

Diameter: 10 ft
Payload: 6985 to LEO
2300 to GTO

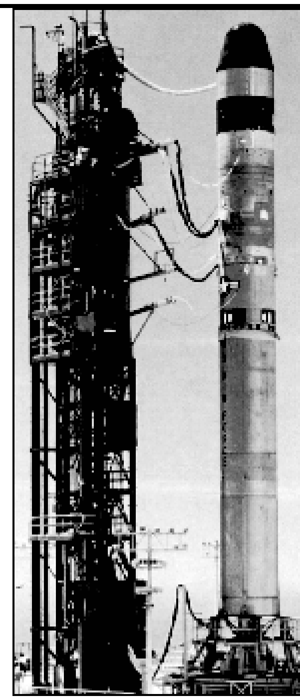


Table 9-4. Titan IVB

Titan IVB

The Titan IV is designed to place heavy payloads into orbit using the Centaur-G or Inertial Upper Stage (IUS) upper stage.

Stage	Thrust (lbs)	Length (ft)
I	551,200	86.5
II	106,150	32.6
SRM	1,600,000 ea. (2)	112.9
SRMU	1,700,000 ea. (2)	112.4
Payload fairing:	N/A	up to 84.0

- Diameter: 10 ft (payload - 16.7 ft)

Payload to GEO: 12,700 lbs

Payload to Polar: 38,000 lbs

Payload to LEO: 49,000 lbs

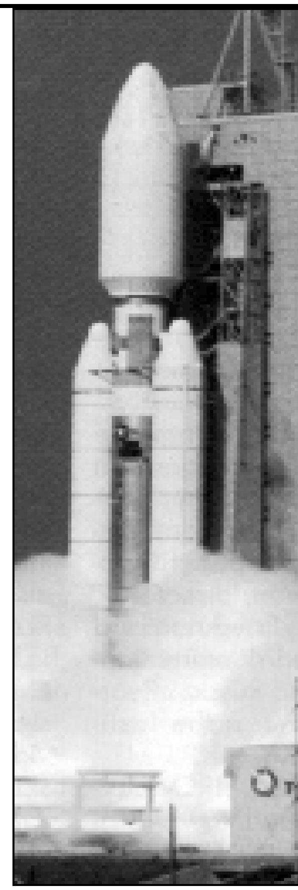


Table 9-5. STS

Space Shuttle	
The Space Shuttle is the only US manned space vehicle.	
	Thrust (lbs)
SRB's (ea)	3,300,000 lbs.
Orbiter (3ea)	393,800 lbs.
Orbiter Dimensions:	
Length: 122ft	
Wingspan: 78ft.	
Payload to GEO (lbs.):	
46-55,000 lbs. (28^o incl)	
32,500-40,900 lbs. (57^o incl)	

Table 9-6. Pegasus

Pegasus

The only air-launched space vehicle in the world. Primarily launches small experimental/scientific payload to LEO from 1B L-1011 carrier aircraft.

Pegasus XL:

Length: 55.18 ft.

Payload:

440 lbs. To GTO (w/fourth stage)
600 lbs. To 287 mi. polar
900 lbs. To 287 mi equatorial

Table 9-7. Delta IV

Background Information

First Launch: October 9, 2002

Launch Site: CCAFS, Space Launch Complex-37

Capability: Up to 45,200 lb to LEO; 29,100 lb to GTO

History: Delta IV developed as part of the USAF Evolved Expendable Launch Vehicle (EELV) program

Description·Five variants built around the Common Booster Core (CBC)

- Stage 1: The CBC sub-assembly includes and interstage, liquid oxygen tank, liquid hydrogen tank, engine section, and nose cones for the Delta IV-H. The three Delta IV-M+ configurations use either two or four Alliant graphite-epoxy motors attached to the CBC. Delta IV-H uses two additional CBCs as strap-on liquid rocket boosters. The CBC is powered by a newly developed Rocketdyne RS-68 engine which has a 21.5:1 expansion ratio and produces 650,000 lbs of thrust at sea level.
- Stage 2: There are two second-stage configurations. A 4-m version used on Delta IV-M and Delta IV-M+(4,2) and a 5-m version used on other Delta IV configurations. The second stage is powered by a Pratt & Whitney RL10B-2 cryogenic engine. The 4-m version produces thrust of 24,750 lbs, the 5-m produces thrust of 60,000 lbs.
- Payload fairings: 4-m and 5-m composite bisector fairings based on the Delta III fairings. 5-m trisector fairing which is a modified version of the Titan IV isogrid fairing.

Table 9-8. Atlas V

Atlas V

Background Information

First Launch: 20 Aug 02
Launch Site: LC-41, CCAFS
Capability:20,000 lb to LEO; 10,900 lb to GTO
Description·Two stage booster.

- Stage 1 utilizes one Russian designed RD-180 booster engine with two chambers burning LOX/RP-1 fed from stage 1 tanks, generating a total of 861,075 lb of thrust at sea level, 933,034 lbs of thrust in vacuum.
- RD-180 engine provides throttling capability (75% - 85% max) and gimbaled chambers for 3-axis control.
- Stage 2 (Centaur) has a one or dual engine version using Pratt & Whitney RL10A-4-2 turbopump-fed engines that burn LH2/LOX and produce 24,750 lb of thrust each.

Profile:

Length:	191.2 ft	Launch Weight:	733,304 lb
Diameter:	12.5 ft	Liftoff Thrust:	860,200 lb

Payload Fairing: 40 ft x 13.8 ft (Large); 43 x 13.8 ft (Extended)

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Chapter 10

SPACECRAFT DESIGN, STRUCTURE AND OPERATIONS

A typical spacecraft consists of a mission payload and the bus (or platform). The bus is made up of five supporting subsystems: structures, thermal control, electrical power, attitude control and telemetry, tracking and commanding (TT&C).

SPACECRAFT DESIGN PROCESS

The design and development of a spacecraft is an engineering process divided into identifiable phases. In the past, the spacecraft development process required several years to accomplish, especially if it was a government project. Recent advances in satellite manufacturing technology, coupled with the growth of commercial markets in satellite communications and imaging, have significantly shortened the process. This change is described by a former commander of U.S. Air Force Space Command:

> "…new commercial geosynchronous satellites are available 18 months after order—soon to be down to 12 months. For the small LEO systems, time from order to delivery is about three years...In contrast, the acquisition of national security systems runs 10 to 15 years... the same plant will build three hundred Teledesic satellites in three years and 15 Global Positioning System (GPS) satellites in seven years..."
>
> - General Thomas Moorman Jr., USAF, Ret. in *Air Power Journal*, Spring 1999

Regardless of how long it takes, spacecraft design and development typically occur in phases identified as: requirements definition, conceptual design, preliminary design, and detailed (or critical) design. These phases and their sequential relationships are shown in **Figure 10-1**.

Spacecraft development begins by defining needs or requirements the system is to satisfy. For example, the need to gather and store weather images and data. Or, take photographic images with less than 15 meter resolution and transmit the information in real time. The spacecraft mission will be a major determiner of the type orbit chosen for the space craft.

Next is the conceptual design phase, in which various system concepts which can satisfy the mission requirements are considered and subjected to analysis. The most proficient means to carry out the mission is selected and major risks, costs, and schedules are identified.

The preliminary design phase follows conceptual design, and may stretch over a couple of years **(Fig. 10-2)**. During this phase, variations of the concept chosen in the conceptual design phase are analyzed and refined. Subsystem and component level specifications are defined and major documents such as the interface control document are written. Anticipated performance of systems and subsystems is substantiated and, from the detailed specifications, a preliminary parts list is identified.

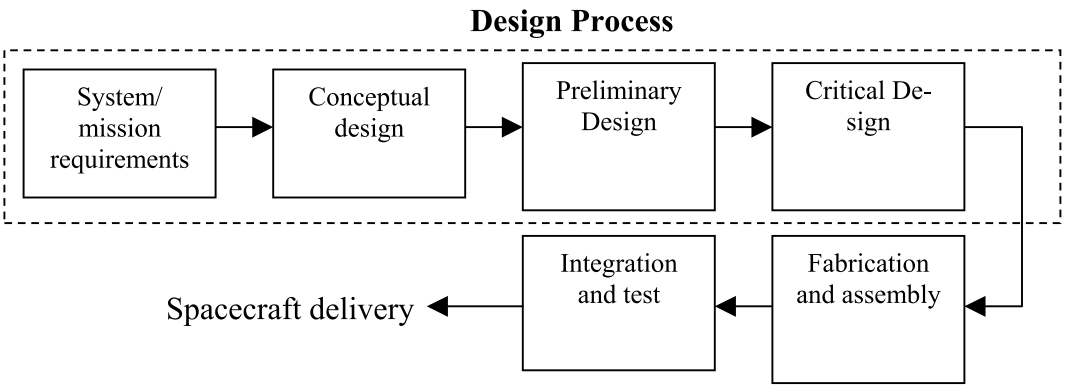


Fig. 10-1 Spacecraft design phases

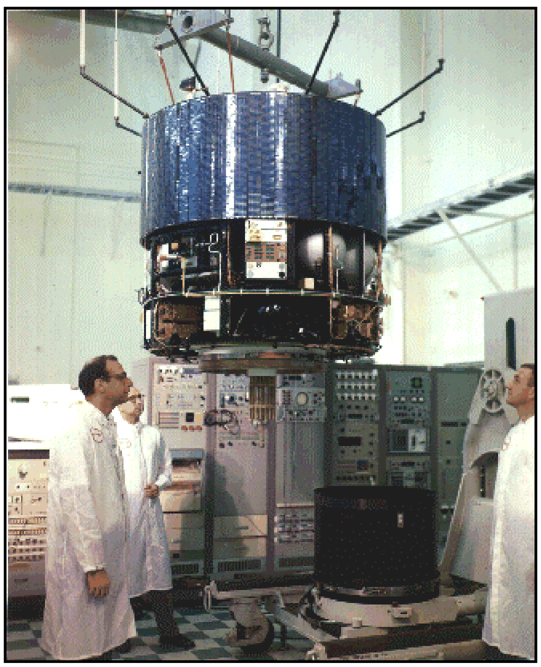


Fig. 10-2 Spacecraft in Preliminary Design

The final phase is the critical (or detailed) design phase which can take four to five years. It is within this phase that the specific aspects of structural design are identified, such as finalizing the thickness of structures and load paths. The spacecraft design must accommodate everything that fits into the structure, including equipment, crew, provisions and payload. Options for secondary structures (plumbing, wiring, etc.) are also analyzed and evaluated several times during the critical design phase. Design verification is an important part of this phase. Verification involves tests of electronic circuit models, software and engineering models. Design and performance margin estimates are refined and test and evaluation plans finalized.

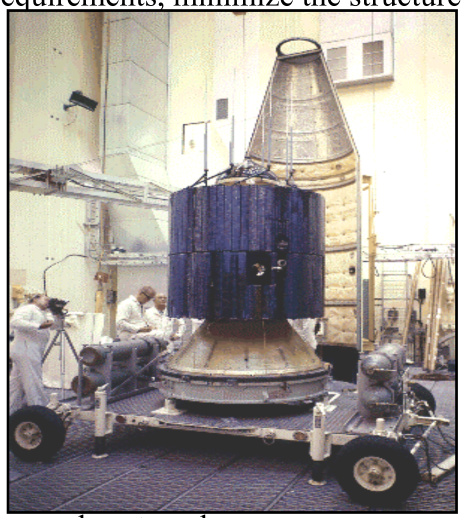
STRUCTURES SUBSYSTEM

The functions of the structural subsystem are to enclose, protect and support the other spacecraft subsystems and to provide a mechanical interface with the launch vehicle.

The enclose and protect functions are especially necessary during spacecraft assembly, handling and transportation from the manufacturing facility to the launch facility. Structural members provide the mating and attachment points for subsystem components such as batteries, propellant tanks, electronics modules and so on. The structure must also sustain the stresses and loads experienced during environmental testing, launch, perigee and apogee firings, and deployment of booms, solar arrays and antennas. Noises and vibrations can be especially severe as the spacecraft experiences high G forces during launch. Acoustic noise is the highest in the early stages of the launch and is transmitted from the rocket motors by the air through the fairings or housing and into the spacecraft. Steady loads are transmitted through the structure as the rockets accelerate the spacecraft to the high velocities required for injection into orbit.

A wide range of vibration frequencies is transmitted through the spacecraft supports from the rocket motors. The separation ring and other pyrotechnic devices send sudden shocks through the structure.

Upon reaching its final orbit position, the loads on the spacecraft are greatly reduced in the zero gravity environment, but the alignment requirements are more rigorous. The designer must satisfy all requirements, minimize the structure



mass and cost, and **Fig. 10-3 Satellite being fitted to rocket faring**

Still keep the probability of failure near zero.

Structure Types

There are two main types of satellite structures: open truss and body mounted. An open truss structure has a specific shape to it (see **Fig. 10-3**), usually a box or a cylinder.

Inside the body of the spacecraft is a honeycomb structure where the equipment boxes are attached. In a body mounted structure equipment is attached directly on primary equipment such as an antenna or apogee kick motor. These satellites do not have a specific shape to them. There are also combinations of these two structure types where part of the satellite would have a shape such as a box, with some equipment attached to the exterior.

Materials

When designing a component for structural use in a spacecraft, the engineer must at some point in the analysis, decide what materials to use (**Fig. 10-4**). Thousands of different materials are used in making a spacecraft. Many of them serve dual or

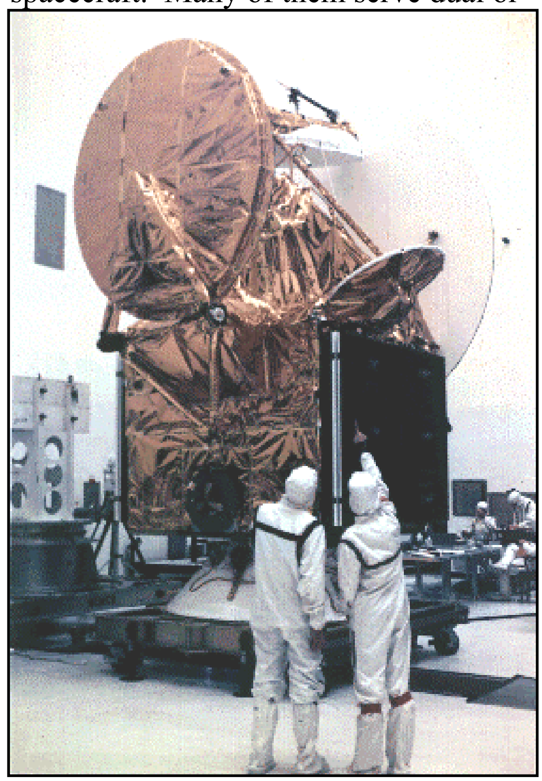


Fig. 10-4 Various materials evident in a spacecraft

complexity. For example, the frame of a spacecraft could be a heat sink and electrical ground as well as the main structure.

During its lifetime, the spacecraft will be subjected to severe conditions. These may include various mechanical loads, vibrations, thermal shocks, electrical charges, radiation, and a chemical and particulate environment that starts with the salt and sand spray at our launch sites.

The material selected must meet standards of yield, ultimate and fatigue strength, specific stiffness, hardness and toughness, ductility, thermal expansion, creep resistance and melting point. Other properties must also be examined, since structural materials often serve more than one role. Depending on the circumstances, electrical conductance may be a favorable attribute of a structural member. Thermal conductance and capacitance may also be desirable depending upon whether the structure is to insulate internal components or relieve thermal stresses by conducting thermal energy away from hot spots.

Finally, the availability, formability and ease with which parts can be machined out of a particular material will influence the selection process. Some are scarce and expensive. Others are extremely brittle or soft. Some are hard to cast, forge or to machine. Almost every material presents some type of fabrication problem.

Aluminum, magnesium, titanium and beryllium are the elements that make up the major lightweight alloys used in space vehicles. They are all much lighter than steel and are non-magnetic. Aluminum alloys are the most widely used structural materials. Their strength to weight ratio is equal to steel, which combined with its availability and ease of manufacture, makes them very desirable. Aluminum can be made into wire, thin sheets, cast into complex and thick parts, machined, welded, forged and stamped. Unfortunately, aluminum and its alloys are unable to withstand high temperatures. Prolonged exposure to temperatures above 400° F results in a loss of strength and creep can set in at lower temperatures.

Magnesium is lighter than aluminum, but not as strong. It is useful for lower strength, lightweight applications at temperatures up to 400° F. Fabrication is similar to that of aluminum in that parts can be made and joined together in much the same way. Corrosion in the presence of moisture is a problem with magnesium and its alloys; coatings and finishes are needed for protection.

Titanium can replace aluminum in higher temperature environments, as it has the ability to remain strong at temperatures up to 1,200° F. In situations where a structure must be lightweight and strong when subjected to 400 - 1,200° F, aluminum cannot be used. Unfortunately, titanium is not as light or durable as aluminum. It has a tendency to become brittle at low temperatures and when placed under repeated loads. It is also more difficult to weld.

Beryllium is used to make phenomenally light alloys. Its strength is close to that of steel and its density is comparable to aluminum. This makes for extremely stiff, lightweight structures. An added plus is its ability to retain its properties at temperatures up to 1,000° F.

Beryllium is more difficult to fabricate than aluminum and is susceptible to surface damage while it is being machined due to its brittle properties. An additional consideration is beryllium's toxicity. It presents a serious health hazard to unprotected workers. Finally, beryllium is more costly than many other metals.

Graphite, plastics, nylon and ceramics comprise the non-metallic materials used in spacecraft. Graphite is not usually thought of as a structural material. It is weak and brittle at room temperature, but is widely used as a thermal protection material. Since the strength of graphite improves with temperature up to about 4,500° F, it is very possible that vehicles which must enter Jupiter's atmosphere, or orbit very close to the Sun, may have some structural parts made out of graphite.

Plastic has many desirable qualities as a spacecraft component material. It is very inexpensive, very available and easy to fabricate into intricate shapes. It is also durable and is a good electrical and thermal insulator. For spacecraft interiors, where temperatures are relatively low, plastic may be a good replacement for light alloys.

Nylon has a unique advantage in that mechanisms made of it may not need lubrication. Nylon may be the optimal material for low power gear trains in space.

The general property of ceramics is that they are extremely weak in tension and are very brittle. They can, however, withstand very high temperatures, protecting themselves by gradual erosion. Hence, ceramics are useful in some radomes, jet vanes, leading edges and solid rocket nozzles.

In the future, aerospace fabrication will make greater use of composites. Composites are two or more materials manufactured together to form a single piece that can have almost any property an engineer specifies. Uni- or omni-directional strength, resistance to high temperatures and resistance to corrosives are a few of these properties. Examples of composites are: fiberglass and carbon epoxy, both structural materials; and carbon-composite, a thermal protection material used on leading edges of the space shuttle.

THERMAL CONTROL SUBSYSTEM

The spacecraft thermal environment is determined by the magnitude and distribution of radiation from the Sun and Earth. The purpose of the spacecraft thermal control subsystem is to control the temperature of individual components to ensure proper operation through the life of the mission. Some components are required to be maintained below a critical temperature, i.e. high temperature limits the reliability and lifetime of transistors due to increased electromigration effects. Optical sensors require temperature be maintained within a critical range to minimize lens distortion, and hydrazine propellant must be maintained above a critical temperature (10° C) or it will freeze.

The thermal control process has to meet the requirements of all subsystems. Balance between structural and thermal requirements is necessary to achieve the best spacecraft configuration to permit proper thermal balance.

The thermal control subsystem uses every practical means available to regulate the temperature on board a satellite. Selection of the proper thermal control system requires knowledge of mission requirements as well as the operational environment. Temperatures within space vehicles are affected by both internal and external heat sources.

Sources of Thermal Energy

The sources of heat energy in a spacecraft include people (in manned missions), electronic equipment, frictional heat generated as the vehicle leaves or reenters the atmosphere, the Sun, heat reflected from the Earth (altitude dependent), and Earth thermal radiation (altitude dependent). Thermal control techniques can be divided into two classes: passive thermal control and active thermal control.

Passive Thermal Control

A passive thermal control system maintains temperatures within the desired temperature range by control of the conductive and the radiative heat paths. This is accomplished through the selection of the geometrical configuration and thermo-optical properties of the surfaces. Such a system does not have moving parts, moving fluids or require electrical power. Passive systems offer the advantages of high reliability due to absence of moving parts or fluid, effectiveness over wide temperature ranges, and light weight. A disadvantage is low thermal capacity. Passive thermal control techniques include thermal coatings, thermal insulations, heat sinks and phase change materials.

Spacecraft external surfaces radiate energy to space. Because these surfaces are also exposed to external sources of energy, their radiative properties must be selected to achieve a balance between internally dissipated energy, external sources of energy and the heat rejected into space. The two properties of primary importance are the emittance of the surface and solar absorbency. Paints and coatings can be used to reduce reflection and to increase or decrease absorption of heat or light energy.

Two or more coatings can be combined in an appropriate pattern to obtain a desired average value of solar absorbence and emittance (i.e. a checkerboard pattern of white paint and polished metal).

For a radiator, low absorbence and high emittance are desirable to minimize solar input and maximize heat rejection to space. For a radiator coating, the initial values are important because of degradation over the lifetime of the mission. Degradation can be significant for all white paints. For this reason, the use of a second surface mirror coating system is preferred. An example of such a coating is vapor deposited silver on 0.2 mm thick fused silica, creating an optical solar reflector. Degradation of thermal coatings in the space environment results from the combined effects of high vacuum, charged particles and ultraviolet radiation from the Sun.

Thermal insulation is designed to reduce the rate of heat flow per unit area between two boundary surfaces at specified temperatures. Insulation may be a single homogeneous material such as low thermal conductivity foam or an evacuated multi-layer insulation in which each layer acts as a low-emittance radiation shield and is separated by low-conductance spacers.

Multi-layer insulations are widely used in the thermal control of spacecraft and components in order to:

- Minimize heat flow to or from the component
- Reduce the amplitude of temperature fluctuations in components due to time-varying external radiative heat flux
- Minimize the temperature gradients in components caused by varying directions of incoming external radiative heat.

Multi-layer insulation consists of several layers of closely spaced radiation-reflecting shields which are placed perpendicular to the heat-flow direction. The aim of the radiation shields is to reflect a large percentage of the radiation the layer receives from warmer surfaces. Heat sinks are materials of large thermal capacity, placed in thermal contact with the components whose temperature is to be controlled. When heat is generated by the component, the temperature rise is restricted because the heat is conducted into the sink. The sink will then dispose of this heat to adjacent locations through conduction or radiation (**Fig. 10-5**). Heat sinks are commonly used to control the temperature of those items of electronic equipment which have high dissipation, or a cyclical variation in power dissipation.

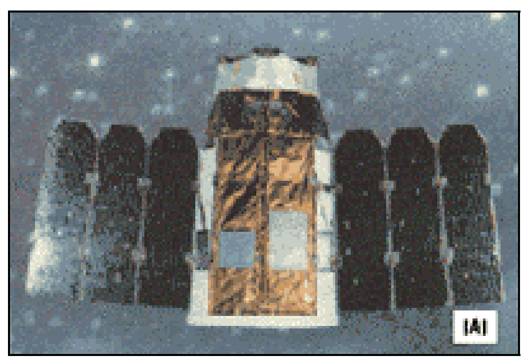


Fig. 10-5. Satellite body with thermal heat sinks

Solid-liquid phase-change materials (PCM) present an attractive approach to spacecraft passive thermal control when the incident orbital heat fluxes, or on-board equipment dissipation, changes widely for short periods. The PCM thermal control system consists primarily of a container filled with a material capable of undergoing a chemical phase change. When the temperature of spacecraft surfaces increases, the PCM will absorb excess heat through melting. When the temperature decreases, the PCM gives heat back and solidifies. Phase-change materials used for temperature control are those with melting points close to the desired temperature of the equipment. Then the latent heat associated with the phase change provides a large thermal inertia as the temperature of the equipment passes through the melting point. However, the phase-change material cannot prevent a further temperature rise when all the material is melted.

One of the more common methods of rejecting electronic heat is to mount the electronics just inside the spacecraft bus structure. Thus, the energy is conducted over a short path to an external spacecraft thermal control surface (frequently referred to as a radiator and sometimes as a shearplate). This surface is usually coated with a low solar absorbence/high infrared emittance coating (usually a white paint). Such surfaces are usually positioned by spacecraft orientation to point to deep space. Thus, the natural environment is minimized or eliminated and maximum heat rejection occurs.

Active Thermal Control

Passive thermal control may not be adequate and efficient for the applications where the equipment has a narrowly specified temperature range, or where there is great variation in equipment power dissipation and solar flux during the mission. In such cases, temperature sensors may be placed at critical equipment locations. When critical temperatures are reached, mechanical devices are actuated to modify the thermo-optical properties of surfaces, or electrical power heaters turn on or off to compensate for variations in the equipment power dissipation. Active thermal control techniques include louvers, electrical heaters, refrigerative thermal control and expendable heat sinks.

For a spacecraft in which the changes in internal power dissipation or external heat fluxes are severe, it is not possible to maintain the spacecraft equipment temperatures within the allowable design temperature limits unless the ratio of absorbence to emissivity can be varied. A very popular and reliable method which effectively gives a variable ratio is through the use of louvers. When the louver blades are open, the effective ratio is low (low absorbtivity, high emissivity); when the blades are closed, the effective ratio is high (high absorbtivity, low emissivity). The louvers also reduce the dependence of spacecraft temperatures on the variation of the thermo-optical properties of the radiator.

Louvers consist of five main components: baseplate, blades, actuators, sensing elements and structural elements. The baseplate is a surface of low absorbence to emittance ratio which covers the critical set of equipment whose temperature is being controlled. The blades, driven by actuators, are the elements of the louvers that give variable radiation characteristics at the baseplate. When the blades are closed, they shield the baseplate from its surroundings. When they are fully open, the coupling by radiation from the baseplate to the surroundings is the largest. The radiation characteristics of the baseplate can be varied in the range defined by these two extreme positions of the blades. The actuators are the elements of the louvers which drive the blades according to the temperature sensed by sensors placed in the baseplate. The commonly used actuators are bimetal springs or bellows. Generally, bimetals are used with the multiple-blade actuation system and bellows with the single-blade actuation system.

Electrical heaters (resistance elements) are used to maintain temperatures above minimum allowable levels. The heater is typically part of a closed loop system that includes a temperature sensing element and an electronic temperature controller (thermostat). Electrical heaters are used in an on-off control mode, a ground controllable mode, a proportional control mode or simply in a continuous-on mode. The heaters are strips of kapton with etched foil-heating elements and welded power leads. Heaters are bonded on structures to maintain temperature levels and gradients consistent with interface and alignment requirements. In all applications, primary and backup redundant sets of heaters should be implemented and controlled by redundant mechanical thermostats with predetermined set-points.

Some sensors require constant cold temperatures. These types of sensors on board spacecraft must be isolated from other system components and may need a cooling system to function properly. A closed system refrigeration cycle may be necessary for high heat loads.

Radiators are closed loop systems used in conjunction with other types of thermal control devices. They are active due to this interaction (i.e., use working fluids etc.). Radiator systems require large surface areas to dissipate heat into space; a major disadvantage of this type of system.

Expendable heat sinks work by transferring heat to a fluid or gas and then the fluid or gas is vented overboard. Thus, the working fluid or gas is expended. Water, because of its high latent heat of vaporization, is generally the best expendable coolant. This is an open loop system.

ELECTRICAL POWER SUBSYSTEM

The successful fulfillment of a space mission is dependent on the reliable functioning of the power system of the orbiting spacecraft. The stringent demands on performance, weight, volume, reliability and cost make the design of the spacecraft power system a truly challenging endeavor.

Significant advances have been made in this area resulting in the development of reliable and lightweight power systems for long duration missions (typically more than five years). Since a space mission is inherently expensive, the necessity of optimization and built in reliability becomes a rule rather than an exception for all on-board systems. Therefore, continuous efforts are being made to realize better performance from power systems.

Elements of a Spacecraft Power System

The amount of electrical power required on board a spacecraft is dictated by the mission goals (i.e. the nature and operational requirements of the payloads, the antenna characteristics, the data rate, the spacecraft orbit, etc.) Uninterrupted power must often be supplied for durations up to ten years or more.

The generation of electrical power on board a spacecraft generally involves four basic elements:

- A source of energy, such as direct solar radiation, nuclear power or chemical reactions
- A device for converting the energy into electrical energy
- A device for storing the electrical energy to meet peak and/or eclipse demands
- A system for conditioning, charging, discharging, regulating and distributing the generated electrical energy at specified voltage levels

The most favorable energy source for Earth-orbiting satellites is solar radiation (**Fig. 10-6**). Solar radiation bombards the Earth at a level of 126 watt/ft^2. Nearly

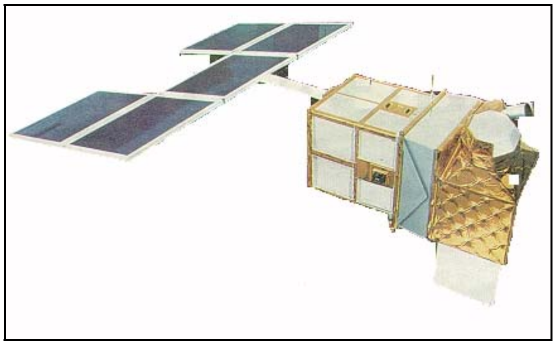


Fig. 10-6. Solar Panels provide energy for earth-orbiting satellites

all Earth-orbiting spacecraft use solar radiation as a source of energy. Because satellites pass into and out of the Earth's shadow solar radiation may not be useable by itself. A supplemental energy storage device must be used to provide power during eclipse and peak demand periods. Chemical sources such as rechargeable storage batteries serve this purpose. These batteries employ electrochemical processes and have typical efficiencies of 75%.

As an alternative to solar energy, radioactive isotope generators have also been used. This power source is especially practical for exploration missions to the outer planets where solar radiation levels are low. For example, the solar radiation reduces from about 54 watt/ft^2 in the vicinity of Mars to about 4.6 watt/ft^2 near Jupiter. It therefore becomes necessary to use other primary sources of energy for spacecraft missions to Jupiter and beyond.

Batteries and fuel cells produce electrical power through chemical reactions. The chemical dynamic system uses the heat energy liberated by some chemical reactions to heat a working fluid, such as sodium, and turn a generator. The chemical dynamic system is not considered practical for space usage and will not be addressed.

Photovoltaic and solar thermoionic devices both harness energy from the Sun. The photovoltaic energy source uses potential differences created by electromagnetic radiation illuminating semiconductors to provide power. The solar thermoionic system uses a temperature gradient set up across different types of semiconductors to create a flow of current. It is seldom used and thus, will not be discussed.

Another source is the solar dynamic system. This system can theoretically provide many kilowatts of power for extremely long mission durations. In this system, the energy from the Sun is focused onto a vessel containing a working fluid. The fluid heats, expands and can be used to turn a generator. This method will be employed on the International Space Station to supplement its batteries and solar arrays.

Nuclear power uses the heat energy produced during nuclear fission to generate power.

Choosing a spacecraft power source for a particular mission may be difficult. Continuous power requirements, eclipse conditions as well as power subsystem weight are major factors in the final choice. Sometimes, a combination of energy sources is may be required.

Solar Arrays

Solar arrays are mounted on the satellite in various forms. They may be body mounted, stationary, or on directional, steerable wings. A solar array consists of solar cells which convert solar energy into electric power by the photovoltaic effect. An array also contains interconnectors to connect the solar cells, panels on which the solar cells are mounted and mechanisms to deploy the panels in orbit (**Fig. 10-7**).

The power output of a single cell is quite low, so the individual cells are arranged in series to provide the desired voltage, and in parallel to render the desired current requirements. In addition, solar array modules are often

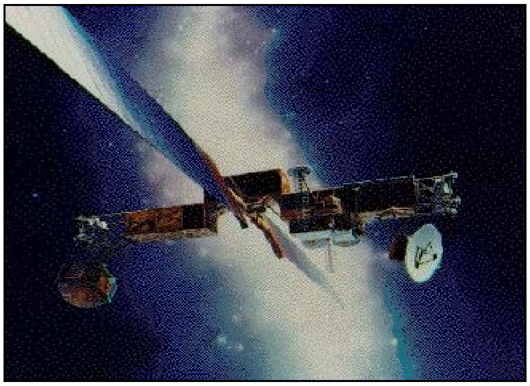


Fig. 10-7. Spacecraft with large solar array

constructed with several strings in parallel which are connected together in a series; a parallel “ladder” network. This is done to minimize power loss with a single cell failure. If each string were used independently, the loss of a single cell would create an open circuit for that entire string and the output from that string would be totally lost. With the ladder network arrangement, connectivity among the remaining cells is maintained in any string with a failed cell. However, the output may be somewhat degraded.

Some satellites cannot use deployable solar arrays because of the type of attitude control system they employ. Spin-stabilized satellites cannot support deployable solar arrays because of the stresses placed on the panels while the satellite rotates. For this reason, spin stabilized satellites require body mounted solar arrays. Body mounting is a very simple approach that utilizes available space on the satellite surface.

Some solar arrays are directional. A solar array drive is employed to control the angle of the arrays continuously so they may be always perpendicular to the sun's rays. In contrast, stationary arrays are deployable arrays locked into position relative to the spacecraft body once deployed.

The power of a solar array varies with time due to:

- The variation in solar intensity
- Variation in the angle between the solar array surface normal and solar rays
- Radiation degradation in solar cell power characteristics
- Array contamination by thruster propellants, etc.

The solar array power characteristics during the lifetime are obtained by superimposing the seasonal variation in power output on the time-varying radiation thermal degradation characteristic.

Solar array size is driven by a combination of satellite power requirements and the efficiency of the solar cells to convert solar energy to electrical energy. At the distance the Earth is from the sun (1 AU), the solar constant is 126 watt/ft^2. A new cell is only 11-12 % efficient when the Sun’s rays are incident at 90° to the surface. As a result, solar cell output is about 10 watt/ft^2. To improve their efficiency and protect the cells from particles and radiation, the cells are covered with multiple layers of materials to protect them and enhance conversion. A silicon dioxide layer is used to enhance the desired wavelengths resulting in higher efficiency and giving the cells their characteristic blue color. In order to provide a kilowatt of power to the satellite payload and vehicle subsystems, solar array must have about 100 ft^2 of surface area.

Optimum solar array efficiency is usually achieved between 25° C (77° F) and 28° C (82° F). The cell may be laminated with a material to reflect the 4,000 Angstrom wavelength radiation to keep the cell cooler. A change in cell temperature will change its voltage-current characteristics. An increase in the cell operational temperature causes a slight increase in the cell current and a significant decrease in the cell voltage. Therefore, the overall efficiency decreases as temperature increases. Thermal control of the solar array panels is achieved by the absorption of solar radiation by the solar cells on the front surfaces of the panels and reemission of infrared energy from the front and back of the panels.

The power from the solar cell will be maximum when the angle of incidence of illuminating light is zero (i.e. it is perpendicular to the solar cell surface). The power decreases as the angle of incidence deviates from zero. The primary reason for the increased loss of power at greater angles of incidence is the change in reflection coefficients at large angles.

Storage Batteries

In most spacecraft power systems that use solar radiation, the storage battery is the main source of continuous power. Batteries must provide continuous power to the spacecraft during peak power cycles and eclipse periods. The frequency and duration of eclipse periods depend on the spacecraft orbit.

The eclipse seasons in geostationary orbits occur twice per year, during spring and autumn. These eclipse seasons are 45 days long and center around the vernal and autumnal equinoxes. There is one eclipse period per 24 hours with the maximum period of 72 minutes. The batteries discharge during an eclipse and are charged during the sunlight period. So, the charge-discharge cycles for any storage battery on board a spacecraft in geosynchronous orbit will be about 90 per year.

In the case of low orbiting satellites, the number of eclipses increases as the altitude of the satellite decreases. For a 550 km circular orbit there will be about 15 eclipses per day. The maximum shadow duration is about 36 minutes during each 96 minute orbit. There will be about 5,500 charge-discharge cycles per year in this orbit. Depending on the orbit inclination, the spacecraft may be in continuous sunlight for long periods several times a year

As mentioned above, batteries are necessary to maintain steady, reliable spacecraft power. A battery is an electrochemical device that stores energy in the chemical form and then converts it into electrical energy during discharge. Chemical reactions taking place inside the battery produce electrical energy whose magnitude is dependent upon various cell characteristics (i.e. individual cell voltage, efficiency of the electro-chemical reaction, size of the cell, etc.).

Batteries are classified as either primary or secondary. Primary batteries are used on spacecraft in which the battery is the only source of electrical power and it cannot be recharged. Thus, primary batteries are used for short duration missions of usually less than a week. Primary batteries have the advantages of being cheap, reliable and can deliver relatively large amounts of energy per pound of battery (20-100 watt-hr/lb).

Secondary batteries are rechargeable. They convert chemical energy into electrical energy during discharge, and convert electrical back to chemical energy during recharge. This process can be repeated many times. Secondary batteries are used for longer duration missions such as Defense Meteorological Satellite Program (DMSP), Defense Satellite Communications System (DSCS) and many others, where solar arrays are the primary source of power.

The advantages of secondary batteries are:

- Capability of accepting and delivering unscheduled power at high rates (eclipse operations and peak power demands)
- Large number of charge-discharge cycles or long charge-discharge cycle life under a wide range of conditions
- Long operational lifespan
- Low volume
- Low cost
- High proven reliability

The disadvantages are:

- The memory effect process
- The complexity and expense of charge-discharge monitoring equipment
- Low energy storage capability per pound of battery (2-15 watt-hr/lb)

There are many types of secondary batteries available. However, only some are considered suitable for space applications.

The nickel-cadmium (Ni-Cad) battery is probably one of the most common batteries used in spacecraft today. It has four main components: the cadmium negative electrode, which supplies electrons to the external circuit when it is oxidizing during discharge; the nickel positive electrode, which accepts the electrons from the external circuit; the aqueous electrolyte, 35% KOH, which completes the circuit internally; and a separator made of nylon or polypropylene, which holds the electrolyte in place and isolates the positive and negative plates.

The primary factors affecting the useful life of a Ni-Cad cell are battery temperature, depth of discharge and excessive overcharge. The most important effect of high battery temperature is the reduction of separator life. Prolonged exposure of a Ni-Cad battery to high temperature will hasten the decomposition of the separator material. The repeated overcharging at low temperatures can result in pressure buildup. Therefore, battery temperature is an extremely critical parameter in the battery life design. It is common practice to use a thermal radiator to keep battery temperature below 24° C (75° F) and to use heaters to keep it above 4° C (39° F).

Repeated deep discharges tend to degrade the cell plate structures, causing cracking. These cracks absorb electrolyte and gradually the separator dries out. For a synchronous orbit application of 7 to 10 years, a battery will encounter approximately 1,000 charge-discharge cycles over its lifetime. For this number of cycles, Ni-Cad battery depth of discharge is generally limited to 50 to 60%.

The batteries exhibit a gradual decay of terminal voltage during successive discharge periods. This effect is most pronounced when the charge-discharge cycle is repetitive, and is referred to as the "memory effect." When the battery is cycled to a fixed depth of discharge, the active material that is not being used gradually becomes unavailable, resulting in an effective increase in depth of discharge. In addition to the gradual decay of discharge voltage, the batteries will also exhibit a tendency toward the divergence of the individual cell voltages during charge and discharge. Battery performance can be restored to a certain extent by reconditioning. A typical reconditioning process for a rechargeable battery consists of effecting a deep discharge and then recharging at a high rate. Reconditioning is a process begun a few weeks before eclipse season on many spacecraft.

Procedures to enhance battery life include maintaining batteries within a small temperature range, proper reconditioning, and trickle charging between eclipse seasons, to prevent cadmium migration from negative electrodes to positive electrodes.

Another type of secondary battery is the nickel-hydrogen battery (Ni-H_2). This battery is actually hybrid battery-fuel cell device. It has a positive electrode, much like a conventional battery and a fuel cell negative electrode. Hydrogen gas is diffused onto a catalyst, usually platinum, at the negative electrode where the reaction occurs. High pressure vessels (500 psi) are required to contain the gas.

Nickel-hydrogen batteries are increasingly being used on newer spacecraft such as MILSTAR and replacement GPS satellites. Compared to Ni-Cad batteries, NiH_2 have higher specific energy, can tolerate a higher number of discharge-recharge cycles and operate at near-optimum output over a wider range of temperatures.

Fuel Cells

Fuel cells have played a major role in the NASA manned spaceflight programs. They were originally chosen over batteries as primary electrical power sources for these applications because conventional batteries could not meet the energy density requirements for the Gemini and Apollo space missions. Consequently, the decision was made to develop fuel cells for manned orbital flights. The fuel cells were to be powered by cryogenic hydrogen and oxygen stored in pressurized insulated tanks.

A fuel cell is a device that directly converts the chemical energy of reactants (a fuel and oxidizer) into low voltage direct current (DC) electricity. Like the primary and secondary batteries discussed earlier, a fuel cell accomplishes this conversion via electrochemical reactions. However, unlike these conventional batteries, it does not consume reactants that are stored within its structures, but uses reactants that are stored in external tanks. A fuel cell consists of two sintered, porous nickel electrodes separated by an ion-conducting electrolyte like potassium hydroxide. The fuel cell can operate as long as it is continuously fed with reactants and reaction products are removed. Because it is easy to make the reactant tanks larger, a fuel cell's period of operation can be made much longer than that for a conventional electrochemical battery.

At the negative electrode, incoming hydrogen gas ionizes to produce hydrogen ions and electrons. Since the electrolyte is a non-electronic conductor, the electrons flow away from the electrode into the external circuit. At the positive electrode, oxygen gas reacts with migrating hydrogen ions from the electrolyte and incoming electrons from the external circuit to produce water. Depending on the operating temperature of the fuel cell, the product, water, may enter the electrolyte, thereby diluting it or be lost as vapor through the cathode. In fuel cells with liquid electrolytes that operate below the boiling point of water, an electrolyte circulation system incorporating an external evaporator may be necessary to remove the water.

In any event, as long as hydrogen and oxygen are continuously fed to the fuel cell, the flow of electric current will be sustained. By electrically connecting a number of cells together in series or parallel, it is possible to form a fuel cell "stack" of any desired voltage or current. The U.S. Space Shuttle uses three fuel cells, each with an output of approximately 30-33 V at 250 A, to produce power for various loads during a mission. Since fuel cells produce water as a by-product, fuel cells provide potable drinking water for the crew and can be used as evaporator cooling for the vehicle.

Among the primary advantages of fuel cells are that they provide continuous power (as long as fuel and oxidizer are supplied), have low weight but high output power and produce water as a by-product. Their advantages make them very useful for manned missions.

The main disadvantages of fuel cells are their expense and the possibility that loss of cooling can result in an explosion. Consequently, elaborate control systems are required to keep them operating.

Nuclear Power

Most spacecraft nuclear power generators are capable of delivering a range of power from a few watts up to several hundred. The challenging problems encountered with shielding nuclear power generators have precluded their use on manned missions **(Fig. 10-8)**. However, they have been used very successfully on many deep space missions where solar flux levels are too low for photovoltaic solar cells to be effective.

Political and environmental problems with nuclear powered satellites were underscored in 1978 after COSMOS 954 plunged to earth, scattering nuclear material over a large part of northwest Canada. From the beginning of the U.S. space nuclear power program, great emphasis has been placed on the safety of people and the protection of the environment. The operational philosophy adopted for orbital missions requires that the normal lifetime in space be long enough to permit radioactive decay of the radioisotope fuel to a safe level prior to reentry into the Earth's biosphere. Stringent design and operational measures are used to minimize the potential interactions of the radioactive materials with the global populace and to keep any such exposure levels within limits established by international standards.

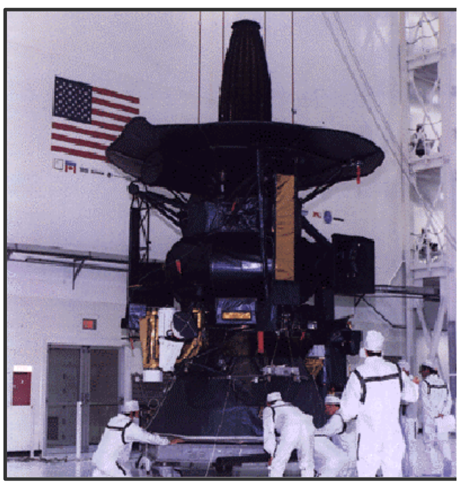


Fig. 10-8 NASA Galileo Spacecraft with two nuclear powered generators

Like fuel cells, nuclear power generators have a major role in space exploration. There are two basic types of nuclear powered generators. Radioisotope thermoelectric generators (RTG) rely on the decay of radioisotopes. The second type uses the heat of the nuclear fission process, much like nuclear generators on earth. Both processes involve material having high energy radiation levels of several types: alpha particles, beta particles and gamma particles.

This energy can be harnessed to produce electricity on spacecraft. The radioactive material is encased in a special metal container from which the decay particles cannot escape. As the container absorbs energy produced by the alpha and beta particles, it is heated to a high temperature. This heat can be employed in conjunction with a thermoelectric couple to produce the necessary electricity. The heat from a nuclear reactor can be utilized in two basic methods called static and dynamic. The static method uses no moving parts and is usually preferred for this reason. The dynamic conversion systems use the heat to perform mechanical work on a turboalternator assembly which generates the electricity.

The advantages of nuclear energy include its ability to provide power for long duration missions without reliance on solar illumination, high system reliability and high power output versus low mass.

Among the primary disadvantages of nuclear power systems are their high cost, heavy shielding requirements (which restricts their use on manned missions), need for complex cooling systems to prevent core meltdown and relatively low efficiencies (less than 18% efficiency). The high level of environmental concern and corresponding political ramifications all but preclude use of nuclear systems in Earth orbiting satellites.

ATTITUDE CONTROL SUBSYSTEM

Attitude control can be defined as the process of achieving and maintaining a desired orientation in space. An attitude maneuver is the process of reorienting the spacecraft from one attitude to another. An attitude maneuver in which the initial attitude is unknown, when maneuver planning is being undertaken, is known as attitude acquisition. Attitude stabilization is the process of maintaining an existing attitude relative to some external reference frame. This reference frame may be either inertially fixed or slowly rotating, as in the case of Earth orbiting satellites.

An attitude control system is both the process and hardware by which the attitude is controlled. In general, an attitude control system consists of three components: navigation sensors, guidance section and control section. A navigation sensor locates known reference targets such as the Earth or Sun to determine the spacecraft attitude. The guidance section determines when control is required, what torques are needed and how to generate them. The control section includes hardware and actuators that supply the control torques.

Definitions

Station Keeping—The sequence of maneuvers that maintains a vehicle in a predetermined orbit

Attitude—The position or orientation of a body, either in motion or at rest, as determined by the relationship between its axes and some reference line or plane such as the horizon

Attitude Adjustment—Changing the orientation of the spacecraft within its orbit

Orbit Adjustment—Changing the orbit itself

Navigation—Determination of spacecraft's current position and velocity

Guidance—Computation of corrective actions

Control—Implementation of corrective actions

Stabilization—The property of a body to maintain its attitude or to resist displacement, and, if displaced, to develop forces and movements tending to restore the original condition

Perturbation—A disturbance in the regular motion of a celestial body, the result of a force additional to that which caused the regular motion, specifically, a gravitational force.

Coordinate System—Any scheme for the unique identification of each point of a given continuum. Various systems in use are Polar, Cartesian, Spherical, and Celestial

Active and Passive Control Systems

There are two categories of attitude control systems: active and passive. Active systems use continuous decision making and hardware (closed loop) to maintain the attitude. The most common sources of torque actuators for active control systems are thrusters, electromagnets and reaction wheels. In contrast, passive attitude control makes use of environmental torques (open loop) to maintain the spacecraft orientation. Gravity gradient and solar sails are common passive attitude control methods (**Fig. 10-9**).

Attitude control systems are highly mission dependent. The decision to use a passive or active control system or a combination of the two depends on mission pointing and stability requirements, mission orbital characteristics and the control system's stability and response time. For example, a near-Earth, spin-stabilized spacecraft could use magnetic coils for attitude maneuvers and for periodic adjustment of the spin rate and attitude.

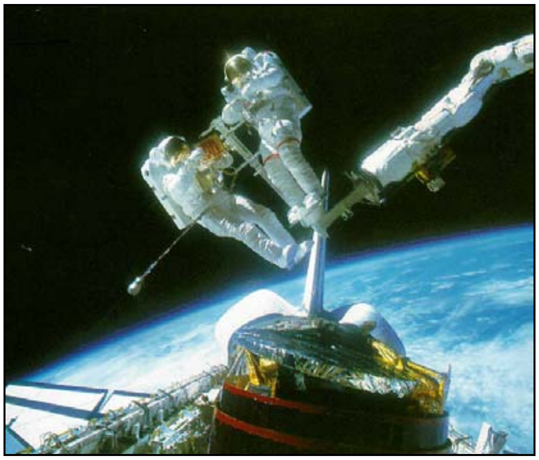


Fig. 10-9. Astronauts working on satellite with a gravity boom

Above synchronous altitudes, thrusters would be required for these functions because the Earth's magnetic field is generally too weak at this altitude for effective magnetic maneuvers.

Any satellite orbit requires stabilization to increase its usefulness and effectiveness. For instance, when a satellite is not stabilized, it must use omni-directional antennas so that ground stations can receive its downlink information regardless of the satellite's orientation. This necessitates a high power transmitter and only a small portion of the total power is radiated to Earth. On the other hand, if there are means to stabilize the satellite so its directional antennas can be pointed at the Earth, then lower power may be used to transmit information to the ground.

There are four functions spacecraft attitude control systems incorporate: satellite pointing, orbital transfer maneuvers, stabilization against torques and satellite de-spin.

Solar arrays generate maximum power when they are perpendicular to the Sun. In addition, some satellites carry scientific payloads which must observe a celestial body. In order to observe it, the spacecraft must be able to accurately find the object, track it and point applicable sensors at it. Sensors must be accurately pointed at Earth to detect ICBM launches as well as movement of troops, ships, aircraft, etc.

During orbital transfer maneuvers, it is necessary to be as precise as possible. Therefore, stringent requirements on the accuracy of the spacecraft orientation must be achieved by the attitude control system before firing. Aligning the spacecraft for perigee and apogee motor firing requires a knowledge of the orbit characteristics at the time at which the motors are fired. This knowledge optimizes the transfer maneuver by minimizing both time and propellant requirements for the orbital transfer. If the spacecraft relies on solar energy for electrical power generation during the transfer maneuver, then the spacecraft must be optimized for maximum solar cell illumination during the transfer. Finally, the spacecraft must be reoriented again after the completion of the transfer maneuver.

Disturbance torques are environmental torques (i.e. drag, solar wind, magnetic field, gravity, micrometeoroid impacts) or unintentional internal torques (i.e., liquid propellant slosh, center of gravity changes). Because these can never be totally eliminated, some form of attitude control system is required. Control torques, such as those produced by thrusters, are generated intentionally to control spacecraft attitude.

Traditionally, spacecraft employing solid propellant apogee motors have adopted spin-stabilization during the parking and transfer phases. Even spacecraft that have active attitude control systems in their operational orbits are frequently spin-stabilized in an initial (transfer orbit) phase of their mission. Spin stabilization during transfer orbit allows thermal control to be distributed evenly throughout the spacecraft. If the spacecraft is required to be three-axis stabilized, it must be despun before being injected into the appropriate attitude. If the spacecraft is to be spin stabilized then the spin rate must be increased or decreased, depending on the final spin rate required.

Navigation Sensors

As mentioned before, sensors are required to determine the orientation of the spacecraft and its current state. The types of sensors used on a particular vehicle depend on several factors including the type of spacecraft stabilization, orbital parameters, operational procedures and required accuracy.

Sun sensors are the most widely used sensor types; one or more varieties have flown on nearly every satellite. The Sun is sufficiently bright to permit the use of simple, reliable equipment without discriminating among sources and with minimal power requirements. Many missions have solar experiments, most with Sun-related thermal constraints, and nearly all require the Sun for power. Consequently, missions are concerned with the orientation and time evolution of the Sun vector in body coordinates. Attitude control systems are frequently based on the use of a Sun reference pulse for thruster firings, or more generally, whenever phase-angle information is required. Sun sensors are also used to protect sensitive equipment, such as star trackers, from harmful particle bombardment as well as to position solar arrays to achieve maximum power con-version efficiency.

The orientation of the spacecraft to the Earth is of obvious importance to space navigation, communications, weather and Earth resources satellites. To a near-Earth satellite, the Earth is the second brightest object and covers up to 40% of the sky. The Earth presents an extended target to a sensor compared with a point source approximations used for Sun and star detectors. Consequently, detecting only the presence of the Earth is normally insufficient for even crude attitude determination and nearly all sensors are designed to locate the Earth's horizon .

Unfortunately, the location of the Earth's horizon is difficult to define because its atmosphere causes a gradual decrease in radiated intensity away from the true or hard horizon of the solid surface. Earth resources satellites such as

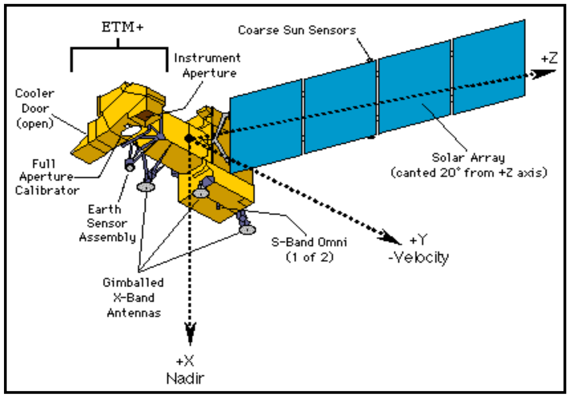


Fig. 10-10 LANDSAT with earth and star sensors

Landsat **(Fig. 10-10),** communications and weather satellites typically require a pointing accuracy of 0.05 degrees to less than a minute of arc, which is typically beyond the state of the art for horizon sensors.

Earth emanates infrared radiation, and the IR intensity in the 15 micron spectral band is relatively constant. Most horizon sensors now use the narrow 14 to 16 micron bands. Use of the infrared spectral band avoids large attitude errors due to spurious triggering of visible light horizon sensors off high altitude clouds. In addition, the operation of an infrared horizon sensor is unaffected by night. Infrared detectors are less susceptible to sunlight reflected by
the spacecraft than are visible light detectors and therefore, avoid reflective problems. Sun interference problems are also reduced in the infrared band where the solar intensity is only 400 times that of the Earth, compared with 30,000 in the visible spectrum.

Most horizon sensors consist of four basic components: a scanning mechanism, an optical system, a radiance detector and signal processing electronics. The scanning mechanism is used to scan the celestial sphere and houses the actual sensor.

The optical system of a horizon sensor consists of a filter to limit the observed spectral band and a lens to focus the target image on the radiance detector. Optical system components depend greatly on the sensor design. In many cases, rotating mirrors or prisms are incorporated into the optical system to provide the scanning mechanism.

Knowledge of the scan rate or duty cycle allows the conversion from time to angle either on board the satellite or on the ground. Typically, sensors are designed and calibrated so that the system output may be used directly for attitude control and determination within a specified accuracy under normal operating conditions.

Some horizon sensor systems have been designed for specific mission conditions and thereby achieve increased accuracy and simplicity but at the cost of reduced versatility. These systems operate over a narrow range of orbits and attitudes and include moving and static edge trackers and radiometric balance systems.

Star sensors measure star coordinates in the spacecraft frame and provide attitude information when these observed coordinates are compared with known star positions and magnitudes obtained from a star catalog. In general, star sensors are the most accurate of navigation sensors, achieving accuracy to the arc-second range. However, this capability is not achieved without considerable cost. Star sensors are heavy, expensive and require more power than most other navigation sensors. In addition, computer software requirements are extensive, because measurements must be preprocessed and identified before attitudes can be calculated. Because of their sensitivity, star sensors are subject to interference from the Sun, Earth and other bright objects. In spite of these disadvantages, the accuracy and versatility of star sensors have led to applications in a variety of different spacecraft attitude control systems.

Star sensing and tracking devices can be divided into three major categories: star scanners, which use the spacecraft rotation to provide searching and sensing function; gimbaled star trackers, which search out and acquire stars using mechanical action; and fixed head star trackers, which have electronic searching and tracking capabilities over a limited field-of-view. Sensors in each of these classes usually consist of the following components: a sun shade; an optical system; an image definition device which defines the region of the field of view that is visible to the detector; the detector; and an electronics assembly. Furthermore, gimbaled star trackers have gimbaled mounts for angular positioning.

Stray light is a major problem for star sensors. Therefore, an effective sun shade is critical to star sensor performance. Carefully designed light baffles are usually employed to minimize exposure of the optical system to sunlight and light scattering caused by dust particles, clouds and portions of the spacecraft itself. Even with a well designed sun shade, star sensors are typically inoperable within 30 to 60 degrees of the Sun.

The star sensor optical system consists of a lens which projects an image of the star field onto a focal plane. The image definition device selects a portion of the star field image in the sensor's field of view which will be visible to the detector. This portion is known as the instantaneous field of view (IFOV). The image definition device may be either a reticle consisting of one or more transparent slits etched on an opaque plate, or an image dissector tube in which the IFOV electronically scans the FOV. The detector transforms the optical signal into an electronic signal. Finally, the electronics assembly filters the amplified signal received from the detector and performs many functions specific to the particular star sensor.

These functions include defining the magnitude of the stars as well as relative positions which will be used to determine spacecraft attitude.

Star scanners used on spinning spacecraft are the simplest of all star scanners because they have no moving parts. The image definition device employed by this type of sensor consists of two V-slits through which the star light passes. The spacecraft rotation causes the sensor to scan the celestial sphere. As the star image on the focal plane passes a slit, the star is sensed by the detector. If the amplified optical signal passed from the detector to the electronics assembly is above a threshold value, then a pulse is generated by the electronics signifying the star's presence. The interpretation of the star scanner measurements becomes increasingly more difficult as spacecraft motion deviates from a uniformly spinning body.

Gimbaled star trackers are commonly used when the spacecraft must operate at a variety of attitudes. This type of tracker has a very small optical field of view (usually less than one degree). Gimbaled star trackers normally operate on a relatively small number of target stars. A major disadvantage of gimbaled star trackers is that the mechanical action of the gimbal reduces their long term reliability. In addition, the gimbal mount assembly is frequently large and heavy.

Fixed head trackers use an electronic scan to search their field of view and acquire stars. They are generally smaller and lighter than gimbaled star trackers and have no moving parts.

Magnetometers can be used to measure both the direction and magnitude of the Earth's magnetic field to the milligauss accuracy. They are reliable, lightweight and have low power requirements. They operate over wide temperature range and have no moving parts. However, magnetometers are not accurate inertial navigation sensors because the Earth's magnetic field is not completely known and the models used to predict the magnetic field direction and magnitude at the spacecraft's position are subject to relatively substantial errors. Furthermore, because the Earth's magnetic field strength decreases with distance from the Earth (Earth's magnetic field in low Earth orbit is about 0.5 gauss) residual spacecraft magnetic biases eventually dominate the total magnetic field measurement. Magnetometers are generally limited for use to spacecraft with altitudes below 1,000 km.

A gyroscope is any instrument which uses a rapidly spinning mass to sense and respond to changes in the inertial orientation or its spin axis. There are three basic types of gyroscopes used on spacecraft: rate gyros, rate-integrating gyros, and control moment gyros. The first two types are attitude sensors used to measure changes in the spacecraft orientation. Control moment gyros generate control torques to change and maintain the spacecraft's orientation.

Rate gyros measure spacecraft angular rates and are frequently part of a feedback system for spin rate control or attitude stabilization. The angular rate outputs from rate gyros may also be integrated by an on-board computer to provide an estimate of spacecraft attitude displacement from some initial reference. Rate-integrating gyros measure spacecraft angular displacement directly. In some applications, rate-integrating gyro output consists of the total spacecraft rotation during small time intervals. An accurate measure of the total attitude displacement may then be obtained by integrating the average angular rates constructed from incremental displacements.

Control Actuators

Control actuators are used to correct the attitude of a spacecraft such that it attains and stays in the desired attitude. There are two types of attitude control methods: passive and active.

Passive Attitude Control

Passive attitude control techniques include spin stabilization and gravity gradient stabilization. Passive systems involve no active elements, require no altitude sensors and have a high reliability. However, passive systems are extremely sensitive to environmental torques and payload motion, limited to near circular orbits, and have a local vertical accuracy from 2 to 3 degrees at 500 miles to 10 degrees at synchronous altitude.

Spin-stabilization is a passive technique that involves spinning the vehicle is at a constant rate (on the order of once per second). Because of their motion, spinning satellites can only scan a target rather than fix on a point . Thus “dual-spin” satellites were developed in which part of the satellite is spun for stabilization, while another part is nonspinning ("despun") for mission requirements such as pointing an antenna. The spinning motion gives angular momentum to the vehicle, which tends to reduce the effects of small disturbance torques on vehicle orientation.

Gravity gradient stabilization works by orienting the spacecraft along an axis of gravitational force. Gravitational influences can be significant enough at low altitude that a satellite can maintain fairly stable orientation. The gravity gradient approach takes advantage of gravitation's stronger pull closer to the Earth than when farther away. The difference between the close and far conditions can be used to generate a torque which aligns the satellite long axis with the local vertical. One method is to place the vehicle such that the maximum moment of inertia (usually the longest dimension) aligns with the local vertical pointing towards or away from the Earth. If a disturbance alters the vehicle out of this orientation, the varying force of gravity acting on different parts of the vehicle returns it to its original stable orientation. This effect can be greatly enhanced by extending lightweight booms with small weights on the ends. The boom attempts to align with the vertical, but will oscillate about the vertical, unless some damping mechanism is employed. In order to stiffen the damping force, horizontal biasing booms or high gain electrical nulling devices are used. Passively damped systems are favored for small satellites (less than 1,000 pounds) and for low altitudes (below 1,000 nautical miles), where the gravity gradient torque is stronger.

Active Attitude Control

Active attitude control techniques include momentum exchange, mass expulsion, external magnetic torques and solar torques. Momentum control devices are the most common attitude control actuators. They work by varying the angular momentum of small masses within the spacecraft. There are three types of these devices: momentum wheels, reaction wheels and control-moment gyroscopes.

Momentum wheels are the simplest, and consist of a single, constantly spinning wheel. The rotating mass gives the satellite a stiffness or resistance to outside torques. To provide pointing in more than one axis, momentum wheels are oriented at 90° angles to each other. Thus, the satellites orientation can be fixed within 0.1 and 10°.

Reaction wheels differ from momentum wheels in that they spin only when the satellite needs to be oriented differently or when controlling the effect of an externally produced torque. Spacecraft employing these devices usually have three or four, oriented at right angles. The fourth is for redundancy. Reaction wheels can achieve 0.001° pointing accuracy.

Both the momentum and reaction wheel devices have limiting speeds. If disturbances act continuously in the same direction so that wheel speed approaches maximum (saturation), the spacecraft must use another method (like mass expulsion) to reduce or "dump" angular momentum. To change a vehicle’s orientation, the motor can be commanded to change the spin rate of the wheel. The vehicle compensates in the opposite direction in order to conserve momentum.

Control-moment gyroscopes are the other momentum-based active control devices. They are as accurate as reaction wheels but can respond at a faster rate, making them more desirable in tracking applications. They are also more expensive and complex than reaction wheels. Mass expulsion uses a propulsion system to perform both small velocity corrections and attitude control. A large number of small thrusters, called reaction-control jets, can work together to provide translational acceleration (velocity correction) or can work in pairs to provide torques for attitude control. For angular motion, the thrusters are located near the vehicle extremities in order to develop the maximum torque for the least thrust or thruster size. Thrusters operate by expelling either hot or cold gas. Cold gas is stored under pressure and released to provide thrust. Hydrozine is a hot gas system using a chemical catalyst instead of an oxidizer for combustion. The rate of mass expenditure, or the total mass expended, depends upon the angular or linear velocity required, the size of the vehicle and the location of the thrusters. This active control system is insensitive to disturbance torques, provides the widest variety of control orientations and is highly precise. The major drawback in any mass propulsion system is the need to carry propellant, which adds considerable weight to the vehicle, especially for long missions.

Magnetic and solar torquers make use of environmental forces to impart stability and develop attitude changes. Electrical current run around a piece of metal on the spacecraft creates an electromagnet which will align itself along the Earth's magnetic field. These magnetic controls are relatively light and can be programmed to desaturate the momentum wheels. They can also be used to compensate for the natural magnetic effects of satellite components.

Torques caused by solar radiation pressure can be used for attitude control by orienting panels in the flow of solar radiation. The torques are small, but when extended over a long period, can have significant affect. Advantages to solar and magnetic torquers are that they do not require onboard propellant and they provide smooth corrections. On GPS satellites, magnetic torquing is the primary method of reaction wheel desaturation. Solar torques provided attitude control on the Mariner IV spacecraft.

TELEMETRY, TRACKING AND COMMANDING SUBSYSTEM (TT&C)

Telemetry

Telemetry is measurement data transmitted to operators at ground stations over a radio link. It contains information which is used to evaluate both the satellite's and the booster's performance. Telemetry data transmissions begin prior to launch, and continue throughout the life of the satellite. Launch and injection into orbit are especially critical times because data from the booster, upper stages (if used) and satellite must be received and evaluated.

The satellite's telemetry data, whether analog or digital, contains two general classes of information. The first, payload or mission data, varies with the mission of the satellite. Examples of payload data types are meteorological, oceanographic, astronomical and Earth resources information. Spacecraft health and status data types are relatively standard, regardless of the type of mission. This data consists of pressure, temperatures, flow rate, current, voltages and events as they occur throughout the satellite systems, subsystems and components. Once the satellite is on orbit, operators settle into more or less routine operations in which they continuously monitor the bus and payload telemetry in order to respond quickly to problems.

Tracking

Before we can communicate with a ballistic missile or orbiting satellite, we must know where it is with respect to our ground stations. Tracking is the process of making observations of the spacecraft's position relative to a tracking station or other fixed point whose position is accurately known. Orbit determination is a process in which the tracking observations are used to determine the spacecraft's orbital characteristics and its position in space. Tracking stations use elevation, azimuth, range and range rate data to determine satellite position relative to time.

The simplest way to track a satellite is through the use of a beacon or a transponder which announces the satellite's presence. In current tracking arrangements, most satellites use a transponder system from which range rate data is extracted. Beacons are also used as locating devices on recovery capsules. A transponder is triggered "On" only after receiving a specially coded signal from a ground tracking station. Upon receipt of this signal, the transmitter is activated and the coded signal is turned around by satellite and sent back to the tracking station. In addition to providing a greater degree of security, coded transponders enable operators in the tracking system to derive extremely accurate range information by measuring the elapsed time between the transmission and subsequent reception of the coded signal. Various other tracking methods include Doppler tracking, radar tracking and ranging, interferometer tracking and optical tracking.

Radar tracking satellites is similar to radar tracking aircraft. Radio frequency energy is transmitted from a ground antenna up to the satellite. The energy reflected back to the ground is received by the tracking station. Satellite range is then computed by measuring the time required for the signal to make the trip. These measurements and calculations, taken over time, are used to determine range rate and relative motion.

Doppler tracking measures changes in transponder frequencies (satellite radio wave transmissions) which are caused by relative velocity differences. It requires calculation of the relative velocity of a satellite in relation to an observer (ground station).

Interferometer tracking measures phase differences in signals from the spacecraft, as received on the ground by precisely located antennas and reflectors.

As the name implies, optical tracking employs telescopes and optical instruments to search for and track the satellite via light reflected off its surfaces. This method can only be used at night and under clear skies.

Commanding

Commanding is the process of communicating to the satellite from a ground site (**Fig. 10-11**). The satellite is controlled via commands sent to change voltages, temperatures, aperture settings and other parameters aboard the spacecraft. This task is accomplished by

Fig. 10-11. A Ground Command and Control Site

transmitting coded instructions from the ground station over radio frequency carrier, referred to as the uplink, to the satellite's receiving equipment.

Examples of events executed by commanding include ascent control, orbit adjust, reentry by separation, engine ignition or cutoff and on/off of internal systems. In some cases, an entire sequence of events may be started by a single, preprogrammed command.

SINGLE commands are employed when controlling specific satellite functions. A SINGLE command is a command that is equal to one set of binary digits which will cause only one function to be performed in the satellite. A BLOCK command is one in which one command number may represent a number of single commands which will be transmitted to the satellite in a specific order.

Commands can be further identified as either Real-time Commands (RTC) or Stored Programs Commands (SPC). The primary difference between these commands is the time of execution. A Real Time Command initiates events on the satellite upon receipt of the command. RTC's are desired if command execution is necessary while the satellite is still within sight of a ground station. SPC's are sent to the satellite while it is still within a ground station view, but it causes certain functions to be performed after the satellite has passed out of sight of a ground station.

Some spacecraft have self-sustaining reference packages which contain preloaded commands. The advantage of such systems is that the preloaded commands allow the satellite to respond autonomously to situations and changes which are within an expected range of values. Spacecraft which contain no self-sustaining reference package must be continuously monitored and commanded by the ground control site for proper station keeping.

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TOC

Chapter 11

U.S. SATELLITE COMMUNICATIONS SYSTEMS

Instantaneous worldwide communications, connecting all nations, has been a dream of mankind for ages. Until the development of technologies to build, launch and operate artificial earth satellites, specifically communications satellites, the means to make such connections was unavailable. Through communications satellites, it is now possible to access telephone, telegraph, instant news information and computer links around the globe. This global connectivity provides military commanders with the ability to exercise nearly on-scene command and control. Communication satellite systems and uses continue to develop rapidly.

HISTORY

One of the most remarkable prophecies of the twentieth century was published in the magazine *Wireless World* in 1945. In a short article, *"Extra-Terrestrial Relays,"* British scientist and fiction writer Arthur C. Clarke described the use of, in 24-hour orbits positioned above the world's land masses, to provide global communications (**Fig. 11-1**).

Clarke stated:

"An artificial satellite at the correct distance from the earth could make one revolution every 24 hours, i.e., it would remain stationary above the same spot and would be within optical range of nearly half of the earth's surface. Three repeater stations, 120 degrees apart in the correct orbit, could give television and microwave coverage to the entire planet."

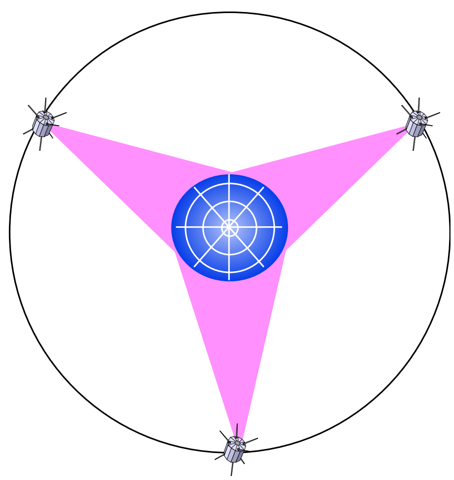

Fig. 11-1. Clarke Orbit

Clarke's theory made little impact until John R. Pierce of AT&T's Bell Laboratories evaluated the various technical options and financial prospects of satellite communications. In a 1954 speech followed by an article published in 1955, Pierce, unaware of Clarke's article 10 years earlier, elaborated on the utility of communications "mirrors" in space: a medium-orbit "repeater" and a 24-hour orbit "repeater." Pierce compared the communications capacity of a satellite, estimated to be 1,000 simultaneous telephone calls, and the communications capacity of the first transatlantic telephone cable (TAT-1), which could carry 36 simultaneous telephone calls. Since the cable cost $30-50 million, Pierce wondered if a satellite would be worth a billion dollars.

Communications by Moon Relay

The U.S. Navy began conducting experiments in 1954 bouncing radio signals off of the moon. These experiments led to the world's first operational space communications system, called Communication by Moon Relay (CMR) (**Fig. 11-2**), The relay was used between 1959 and 1963 to link Hawaii and Washington, DC.

In 1957, the Soviet Union launched the world's first artificial satellite, Sputnik I. This sparked great interest and speculation, as many began to consider

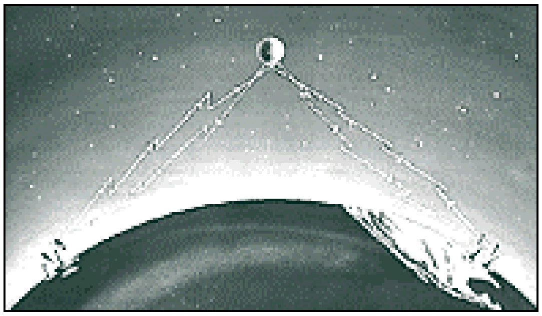

Fig. 11-2. Communications by Moon Relay

the benefits, profits and prestige associated with satellite communications.

In the late 1950's and early 1960's, NASA began experimenting with passive (reflector) communications satellites such as Project Echo. About the same time, the Department of Defense, with ADVENT program, worked to develop active (or "repeater") satellites that amplify the received signal at the satellite.

NASA launched Echo 1 on 12 August 1960 (**Fig. 11-3**). Leonard Jaffe, the director of the communications program

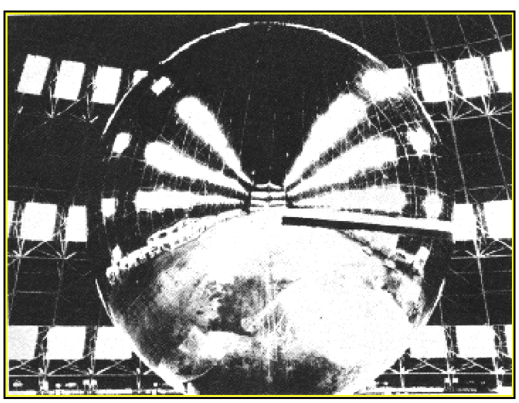

Fig. 11-3. Echo I Satellite

NASA Headquarters, wrote:

"Numerous experiments were conducted with Echo I in the early months involving practically all of the types of communications. Echo I not only proved that microwave transmission to and from satellites in space was understood and there would be no surprises but it dramatically demonstrated the promise of communications satellites. The success of Echo I had more to do with the motivations of following communications satellite research than any other single event."

The Echo I spacecraft was a 100-ft. diameter balloon made of aluminized polyester. It was inflated after being put into a 800-900 nautical mile orbit. Radio waves could be reflected off of the smooth aluminum surface.

Echo demonstrated satellite tracking and ground station technology that would later be used in active systems. After Echo II was launched on 25 January 1964, NASA abandoned passive communications systems in favor of the superior performance of active satellites.

In 1961, three active satellite programs were started under contract to and with cooperation of NASA. Two were for medium-orbit satellites and one for a 24-hour-orbit "repeater." The programs culminated in the 1962 launch of two medium-orbit satellites, TELSTAR and RELAY, and the 1963 launch of SYNCOM, the first 24-hour orbit (geostationary) satellite.

Meanwhile, the military program to build a geostationary satellite (ADVENT) was experiencing delays in launcher availability and cost over-runs. Therefore, and also in light of the complexity of the satellite, the program was canceled.

The first operational military satellite communications system began five years later and was comprised of two Initial Defense Communications Satellite Program (IDSCP) satellites, which were launched in July 1967. These satellites were designed to launch in groups of up to eight, and a total of 26 IDSCP satellites were launched in four groups to near geostationary, 18,300 statute mile orbits. The IDSCP evolved into what is today's Defense Satellite Communications System (DSCS). The IDSCP satellites are often referred to as DSCS Phase I.

In February 1969, the IDSCP was followed by the Tactical Satellite Communications (TACSATCOM) program. This program was used to evaluate mobile user needs in tactical situations. One

TACSATCOM satellite was placed in geostationary orbit to support the Tactical Communications Program. The TACSATCOM would become the Fleet Satellite Communications (FLTSATCOM) Program.

CURRENT OVERVIEW

Continuous global coverage from a medium altitude satellite orbit (200-10,000 NM above the earth) would require from 18 to 24 satellites. Full global coverage between 70^{O} North latitude and 70^{O} South latitude can theoretically be achieved using three equally spaced (120^{O} apart) geostationary satellites. Operationally, four or more satellites are required to provide this coverage in order to mitigate the effects of a satellite failure on our networks. Four satellites provide overlapping capabilities, greater traffic handling capacity and a measure of redundancy.

Satellite systems have significantly improved the reliability and the accuracy of aviation and maritime communications, moving those functions out of the high frequency (HF) portion of the radio spectrum. The advantages of satellite communications are extensive. Although submarine cables, fiber optics and microwave radio can effectively compete with satellites for geographically fixed wide-band service, the satellite is unchallenged in the provision of wide-band transmissions to mobile terminals. The inherent flexibility that a satellite communications system provides is essential to the conduct of military operations both nationally and globally. There no viable alternatives to satellite communications for military applications.

Military Satellite Communications (MILSATCOM) comprises three primary systems (all in geosynchronous orbits), operating in three specific frequency regimes as follows:

- The Fleet Satellite Communications System (FLTSATCOM), consisting of the Fleet Satellites (FLTSAT) and UHF Follow-on (UHF F/O) satellites, operate in the Ultra-high Frequency (UHF) spectrum at 225 - 400 MHz.
- The Defense Satellite Communications System (DSCS) operates in the Super-high Frequency (SHF) spectrum at 7250 - 8400 MHz.
- The third system, Milstar, operates mainly in the Extremely-high Frequency (EHF) spectrum at 22 - 44 GHz.

Each of the three systems above provide support for a fourth system, the Air Force Satellite Communications system (AFSATCOM). AFSATCOM is not a system of dedicated satellites, but a system of dedicated channels or transponder packages riding on the satellites of the MILSATCOM system. AFSATCOM is used to disseminate Emergency Action Messages (EAMs) and Single Integrated Operations Plan (SIOP) information.

The 50th Space Wing, located at Schriever AFB, Colorado, controls DSCS and Milstar, through the 3rd and 4th Space Operations Squadrons (3SOPS, 4SOPS), respectively. Control of the UFO and FLTSAT constellations transferred from 3SOPS to the Navy's Satellite Operations Center (NAVSOC), Pt. Mugu CA, in mid 1999. The responsibilities of 3SOPS, 4SOPS and NAVSOC for satellite control include commanding on-board satellite systems, providing tracking data for orbit determination and conducting telemetry analysis. The operators also provide trend analysis and vehicle anomaly resolution. Program direction for the above communication systems is the responsibility of the agencies that manage the various communications payloads.

FLEET SATELLITE COMMUNICATIONS (FLTSATCOM)

The FLTSATCOM system provides near global operational communications for naval aircraft, ships, submarines and ground stations. It also provides communications between the National Command Authority (NCA) and the strategic nuclear forces as well as between other high-priority users. High priority users include the White House Communications Agency, reconnaissance aircraft, Air Intelligence Agency and ground forces (e.g., Special Operations Forces).

FLTSATCOM operates primarily in the UHF band, but uses SHF for the Navy's shore-based Fleet Satellite Broadcast uplink. Some of the satellites also carry EHF transponders for use with MILSTAR ground terminals. The FLTSATCOM constellation comprises four FLTSATCOM satellites (**Fig. 11-4**) located in geosynchronous orbits. The remaining FLTSATs will be retired and replaced by UHF F/O satellites (already in orbit) after the EAM dissemination and nuclear reporting mission of AFSATCOM transitions to Milstar.

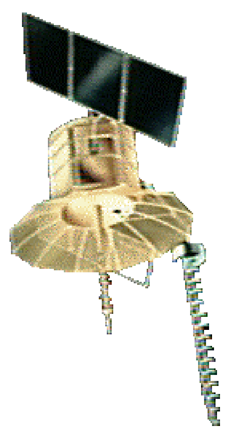

Fig. 11-4. FLTSAT

FLTSAT Mission Subsystems

FLTSAT communications packages include one SHF uplink/UHF downlink fleet broadcast channel on a 25 KHz transponder, nine 25 KHz channels, twelve 5 KHz narrow-band channels and one 500 KHz wide-band channel for use by high-priority users. Up to fourteen 25 KHz users can be accommodated on the 500 KHz wide-band channel at any one time. Antennas include UHF transmit and receive antennas, S-band omnidirectional antenna (to relay Navy SHF broadcasts) and the EHF transmit and receive antennas on Flights 7 and 8.

The U.S. Navy's NAVSOC at Pt. Mugu, CA performs Command and Control (C2) of FLTSAT and UHF F/O constellations under the Operational Control (OPCON) of Naval Space Command (NAVSPACECOM).

AIR FORCE SATELLITE COMMUNICATIONS SYSTEM (AFSATCOM)

AFSATCOM provides secure, reliable and survivable two-way global communications between the NCA and the strategic nuclear forces. The AFSATCOM system is used for EAM dissemination, JCS/CINC Internetting, CINC force direction message dissemination, force report back and other high-priority user traffic dissemination. Strategic nuclear forces include ICBM launch and control centers, B-52, B-1B and B-2 bombers and nuclear capable submarines (SSBNs). On the FLTSATCOM satellites, all twelve 5 KHz narrow-band channels and the one 500 KHz wide-band channel have been dedicated to the AFSATCOM mission. Seven of the twelve 5 KHz narrow-band channels are regenerative and can only be used for 75 BPS digital communications (not voice). The frequency range is UHF. In addition to FLTSATCOM satellites, AFSATCOM also has transponders on board other host satellites to provide coverage over the North Pole. There are two systems in use for polar coverage: the Satellite Data System (SDS) and Package D, a piggyback payload on classified host vehicles. SDS satellites include a payload similar to the twelve-channel 5 KHz system onboard the FLTSATs. However, all twelve are regenerative and can only be used for 75 BPS data. Package D satellites provide a UHF package similar to the SDS satellites. Ground control is accomplished by the host satellite network.

UHF FOLLOW-ON (UHF F/O)

The UHF F/O system consists of eight (plus one spare) satellites (**Fig. 11-5**), located in the same geosynchronous orbital positions as FLTSATCOM (two UHF F/Os at each FLTSAT location). The Navy owns the FLTSATCOM and

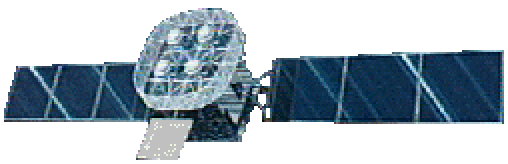

Fig. 11-5. UHF Follow-on (UHF F/O)

UHF F/O systems and is responsible for the system configurations and for their communications support to all services. The main mission of UHF F/O is to support global communications to Naval forces. UHF F/O provides channels to replace the 5 KHz narrow-band channels previously available on FLTSATCOM and replaces the 500 KHz DOD wide-band channel with an appropriate number of 5 and 25 KHz channels. UHF F/O does not replace the regenerative, frequency-hopped 5 KHz channels serving the EAM dissemination and nuclear reporting mission of AFSATCOM. The Milstar system and the EHF transponders on UHF F/O fulfill these latter requirements.

Each UHF F/O has 18 channels of 25 KHz bandwidth and 21 channels of 5 KHz bandwidth; essentially doubling the FLTSATCOM capability. Since there are two satellites at each orbital position, 78 UHF channels will be available over the Atlantic, Pacific and Indian Ocean regions as well as CONUS. There are no 500 KHz wide-band channels on UHF F/O. Flights four through ten have EHF transponders for use by Milstar ground terminals. Flights eight through ten also carry EHF Ka band transponders for use by the Global Broadcast Service (GBS) to broadcast missile warning, intelligence, video and imagery data to tactical units.

All UHF F/Os are Electromagnetic Pulse (EMP) protected. Although each channel can relay signals from all current military UHF SATCOM radios (those that do not require processed channels), the JCS requires all UHF SATCOM radios operate in the Demand Assigned Multiple Access (DAMA) mode unless a waiver has been granted. DAMA is a modified time sharing technique to allow more users to share the same UHF channel, 5 KHz or 25 KHz.

DEFENSE SATELLITE COMMUNICATIONS SYSTEM (DSCS)

The DSCS is a general-purpose satellite communications system operating in the Super-high Frequency (SHF) spectrum. The system is comprised of geosynchronous satellites, a variety of ground terminals and a control segment. It provides secure voice, teletype, television, facsimile and digital data services for the Global Command and Control System (GCCS). The system also provides communications links for management, command and control, intelligence and early warning functions.

The primary users of the DSCS are GCCS, Defense Information Systems Network (DISN), Defense Switched Network (DSN), Defense Message System (DMS), Diplomatic Telecommunications Service (DTS), Ground Mobile Forces (GMF) and the White House Communications Agency (WHCA). DSCS also supports allied nations.

Several types of ground terminals are in use. The Air Force and Navy are responsible for airborne and shipborne terminals, respectively. The strategic terminals, AN/FSC-78, AN/GSC-39 and AN/GSC-52 are maintained and operated by the Army, Air Force and Navy, depending on their location. These large terminals are equipped with 60-ft or 38-ft diameter, high-gain parabolic dish antennas, have power outputs on the order of 10,000 watts and are capable of processing thousands of voice channels. Other terminals include Tactical Satellite (TACSAT) terminals used by the Ground Mobile Forces (GMF). Owned by the Army and Marine Corps, these terminals consist of the AN/TSC-93B, with an 8 ft dish antenna, and the AN/TSC-85B with an 8 or 20 ft dish antenna. The Air Force TACSAT terminals are the AN/TSC-94A, with an 8 ft. dish antenna, and the

AN/TSC-100A, with both the 8 and 20 ft. dish antennas. The TACSAT terminals are housed in shelters that can be transported by HMMWV (TSC-93B & TSC-94A), 2 ½ ton or 5 ton truck (TSC-85B) or mobilizers (TSC-100A).

Other special user terminals controlled by the JCS include the AN/TSC-86 DSCS standard light terminal and the Jam Resistant Secure Communications (JRSC) terminal, AN/GSC-49. Both terminals are deployed with 8 as well as 20 ft dish antennas.

Some smaller terminals have only a single link capability (e.g., AN/TSC-93), whereas others are able to transmit as many as 9 links (carriers) and can receive 12 links (e.g., AN/FSC-78). The capacity of each link can vary from 1 to 96 voice circuits or digital data at rates from several kilobits per second to greater than 10 MPS. Currently, both Frequency Division Multiple Access (FDMA) and Spread Spectrum Multiple Access (SSMA) are used, with some terminals having both types of equipment. During Operation Desert Storm, over 100 TACSAT terminals were deployed to Saudi Arabia and provided more than 80% of the communications.

Each of the five operational and spare satellites has a primary and alternate network control station located at major nodes such as Ft. Detrick, Maryland.

The DSCS control segment allocates satellite capacity to best serve user requirements. Control segment computer algorithms provide an allocation process that makes use of the considerable flexibility of the DSCS III satellites. This flexibility includes the antenna patterns and connectivities and also involves precise calculations of the Effective Isotropic Radiated Power (EIRP) required to meet specified link quality. The control segment optimizes the network configuration for the FDMA, TDMA and SSMA operations. It also responds to jammers and generates command sets to configure the satellite and processes telemetry from the satellites.

DSCS Space Segment

DSCS evolved in three phases starting with the IDSCP satellites as Phase I (sometimes called DSCS I). Phase II began in 1971 with the launch of two DSCS II satellites (**Fig. 11-6**) into geostationary orbit. The third phase began in 1982 with the launch of the first DSCS III satellite.

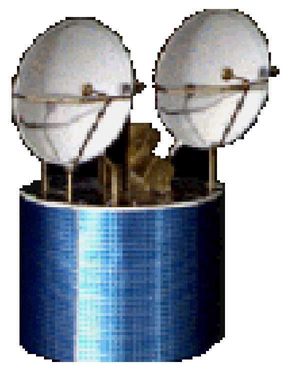

Fig. 11-6. DSCS II Satellite

The constellation today (**Fig. 11-7**) consists of five primary DSCS III satellites and five residual "spares" with limited operational capabilities. The satellites are at an altitude of approximately 22,300 miles in geostationary orbits around the equator. All ten satellites are in continuous 24-hour operations with the spares primarily used for GMF training missions.

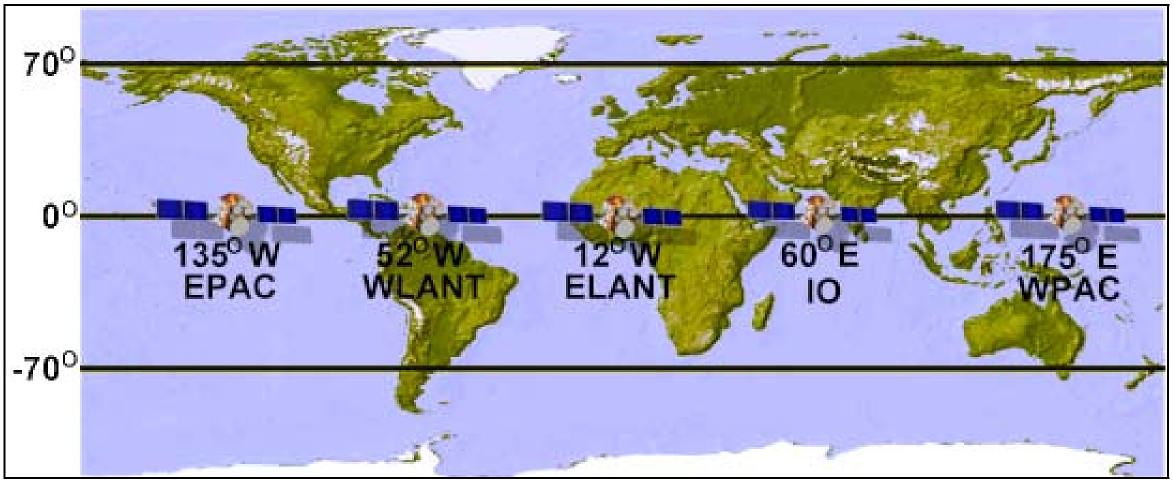

Fig. 11-7. DSCS III Notional Constellation

In addition to the DSCS III satellites, there are some DSCS II satellites (turned off) still in orbit that could be activated, on a limited basis, at any time. The DSCS II satellite located over the Indian Ocean is still active and used for training purposes.

The five primary DSCS III satellites provide overlapping footprints for worldwide communications between 70° North latitude and 70° South latitude. Communications beyond these latitudes becomes very weak due to earth's flattening in the vicinity of the poles. Heavy terminals, such as the FSC-78 with the large 60 foot antenna, could access a DSCS III satellite from some locations above 70° North or below 70° South latitude. The five satellite constellation of DSCS allows most earth terminal locations to access at least two satellites.

Key sites around the world are equipped with two earth terminals, each accessing a different satellite. These dual terminal sites allow the signal from one satellite to be retransmitted to another, extending the distance beyond one satellite's coverage area. This is called an "M-hop" (**Fig. 11-8**). M-hops make communications between opposite sides of the planet possible.

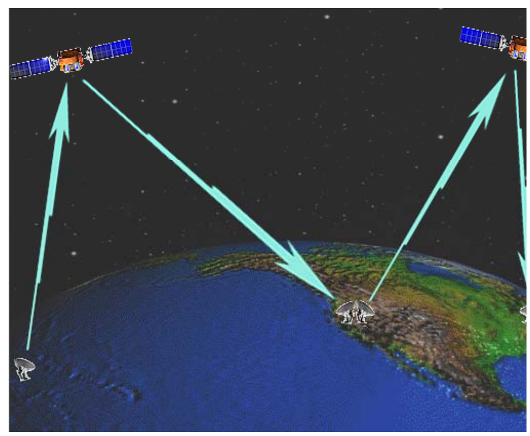

Figure 12-8. M-Hop

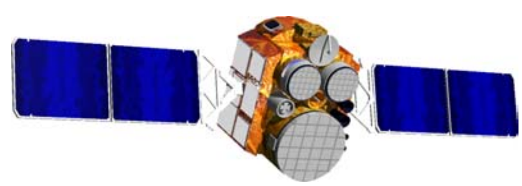

Fig. 11-9. DSCS III

DSCS III Satellite

The DSCS III spacecraft (**Fig. 11-9**) is a three-axis, momentum stabilized vehicle with an on-orbit weight of about 2,350 pounds. The spacecraft's rectangular body is 6 x 6 x 7 cubed feet, with a 38 foot span (with solar arrays deployed). The solar arrays generate 1,100 watts, decreasing to 837 watts after five years. The communications payload aboard each satellite provides a wide-band spectrum of 1000 MHz (500 MHz uplink and 500 MHz downlink) that is divided into six channels by six limited bandwidth transponders (**Table 11-1**). Four of the six channels/transponders can be switched by ground command between a number of antennas consisting of:

- Four earth coverage horns: two transmit while two receive.
- A 61-beam waveguide-lens, receive Multiple Beam Antenna (MBA) that provides selective coverage and nulling for anti-jam protection.
- Two 19-beam, waveguide-lens transmit MBAs to provide selected antenna patterns that match the network of ground receivers, and a high-gain, gimbaled dish transmit antenna for adjustable spot beam coverage.

The DSCS frequency plan falls within the SHF spectrum (X band) with uplink frequencies of 7900MHz to 8400 MHz which the transponders down-translate to the downlink frequencies of 7250 MHz to 7750 MHz. Any type of modulation or multiple access may be used since none of the transponders process or demodulate the signals.

In addition to the six wide-band SHF transponders, a Single Channel Transponder (SCT) provides secure and reliable dissemination of EAM and the SIOP communications from command post ground stations and aircraft world wide. The SCT receives communications from the ground terminals and airborne command posts at SHF or UHF, and transmits them at UHF and SHF.

The last four DSCS III satellites are being upgraded prior to launch under the DSCS Service Life Enhancement Program (SLEP). The first two SLEP improved satellites, B8 and B11, were launched in 2000. The remaining two will launch in 2002 and 2003. Under SLEP, the solar panels are upgraded to provide more power and all of the transponders are to be upgraded to

Antennas	
Receive:	Two earth Coverage (EC) One Multiple Beam (MBA)
Transmit:	Two Earth Coverage (EC) Two Multiple Beam (MBA) One Gimbaled Dish (GDA)
Transponders	
Channel 1	
Bandwidth:	50 MHz
Transmitter Power:	40 W
Transmit Ant. Options:	MBA, GDA
Receive Ant. Options:	EC, MBA
Channel 2	
Bandwidth:	75 MHz
Transmitter Power:	40 W
Transmit Ant. Options:	MBA, GDA
Receive Ant. Options:	EC, MBA
Channel 3	
Bandwidth:	85 MHz
Transmitter Power:	10 W
Transmit Ant. Options:	EC, MBA
Receive Ant. Options:	EC, MBA
Channel 4	
Bandwidth:	85 MHz
Transmitter Power:	10 W
Transmit Ant. Options:	EC, MBA, GDA
Receive Ant. Options:	EC, MBA
Channel 5	
Bandwidth:	60 MHz
Transmitter Power:	10 W
Transmit Ant. Options:	EC
Receive Ant. Options:	EC
Channel 6	
Bandwidth:	60 MHz
Transmitter Power:	10 W
Transmit Ant. Options:	EC
Receive Ant. Options:	EC

Table 11-1. DSCS III Communications Subsystem

provide 50 watts of transmitted power; the channel five transmit antenna options will be changed to allow connection to the Gimbaled Dish Antenna (GDA).

DSCS Ground Segment

The ground segment consists primarily of three groups of earth terminals:

- The strategic terminals are the medium and heavy class terminal located at fixed stations
- The TACSAT terminals are used by the GMF and are deployed by the Army, Air Force and Marine Corps throughout the world
- Finally, the special user terminals are the airborne and shipborne terminals, the JRSC terminal and the JCS controlled DSCS Standard Light terminal.

The strategic terminals provide 24-hour support to both DOD and non-DOD users. These users include GCCS, DISN, DSN, DMS and the DTS.

The medium class of the strategic terminals consists of the AN/GSC-39 and AN/GSC-52. Both terminals utilize a 38 foot antenna with redundant solid-state low noise amplifiers.

The AN/GSC-39 is capable of transmitting up to 18 individual carriers and receiving as many as 30. It is equipped with two 5,000 watt transmitters that can be combined for a total output of near 10,000 watts.

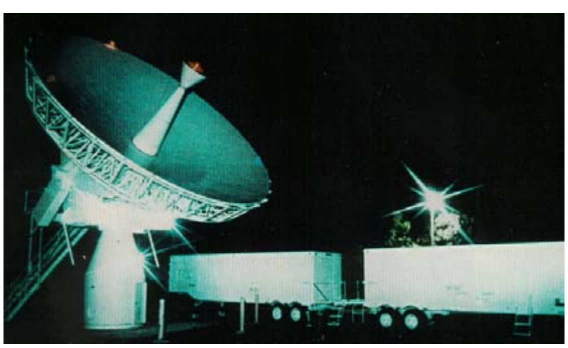

Fig. 11-10. AN/GSC-52

The AN/GSC-52, a state-of-the-art Medium Terminal (SAMT) (**Fig. 11-10**) comes equipped to transmit and receive up to 12 carriers with the ability to expand into 18. The terminal can transmit up to approximately 2,600 watts by combining the four 650 watt transmitters.

The heavy class terminal, FSC-78, is electrically the same as the GSC-39 with the exception of the antenna and low noise amplifiers. The FSC-78 is equipped with a 60–ft antenna (**Fig. 11-11**) that uses cryogenically cooled parametric amplifiers. Even though the maximum transmitter output of both terminals is the same, the maximum EIRP of the FSC-78 is far greater than that of the GSC-39 due to the increased gain of the larger antenna.

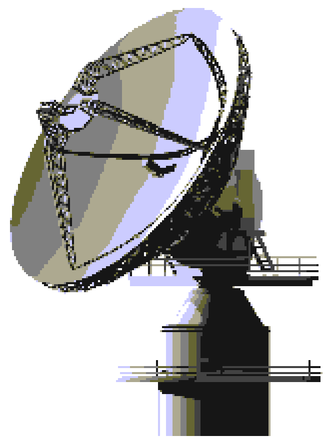

Fig. 11-11. FSC-78 60-ft Antenna

DSCS Ground Mobile Forces (GMF)

GMF operate in their own sub-network on the DSCS satellites. The GMF sub-network is not operationally compatible with the DSCS networks. This is due to the incompatibility of the GMF TACSAT terminal's signal processing equipment with that of the DSCS strategic terminal. In order for the GMF to gain access to the DSCS network, a DSCS Gateway terminal must be used.

A DSCS Gateway terminal is a strategic terminal with a complement of signal processing equipment used by the TACSAT terminals. The signal from the GMF network is processed to its lowest form by this equipment and then reprocessed by the DSCS signal processing equipment for retransmission in the DSCS network.

A GMF network consists of at least two TACSAT terminals, each transmitting one carrier which is received by the other. The TACSAT terminals are classified in one of two categories: Nodal or Non-nodal. Nodal terminals (AN/TSC-85B and AN/TSC-100A) have the ability to transmit one carrier and receive up to four. Non-nodal terminals (AN/TSC-93B and AN/TSC-94A) can transmit and receive only one carrier. Each carrier has the capacity of up to 96 telephone calls or 10 MPS of data. Links with more than 32 telephone circuits or a data rate greater than 3 MPS are far too difficult to support with the small 8 and 20-ft antennas and are rarely used.

There are three basic GMF network configurations. The simplest consists of two terminals, each transmitting one carrier received by the other. This is called a "Point-to-point" configuration. Any combination of Nodal or Non-nodal terminals can be used. One terminal could be a DSCS Gateway terminal, while the other two configurations are called "Hub-spoke" and "Mesh."

The Hub-spoke configuration consists of a Nodal terminal as the "Hub" and up to four "spokes" that can be Nodal, Non-nodal or DSCS Gateway terminals. In the Hub-spoke configuration, the hub terminal transmits one carrier that is received by all four spokes. In turn, each spoke transmits one carrier back to the hub.

A Mesh configuration is a combination of two or more hub-spoke configurations that are linked together. If a Nodal terminal is used as one of the spokes in a hub-spoke configuration, three additional terminals could be added as spokes to this terminal to create a mesh.

The TSC-85B is the nodal terminal used by the Army and Marine Corps. This terminal is equipped with two redundant 500-watt transmitters and equipment to transmit one and receive up to four carriers. It is deployed with either an 8 or 20-ft antenna, and is housed in a modified S-250 shelter transported on a 2 ½-ton or 5-ton truck.

The Army and Marine Corps' Non-nodal terminal is the TSC-93B, which is equipped with one 500-watt transmitter and can transmit and receive only one carrier. It is housed in a shelter transported on a HMMWV and is deployed with an 8-ft antenna.

The Air Force nodal terminal is the TSC-100A, which is similar to the TSC-85B. The TSC-100A is equipped with two higher power transmitters that can be combined for a total output power of approximately 1,800 watts. It is capable of transmitting and receiving up to four carriers and is deployed with both an 8 and 20-ft antenna. These antennas allow the TSC-100A to access two satellites simultaneously. It is housed in a modified S-280 shelter transported on mobilizers.

The TSC-94A is the Air Force's Non-nodal terminal which is equipped much like the TSC-93B, except for the two 500-watt transmitters and other equipment redundancy. It also deploys with only the 8-ft antenna and is housed in a shelter transported on a HMMWV.

DSCS Control Segment

The Chairman, Joint Chiefs of Staff has primary responsibility for DSCS with USCINCSPACE having Satellite Operations Manager (SOM) responsibilities as defined in CJCSI 6250.01. The Defense Information Systems Agency (DISA) is the DSCS SATCOM System Expert (SSE), and network manager, and executes DSCS command and control in support of the Global and Regional SATCOM Support Centers (GSSC, RSSC). DISA is a DOD agency that reports directly to the Chairman of Joint Chiefs of Staff and the Assistant Secretary of Defense for C3I. The DISA mission is to develop, test, manage, acquire, implement, operate and maintain information systems for C4I and mission support under all conditions of peace and war. The DISA core mission areas include:

- <u>Global Command and Control System (GCCS)</u>**.** An information system designed to support deliberate and crisis planning with the use of an integrated set of analytical tools and flexible data transfer capabilities. It will become the single C4I system to support the warfighter, foxhole to command post.

- Defense Information Systems Network (DISN). A program for the graceful technology evolution from the use of DOD networks and systems to the use of commodity services wherever possible. It replaces DSNET and supports DSN, SIPRNET, NIPRNET and FTS 2000 (Fed Telecomm System). DISN also provides information transport services for voice, text and imagery.
- Defense Message Service (DMS). A program geared towards reducing cost and staffing while maintaining existing levels of service and security for DOD messages. Its goal is for secure, accountable and reliable writer to reader messaging for the warfighter at reduced cost.
- Global Combat Support System (GCSS). GCSS uses GCCS as a baseline. It is a strategy to integrate existing combat support systems to gain efficiency/interoperability in supporting the warfighter. It will provide a fused, real-time combat support view of the battlespace, eliminating stove-piped systems by achieving a common operating environment (COE).

DSCS launch, on-orbit operations (station-keeping), telemetry analysis, tracking data for orbit determination and commanding of on-board subsystems is the responsibility of the 3SOPS. 3SOPS is a component of the 50th Operations Group, 50th SW at Schriever AFB, Colorado.

Under USARSPACE, the 1st Satellite Control (SATCON) Battalion mission is to provide communications network control for the DSCS. The 1st SATCON Battalion operates and maintains five DSCS Operations Centers (DSCSOCs) worldwide. The DSCSOCs provide real-time monitoring and control for the DSCS and GMF networks. They also perform payload control, which involves making changes to transponder and antenna configuration.

JCS, as specified in CJCSI 6250.01, validates all DOD and non-DOD MILSATCOM requirements, apportions resource capacity, approves satellite repositioning and resolves conflicts. USSPACECOM, for the JCS, provides operational direction along two paths.

USCINCSPACE is responsible for assuring access to, and use of, space for the U.S. and its allies and for operating Joint Staff designated space systems in support of U.S. and allied military forces.

USCINCSPACE is also the principal space advocate and advisor to the CJCS. Responsibilities include:

- Assessing the worldwide impact of proposed satellite movements
- Providing recommendations to the CJCS
- Providing a space assessment to DISA and the Joint Staff based on MILSATCOM requirements as documented in the Satellite Database (SDB).

USCINCSPACE provides operational command through its components in order to:

- Operate and maintain the Mission Control Centers (MCCs)
- Execute tracking, station-keeping and ephemeris generation
- Execute satellite movements as directed by the CJCS.

USCINCSPACE provides operational command through USARSPACE in order to:

- Operate and maintain all DSCSOCs
- Provide personnel resources to ensure network and payload control
- Operate and maintain GSSC and RSSC's and for GMFSC network planning and coordination

DISA Code DOT provides technical direction through the GSSC and RSSC's in order to:

- Direct network and payload control executed by the DSCSOCs
- Direct station keeping and movements executed by the MCCs

The RSSCs, through coordination, will:

- Obtain satellite-engineering parameters to be used for resource allocation to the GMFSC and assistance in resolving conflicts from the DISA.
- Receive and process satellite access requests from the CINCs for GMFSC access and provide satellite access authorizations.

DSCS Access

Access to the DSCS satellites is accomplished differently depending on whether the user desires the DSCS network and the GMF network. For DSCS network access, the following is a summary of the process:

1) Users identify their requirements.
2) Users submit their requirements to their respective CINC.
3) The CINC's J6 will coordinate with the GSSC, applicable RSSC and DISA for the required resources.
4) DISA will engineer the link parameters to support the requirements. The information is passed to the DSCS Ops Centers where the Network Controllers add/subtract/ monitor the entire net.
5) The user is informed of the circuit design (power/bandwidth/times of usage).
6) Communication stays open between all parties to assure the warfighters' needs are met.

For GMF access, the tactical user receives mission tasking and begins the planning process with the Communications Systems Planning Element (CSPE). The CSPE determines the mission's satellite communications requirements and develops a Satellite Access Request (SAR) for the RSSC.

The SAR consists of the following:

- Who, When, What, Where and How
- Unit and Mission, date/time, data rate, terminal types and location, network configuration and priority

The RSSC will:

- Coordinate with DISA for resources to support the SAR
- Perform network planning with parameters given by DISA if the SAR can be supported.
- Develop Satellite Access Authorization (SAA) with the satellite, look angles, power, frequency and controller.

The SAA is sent to the originating CSPE, DISA and the controller. The CSPE produces deployment orders and configuration sheets for terminals while DISA directs the controlling DSCSOC to update their operational database. Finally, 30 minutes prior to the mission start time, the controller contacts the terminals and directs access to the satellite.

MILSTAR

Milstar provides highly robust, secure and survivable communications among fixed-site and mobile terminals. The name "Milstar" originated as the acronym for Military Strategic and Tactical Relay satellite system. In the early '90's the acronym was adopted as the system name, and is therefore not written in capital letters. The MILSATCOM Joint Program Office manages Milstar at the Space and Missile Systems Center, Los Angeles AFB, California.

Originally, Milstar was required to provide assured connectivity through all levels of conflict for strategic nuclear and strategic defense forces. The Milstar Low Data Rate (LDR) payload was designed to meet this requirement, and each of three Services developed LDR terminals to use the Milstar LDR payload. However, in the National Defense Authorization Act for FY91, Congress requested the DOD to restructure the Milstar system to reduce cost, increase the utility of the system to tactical users, and eliminate the most enduring nuclear warfighting capabilities. The DOD responded by reducing the number of large strategic terminals and increasing the number of smaller tactical terminals. Other changes included the elimination of the most durable nuclear survivable capabilities for satellites and terminals and the addition of a Medium Data Rate (MDR) capability on satellite 3 and beyond, to support tactical users.

Operating primarily in the Extremely High Frequency (EHF) and Super High Frequency (SHF) bands, Milstar satisfies the U.S. military's communications requirements with worldwide, anti-jam, scintillation resistant, Low Probability of Intercept (LPI) and Low Probability of Detection (LPD) communications services.

The first Milstar satellite (**Fig. 11-12**)

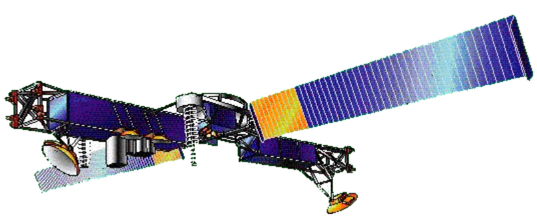

Fig. 11-12. Milstar

was launched from Cape Canaveral on 7 February 1994 aboard a Titan IV booster with a Centaur upper stage. The second Milstar satellite was launched from Cape Canaveral on 6 November 1995. They are in low-inclination, geosynchronous orbits at an altitude of approximately 22,300 miles. The first two satellites are block I units with only LDR (75 to 2400 BPS) capability. Milstar flight 1 is positioned at 120° West longitude and flight 2 is positioned at 4° East longitude. The block I satellites will be replaced with an operational constellation of block II satellites having MDR (4.8 KBPS to 1.544 MBPS) payloads. Four block II vehicles were produced. However, the first Milstar II failed to reach orbit after its April 1999 launch. Three Milstar II's remain to be launched.

Like other satellite systems, Milstar is comprised of three segments, the Space Segment, Mission Control Segment and the Terminal Segment.

Space Segment

The Space segment consists of 3-axis stabilized satellites measuring approximately 51 feet in length. The 116-ft. solar arrays generate almost 8,000 watts of power. Often described as a "switchboard in the sky", the Milstar payloads have onboard computers that perform communications resource control. Milstar responds directly to service requests from user terminals without satellite operator intervention, providing point-to-point communications and network services on a priority basis. The Milstar payloads can reconfigure in real-time as user connectivity needs change. Milstar also employs satellite crosslinks to establish and maintain worldwide connectivity without having to rely on M hops. In the satellite's EHF and SHF bands, high gain transmit and receive antennas with small apertures produce narrow beams which are difficult to jam.

Mission Control Segment

The Mission Control Segment performs Milstar state of health maintenance, constellation control, satellite repositioning and communications management. A primary feature of this segment is its survivability, which derives from its combination of fixed station at Schriever AFB, Colorado and ground mobile control stations.

Terminal Segment

The Terminal Segment includes fixed and mobile ground terminals, ship and submarine terminals and airborne terminals. The Army, Navy and Air Force are developing and procuring terminals that are inter-operable.

The 4SOPS, a component of the 50th Operations Group, 50th Space Wing, Schriever AFB, is responsible for overall command and control of the Milstar satellite constellation. The 4SOPS executes these responsibilities through the Milstar Operations Center (MOC) at Schriever AFB, Mobile Constellation Control Stations (MCCSs) and the Milstar Support Facility (MSF). MOC personnel located in the Operations Building at Schriever AFB, perform satellite command and control, communications resource management, systems engineering support, mission planning and anomaly resolution for the Milstar system. The MOC has two fixed CCSs which interface with the geographically distributed Mobile CCSs, to execute satellite command and control. The Milstar Support Facility personnel, also located in the Operations Building, perform ground control maintenance and testing, and hardware and software configuration control.

GLOBAL BROADCAST SERVICE (GBS)

The Global Broadcast Service (GBS) is based on technology of the commercial TV industry to broadcast one-way, very large streams of data (or video) to large numbers of small receiver antennas simultaneously. The need for a worldwide, high throughput broadcast system became evident during the Gulf War. Service-owned and leased commercial communications channels were so overwhelmed that crucial information such as maps and intelligence data had to be airlifted to the warfighter. GBS was initiated as the program to fill that need. The GBS is intended to provide a large quantity of broadcast data to the warfighter, and consistently provide it in a time frame that allows the warfighter to act within the decision cycle time of the adversary. The amount of time to transmit a single Air Tasking Order (ATO) over Milstar LDR is in excess of one hour. Milstar MDR, at a full T1 data rate, requires close to 6 seconds **(Fig. 11-13).** GBS, even with the limiting factor of current encryption equipment, transmits the data in less than one half second. Additionally, because it is a broadcast stream of data, it can send to many small receivers simultaneously.

GBS High Capacity Data Dissemination (JWID 96)

SATCOM	2.4 Kbps MILSTAR	56 Kbps WIN	512 Kbps SIPRNET	1.4 Mbps MILSTAR	23 Mbps* GBS
ATO 1.1 MB	1.02 Hrs	2.61 Min	17.09 Sec	5.7 Sec	0.38 Sec
Tomahawk MDU 0.03 MB	100 Sec	4.29 Sec	0.47 Sec	0.16 Sec	0.01 Sec
8x10 Imagery 23 MB	22.2 Hrs	57 Min	6.25 Min	2.07 Min	8.4 Sec
DS TPFDD 250 MB	9.65 Days	9.92 Hrs	1.09 Hrs	21.59 Min	1.45 Min

* Currently limited to 12 Mbps encrypter rates

Fig. 11-13 Capacity Comparison

Another unique benefit of GBS is that it can transmit to relatively small, phased array receive antennas mounted on mobile platforms. This provides the capability to send imagery or other large file products in real-time to aircraft, ships and vehicles in motion.

The GBS program leveraged Commercial Off The Shelf (COTS), Government Off The Shelf (GOTS) technology and Non-Developmental Items (NDI) to facilitate faster system acquisition and fielding. Additionally, the acquisition was divided into three phases.

GBS Phase I is a continuation of a Concept of Operations (CONOPS) testbed initially placed in service by the National Reconnaissance Office (NRO). The testbed is operated by DISA and managed by USSPACECOM. It employs a single over-CONUS leased commercial Ku band satellite transponder and is used to support operational military broadcasts, exercises and to integrate system lessons learned into GBS Phase II.

GBS Phase II establishes an interim operational capability using GBS transponder packages hosted on UHF F/O satellites 8, 9, and 10. Each of these GBS transponder packages has two 30 GHz (K band) uplink antennas and three 20.2-21.2 GHz (Ka band) downlink spot beams. Two of the spot beams provide 500 nm nadir footprints while the third provides a 2000 nm nadir footprint. **Fig. 11-14** shows representative GBS Phase II spot beam footprints. The beams can be shifted from one edge of the coverage to the opposite edge in approximately three minutes.

GBS Phase III will further evolve the capabilities of GBS beyond the 2005 timeframe.

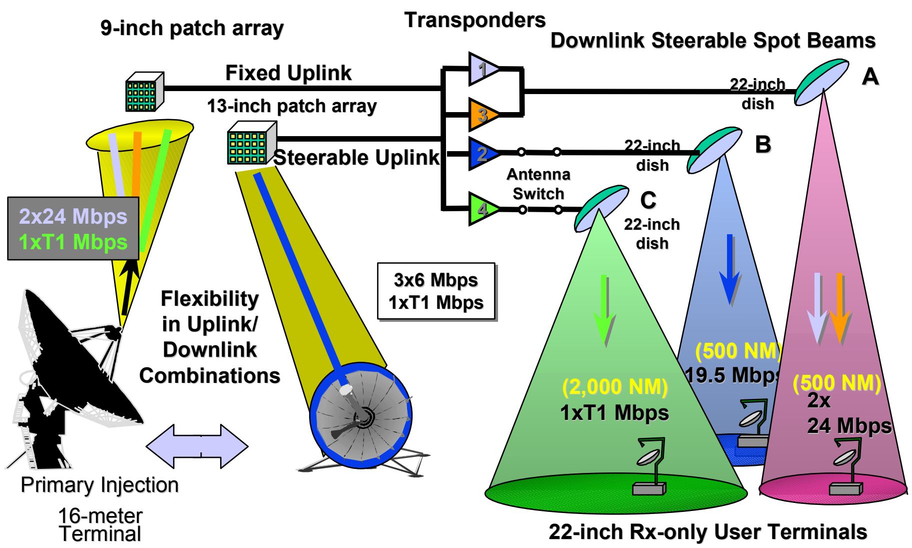

Fig.11-14 Phase II Transponder Footprint

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Chapter 12

MULTISPECTRAL IMAGERY

Multispectral Imagery (MSI) is steadily growing in popularity within DOD as a digital means for mission planning, thermal signature detection and terrain analysis. It is frequently used as a map substitute when standard Mapping, Charting and Geodesy (MC&G) products are outdated or inadequate. The ability to record spectral reflectances in different portions of the electromagnetic spectrum is the main attribute of MSI, which can be useful in a number of applications. This chapter addresses some of the theory and applications related to MSI.

OVERVIEW

In recent years, an increasing share of training and equipment resources have been dedicated to field users of MSI, such as US Marine Corps (USMC) and US Army (USA) topographic units. US Air Force (USAF) and US Navy applications of MSI have also been gaining acceptance, supporting image mapping, mission planning, navigation and targeting. These products and others have been widely used in operations such as DESERT SHIELD/DESERT STORM, support to activities in the former Yugoslavia, Somalia, Haiti, many "special" operations and in a large number of training exercises.

MSI provides information not available by only exploiting the visible region of the electromagnetic spectrum. It typically provides such things as terrain information over broad areas in an unclassified format. These attributes make MSI convenient to share with personnel and organizations that are not usually privileged with controlled information from "national" assets. Multinational forces, news media and civil authorities can all share the benefits of MSI.

MSI is currently available from commercial sources for Government or private users. Copyright law and restrictions on sharing data protect almost every image (except older imagery with little commercial value). The National Imagery and Mapping Agency (NIMA) is the executive agent for the purchase of commercial satellite imagery within DOD. Imagery purchased through NIMA was bought with a DOD-wide distribution license and can be copied and distributed freely within DOD, without copyright constraints. The Commercial Satellite Imagery Library (CSIL) is an archive of all DOD purchased commercial satellite imagery. The CSIL is maintained by the Defense Intelligence Agency (DIA) for NIMA and available electronically on the Intelink Network. Further information on how to order CSIL products can be obtained by visiting the list of NIMA/CIP & CSIL Websites provided in the references at the end of this chapter.

Many DOD organizations use MSI and are capable of production capabilities or are knowledgeable of where to obtain support for operations and exercises. Historically, MSI users who develop a support network along the lines of their most important applications generally fare better in their use of MSI. Though this type of loose organizational structure is anathema to many DOD leaders, it is this informal network of users that has been largely responsible for the successes of MSI and its applications.

HISTORY

Remote sensing was used by the military in World War II, Korea and Vietnam for tactical and strategic reconnaissance and surveillance. MSI is a direct outgrowth of the operational success of Color Infrared (CIR) imagery of the 1960's. In Vietnam, CIR imagery was frequently used to distinguish artificial features, such as camouflage, from a background of natural vegetation. The successes of this and other applications of CIR imagery fueled practical consideration of imaging devices that could not only exploit the IR (Infrared) spectral region, but could also discriminate between blue, green, red and near IR regions of the electromagnetic spectrum. The electromagnetic spectrum extends from the short wave cosmic ray region to the long wave TV and radio wave region received at home. Technology of the early 1970's led to the development of a new sensor, the 4-band Multispectral Scanner (MSS), which was used on the original Landsat 1 (see below). This sensor digitally imaged four spectral regions (blue, green, red and near infrared). Today, MSI covers the portion of the electromagnetic spectrum from the ultraviolet region through the infrared region.

Remote sensing and the MSS sensor offer other advantages besides being able to image in specific spectral regions. These include the ability to "capture" images digitally, transmit the imagery electronically, store the information on magnetic media and process the digital information using computers. Since the information is captured by the sensor as a matrix (rows and columns) of numbers, computers provide a perfect means to sift through the combinations of bands and present the information on a computer monitor. The information can be easily manipulated to support specific analysis. An image can be merged electronically with other information, such as slope or land cover data, allowing analysts to derive greater information from the imagery.

In the early days of space-borne multispectral imaging, computers were only readily available at fixed sites within DOD and at large civil institutions such as universities. Therefore, much of the early work performed with MSI was conducted using "hardcopy" (paper or film) products derived from the digital information provided by the sensor. These digital-film techniques initially were very expensive, but as the cost of computers fell and versions of image processing software which could run on most types of operating systems became available, many new MSI applications found markets within military units, other DOD agencies and the civilian sector.

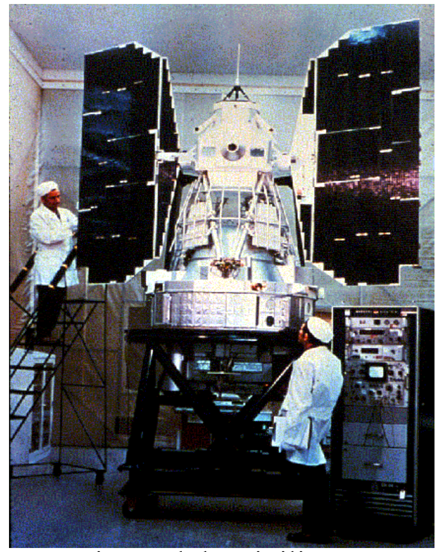

Fig. 12-1: ERTS-A in Checkout

The first satellite to use MSI for Earth remote sensing was the Earth Resources Technology Satellite-A (ERTS-A), **(Fig. 12-1)** which was later renamed Landsat 1 by the National Aeronautics and Space Administration (NASA). It was the first in a series of satellites designed to provide repetitive global coverage of the Earth's landmasses. Landsat 1 was launched in July 1972 and finally ceased to operate in January 1978. The second satellite in the series was launched in January 1975. Four additional LANDSATS have been launched in 1978, 1982, 1984, and 1999 (LANDSAT 3, 4, 5, and 7 respectively. Landsat 5 is operating beyond its design life. LANDSATs 1, 2, 3 and 4 are no longer operational.

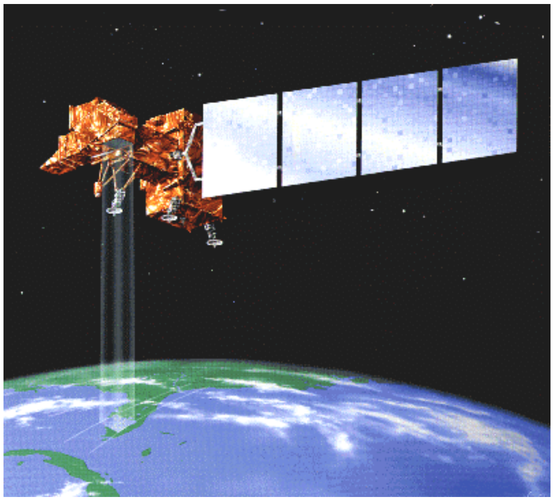

Fig. 12-2: Landsat 7

LANDSAT 6 also was launched but failed to successfully achieve orbit in October 1993. LANDSAT 7 was launched on April 15, 1999 (**Fig. 12-2)**. One of the LANDSAT 7 improvements is the Enhanced Thematic Mapper Plus (ETM+), which will produce data in six spectral bands at 28.5 meter spatial resolution, one panchromatic band with a 15 meter spatial resolution, and one long wave IR band with a 60 meter spatial resolution.

NASA was responsible for operating the LANDSAT satellites through the early 1980's. In 1985, as part of an effort to precipitate commercialization of space, LANDSAT was commercialized and all rights became the property of the Earth Observation Satellite Company (EOSAT). However, in November 1996, Space Imaging and Lockheed-Martin reached an agreement to purchase EOSAT; now referred to as Space Imaging EOSAT.

Landsat 7 was developed as a tri-agency program between NASA, NOAA, and the USGS. NASA was responsible for the development and launch of the satellite as well as the development of the ground system. NOAA provided its operational expertise to the developers of the ground system while USGS is responsible for receiving, processing, archiving and distributing the data.

Earlier LANDSAT satellites carried the MSS, the most capable sensor on LANDSATs 1, 2 and 3. The sensor suite used on LANDSATs 4 and 5 included MSS, but a more capable sensor called the Thematic Mapper (TM) was added to increase the spectral and spatial capability of these systems. The TM sensor captures information in seven spectral bands:

- Band 1 - .42-.52 microns (blue) used for such things as soil, vegetation and coastal water mapping
- Band 2 - .52-.60 microns (green) used for such things as depicting green reflectance of vegetation
- Band 3 - .63-.69 microns (red) used for such things as differentiating vegetation based on chlorophyll absorption
- Band 4 - .76-.90 microns (near IR) used for such things as vegetation and biomass surveys
- Band 5 - 1.55-1.75 microns (short wave IR) used for such things as to sense vegetation moisture and snow/cloud reflectance differences
- Band 6 - 10.4-12.5 microns (long wave IR) used for such things as thermal mapping
- Band 7 - 2.08-2.35 microns (short wave IR) used for such things as determining vegetation moisture and depiction of minerals (based on hydroxyl ions) for geological mapping

Another satellite whose product has enjoyed broad acceptance within DOD is the French satellite called "SPOT" (Satellite Pour L'Observation de la Terre). SPOT satellites carry two High Resolution Visible (HRV) sensors with the capability of collecting imagery in either three spectral bands (green, red and near infrared regions) or one panchromatic band. SPOT 4, the newest satellite in the line **(Fig. 12-3)**, added a fourth short wave band to its MSI. MSI bands are collected at 20 meter spatial resolution while the panchromatic band is collected at 10 meter spatial resolution. The SPOT data most frequently used by the DOD is the panchromatic imagery. SPOT sensors have the capability to scan 27 degrees off-nadir, allowing for repeat coverage of an area every two to twenty-six days, depending where on the earth's surface the image is being taken. SPOT's panchromatic mode also yields an image with a better spatial resolution (see the "Theory" section for a complete discussion of resolution).

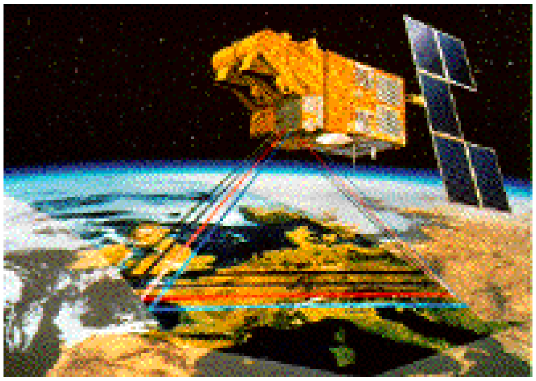

Fig. 12-3: Spot 4

By the mid-1980's, India was well on its way to developing the Indian Remote Sensing Satellite (IRS). IRS-1A was launched in 1988, and an identical follow-on satellite, IRS-1B, was launched in 1991. Both satellites are equipped with sensors that acquire multispectral data comparable to that available from LANDSAT and SPOT satellites. In December 1995, the IRS-1C was launched. IRS-1C has enhanced capabilities in terms of spatial resolution, with a 5 meter panchromatic band and a wide-field capability for large area monitoring. IRS-1D, identical to IRS-1C, became India's newest imaging satellite with its launch in September 1997 **(Fig. 12-4)**.

RADARSAT, a Canadian satellite, was launched in 1995 and is equipped with an advanced Synthetic Aperture Radar (SAR). A SAR is a powerful microwave instrument that transmits pulsed signals to Earth and then processes the returned signals. SAR-based technology provides its own illumination, enabling it to see through clouds, haze, smoke and darkness, thus providing images of the Earth in all weather conditions, at any time. This ability to actively image in all weather conditions offers a much needed alternative during periods when cloud cover prevents imaging with a passive sensor (sensors that do not provide their own illumination) such as LANDSAT, SPOT and the IRS satellites. RADARSAT provides the first routine surveillance of the entire Arctic region and accurately monitors disasters such as oil spills, floods and earthquakes. RADARSAT provides imagery that is of exceptional value in supporting a wide range of DOD and civilian applications.

Fig. 12-4: IRS-1D at liftoff

The first European Remote Sensing Satellite (ERS-1) was launched in July 1991 **(Fig. 12-5)**, with a second (ERS-2) launched in April 1995. The ERS satellites use SAR microwave techniques to acquire measurements and images, regardless of cloud and sunlight conditions. ERS sensors have the capability to measure echoes from ocean and ice surfaces, sea surface and cloud-top temperatures and provide information about ocean waves (length and direction). The ERS mission is oriented primarily towards ocean and ice monitoring, which is particularly important since oceans cover approximately three-quarters of the Earth's surface and have a dominant effect on the global climate system.

Fig. 12-5: ERS-1 at Checkout

THEORY

The electromagnetic spectrum (**Fig. 12-6**) provides the medium exploited by Multispectral Imagery. Regions of the spectrum are selected for coverage by sensor bands to optimize collection for certain categories of information most evident in those bands. Multispectral bands in the near infrared (NIR) region and shortwave infrared (SWIR) regions are used to discriminate features that are not visible to the human eye. Important features like mineral and oil-bearing rock structures are more easily detected using data collected in these longer wavelength IR bands. For instance, actively growing vegetation can be easily separated from many other features in the near infrared (NIR) region because the chlorophyll in the plants is reflected to a far greater extent in the NIR band than any other feature return. Emitted or thermal radiance in the midwave and longwave regions is also detectable by passive spectral sensors. Heat sources such as industrial processes and power-generating facilities generate IR energy that are detectable from both aircraft and satellite sensors sensitive to these spectral regions.

Multispectral sensors are designed to support applications by providing bands that detect information in specific combinations of desirable regions of the spectrum. **Figure 12-7** illustrates the utility of spectral regions.

The number and position of bands in each sensor provide a unique combination of spectral information and are tailored to the requirements the sensor was designed to support. For example, LANDSAT TM, with bands in both the near IR (chlorophyll detection) and shortwave IR (wetness) are capable of measuring the health of vegetation.

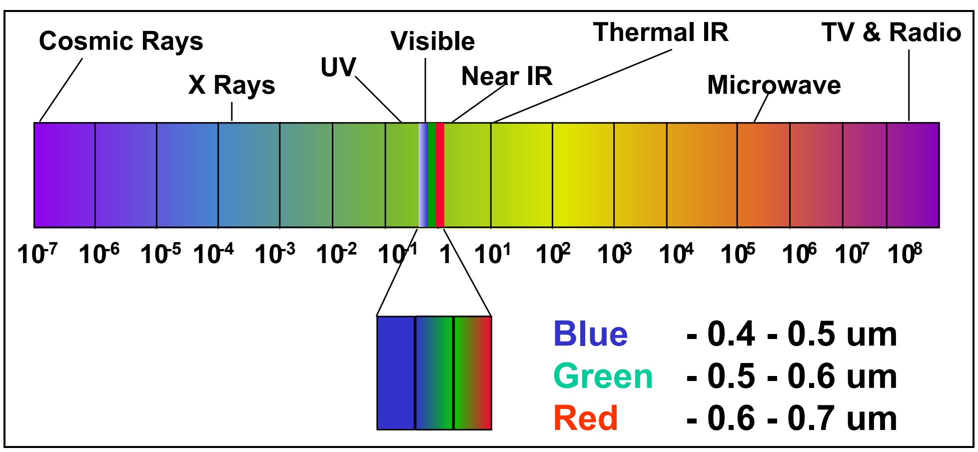

Fig. 12-6 Electromagnetic Spectrum

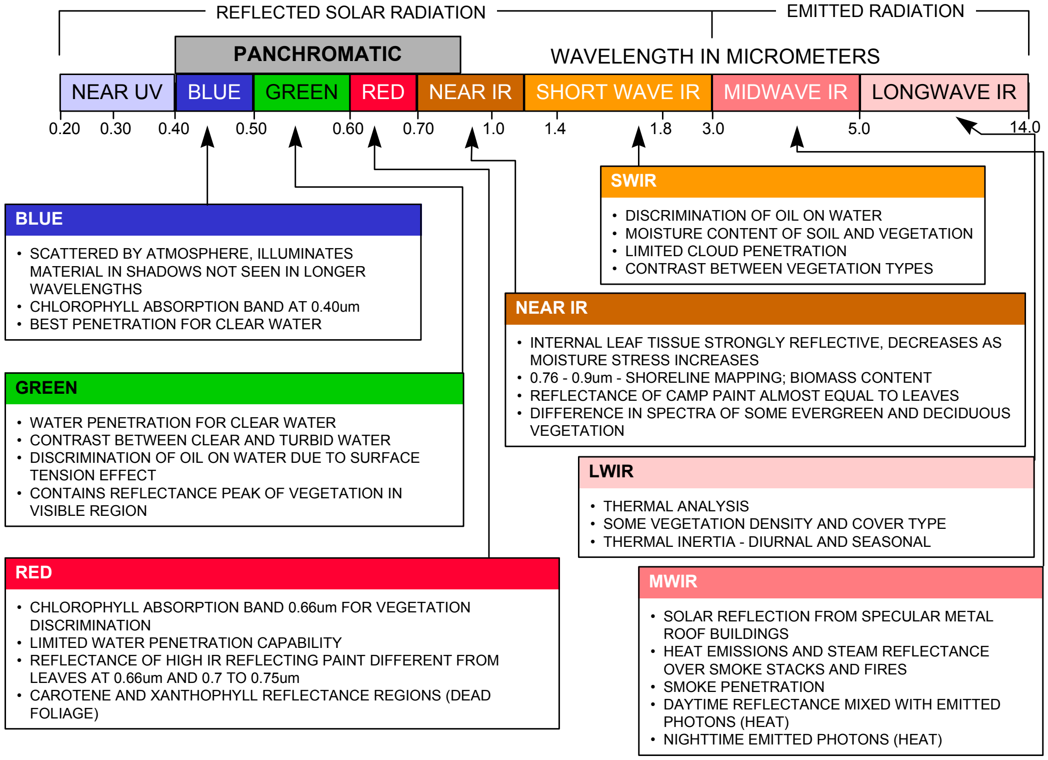

Fig. 12-7. Spectral Regions

Numeric values (also called brightness values) are recorded as a means of identifying the brightness associated with the light reflected from different material in each spectral band.

Figure 12-8 illustrates the difference in reflectivity of materials across a portion of the electromagnetic spectrum, matched against four LANDSAT bands. In this example, grass and artificial turf show similar reflectivity properties across this portion of the spectrum, except for LANDSAT band 4 (NIR).

Choosing the correct position across the spectrum optimizes the ability to discriminate between various materials. In

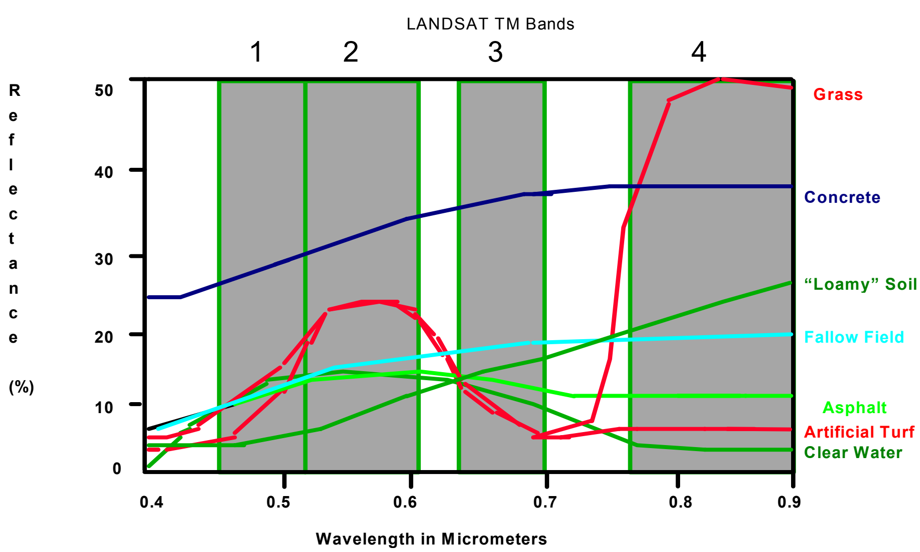

Fig. 12-8. Spectral Responses and Band Positions

this example, band 4 should be used to discriminate between grass and artificial turf.

A spectral collection system records electromagnetic (EM) radiation. The EM radiation detected by the collection system may be solar reflected energy or thermal (photons) emitted by an object. EM radiation may be thought of as a wave, having an associated wavelength measured from wave peak to wave peak.

Figure 12-9 depicts how wavelengths are measured between wave peaks. Shorter wavelengths have shorter distances between wave peaks; longer wavelengths have greater distances between wave peaks. The amount and type of radiation reflected are directly related to an object's surface chemical and physical characteristics.

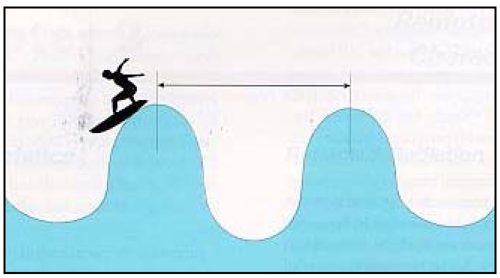

Fig. 12-9. Wavelength Measurement

A portion of the reflected EM radiation exits through the atmosphere and is received and recorded by the satellite. Those areas of the atmosphere that allow for transmission of EM radiation are known as atmospheric windows. In other areas of the electromagnetic spectrum, the atmosphere itself reflects, absorbs or scatters too much energy (because of particulate matter, aerosols and water vapor) blocking the passage of EM radiation, making it impossible for the sensor to obtain measurable information. This blocking effect is called "atmospheric attenuation." Remote sensing instruments are designed primarily to record information passed through these atmospheric windows. **Figure 12-10** demonstrates this concept.

This reflected energy is received by the sensor array in the form of individual brightness values or picture elements (pixels). In a digital system, a pixel represents an area on the Earth's surface. The SPOT panchromatic sensor has pixels that are the average of the light reflected from a 10 meter by 10 meter area (10m x 10m) on the ground. Therefore, SPOT panchromatic imagery can be said to have 10 meter pixels. LANDSAT TM has a 28.5 meter pixel size.

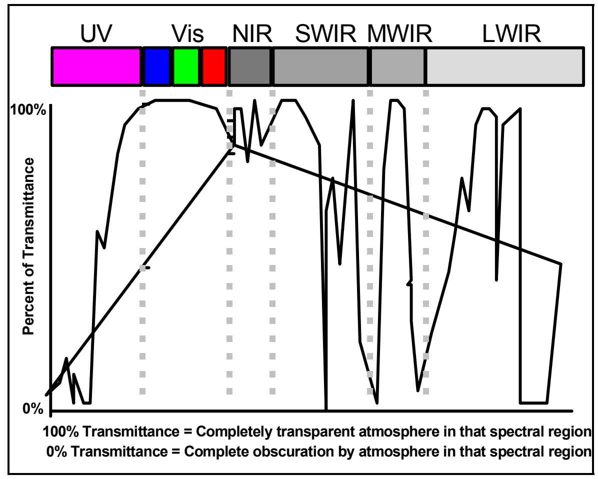

Fig. 12-10: Atmospheric Windows

Spatial resolution is another way of stating the size of pixels for a digital system. Pixel size is a direct indicator of the spatial resolution of the sensor because pixels are the smallest elements that can be detected by the sensor. Spatial resolution is a measure of the smallest angular or linear separation between two objects that can be resolved by the sensor. More simply put, it is the smallest separation between two objects on the ground that can be detected as a separate object. This type of resolution is related to the Ground Sampling Distance (GSD) of a system. GSD is defined as the distance between centers of pixels or in other words, the centers of areas sampled on the ground. An image from the LANDSAT TM sensor, which has a GSD of 28.5 meters, will not normally allow for detection of an object that is five meters. With current systems, resolution is usually referred to in meters and each pixel will sample a square area on the ground in terms of meters.

Spectral resolution refers to the spectral position and bandwidth of the bands a sensor collects. The LANDSAT TM sensor could be said to have moderate spectral resolution (seven relatively wide bands) in contrast to the SPOT panchromatic sensor that has poor spectral resolution due to its single very broad band. Generally, the narrower the band and the higher the number of bands, the better the spectral resolution.

A temporal resolution refers to the time it takes an imaging system to return to an area to collect another image. It is essentially a satellite's revisit time. All imagery collected provides an electronic "snapshot" of a particular area and moment. To understand changing conditions of a particular area may require a number of images.

Temporal resolution must be considered when ordering imagery from any source. If a satellite is not over a requester's area of interest when needed, you must wait until the satellite's next revisit time. If the area is cloud-covered during imaging, the user may have to wait for another imaging opportunity. If using LANDSAT 5, the revisit time would be 16 days (in conjunction with LANDSAT 7, it is cut to 8 days).

Radiometric resolution refers to the sensitivity of a spectral band. LANDSAT, SPOT and IRS detect and record an image in each band in 256 levels of brightness (an 8-bit image). One multispectral imager aboard the TIROS weather satellite, called the Advanced High Resolution Radiometer (AVHRR), collects imagery in 1,024 levels of brightness (a 10-bit image). Therefore, TIROS is said to have greater radiometric resolution than LANDSAT, even though the spatial resolution of this sensor is significantly less than that of the other.

Viewing geometries for MSI satellites are available in two varieties: nadir viewing and off-nadir/directional viewing. Nadir refers to the point on the planet directly below the satellite. Nadir imagers look straight down at the Earth and have no ability to look at objects away from nadir under any deliberate circumstance. Such systems are excellent for providing images that have minimal geometric distortions. Distortions in nadir imagers are normally due to Earth's curvature and space environmental effects that disrupt the stability of the satellite, introducing pitch, yaw or roll. LANDSAT, being a nadir imager, is restricted to imaging along predictable tracks, or "paths," according to orbital characteristics and the field of view of the sensor.

Directional systems have the ability to view the Earth away from the ground track of the satellite's orbit or, "off-nadir." SPOT is an off-nadir imager with the ability to image up to 27 degrees across track (side-to-side) in each direction. The opportunities presented by off-nadir systems include a reduction in the amount of elapsed time between the periods when the satellite can image the same point on Earth, referred to as "revisit time" or temporal resolution, and the ability to produce stereo views. However, due to the effect of imaging across a spherical surface, users of off-nadir imagery pay the price of higher geometric distortions within the image.

Orbital characteristics have direct influence on the imaging capacity of all spaceborne sensors. Systems such as LANDSAT, SPOT and IRS are dependent upon reflected energy from the sun that makes them effective imagers only during periods of sunlight. In addition, the usefulness of MSI is enhanced for many applications when the images are captured at specific sun elevation angles. Therefore, commercial imaging satellites are typically placed in an orbit described as a "sun-synchronous orbit," allowing the satellites to predictably collect imagery in specified sun angles. Each satellite orbits with specific times established for equatorial crossing; a feature that allows reliable prediction of imaging times at points along its ground track.

These satellites are also dependent upon maintaining a standard distance from the Earth's surface in order to maintain a consistent spatial resolution. If the satellite were to drift higher or lower in relation to the Earth's surface, the spatial resolution of each image would change as well, reducing the usefulness of the images to users who depend upon consistency. "Circular" or "low eccentricity" orbits are a necessity for imaging systems to ensure consistent spatial resolution. Each satellite is carefully placed in an orbit to meet the specifications of its sensor package.

Space environmental effects impact MSI satellites the same as they affect other satellites. Because they are in relatively low Earth orbits, they are particularly susceptible to the Earth's atmospheric effects.

MILITARY APPLICATIONS

Although not a complete list, the following MSI applications are among the more commonly used by today's military.

Analysis Images are among the simplest of MSI products, normally consisting of a natural colored image of the desired site. The image is minimally processed to reduce the production time and is constructed in pre-determined sizes according to need.

Context Images are similar to Analysis Images but are frequently produced in black and white to facilitate correlation with black and white high resolution images used by intelligence analysts. The purpose of Context Images is to provide a broad area perspective around a target.

Image Maps are a common application of Multispectral Imagery and exploit the broad-area coverage capabilities of MSI. An Image Map is nothing more than an image of the area of interest with a commonly understood grid overlaid. Typically, the images are rectified so that features on the Image Map correspond to features on a selected coordinate system and are in proper relationship to features on the Earth's surface. The advantage of these products is that the user receives a literal image that requires little experience or training to use. These images can portray the terrain in near-natural colors, with some enhancements applied to ease utilization by non-trained personnel. Image maps are most useful when topographic maps are not available or when used as supplements to older maps. MSI provides a means of rapidly updating older, out-of-date topographic maps with image maps that provide a current, broad-area, synoptic view of the area of operations. The maps are processed to user specifications in terms of color, size, map projections and scale.

Image Mosaics are produced from two or more products and made into one larger geographic area. Mosaics are produced by digitally "stitching" images together, usually for visual effect. Prior to "stitching," images are pre-processed to ensure an acceptable match of brightness value ranges (histogram matching) and those bands selected for the final product appear visually similar.

Perspective Views are a combination of MSI and elevation data such as Digital Terrain Elevation Data (DTED) and Digital Elevation Model (DEM) (produced and maintained under the auspices of the NIMA). The two-dimensional MSI image is draped over the three-dimensional digital terrain data and processed to simulate a view of an area or target of interest from a given position, altitude, azimuth and distance.

Relocatable Target Graphics are developed from many sources of information including MSI. In this product, several inputs are combined and evaluated using geographic information system techniques to enable prediction of the movements of mobile targets. Elevation matrices are converted to slope and evaluated to determine places where mobility restrictions would prevent target movement. MSI data is thematically classified to further reduce the potential hiding areas. Known information about operating characteristics of relocatable mobile targets is included in the analysis to provide predictive movement information. High-resolution imagery is used to evaluate areas too small to be identified through other processes.

The data is combined in a processing scheme to predict the movement of vehicles given a known point of origin and terrain factors revealed through the analysis of the above data. Graphics registered to a selected map base are then produced to indicate the probability of movement across the terrain. Both hardcopy and softcopy products are constructed in this manner, depending upon user requirements.

Stereo Imagery is used to create elevation matrices and is made possible by off-nadir imaging systems or, less frequently, by two images from a single nadir imaging system. Two images of the same ground area are captured from different points in space (producing a stereo view of the area) and software is used to establish a mathematical relationship between points that can be identified on each image. Elevation data is then extracted using specially designed software and placed in a file to be used as needed.

TERCAT (TERrain CATegorization) is a pseudocolor thematic image in which the MSI data has been classified into groups representing different terrain types and land cover. TERCATs are useful in displaying vegetation classes, soil types and hydrology. They also support the analysis of lines of communications (LOCs), avenues of approach, cover and concealment, landing and drop zones.

Terrain Analysis Products are emerging as an important MSI product, drawing upon the ability of MSI to "thematically classify" statistically similar brightness values representing various types of terrain occurring in the image. Land-cover types (vegetation, urban areas, water) and density information are locked in the spectral images awaiting extraction using a variety of automated techniques and human judgment. Although terrain analysis products derived from MSI are not as accurate as "objective terrain databases," in most cases, they can be developed much more quickly and within acceptable tolerances for supporting many tactical and strategic activities.

HISTORICAL USE IN MILITARY OPERATIONS

Prior to DESERT SHIELD

Before DESERT SHIELD, MSI was generally treated as a dubious source of terrain information. Institutional DOD production agencies maintained a dogma that MSI was nearly useless as a source of mapping and terrain information. Many service-specific agencies felt the same way. However, several organizations refuted this negative position and prevailed in establishing educational and training opportunities. Their goal was the establishment of MSI as a source of information that could be exploited profitably at the tactical level. Organizations most effective in this pursuit included:

- Army Deputy Chief of Staff for Intelligence - Imagery Branch;
- Army Intelligence and Threat Analysis Center (ITAC);
- Army Space Command (ARSPACE);
- U.S. Army 30th Engineer Battalion;
- Naval Space Command (NAVSPACE) Detachment of U.S. Space Command (USSPACECOM);
- Defense Intelligence Agency ;
- U.S. Air Force 497th Intelligence Group (IG).

DESERT SHIELD/DESERT STORM

DESERT SHIELD/DESERT STORM saw the first wholesale application of MSI, led by the organizations listed above. MSI became quite useful among tactical forces and other agencies that soon provided MSI products. MSI developed into a useful tool and provided map supplements to out-of-date maps as well as a terrain database. Products that were of greatest value included:

- USAF Mission Planning (Mission Support System) using panchromatic SPOT imagery as a backdrop for mission planning and in 3D renderings of the battlefield;
- U.S. Army Image Maps produced by the 30th Engineer Battalion;
- U.S. Army Intelligence templates (B&W I-Maps with daily updates of enemy positions E-Mailed from U.S. Army ITAC to Riyadh);
- U.S. Army 30th Engineer Battalion graphics that displayed a B&W image map at the center of a map-size graphic with actual reconnaissance imagery imbedded around the margin. These showed high resolution views of enemy positions not otherwise visible on the lower resolution I-Maps;
- DIA Scud-busting operations.

Former Yugoslavia

MSI production covering the former Yugoslavian area was a free-for-all as agencies attempted to use the capabilities assembled for DESERT STORM. Every unit produced data for their own users, resulting in a plethora of partially coordinated products and images. Perspective views came into their own as a separate product during this period. Several organizations placed dedicated commercial-off-the-shelf (COTS) and government-off-the shelf (GOTS) mission planning and rehearsal systems with units alerted for possible deployment to the former Yugoslavia.

A variety of products were produced during this event including Image Maps, terrain analysis graphics and useful graphics of the ground routes for relief supplies bound for civilian enclaves. Briefings by MSI production agencies were used to show senior national and military leadership the extremely hostile terrain U.S. forces would face if deployed to that theater. Participants during this period included ARSPACE, NAVSPACE, Air Force Space Command, the former Defense Mapping Agency (DMA), U.S. Army Topographic Engineering Center (TEC), U.S. Army ITAC, EROS Data Center and the USAF Mission Support System.

Somalia

During operations in Somalia, a large number of organizations pooled resources to acquire and produce MSI products in a fairly coordinated fashion. Most resulting products were centered around Mogadishu, but the Army produced terrain analysis graphics at the Army Space Command, Topographic Engineering Center and at the deploying Army organization, the 10th Mountain Division. The USMC developed products in support of the forces deploying, as did the Naval Space Command, the U.S. Army ITAC and the USAF.

Haiti

MSI support to Haitian operations was similar to that seen in Somalia, with organizations working together to produce a number of what, by this time, had become standard products. One unique product that emerged from the Haitian experience was produced by the Army Space Command, featuring an MSI product in the center of a full-sized Image Map, with video snapshots of key points along President Aristede's repatriation motorcade route.

PRODUCT AND DATA AVAILABILITY

The National Imagery and Mapping Agency (NIMA) was established 1 October 1996. This agency combined into a single organization, the imagery tasking, exploitation, production and dissemination responsibilities as well as the mapping, charting and geodetic functions of eight separate organizations of the defense and intelligence communities.

NIMA incorporates the former DMA, Central Imagery Office (CIO) and the Defense Dissemination Program Office in their entirety as well as the mission and functions of the CIA's National Photographic Interpretation Center tographic Interpretation Center (NPIC). Also included in NIMA are the imagery exploitation, dissemination and processing elements of the DIA, National Reconnaissance Office (NRO) and the Defense Airborne Reconnaissance Office (DARO).

Besides this major restructuring for support, a new system is in place for the handling of Production Requirements (PRs) within DOD. This system is called COLISEUM, or the Community On-Line Intelligence System for End-Users and Managers. Eventually, anyone with a PC and having access to the Global Command and Control System (GCCS) will be able to enter PRs via this method.

Although NIMA and COLISEUM represent a major change in terms of support to DOD, the process in the Air Force for acquiring MSI is still through intelligence channels. As a result, the Collection Manager remains the best starting point for operational and intelligence driven MSI requirements at the unit level.

The following organizations provide an informal union of MSI related talent especially supportive on short notice and during periods of crisis and contingencies:

- ARSPACE;
- NAVSPACE;
- Air Force Space;
- U.S. Army TEC;
- USAF 480th IG (replaced the 497th IG as MSI POC);
- USSPACECOM MIMES (Joint requirements only).

MSI PROCESSING REQUIREMENTS

The following information is provided as a means for students to understand common processing requirements for MSI products.

Softcopy systems:

- CPU: PCs will support elementary processing, although standards for production systems call for UNIX work stations
- I/O Devices: CD-Player, 8mm & 4mm tape reader/writer
- Storage: Large Disk Drive (typically no smaller than five GB, although production systems may have greater than 25GB of storage)
- Graphic display screen: 8-bit color supports elementary processing; 24-bit color is required for analysis and production activities

Hardcopy systems:

- CPU, I/O, Storage and Display: same capabilities as soft-copy systems
- Hardcopy Output: High resolution color printers of the size required to support the application

Rectification requirements:

- A means of establishing ground control
- A means of associating ground control with features on the image (software)
- Software to “warp” or rectify the image to a specified coordinate system

Orthorectification:

- A means of establishing extremely accurate ground control
- A means of associating ground control with features on the image
- Software to warp image to a coordinate system and elevation

Digital Elevation Data Extraction:

- Orthorectification capability
- Software to extract the digital elevation matrix

Perspective View Generation:

- Imagery of the area of interest
- An elevation matrix (file) of the area of interest

- Software to process imagery and elevation data into a softcopy or hardcopy graphic

RESOLUTION REVOLUTION

With the successful launch of Space Imaging's IKONOS 2 in 1999, the spatial resolution available with commercial imagery has improved significantly. IKONOS 2 offers one meter panchromatic and four meter multispectral imagery, using bands similar to LANDSAT. By 2003, it is expected that there will be somewhere in the range of 13 satellites from five different nations on orbit with one meter or better panchromatic. Some of these satellites will also have MSI and even hyperspectral imagery (HSI) with eight meter or better resolution. HSI will provide capabilities similar to MSI, but with greater refinement. Instead of collecting reflectivity in seven relatively wide bands as we do with Landsat, HSI sensors will collect against hundreds of narrower bands. It is expected that this will greatly improve the ability to discriminate between various materials as previously explained in discussing Figure 12-8.

MSI LEXICON

- ***Digital Image*** - an image that has been placed in a digital file with brightness values of picture elements (pixels) representing brightness of specific positions within the original scene. The original scene may be the Earth as digitized by sensors in space or it may be a picture scanned by a desktop or other variety of scanner

- ***Hyperspectral Imagery*** – similar to MSI but with data collected in hundreds of spectral bands. The increased number of sensor bands provides higher spectral resolution and more opportunities to detect subtle spectral differences in signatures that are too narrow to be differentiated on MSI.

- ***Multispectral Imagery*** - imagery collected by a single sensor in multiple regions (bands) of the electromagnetic spectrum.

- ***Panchromatic Imagery*** - black and white imagery that spans an area of the electromagnetic spectrum, typically the visual region.

- ***Pixel*** - Picture element, the smallest element of a digital image.

- ***Radiometric resolution*** - the ability of a sensor to detect levels of reflectance.

- ***Resolution*** - a unit of granularity.

- ***Spectral resolution*** - the ability of a sensor to detect information in discrete regions of the EM spectrum.

- ***Spatial resolution*** - the smallest sized feature that can be distinguished from surrounding features usually stated as a measure of distance on the ground and, in a digital image, directly associated with pixel size.

- ***Temporal resolution*** - the span of time between collection of successive images.

OPERATIONAL EARTH OBSERVATION SATELLITES

Table 12-1 is provided as a reference for operational Earth Observation Satellites.

Table 12-1. Operational Earth Observation Satellites*

SYSTEM	SENSOR	LAUNCH DATE	ORBIT (km/degrees)	SPATIAL RESOLUTION (in meters)	TEMPORAL RESOLUTION (in days)	SWATH (in km)
Canada						
Radarsat	SAR	4 Nov 95	792 / 98.6	8 - 100	24	50 - 500
ESA						
ERS-1	SAR	17 Jul 91	780 / 98.5	26 / 102	35	100
ERS-2	SAR	21 Apr 95	780 / 98.5	26	3 - 35	99
France						
SPOT 1	Pan, MSI	22 Feb 86	825 / 98.7	10 / 20	2.5 - 26	117
SPOT 2	Pan, MSI	22 Jan 90	820 / 98.7	10 / 20	2.5 - 26	117
SPOT 4	Pan, MSI	24 Mar 98	820 / 98.7	10 / 20	2.5 - 26	
India						
IRS-1B	Pan, MSI	29 Aug 91	900 / 99.3	36.25 / 72.5	22	148
IRS-1C	Pan, MSI	28 Dec 95	817 / 98.69	5.8 / 23.5 / 70.5	24	142
IRS-1D	Pan, MSI	28 Sep 97	300 x 823 / 98.6	5.8 / 23.5 / 70.5	24	142
IRS-P2	MSI	15 Oct 94	817 / 98.6	36.25	22	142
U.S.						
LANDSAT 5	MSI	1 Mar 84	705 / 98.2	30	16	185
LANDSAT 7	Pan, MSI	15 Apr 99	705 / 98.2	15 / 30	16	185

*Basic information taken from Jane's Space Directory, 1995-96 and updated with *Air Force Magazine* (April 1997) and various Internet references.

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Space Imaging, Inc.	http://www.spaceimaging.com/
SPOT Image Corp.	http://www.spot.com

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Chapter 13

WEATHER/ENVIRONMENTAL SATELLITES

Timely knowledge of weather conditions is of extreme importance in the planning and execution of military operations. Real-time night and day observations of current weather conditions provide the operational commander with greater flexibility in the use of resources for imminent or ongoing military operations. The military has firmly established the importance of meteorological data from satellites in the effective and efficient conduct of military operations. Satellite-based remote sensors provide situational awareness of environmental conditions and allow geographical access to areas that otherwise would not be directly available.

DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

Mission

The DMSP mission is to provide an enduring and survivable capability to collect and disseminate global visible and infrared cloud data and other specialized meteorological, oceanographic and solar-geophysical data in support of worldwide DOD operations. This service must be available through all levels of conflict.

DMSP was designed to provide the military with a dedicated weather observing system. Under peacetime conditions, weather data are also available from civil weather satellites, such as Geostationary Operational Environmental Satellite (GOES) and the Television InfraRed Operational Satellite (TIROS) polar orbiting satellite. The National Oceanic and Atmospheric Administration (NOAA) now operates all of these systems. While such systems provide useful information, the DMSP has specialized meteorological capabilities to meet specific military requirements. Through DMSP satellites, military weather forecasters can detect developing patterns of weather and track existing weather systems over remote areas.

The DMSP accomplishes its mission through a system of space and ground based assets categorized into three segments: the Space Segment, the Control Segment and the User Segment.

Space Segment

The Space Segment consists of the expendable launch vehicle, the spacecraft (vehicle) and the individual sensor payloads. Currently, the DMSP satellite is launched on the Titan II launch vehicle from Vandenberg AFB, California. The launch weight of the satellite is 3,212 lbs., with a final on-orbit weight of 1,750 lbs (including the 520 lb sensor payload). The satellite is injected into a near circular, sun-synchronous, 450 nautical mile (NM), near-polar orbit with a period of 101.6 minutes and an inclination of 98.75 degrees. This sun-synchronous orbit is crucial for DMSP operations. The launch profile is such that the satellite crosses the Equator at the same local solar time and, consequently the same light level, each day. In this sun-synchronous orbit, the orbital plane precesses eastward at the same rate the earth orbits about the Sun (approximately one-degree per day).

The space-based portion of DMSP nominally consists of two satellites with nodal crossings of early morning and midmorning. The on-orbit satellites operational at the end of December 2000 were designated as the Block 5D-2 (**Fig. 13-1**).

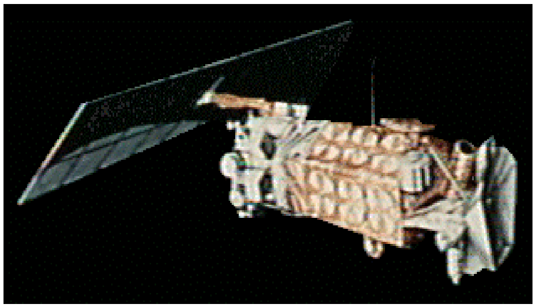

Fig. 13-1. DMSP 5D-2 Deployed

This model is the second in the Block 5D series and was first launched on 20 December 1982. This $40 million spacecraft is a 3-axis stabilized, earth-oriented vehicle. Using a hands-off, precision attitude-control system, the spacecraft is capable of maintaining a .01 degree pointing accuracy in all three axes.

This pointing accuracy is required to avoid optical distortion in the primary sensor. The vehicle carries redundant on-board computers in both the spacecraft body and primary sensor. This redundancy has reduced the possibility of a single-point failure and increased the mean on-orbit lifetime of the spacecraft to 3-4 years.

The next version if DMSP satellites is the Block 5D-3. Block 5D-3 satellites consist of the same major component subsystems as the Block 5D-2 satellites (**Fig. 13-2**). However, 5D-3 satellites have increased payload capacity, increased power capability, improved on-orbit autonomy (60 days), and a design life duration of 5 years. The first launch of a 5D-3 satellite (DMSP F-16) is scheduled for early 2001. Although DMSP F-15, launched in December 1999, featured the new 5D-3 satellite bus, it carried the legacy 5D-2 sensors. Precise launch dates depend on how long the satellites are able to remain on orbit and meet mission requirements. The 5D-3 satellites will be designated Flights 16-20.

Each satellite carries an Operational Linescan System (OLS) as the primary sensor. Up to 12 additional mission sensors can be carried on-board the satellites. The combination of the OLS and the other mission sensors results in an existing capability for the DMSP to satisfy many of the meteorological requirements of the DOD. While each of the sensors provides valuable mission data, only the OLS and the Special Sensor Microwave Imager (SSM/I) will be addressed in detail. A brief description of the other sensors will follow.

<u>Operational Linescan System</u>. The OLS

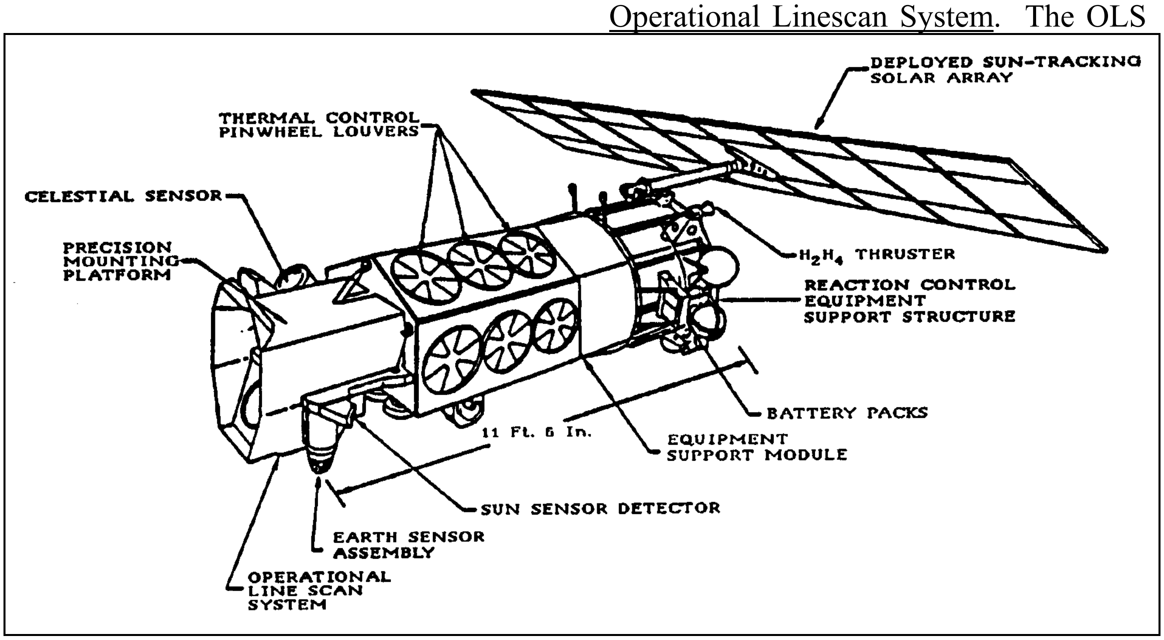

Fig. 13-2. DMSP Block 5D-2 Satellite

is the primary sensor on-board the satellite for providing visual and infrared imagery. The OLS, built by Westinghouse Corporation, is a sophisticated cloud imager consisting of an oscillating-scan radiometer and a data processor and storage system. It is designed to gather, process and output data in real-time to tactical sites, and store (on four recorders), both day (**Fig. 13-3**) and night visual data and infrared spectrum imagery. The recorders on 5D-3 satellites have been upgraded from digital tape recorders to a more reliable solid state design. The OLS scanning radiometer (in actuality, a Cassegrainian telescope) oscillates at six cycles per second and scans a 1,600 nautical mile-wide swath with little or no distortion at the edges.

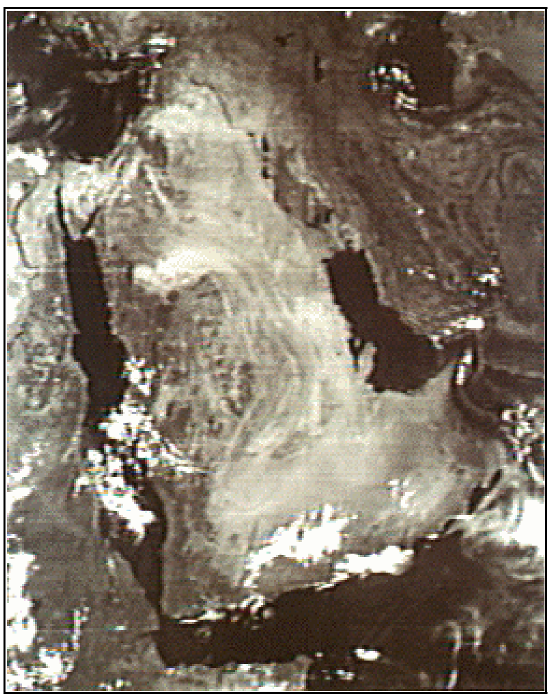

Fig. 13-3 OLS Image

Imagery collected by OLS is formatted into three data types:

- The thermal detector collects thermal fine resolution data continuously day and night.
- Light (visual) fine data is gathered during daylight only. Fine resolution data has a nominal linear resolution of .3 nautical miles. However, satellite contact duration (typically 10 minutes) limits the vast quantity of fine resolution data, which can be stored for subsequent transmission to the ground. As a solution, the capability exists on board the spacecraft to digitally average or "smooth" the fine data into a 1.5 nautical mile resolution format.
- Data smoothing permits global coverage in both the Thermal Smooth (TS) and visual Light Smooth (LS) modes. Nighttime collection of visual imagery can be accomplished in the LS mode by using a low-resolution Photo Multiplier Tube (PMT). The PMT is effective under one-quarter or better moonlight conditions. The OLS also has the capability to combine fine-resolution data, interleaved with "smooth," for real time downlink to remote ground terminals.

The capacity for on-orbit storage of fine-resolution data for subsequent transmission to the ground is limited to 40 minutes. This is less than half of the satellite's 101 minute single-orbit period. The stored data is transmitted down to a ground station at a 4:1 ratio during a single satellite contact.

Smoothing the fine-resolution data inputs permits global coverage in a LS or TS mode. Up to 400 minutes of smoothed recorded data can be played back at a 40:1 ratio during typical ground station contact.

The OLS data management unit has a capability for acquiring, processing, recording and outputting data from up to 12 other mission sensors. One of the most significant of these sensors is the SSM/I.

<u>Special Sensor Microwave Imager (SSM/I)</u>. The SSM/I is a seven channel, passive microwave radiometer sensing radiation at 19, 22, 37 and 85 GHz. It detects the horizontal and vertical polarizations at 19, 37 and 85 GHz. The

microwave brightness temperatures are converted to environmental parameters such as sea surface wind speeds, rain rates, cloud water, liquid water, solid moisture, ice edge and ice age. The SSM/I data are processed at centralized weather facilities and some tactical sites. The data are collected in a swath width of almost 760 NM. The resolution is 13.6 NM at the lower three frequencies and 7.8 NM at 85 gHz.

Other Sensors: Other DMSP sensors include:

- Microwave Temperature Sounder (SSM/T-1). A passive microwave sensor used to obtain radiometric measurements at seven frequencies. The data provides atmospheric temperature profiles for pressure levels between the earth's surface to 30 km.
- Microwave Water Vapor Profiler (SSM/T-2). A passive microwave sensor used to obtain water vapor mass in seven layers and relative humidity at six levels. It provides data on contrail formation as well as location of weather systems with high water vapor content with no associated clouds.
- Microwave Imager/Sounder SSMIS (Block 5D-3 only). Also a passive microwave sensor; however, it combines the capabilities of the SSM/I, SSM/T-1 and SSM/T-2 for the Block 5D-3 satellite.
- Ionospheric Plasma Drift and Scintillation Monitor (SSI/ES). A suite of four sensors that measures ion and electron temperatures, densities and plasma irregularities characterizing the high latitude space environment.
- Enhanced Ionospheric Plasma Drift and Scintillation Monitor (SSI/ES-2). This sensor is an upgrade to the SSI/ES. Data is used to support HF and UHF communications and is used for atmospheric drag calculations for low earth orbit satellites.
- Plasma Monitor System SSI/ES-3 (Block 5D-3 only). This sensor is an upgrade to the SSI/ES-2 and performs the same mission.
- Precipitating Electron and Ion Spectrometer (SSJ/4). Detects and analyzes electrons and ions that precipitate into the ionosphere producing the auroral displays. The sensor supports those missions which require knowledge of the state of the polar ionosphere such as communications, surveillance and detection systems (for example, the Over-the-Horizon (OTH) radar) that propagate energy off or through the ionosphere.
- Precipitating Particle Spectrometer SSJ/5 (Block 5D-3 only). A follow-on to the SSJ/4 with a new detector design capable of providing a greater detailed analysis of the ionosphere.
- Gamma Ray Detector (SSB/X). The SSB/X sensor is an array-based system that detects the location, intensity and spectrum of x-rays emitted from the Earth's atmosphere.
- Gamma Ray Detector (SSB/X-2). An upgraded SSB/X with the additional capability to detect gamma ray bursts.
- Triaxial Fluxgate Magnetometer (SSM). Provides information on geomagnetic fluctuations that affect HF communications.
- Ultraviolet Limb Imager (SSULI-Block 5D-3 only). Uses the ultraviolet spectrum to provide additional data for users of HF communications, satellite drag and vehicle re-entry issues and OTH radar.
- Ultraviolet Spectrographic Imager SSUSI (Block 5D-3 only). Gives the 5D-3 satellite the ability to obtain photometric observations of the nightglow and nightside aurora.
- Laser Threat Warning Sensor (SSF). An operational static earth viewing, laser threat warning sensor. Currently in prototype on the 5D-2 satellites, the operational version will fly on the 5D-3 satellites.

Control Segment

The Control Segment (**Fig. 13-4**) makes use of ground station sites that operate to command and control the DMSP satellites. These sites collect and process environmental data collected by the DMSP constellation, which is then routed, to the DMSP user community. Through its communications links, the control segment provides all functions necessary to maintain the state of health of the DMSP satellites and to recover the payload data acquired during satellite orbit. Although real-time, primary-sensor payload data are available to deployed tactical terminals worldwide, access to stored data is obtained only when the DMSP satellite is within the Field-Of-View (FOV) of a DMSP compatible ground station.

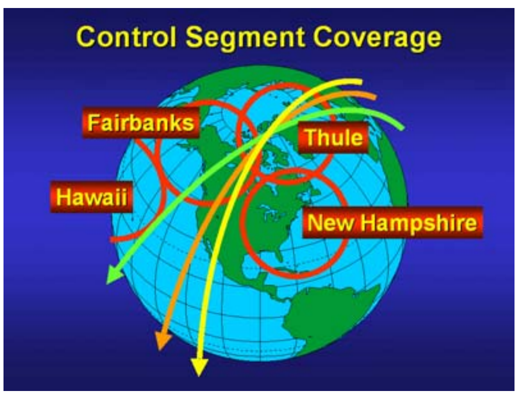

Fig. 13-4. DMSP Control Segment Coverage

The Multi-Purpose Satellite Operations Center (MPSOC) manned by the 6 SOPS at Offutt AFB, Nebraska (co-located with the Air Force Weather Agency), was the primary center for DMSP operations. As part of the merger of DMSP with its civilian counterpart, NOAA, the MPSOC was closed during May 1998. NOAA assumed all functions related to flying and supporting the DMSP constellation at their Satellite Operations Control Center (SOCC) at Suitland, MD on 29 May 1998. All functions to include classified mission planning were assumed by NOAA.

The 6 SOPS was then officially inactivated on 11 June 1998 as a result of the operational mission being assumed by NOAA at the SOCC. Subsequently the 6 SOPS Air Force Reserve Unit was activated at Schriever AFS and provides a "hot backup" capability for the MPSOC plus takes 10-15% of the satellite contacts per week.

The Air Force Satellite Control Network (AFSCN), using its Automated Remote Tracking Station (ARTS) can be used for routine tracking, telemetry and control (TT&C) functions. Only three (Thule ARTS, New Hampshire ARTS, and Hawaii ARTS currently have the necessary hardware and software enhancements to retrieve DMSP mission data. Additionally the NOAA site at Fairbanks, Alaska supports DMSP data retrieval.

User Segment

While the Control Segment meets the ongoing needs of the DMSP satellites, the DMSP user community is serviced by centralized and tactical components of the User Segment. The User Segment consists of earth-based processing and communications functions required to receive, process and distribute global weather data to support Air Force, Army, Navy and Marine Corps requirements. Vans and shipboard terminals, using direct read-out of real-time infrared and visible spectrum images from the DMSP satellites, also form a part of this segment.

The Air Force Weather Agency (AFWA), the 55th Space Weather Squadron (55 SWXS) and the Fleet Numerical Meteorological and Oceanographic Center (FNMOC) are the centralized components of the User Segment. Products provided by AFWA include aviation, terminal and target forecasts; weather warnings and advisories; automated flight plans and exercise/special mission support. They recover the stored mission data from the Control Segment, process it, combine it with data from other sources (GOES, NOAA, etc.), generate weather and space environmental products and provide operational support to their respective customers.

AFWA is the lead DOD organization for the overall processing and distribution of centralized meteorological mission sensor data in support of worldwide military activity. AFWA forwards solar-geophysical mission sensor data to the 55 SWXS, where the data will be processed and used to develop space environmental products for customers.

The FNMOC, located in Monterey, California, receives DMSP data to provide operational products and forecasts to the Department of the Navy. Specifically, FNMOC provides naval forces with analyses and forecasts of oceanographic and marine weather parameters at any global location, to include ocean surface/ocean subsurface temperatures and other meteorological conditions. AFWA and FNMOC also provide support to other elements of the DOD, the NCA and many government agencies.

The tactical components of the DMSP User Segment are the fixed and mobile land and ship-based tactical terminals operated by the Air Force, Navy and the Marine Corps. These terminals are capable of recovering direct readouts of real-time visible and IR cloud cover data from the DMSP satellites as well as SSM/I data.

Tactical terminals (TACTERMs) have been a part of DMSP since the early 1970s. These TACTERMs have the capability to receive, process, decrypt (when necessary), display and distribute the data from any DOD or NOAA meteorological satellite. They also receive localized information from the satellite, with the satellite transmitting the information it is currently observing down to the tactical user. Softcopy data (terminal display) is available real-time and hardcopy data is available within ten minutes. Imagery resolution can be both fine (0.3 NM) and smooth (1.5 NM).

The Mark IV terminal (**Fig. 13-5**) is a transportable satellite terminal designed for worldwide tactical deployment in hostile environments. Mounted in a standard shelter, the Mark IV can be towed over virtually any terrain or transported on C-130 or larger aircraft to areas of deployment. Once deployed, it can be set up and operational within 8-10 hours.

Fig. 13-5, Deployed Mark IV Terminal

The DMSP satellite does not constantly transmit tactical data; it must be commanded to do so. A tactical user (shipboard or land based) must make their requirements known to the AFWA. The AFWA coordinates with the NOAA Operations Center to command the satellite to transmit the tactical data during specific portions of its orbit. Not all mission sensor data is available to the tactical user, but the information from the OLS and SSM/I is available.

Another TACTERM, the Mark IV B, increases the ability to process DMSP, TIROS and GOES satellite data, allowing for processing and displaying OLS and mission sensor data by the tactical user.

The AN/SMQ-10 and AN/SMQ-11 shipboard receiving terminals are complete satellite meteorological terminals that receive, process and display real-time DMSP data. The system is designed to be used aboard aircraft carriers and designated capital ships. The SMQ-11, an upgrade to the SMQ-10, is capable of receiving full resolution DMSP OLS and SSM/I data as well as data from other civilian satellites (NOAA/TIROS).

A fully capable field system, the Small Tactical Terminal (STT) is a lightweight, two-man portable, direct receiving, processing and display system (**Fig. 13-6**). The STT processes and stores data, generates meteorological soft and hard copy display products, and forwards imagery and data to other systems. It receives and automatically processes the DMSP Real-time Data Smooth (RDS) and Real-time Data Fine (RTD). [Note: the basic terminal is only capable of processing smooth data (RDS).]

Fig. 13-6. Small Tactical Terminal Concept

The STT comes in four configurations: Basic, Enhanced, Light-Weight STT (LSTT) and the Joint Task Force Satellite Terminal (JTFST). The basic STT can be upgraded to Enhanced by adding an AN/TMQ-43 enhancement kit. The kit adds the capability to ingest, process and display RTD data from DMSP, and High Resolution Picture Transmission (HRPT) data from NOAA satellites. The new LSTT can do everything the enhanced terminal can do but uses a smaller three-foot tracking dish. The four-foot dishes will be phased out as they need maintenance by replacement with the 3-ft dish. The LSTT also has a smaller display system and can be carried in nine cases vice 12.

The STT receives data directly from the satellites in data streams consisting of visual and infrared imagery and mission sensor data. It receives and displays:

- Polar-orbiting Automatic Picture Transmission (APT) imagery (basic configuration and above).
- High Resolution Picture Transmission (HRPT) imagery. (Enhanced, LSTT, JTFST).
- Weather Facsimile (WEFAX) data (basic and above).
- High-resolution imagery transmitted by geostationary satellites (enhanced and above)

The Army primarily uses the Basic Terminal, which receives only APT and WEFAX data, while the Air Force uses the Enhanced, LSTT and JTFST terminals.

DMSP Summary

DMSP satisfies DOD's requirements for an enduring and survivable capability to collect and disseminate global visible and infrared cloud data to support worldwide DOD operations. Additionally, the DMSP collects and disseminates other specialized meteorological, terrestrial, oceanographic and solar-geophysical data. The nominal two-satellite constellation provides worldwide data in a timely manner to the AFWA, FNMOC and 55 SWXS (these are the three primary centralized processing facilities). Real time regional data are also provided to deployed fixed and transportable (ground or ship-based) tactical terminals.

DMSP and its civil counterpart, TIROS, do have one drawback - they cannot meet the data refresh rate requirements needed by all forecast functions. To partially offset this limitation, TACTERM's receive data relayed from available civilian and foreign geostationary satellites.

CIVIL/FOREIGN GEOSTATIONARY WEATHER SATELLITES

The average time it takes to get a DMSP/TIROS product to its user is 15-45 minutes depending on satellite overpass and priority of the tasking. To help offset this time delay, civilian and foreign geostationary satellites are employed. Geostationary satellite systems such as NOAA's GOES and Europe's METEOSAT offer a rapid refresh rate of cloud/weather data every 30 minutes. These satellites also offer a constant look angle resulting in high quality "nightly news" pictures (**Fig. 13-7**). Spatial resolution can be as good as .5 nautical miles; however, resolution degrades the farther away you get from the nadir (center of the field of view).

Currently NOAA operates three GOES satellites over the United States:

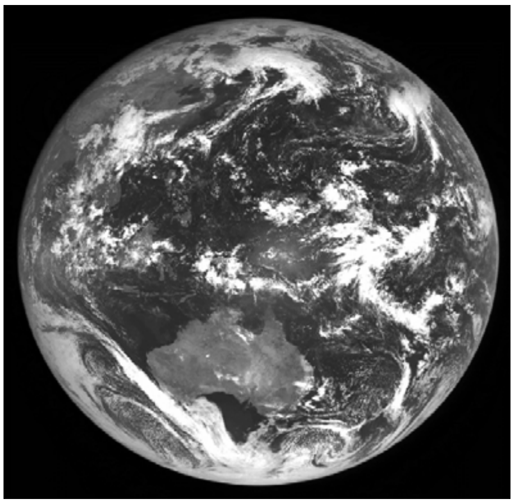

Fig. 13-7. Geostationary METEOSAT Scan

- GOES East at 75^{O} West longitude
- GOES Central 1 spare at 105^{O} West longitude
- GOES West at 135^{O} West longitude

The METEOSAT, similar to GOES, covers the Atlantic Ocean/European landmass. Spatial resolution of the METEOSAT is 2.5-5 km at nadir (located at 0 degrees longitude).

Other international geostationary satellites include Japan's Geostationary Meteorological Satellite (GMS) and the Indian National Satellite System (INSAT).

The GMS is based on an older GOES design and maintains similar capabilities. Operated by Japan, it currently has two satellites geostationed at 135^{O} and 140^{O} East longitude.

INSAT is operated by India and, due to it's imaging over the Indian landmass, India has chosen not to share INSAT data with the rest of the world. However, there is an agreement in place with the Indian government that allows INSAT data to be passed to the US. INSAT also provides a communications relay for India as a secondary mission.

On 26 June 2000, the Chinese launched a geostationary satellite, Feng Yun 2C. The Feng Yun is positioned at 105^{O} East longitude.

The ability for weather satellites to image land masses as well as clouds has opened the door for other types of civil/commercial imaging systems that further study the world environment. Primarily designed to aid in scientific studies of the Earth's environment, such as rain forests, desert regions, etc., environmental satellites have been used to gain wide-area imagery for military purposes.

A LOOK AHEAD

On 10 May 1994, the White House, Office of the Press Secretary, issued a Presidential Decision Directive (PDD) entitled "Convergence of U.S. Polar-orbiting Operational Environmental Satellite Systems (NPOESS)."

The satellite system that will result from that directive will be designated National Polar Orbiting Operational Environmental Satellite System (NPOESS). DMSP and TIROS have already been merged to be operated jointly by the NPOESS Integrated Program Office (IPO) and NOAA. The transition to the NPOESS is scheduled to begin by the year 2008.

NASA, as a convergence participant identified in the presidential directive, developed the TERRA Project (formally known as the Earth Observatory System (EOS) AM-1 satellite). The satellite was launched on December 18, 1999. EOS AM-1 is the first in the EOS program series. It was launched from the U.S. Air Force Western Space and Missile Center, Vandenberg AFB, into a 705 km (438 mile) sun-synchronous orbit with a morning (1030L) sun-shadow crossing time. Operational lifetime is 6 years.

The EOS AM-1 spacecraft provides detailed measurements of clouds, aerosols and the Earth's radiative energy balance, together with measurements of the land surface and its interaction with the atmosphere through exchanges of energy, carbon and water. These interactive processes present scientific questions of the highest priority in the understanding of global climate change.

The suite of instruments on the EOS AM-1 spacecraft is highly synergistic, and measurements from each instrument directly address the primary mission objectives. For example, four of the five instruments will acquire simultaneous complementary observations of cloud properties as well as provide error free earth surface images. All instruments together will contribute to detecting environmental changes and thereby, accelerate understanding of the total Earth system.

SUMMARY

The importance of meteorological information during a hostile conflict cannot be minimized. Environmental conditions impact all phases of military operations from logistics, to mission planning, to strike execution, to post-conflict operations. The timely and reliable relay of environmental data to military planners is critical to the success of any military operation. The DMSP provides this critical information including cloud cover data, ocean surface wind speeds, precipitation information, ocean tides information, sea ice conditions, etc.

Cloud cover data are needed to determine weather conditions in data denied and data-sparse regions and to forecast target area weather, theater weather, en route weather (including refueling areas) and recovery weather. Surface and upper-level wind data are used to support all aspects of military operations, such as assessing radioactive fallout conditions, nuclear, biological and chemical weapon effects, movement of weather systems and predicting winds for weapons delivery. These data are required for all aspects of forecasting support to aircraft and paradrop operations.

Precipitation information (type, rate) is required to forecast soil moisture, soil trafficability, river stages and flooding conditions that could impact troop and force deployment/employment. Ocean tides information is vital to naval operations for the safe passage in and out of ports, river entrances and for the landing of amphibious craft. Sea ice conditions can have a significant impact on surface/subsurface ship operations. The location of open water areas or areas of thin ice are crucial to submarine surfacing operations, submarine missile launch and penetration by air dropped sonobuoys which are used for detecting submarines. Knowledge of the location and size of icebergs is also imperative for the safe navigation of surface ships and submarines. This information could provide an important advantage over adversaries in submarine and antisubmarine warfare.

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Current news on NOAA satellite systems from NOAA's Office of Satellite Operations.

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Technical and operational information on Europe's "Meteosat" meteorological satellite.

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Website of the Space Monitoring Information Support Laboratory, a division of the Russian Academy of Sciences Space Research Institute. Various information and links on space objects and activities.

http://www.ipo.noaa.gov
Explains creation of the National Polar-Orbiting Environmental Satellite System.

Chapter 14

U.S. SATELLITE NAVIGATION SYSTEMS

Satellite navigation systems, such as the U.S. NAVSTAR Global Positioning System (GPS) came of age with the Gulf War of 1991. GPS supported coalition forces in targeting, navigation, reconnaissance, refueling, air- and sea-launched cruise missiles and providing the Army logistics forces with accurate navigation across the trackless desert to keep up with moving ground forces. Today, GPS is used in a variety of applications, both military and civilian, and the uses are continually expanding.

TRANSIT

Transit, the first navigation satellite, was developed by the Applied Physics Laboratory of Johns Hopkins University for updating the inertial navigation systems of the U.S. Navy's Polaris submarines. The Transit System, which had an 80-100 meter accuracy, was operational in the 1960s. Transit Systems provided navigational support to the U.S. Navy and commercial users. The Transit System was deactivated in December 1996 after the Navigation Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS) constellation was declared fully operational on 27 April, 1995. (see **Fig. 14-1**).

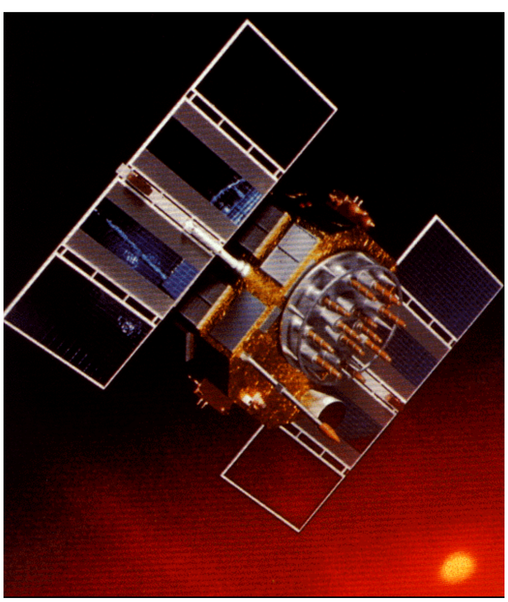

Fig. 14-1. Block II GPS Satellite

NAVSTAR GPS

The NAVSTAR GPS is a dual-use (civil and military) radio navigation system. GPS is the Department of Defense (DOD) solution to the requirement for a worldwide, continuous, all weather positioning system. GPS provides extremely accurate latitude, longitude, altitude and velocity information, together with system time, to suitably equipped users anywhere on or near the earth. In terms of navigation, GPS is nothing short of revolutionary. GPS provides three-dimensional positioning anywhere in the world, in any weather. In terms of accuracy, GPS has an accuracy of 16 meters Spherical Error Probable (SEP), which is a factor of 10 better than its nearest competitor (LORAN-C) in two-dimensional positioning, and it has no equal in three-dimensional positioning. Very rarely does the military develop a system which has specific and tangible benefits to both the military and civilian community. GPS is one of those systems.

From a civilian perspective, NAVSTAR GPS represents a navigational aid which is available at the cost of a NAVSTAR GPS user set. The use of GPS in civilian applications is widespread and changes daily. By 1999 over 700 different models of GPS receivers were available for purchase with prices as low as $100. Examples of civilian use of GPS include public health and safety, aviation, survey/mapping, scientific research, transportation, maritime navigation, agriculture and recreation.

From the military perspective, NAVSTAR is employed in methods ranging from stand-alone systems for supporting ground troops to support of fully integrated systems capable of weapons delivery. GPS is a space-based radio navigation system which is managed for the U.S. government by the U.S. Air Force and the Department of Transportation; the Air Force is the system operator. GPS was originally developed as a military force enhancement system and will continue to play this role.

Services

In an effort to make GPS service available to the greatest number of users while ensuring that national security interests of the United States are protected, two levels of GPS service are provided:

- The Standard Positioning Service (SPS) is designed to provide accurate positioning capability for civil users throughout the world.
- The Precise Positioning Service (PPS) provides full system accuracy, primarily to U.S. and allied military users. Although the military is the prime user of PPS, authorized civilians are also allowed to use the service.

Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available to any user on a continuous worldwide basis. The accuracy of this service will be established by the DOD and DOT based on U.S. security interests, although current policy is to allow the maximum available accuracy.

Both SPS and PPS accuracy specifications are expressed in terms of probability. Currently, SPS 2-D (horizontal) accuracy is 10-20 meters, twice distance root mean squared (2 drms). During the 1990s, the only formal SPS specification called for a 2-D accuracy of 100 meters, 2 drms. In general terms, this meant that 95 percent of the time, SPS accuracy had to be within 100 meters of a receiver's actual location on the earth's surface. This was equivalent to 76 meters, spherical error probable (SEP), meaning that 50 percent of the time a receiver's position solution had to be within a spherical radius of 76 meters from the receiver's actual location. SPS time transfer accuracy was normally to be within 340 nanoseconds (billionths of a second) of Universal Coordinated Time (UTC, or Zulu time, 95 percent) although there was no formal specification for SPS timing or velocity accuracy.

In times of crisis, SPS accuracy could have been degraded much more than the 100 meter specification. (The technical method, called Selective Availability [SA] will be discussed later.) This decision rests with the US National Command Authorities but there is no intent by the US government to ever use SA again.

PPS is invariably the most accurate direct positioning, velocity and timing information available worldwide. PPS is limited to users specifically authorized by the U.S.

Precise Positioning Service (PPS)

Figure 14-2 shows the published accuracy specifications for GPS as determined with four satellites in view.

	SPS	**PPS**
Position	10M(2-D,95%)*	16M (3-D, 50%)
Velocity	N/A	0.1M/s
Time	40ns*	100ns

* New SPS specifications are still to be determined

Fig. 14-2. SPS/PPS Position Accuracies

There are three formal PPS accuracy specifications, as opposed to only one for SPS. PPS 3-D (spherical) position accuracy must be 16 meters (SEP) . In general, PPS position and timing specifications are about five times as accurate as SPS. PPS timing accuracy must be within 100 nanoseconds, drms (i.e., one sigma, or 68 percent of the time). Finally, PPS velocity accuracy must be within 0.1 meter per second, drms (again, 68 percent).

Architecture: Three Segments

The Global Positioning System does not refer only to the NAVSTAR satellites that orbit the earth. It consists of three distinct segments: the Space Segment, the Control Segment, and the User Segment. All three have a role to play in providing users with accurate position, velocity, and timing data.

Space Segment

The GPS Space Segment is composed of nominally 24 satellites in six orbital planes (see **Fig. 14-3**). The satellites operate in circular 20,200km (10,900nm) orbits at an inclination angle of 55 degrees with a 12-hour period. There are four satellites in each orbital plane. The spacing of satellites in orbit are arranged so that five to eight satellites are always visible to users worldwide.

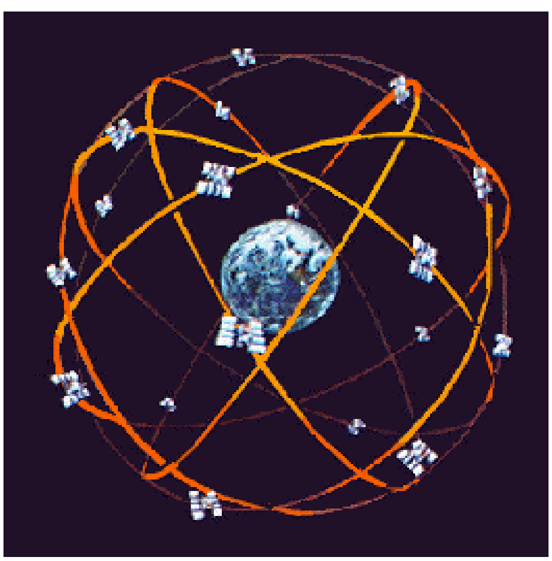

Fig. 14-3. GPS Constellation

Most of the satellites in the constellation are the second generation Block II/IIA satellites. Originally projected to have a design life of seven years. The Air Force revised the projected life of the Block II's to 8.6 years. The last of 28 Block II satellites was launched 6 November 1997. The current generation of satellites is called Block IIR ("R" for "replacement"). They have a ten year design life and are able to operate autonomously (without Control Segment intervention) for up to 180 days. The first successful Block IIR launch took place on 22 July 1997. The follow-on to the Block IIR generation of satellites is in development and will be called Block IIF. Originally, there was a contract for six Block IIF satellites with options for an additional 27, a total of 33. Currently, however, new requirements for 2nd and 3rd civil signals, a new military signal and spot beam capability (described later) have driven DoD to plan for only 6 more Block IIFs for a total of 12. Then a new GPS Block III contract will be let to build the satellites that will incorporate the new requirements.

Nuclear Detection (NUDET) Payload

The GPS satellites carry a secondary payload for detecting the characteristic optical, x-ray, and electromagnetic pulse emissions from nuclear explosions. The payload can pinpoint ground zero to within a 1.5 kilometer radius. NUDET data can be crosslinked between satellites and downlinked to the appropriate agencies on earth.

Control Segment

A worldwide network of GPS ground facilities known as the GPS Control Segment is in place to ensure that the NAVSTAR satellites are operational and passing accurate positioning data to GPS users. These facilities include a Master Control Station, ground antennas, and monitor stations.

The Master Control Station (MCS) at Schriever Air Force Base, Colorado (see

Fig. 14-4) is operated and maintained by the 2nd Space Operations Squadron (2SOPS) of the 50th Space Wing. The 2SOPS at the MCS is responsible for all routine, day-to-day NAVSTAR satellite operations. Another unit, the 1st Space Operations Squadron (1SOPS), provides support during launch, early orbit, and anomaly resolution. An Alternate Master Control Station (ACMS) is under construction at Vandenberg AFB. It's projected operational date is 2005.

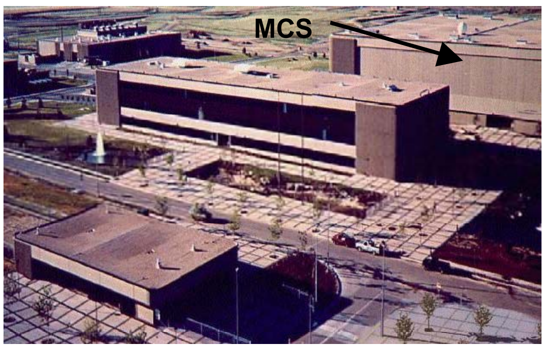

Fig. 14-4. GPS Master Control Station

The other elements of the Control Segment allow the MCS to monitor the quality of the satellites' navigation data and to control the satellites. To monitor the navigation data, monitor stations passively track navigation signals from all NAVSTAR satellites in view and transmit the data to the MCS for processing and error detection.

Navigation error corrections are generated at the MCS and sent to each satellite once every 24 hours as a "navigation upload". The navigation uploads are uplinked to the satellites via ground antennas. The ground antennas also receive and pass telemetry and tracking data to the MCS from the satellites and transmit commands from the MCS to the satellites, as depicted in **Figure 14-5**. The ground antennas are similar to the Remote Tracking Stations used by the Air Force Satellite Control Network (AFSCN); however, the GPS ground antennas can only communicate with GPS satellites. In contrast, the 1SOPS uses the Air Force Satellite Control Network (AFSCN) for launch and anomaly resolution.

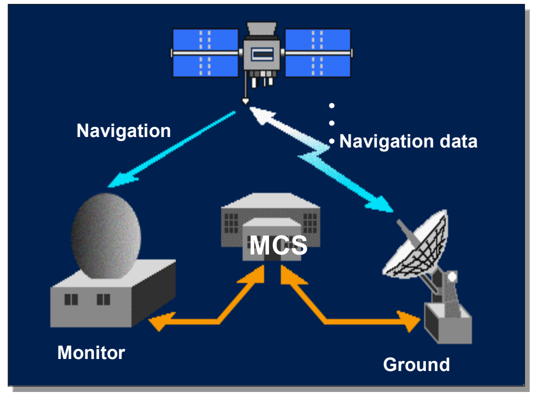

Fig. 14-5. Control Segment Interactions

A total of six monitor stations are located around the world to provide a constant monitoring capability. A total of five ground antennas are located around the world to provide control of the satellites. Most ground antennas are collocated with a monitor station.

The 2SOPS has four dedicated ground antennas collocated with monitor stations at Diego Garcia **(Fig. 14-6)**, Kwajalein Atoll, Ascension Island and Cape Canaveral (currently used only for launch but will eventually become fully operational). The fifth ground antenna is the Colorado Tracking Station (Pike) located at Schriever AFB, Colorado. Pike is an AFSCN resource, but has the necessary hardware and software to allow 2 SOPS usage.


Fig. 14-6. GPS Ground Site at Diego Garcia

Stand-alone monitor stations are at Schriever AFB (not part of the Pike

Tracking Station) and Oahu Island, Hawaii. Future plans call for adding data from fourteen monitor stations operated by the National Imagery and Mapping Agency to enhance navigation data monitoring and processing.

Telemetry, Tracking and Commanding (TT&C)

The three major functions of satellite control, known as telemetry, tracking and commanding (TT&C), are executed by a four-person mission control crew in the MCS who conduct 24-hour operations. The crew consists of a crew commander, payload system operator (for navigation payload and monitor station operations), a space vehicle officer (for satellite bus subsystem operations), and a satellite system operator (for ground antenna/data communications connectivity). Orbital analysts and program engineers provide program specific knowledge and support to the crews. The operators perform pre-contact planning, real time contact and post-contact evaluation.

User Segment

The GPS User Segment is made up of a wide variety of military and civilian users with their GPS receivers, often referred to as user equipment (UE). GPS UE consists of a variety of configurations and integration architectures that typically include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity and precise timing to the user.

How GPS Works

The basic principle behind GPS is "time of arrival" ranging. It is not quite the same thing as triangulation. To determine a 3-D position on the earth, a GPS receiver typically calculates the distance to four NAVSTAR satellites overhead and mathematically solves for time, latitude, longitude and altitude. It essentially uses "four equations to solve for four unknowns". The receiver determines the distance to a satellite by measuring the amount of time for a special radio signal from the satellite to arrive at the receiver's antenna. Since radio waves travel at the speed of light, the receiver multiplies the radio signal travel time by the speed of light to calculate the distances. If only three satellites are used, the receiver can only solve for a 2-D position, i.e., latitude and longitude. Using more than four satellites yields an increase in 3-D position accuracy (i.e., "six equations, four unknowns").

Each satellite broadcasts navigation signals on two frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). A satellite-specific coarse acquisition (C/A) code is modulated onto L1. A satellite-specific precision code (P-code) is modulated onto both L1 and L2. A navigation message is superimposed onto both the C/A and the P-code. It contains the "almanac", or orbit data for all the satellites in the constellation, as well as other information on satellite operational status, etc.

Most civilian GPS receivers can only acquire the C/A code on L1, which is a significant limitation on their accuracy. Since the GPS signals refract and are delayed as they pass through the earth's ionosphere, ionospheric error data is included on the navigation message to allow L1-only SPS receivers to *estimate* the signal delay. However, most PPS military receivers can acquire not only the C/A code on L1 but also the P-code on both L1 and L2. Receiving on two frequencies allows for a real time *measurement* of ionospheric delays. This, combined with the inherent design of the P-code, contributes to a more accurate position solution for PPS receivers than is possible with only one frequency.

Sources of Error

Several sources of error exist which can degrade the accuracy of UE position solutions. Most involve things that produce uncertainty in the time it takes for the signal is space to reach a receiver's antenna. Space Segment errors such as satellite clock errors, variations in satellite subsystem stability, and unexpected orbital perturbations produce timing errors, as do ionospheric and tropospheric delays. Control Segment error contributions include minor errors in the orbital data predictions included in the navigation uploads to the satellites. On the ground, navigation signals reflected from terrain or buildings can create signal time of arrival delays known as multipath errors. Receiver noise and resolution is also a significant source of error, especially in civilian receivers where quality varies based on model and price.

A very important potential source of human error to keep in mind involves the datum, or type of map, being used with the GPS receiver. Most receivers display coordinates in World Geodetic System 1984 (WGS84) mode as well as many other reference frames. Users should double check the datum in use to precluded plotting GPS coordinates based in one datum on a map drawn in another datum. Mixed up datums and grids can cause misinterpretations of position data of up to a *kilometer* (over 0.5 nm).

Fig. 14-7. GPS Receiver used by Ground Forces in Open Terrain

Finally, terrain can affect whether GPS signals are received at all. Receivers give best results when used outdoors in open areas, as in **Figure 14-7**. Tall buildings, canyon walls, foliage, etc. can block the satellite's signals.

Denial of Accuracy and Access

There are two primary methods for denying unauthorized users full use of the Global Positioning System. The first, as mentioned before, is Selective Availability (SA) and the second is Anti-Spoofing (A-S).

Selective Availability (SA)

Selective Availability, the intentional degradation of positioning accuracy, was discontinued by presidential directive on 1 May 2000 and there is no intent to ever use SA again. The SA feature allows the intentional introduction of errors into the satellites' navigation data to prevent unauthorized users from receiving full system accuracy. The errors can come from altering the satellite's atomic clocks (dithering) or altering the orbital data in the satellites' navigation messages (epsilon) or a combination of the two. The epsilon error in satellite position roughly translates to a like position error in the receiver. Encrypted correction parameters are included in the navigation signal that allow PPS receivers with the correct crypto keys to remove the SA errors from the navigation data.

SA was originally activated on 4 July 1991. For almost ten years national policy set the level of SA to limit SPS accuracy to the 100 meter (95 percent) specification. Now that SA is set to zero (it's always turned on), the SPS accuracy is 10-20 meters (95 percent).

Anti-Spoofing (A-S)

A-S is meant to negate hostile imitation of the GPS signals (i.e., fake satellite transmissions) by encrypting the P-code into the Y-code. Otherwise, the false transmissions could lead to false position solutions. The encrypted code is usually referred to as the P(Y) code. The A-S feature was activated when the system became operational. To decrypt the P(Y) code back into usable P-code, a GPS receiver must a have special decryption device. The first generation device was called the Auxiliary Output Chip (AOC). An improved device called the PPS Security Module came next. A new device known as the Selective Availability Anti-Spoofing Module (SAASM) is under development. SAASM will be tamper-resistant and will greatly simplify crypto key distribution and handling.

A receiver that has the ability to decrypt the SA correction parameters or the P(Y) code or both is considered to be a PPS receiver. SPS receivers, by definition, have neither SA nor A-S decryption capability.

GPS Augmentation and Improvements

Many means of making GPS even more accurate by using a second source of data (augmentation) or by some other means are available or are in development. Some of the more prominent methods are described below.

Differential GPS (DGPS)

DGPS is a means of augmenting GPS based on the principle that GPS position errors are generally the same for receivers in the same geographical region. DGPS requires a network of differential stations and special DGPS-capable receivers. A differential station is established at a precisely surveyed position. The station uses a GPS receiver to compare the GPS coordinates to the known location, then transmits the errors to DGPS-capable receivers in the region. DGPS essentially corrects for all errors in the navigation data, including the Selective Availability errors. With the differential corrections, DGPS receivers can achieve accuracies of less than one meter, SEP. Static receivers collecting data over several hours can achieve accuracies of a few centimeters. The US Coast Guard has a fully operational DGPS network along the US coastline with coverage extending approximately 90 kilometers (50 nm) inland and out to sea.

Exploitation of DGPS for Guidance Enhancement (EDGE)

EDGE is an effort to integrate DGPS into precision guided munitions such as the Joint Direct Attack Munition (JDAM). A munition guidance package equipped with a DGPS receiver uses differential corrections to enhance weapon accuracy. The concept has been proven with GBU-15 tests at Eglin AFB, Florida.

Wide Area Augmentation System (WAAS)

WAAS is a Federal Aviation Administration project to expand on DGPS by broadcasting differential corrections not just from a ground based differential station, but from a geostationary communications satellite for continent-sized regions. The architecture calls for 24 Wide area reference stations throughout the US to provide satellite-relayed differential corrections for the entire region. WAAS will allow pilots to perform "Category 1" precision approaches – a technique used in bad weather where a pilot must see the runway at no less than 200 feet above the ground and at a distance of one-half mile – throughout the WAAS coverage area. Accuracies of 3-5 meters (SEP) are expected. A related FAA system under development called the Local Area Augmentation System (LAAS) will be based at major airports and will provide for the more stringent Category 2 and 3 precision approaches. Plans to provide initial WAAS capability have slipped from September 2000 to 2002 due to software problems and increasing costs. One problem area resulting in cost overruns is the requirement for the system to virtually never fail to warn pilots of an erroneous GPS signal, a feature known as integrity.

Wide Area GPS Enhancement (WAGE)

WAGE is an attempt to improve GPS accuracy by providing more accurate satellite clock and ephemeris (orbital) data to specially-equipped receivers. In the current system, accuracy degrades slightly as the data in the daily navigation uploads ages. New software at the Master Control Station allows the latest error corrections for all satellites to be uploaded each time a navigation upload is sent to a satellite. The special receivers are able to use the constellation clock and orbital data from the most recently updated satellite in view. WAGE has the equivalent effect of changing the navigation upload rate from once every 24 hours to once every three hours. Other WAGE related improvements involve including the NIMA monitor station data in MCS navigation data calculations and automating and streamlining the navigation upload process to allow operations focused on a given theater. Accuracy is expected to be 2.5-5 meters (SEP).

Accuracy Improvement Initiative (AII)

AII is planned to enhance GPS accuracy by improving the quality of navigation data calculated at the MCS. It includes several attributes of WAGE including the improved MCS software, data connectivity to fourteen NIMA monitor stations, and shorter navigation uploads to support up to three (vice one) uploads per day per satellite. Unlike WAGE, no special receivers are required to take advantage of the improved accuracy. AII is also compatible with the Block IIF AUTONAV feature described below. The performance objective is a 33% improvement in overall GPS accuracy from 1995 levels.

Autonomous Navigation (AUTONAV)

The AUTONAV feature on Block IIR and IIF satellites is based on crosslinking navigation data between satellites. Currently, each Block IIA satellite requires a dedicated navigation upload every 24 hours. With AUTONAV, all navigation upload data for the whole constellation will be uplinked to one satellite, then crosslinked to all the others. The AUTONAV crosslinks use the same frequency, L3, used for the NUDET data crosslinks. AUTONAV will significantly reduce the MCS crew's workload. Instead of performing one navigation upload per day per satellite, only one upload per month will allow the system to meet accuracy specifications. Full AUTONAV capability will be available by Block IIF flight 18 and will provide accuracies of less than 2.5 meters (SEP) .

GPS Aiding

GPS aiding refers to coupling non-GPS navigation data sources into a composite navigation solution. These sources include inertial navigation systems (INS), barometric altimeters, and/or non-GPS derived data on satellite positions or time. These external inputs can help in acquiring or maintaining lock on GPS signals, thus maximizing the efficiency and reliability of the composite navigation system. The GPS/INS combination in particular synergistically increases the performance and reliability of both systems. INS drift is reduced by frequent GPS updates and in most cases can continue to provide acceptable navigation data if the GPS signal is lost.

Second and Third Civil Signals

The addition of two new GPS "civil signals" was announced in March 1998 by Vice President Al Gore. These second and third civil frequencies would significantly enhance the accuracy of civilian receivers, allowing the ionospheric delays to be measured as PPS receivers do now by using both the L1 and L2 P(Y) Code signals. The second civil signal would be at 1227.6 along with the military L2 signal, and would be used for general, non-safety critical applications. This signal is to be on GPS satellites launched starting in 2003, with initial operational capability (IOC) for users in 2009 when 18 satellites with the new signal are on orbit. The third signal, proposed for 1176.45 MHz (neither L1 nor L2, but a new frequency designated "L5"), is designated for safety-of-life applications such as search and rescue and is planned for GPS satellites launched in 2005 and afterwards. IOC for the L5 civil signal is planned for 2012. The extra signals would increase SPS accuracy down to 7 meters (95 percent).

New Military Signal and Spot Beam

Another upgrade to GPS is a new military signal to allow the US and its allies to keep a navigational advantage over their adversaries. Plans call for the new military signal, along with the new 2nd civil signal, to be on flights 9-14 of the new Block IIR satellites and any subsequent GPS satellites. Just as with the 2nd civil signal, this signal is to be on GPS satellites launched starting in 2003, with initial operational capability (IOC) for military users in 2009 when 18 satellites with the new signal are on orbit. Plans also call for a military spot beam, intended to overcome jamming by increasing the power over a limited area. The spot beam will be on board GPS satellites starting with the seventh Block IIF.

Limitations of GPS

Although GPS has demonstrated a tremendous capability, there are several areas of concern with the system. It is dependent on the Control Segment ground sites, which are potentially vulnerable to attack. If a Differential GPS system is in use, a special DGPS receiver must be used. Also, the satellite signals travel line-of-sight, and tall buildings, canyon walls, foliage, etc. can block the satellite's signals. From a military perspective, however, the most serious limitation is GPS susceptibility to jamming.

GPS Jamming

Any signal can be jammed. The most common jamming method, "brute force" jamming, involves overpowering an adversary's desired radio signals by transmitting noise on the same frequency being used by the adversary. The GPS signal is particularly easy to overpower because the signal strength received at the earth's surface is very low, about –166 dbw for the P(Y) code on L2, even lower than the natural background radio noise of the earth. (The unique nature of the code is what allows a receiver to detect the GPS signal against the earth's background noise.) If the jamming-to-signal ratio is above the level that the receiver can maintain lock on, then all it "hears" is the noise until the jamming stops or the receiver is removed from the area being jammed. However, no one has the resources to jam the entire frequency spectrum.

To maintain a measure of jam resistance, GPS uses several techniques. The first method was designed into the navigation signal at the outset. It involves the bandwidth of the P(Y) code, which is about 20 MHz centered on the L1 and L2 frequencies. This transmission technique is called "spread spectrum" transmission. The result of using spread spectrum is that an adversary must jam the entire 20 MHz bandwidth to effectively jam the navigation signal. Jamming only part of the bandwidth does not prevent users from receiving and reconstructing the navigation signal.

GPS aiding is another method currently available to counter the effects of GPS jamming since an external data source can compensate for the loss of the GPS data. For example, if a GPS receiver is coupled with an INS in an aircraft, the INS can continue to provide navigation data as the plane approaches a jammer and loses lock on the GPS signals.

Spoofing, considered a form of "smart" jamming, is effectively prevented by the encryption of the P-Code into the Y-Code as previously described.

NAVWAR Program

In 1996, President Clinton issued a Presidential Decision Directive (PDD) declaring that within a decade, possibly as soon as the year 2000, GPS Selective Availability would be set to zero. On 1 May 2000, the President decided to set SA to zero, immediately increasing SPS accuracy by a factor of ten. This decision was prompted by the increasing worldwide civilian dependence on GPS. There is a corresponding military dependence and threat from the guidance accuracy provided by GPS. The Navigation Warfare, (NAVWAR) acquisition program was commissioned to investigate technological means to protect the friendly use of satellite navigation, prevent an enemy's use of satellite navigation, and preserve the civilian sector's use of satellite navigation outside a military area of operations.

Protection innovations from the NAVWAR program center on three areas: user equipment improvements, signal augmentation, and improvements to the GPS signal in space. User equipment improvements include jam-resistant antennas and improved receiver electronics. Augmentation efforts include ground-based or airborne "pseudolites" to transmit a signal in a jamming environment that helps receivers acquire and maintain lock on the satellite's signals. The signal in space improvement ideas range from increasing satellite transmitting power to changing the waveform of the signal. An analysis of alternatives is ongoing.

Military Applications of GPS

GPS provides a large share of the terrestrial force enhancement provided by Air Force space forces. Military applications for precision navigation and positioning are prevalent throughout all services. These applications include mine emplacement and location, sensor emplacement, instrument approaches, low-level navigation, guided munitions, target acquisition, and command and control. **(Fig. 14-8)** As in the civilian sector, new military applications are continually being invented.

Fig. 14-8. GPS Military Applications

Military GPS Receivers

GPS receiver capabilities have progressed steadily over the past few years. This discussion will begin with older model military receivers because they may still be in use, perhaps with allied forces if not with US forces. Older model military receivers fall into three categories: low, medium and high dynamic receiver sets. The main differences between the sets are the number of channels and the dynamic range of the environment suitable for the receivers. The number of channels primarily affects the speed at which the receiver can be initialized.

A three dimensional position fix requires four satellites. Old single channel systems, such as the low dynamic sets primarily used by ground units, must lock onto one satellite at a time. The accuracy is not affected, but the time to initialize the set is. Medium dynamic sets add a second channel, while the high dynamic sets are installed on aircraft because they have five or more channels.

In general, as the receivers go from low to high dynamic sets, there is a substantial increase in the number of channels and the acceptable range of velocity, acceleration and jerk is greater. The more turbulence a vehicle experiences, the more channels these sets require. Newer model military receivers are multi-channel sets. The hand-held Precision Lightweight GPS Receiver (PLGR), for example, can lock onto five GPS satellites at once (see **Fig. 14-9**). Its follow-on, the Defense Advanced GPS Receiver (DAGR), like modern aircraft GPS receivers (see **Fig. 14-10**), will be a 12-channel set, allowing it to lock onto all satellites in view.

Fig. 14-9. Hand-held Precision Lightweight GPS Receiver (PLGR)

Fig. 14-10. Miniaturized Aircraft GPS Receiver (MAGR)

Weapon Systems

A wide variety of weapon systems are dependent on GPS or a GPS/INS combination navigation system to provide all-weather day or night precision attack. Many of these weapons were used in Operation Allied Force in Serbia and Kosovo in 1999. For example, the B-2 uses the GPS-Aided Targeting System (GATS) to accurately geolocate fixed targets on the ground which it can then attack with the Joint Direct Attack Munition (JDAM). The JDAM is a 2000 lb. "dumb" bomb with a GPS guidance tail kit that transforms it into an independently targetable, adverse-weather, seekerless precision munition. Other GPS-guided systems in development include the Joint Stand Off Weapon (JSOW) and the Joint Air-to-Surface Standoff Missile (JASSM). Conventional Air Launched Cruise Missiles (CALCMs), the Navy's Tactical Land Attack Missile (TLAMs), and ICBMs all use GPS. US Army indirect fire weapons such as the Multiple Launch Rocket System (MLRS) and the Army Tactical Missile System (ATACMS) take advantage of GPS positioning. The Army also uses the precision timing available from GPS to synchronize its frequency-hopping Single Channel Ground and Air Radio System (SINCGARS) radios. Foreign weapon systems are also incorporating GPS as the French have done with their new Apache cruise missile.

Other GPS applications continue to be explored, two of which will be discussed here: the Hook-112 SAR Radio and the Combat Survivor/Evader Locator (CSEL).

Hook-112 Search and Rescue (SAR) Radio

The Hook-112 SAR radio (see **Fig. 14-11**) combines an aircrew survival radio with a GPS receiver to provide the precise location of a downed crewman. The process, a burst transmission to a satellite then down to a rescue unit, ensures that an enemy cannot easily locate a downed crewman. The system also provides rescue teams with a precise location (within 100 meters, 95 percent) to use in finding the crewman.

In addition, SAR aircraft equipped with interrogator equipment can receive the Hook-112 signal as far as 100 miles away. Image how useful this would have been for Captain O'Grady when his F-16 was shot down in Bosnia and he had to spend several days evading capture, afraid to talk on his radio because the enemy was monitoring the SAR frequencies.

The Hook-112 Survival Radio System provides voice communications, a beacon and a distance measuring equipment transponder, all of which currently exist with the AN/PRC-112 Survival Radio. It also provides accurate GPS Standard Positioning Service, custom or "canned" messages that can be added to location and identification messages as well as location coordinates (using global latitude and longitude or local area military grids).

The U.S. Air Force plans to install interrogator equipment on unmanned aerial vehicles to further reduce the risks to airborne rescue personnel until the pick-up phase of the rescue missions begins.

Combat Survivor/Evader Locator (CSEL)

The Hook 112 radio is an interim solution until the Combat Survivor/Evader Locator becomes available. The CSEL (see **Fig. 14-12**) is a lightweight, low-power, over-the-horizon radio using an integrated GPS receiver. The CSEL is capable of reliable, precise GPS geolocation, over-the-horizon satellite data communication with the Joint Service Rescue Centers, line-of-sight voice communications with rescue teams, and a GPS encryption feature, the new Selective Availability Anti-Spoofing Module (SAASM), that adds improved security in battlefield environments.

Fig. 14-11. Hook 112 SAR Radio

Fig. 14-12. CSEL

The first 30 CSELs were delivered in December 1997 for operational test and evaluation. However, technical and human factors problems have delayed fielding the CSEL until 2002. Plans for initial buys call for the Army, Navy, and Air Force to share 11,000 handheld units.

SUMMARY

The NAVSTAR Global Positioning System is a concept with practically unlimited potential. The capabilities of GPS as a navigation aid make the NAVSTAR satellite constellation an extremely valuable asset to our armed forces in the terms of force projection, enhancement and management. As users develop confidence in the ability of GPS to deliver on its promises, user sets will undoubtedly proliferate and be employed in almost limitless ways.

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Chapter 15

MISSILE WARNING SYSTEMS

This chapter will address the missile warning systems which U.S. Space Command (USSPACECOM) controls in support of the North American Aerospace Defense Command (NORAD) agreement to protect the Continental U.S. and Canada from ballistic missile attack. Also covered are systems developed for theater-level missile defense developed in accordance with the Missile Defense Act of 1991, as amended by Congress in 1992, for the protection of forward deployed U.S. forces and it's allies.

SPACE-BASED WARNING SENSORS

Defense Support Program (DSP)

The Defense Support Program (DSP), with a system of geosynchronous satellites, is a key part of North America's Early Warning System. In approximate 22,000 mile geosynchronous orbits, DSP satellites (**Fig. 15-1**) serve as the continent's first line of defense against ballistic missile attack and are normally the first system to detect missile launches. The system's effectiveness was proven during the Persian Gulf conflict, when DSP detected the launch of Iraqi Scud missiles and provided timely warning to civilian populations and coalition forces in Israel and Saudi Arabia. In addition to missile launches, the DSP system also has numerous sensors on board to detect nuclear detonations (NUDETs).

DSP ground stations feed processed missile warning data via communications links which include the Survivable Communications Integration System (SCIS) and MILSTAR satellites. These reports are sent to USSPACECOM and NORAD operations centers at Cheyenne Mountain Air Station (CMAS), Colorado, the Alternate Missile Warning Center (A/MWC) at Offutt AFB, Nebraska and other forward users.

Fig. 13-1 DSP Satellite

These centers immediately forward the data to various agencies and areas of operations around the world.

The DSP program came to life with the first launch of a DSP satellite in the early 1970s. Since that time, DSP satellites have provided an uninterrupted early warning capability that has helped deter superpower conflict.

Over the years, the DSP system has seen many improvements in both the satellites as well as the ground stations. Initially, there were phase one and phase two, first and second generation, satellites weighing approximately 2,000 pounds with solar paddles generating about 400 watts of power. Then came the third generation satellite called Multiple Orbit Satellite/Program Improvement Module (MOS/PIM). Despite the multiple orbit option available on this generation of satellites, it was never exercised. This generation of satellite brought in, among other things, the anti-jam command capability known as CI-1. CI-1 was continued as part of the fourth generation of satellites known as Sensor Evolutionary Development (SED). The major improvement in this generation was the increase in primary focal plane cells from 2,000 cells to 6,000 cells. Along with the increased cell count was the experimental Medium Wave Infrared (MWIR) package, also known as second color, which was placed on Satellite 6R/Flight 12. This package was a proof-of-concept for implementation on the fifth and final generation of DSP satellites, DSP-1. We refer to this fifth generation as the final generation of DSP satellites because of the development of the Space Based Infrared System (SBIRS), the DSP follow-on which will be discussed later.

The DSP-1 era started with Satellite 14 and will extend through Satellite 23 if all DSP-1 satellites currently in the hanger are launched. DSP-1 brought new innovations to the program: the AFSAT Modulation Compatibility Sub System (AMCSS), introduced to support data requirements of the Mobile Ground System (MGS) as well as local and global summary messages. The AMCSS also provided the replacement for the CI-1 anti-jam commanding system for use by the Large Processing Stations (LPS), such as the Continental U.S. (CONUS) Ground Station (CGS) and the Overseas Ground Station (OGS). The OGS was closed on 1 Oct 99 and the data is now relayed back to the CGS for processing. The satellite downlinks, Link-1 and 2, were changed significantly. Each was broken into two channels, I and Q. The format for Link-1/2 I and Q channels is Quadra Phase Shift-Keyed (QPSK). The purpose for the dual channel downlinks was to support the laser crosslink. The I channel was to support the local satellite and the Q channel was to carry the data from the remote satellite. The laser crosslink project never succeeded and was eventually canceled. The I and Q channels now carry local satellite data only. Another new innovation was the semi-active cooling system. Previous generations of the satellite relied on an ice pack-type of device, which, via freezing and thawing, would maintain the focal plane temperature at -100^{O}F. Unfortunately, at the end of the satellite design life, the focal plane "ice pack" was at its end of life, leaving the focal plane temperature to rise. A rise in the focal plane temperature causes mission degradation.

DSP satellites have routinely exceeded their design life by many years. Launched in December 1984, DSP Flight 12 for example, was on orbit and operational for well over twelve years and its original design life was three years. The design life on DSP-1 era birds is five years. There are currently three DSP-1 satellites that have surpassed their design life. DSP Satellite 14 for example is now going on its tenth year of operational service. As the capabilities of the DSP satellite have grown, so has their weight and power. Unlike the old lightweight, low power satellite, the new generation of DSP satellite weighs over 5,000 pounds and the solar arrays generate more than 1,400 watts of power.

On the ground station side of the DSP house, there have been many upgrades as well. In the early to late 1980s, two programs, the Large Processing Station Upgrade (LPSU) and the Peripheral Upgrade Program (PUP), were executed. These programs resulted in the total replacement of the OGS and CGS suite of mainframe computers and all peripheral devices. This was followed by the replacement of the Satellite Readout Station (SRS) hardware and software under the SRS Upgrade (SRSU) program. Also, the Data Distribution Center (DDC) received a makeover with replacement of all hardware and software under the Ground Communications Network Upgrade (GCNU) project (1990-1992). In the 1980s, the Simplified Processing Station (SPS) was replaced with the European Ground Station (EGS). The SPS, a fixed version of the MGS, was housed in a shelter and used the MGS software suite. The upgrade replaced the shelters, hardware and software completely.

Mission of DSP

The primary mission of DSP (Mission A) is to detect, characterize and report in real time, missile and space launches occurring in the satellite Field Of View (FOV). DSP satellites track missiles by observing infrared (IR) radiation emitted by the rocket's exhaust plume. IR is a small part of the large electromagnetic (EM) spectrum.

DSP also has an additional mission (Mission B) of detecting, characterizing and reporting nuclear detonations in support of Nuclear Test Ban monitoring.

The DSP Satellite

The DSP satellite is approximately 33 feet long, 22 feet in diameter, weighs over 5,000 pounds and is comprised of the satellite vehicle also referred to as the bus and the sensor (**Fig. 15-2)**. The bus is made up of many subsystems that provide power, attitude control, thermal control and communications for the satellite and sensor.

The satellites are placed in a near circular, near equatorial, geosynchronous orbit. Global coverage can be efficiently achieved with three satellites. Additional satellites can provide dual coverage, providing for more accurate processing potential.

The Attitude Control Subsystem (ACS) maintains the spinning motion of the satellite about its earth-pointing axis. The satellite spins one revolution every ten seconds (6 rpm). The sensor bar, containing all the infrared (IR) detector cells, is fixed firmly to the satellite body. The spinning of the satellite then allows the slightly tilted boresight of the sensor bar to scan the entire hemisphere perimeter. The telescope is not aligned along the Z-axis (earth pointing axis) but is tilted slightly off center. This tilt allows coverage by the sensor out past the lim (edge) of the earth. Cells in the center of the sensor bar are placed in such a way as to cover the NADIR (center of the FOV) area called NADIR fill.

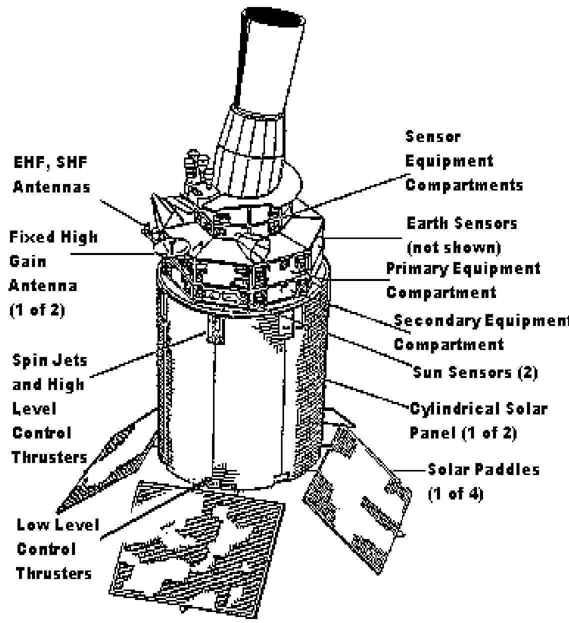

Fig. 15-2. Defense Support Program Satellite

DSP-1 Sensor Overview

The sensor (**Fig. 15-3**) detects sources of IR radiation. A telescope/optical system and a Photoelectric Cell (PEC) detector array, comprised primarily of lead sulfide detectors and some Mercad-Telluride cells for the MWIR detection capability, are used to detect IR sources. IR energy enters the opening in the IR sunshade, passes through the corrector lens, travels past the PEC array, reflects off the mirror and is focused onto the PEC array.

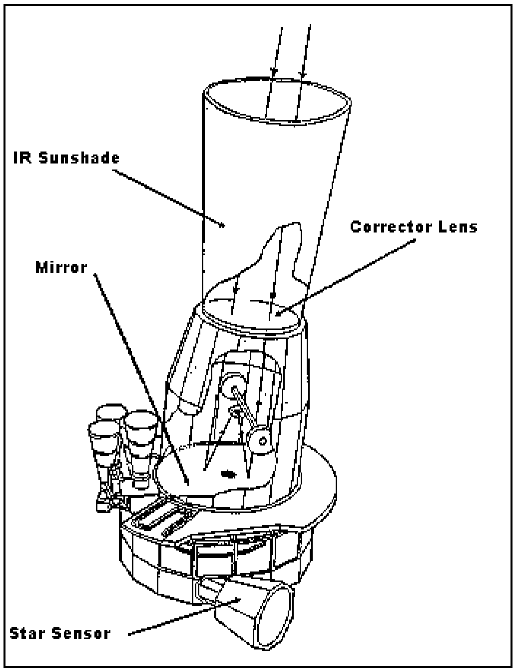

Fig. 15-3. DSP Sensor Schematic

A PEC array (**Fig. 15-4**) contains more than 6,000 detector cells. The cells are sensitive to energy in the infrared spectrum. As the satellite rotates, the earth's surface is scanned by this array. With the PEC array scanning the FOV, a cell passing across an IR source will develop a signal with an amplitude proportional to the source's intensity. The signal is then amplified, passed through an analog to digital converter and placed on the Link-1 downlink for transmission to the ground station.

The intensity of the IR energy is measured in kilowatts (kW). A standard unit of measure for the area of a sphere (IR energy radiated omni-directionally) is a steradian. Therefore, the intensity of the IR energy per unit area can be expressed in kilowatts per steradian (kW/s).

Communications Subsystem Overview

The satellite has transmitters, receivers and antennas for six encrypted communication links used to downlink satellite data and receive uplink command instruction. The links perform as follows:

- Link 1 Downlink - transmits the following data: IR data (Mission A), NUDET sensor data (Mission B), star sensor data, jet firing and calibration alert data.
- Link 2 Downlink - transmits state of health (SOH) information obtained from voltage, current and temperature sensors and various other status monitors.

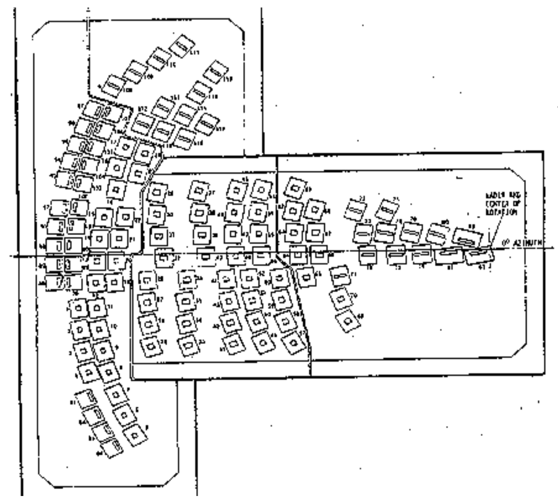

Fig. 15-4. PEC Array

- Link 3 Uplink - transmits satellite and sensor commanding data from the ground station to the satellite.
- Link 4 Downlink - satellite has two onboard impact sensors, which are basically accelerometers, to detect
  impacts on the satellite from space debris. Link 4 is the link on which this data is transmitted.
- Link 5/6 - link associated with the canceled laser crosslink system. Equipment removed and replaced with ballast.
- Link 7, 8 - serve as a backup or secondary set of communications links called the Mission Data Message (MDM) rebroadcast system.

MDM consists of an uplink and downlink, which serve as a transponder to exchange information between various ground stations.

DSP Ground Stations

DSP ground support now consists of one Large Processing Station (LPS) CGS, a simplified processing station known as EGS, and a Mobile Ground System (MGS). The CGS has responsibility for processing and reporting satellite mission data as well as commanding operational DSP satellites within its line of sight. The second processing station, EGS (location classified), has mission data responsibility, but does not have satellite commanding or the NUDET detection processing capability. The CGS has three main functional elements.

Satellite Readout Station (SRS). The purpose of the SRS is to perform the satellite communications and data conditioning function. Conditioned data is forwarded to the DRC for processing. The SRS at CGS has been upgraded as part of the SRS Upgrade (SRSU) program in the early to mid 1990s.

Data Reduction Center (DRC). The DRC operates as a vital part of DSP mission processing. The DRC accomplishes the following:

- Extracts significant data from the mission data stream regarding missile launches and nuclear detonations.
- Either automatically or via operator intervention, generates mission event and status messages for transmission to the users.
- Processes data to support satellite station-keeping and pointing functions.
- Processes data to support ground station equipment checkout and housekeeping.

Satellite Operations Center (SOC). The SOC houses the mission processing crew that evaluates and releases all DSP mission data. This center is the focal point for all ground station operations.

The MGS, located out of Greeley ANGS, CO consists of six fully deployable units (tractor trailer rigs). The MGS is assigned to the 137th Space Warning Squadron. Once deployed, an MGS SOC can send its data back to the DDC or directly to the Missile Warning Center at Cheyenne Mountain Air Station (CMAS) via satellite broadcast methods.

Data Distribution Center (DDC)

The DDC, collocated with CGS, functions as a communications center for all elements of the DSP system. The DDC routes mission data from the ground stations to the users. The DDC contains dual data processors that process both High Speed Data (HSD) and Low Speed Data (LSD), secure-voice terminals and a secure-teletype communications center. Dedicated and encrypted data, voice and teletype links from the ground stations are routed to the DDC. The DDC then retransmits these messages to the users.

Ground Communications Network (GCN)

The GCN provides all required communications capability between the ground stations, DDC and the users. Primarily, the network consists of intersite communication circuits (land lines and satellite links), modems, cryptographic equipment, data terminals and a Technical Control Facility (TCF). The hub of the GCN is the DDC. Data, secure voice, and secure teletype circuits from the ground stations to the DDC are routed over dual, diverse, dedicated and encrypted links.

Another portion of the GCN is the Survivable Communications Integration

System (SCIS). CGS has a SCIS device to broadcast DSP message traffic to forward users. The GCN is the primary mode for transmission of DSP data. The backup for broadcast is the SCIS commercial high speed data circuits. From EGS there are still GCN HSD circuits in place to ship HSD directly to the DDC High Speed Message Processor (HSMP). This function of the GCN is still active because the only way to get DSP data to the Low Speed Message Processor (LSMP) and all the LSD users is through the HSMP at the DDC.

Theater Missile Warning

Due to the growing need to get the smaller tactical threat of theater class ballistic missiles out to the warfighter, the Theater Event System was created.

Theater Event System (TES)

The TES (**Fig. 15-5**) provides highly accurate tactical threat data through the use of stereo processing of the Defense Support Program (DSP) satellite data. The TES is composed of three elements: Attack and Launch Early Reporting to Theater (ALERT), the Joint Tactical Ground Station (JTAGS), and the Tactical Detection and Reporting (TACDAR).

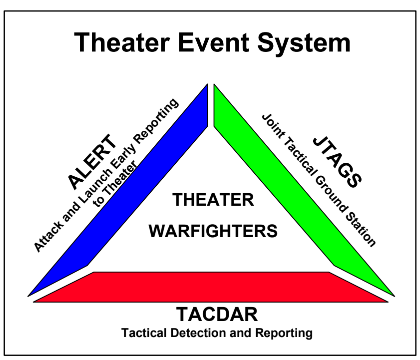

Fig. 13-5. TES

All three legs rely on IR detection for detection and profiling of theater ballistic missile launch.

ALERT. The ALERT facility is run by the Air Force's 11th Space Warning Squadron at Schriever AFB, CO and provides for a central CONUS processing element sending worldwide tactical missile threat data 24 hours a day.

JTAGS. JTAGS is the mobile, in-theater element of TES and provides the theater CINC a direct downlink of DSP data for in-theater processing. ARSPACE has operational control of the JTAGS (**Fig. 15-6**).

Fig. 15-6. Joint Tactical Ground Station

TACDAR. TACDAR is an additional sensor that can provide missile launch reports. The TACDAR sensor rides on a classified host satellite and therefore will not be discussed in this reference. Inquiries on TACDAR may be forwarded through USSPACECOM/J33.

How do I get TES Data?

The TES has the primary mission of reporting theater/tactical type threats. For theater warning, the TES system (ALERT, JTAGS, or TACDAR) reports the launch (voice and data) in theater over two types of satellite broadcast networks known as the Tactical Data Dissemination System (TDDS) and/or the Tactical Information Broadcast Service (TIBS). Theoretically, one event could be reported by all three TES elements, but the "first detect--first report" procedures help control and deconflict multiple reports of the same event.

Warning data goes out over the theater satellite broadcast networks and can be incorporated in battle management systems such as Air Defense Systems Integrator (ADSI), the Constant Source Terminal, the Combat Intelligence Correlator (CIC), and the Airborne Warning and Control System (AWACS). The Air Force's ALERT Facility (11th SWS) is under the 21st SW for TES reporting.

TES Capabilities/Limitations

ALERT. ALERT is dependent upon the DSP ground sites for receipt of DSP data. The DSP Ground Stations, TACDAR, and ALERT are all fixed ground sites. Critical spares, redundant power supplies, and logistics support infrastructures (including the use of the Mobile Ground Stations to reconstitute strategic warning) are in place for each of these sites. If a ground site outage occurs and it prevents getting a particular DSP satellite's data, then ALERT could also use 1st Satellite Operations Squadron (1SOPS), 50 SW, and the Air Force's Satellite Control Network (AFSCN) to receive the needed downlink. However, use of the AFSCN is based on a priority scheme, and there will be times when ALERT will not get a contested AFSCN antenna.

JTAGS. To get a JTAGS into theater, a warfighting CINC simply requests for the deployment. JTAGS is deployed on a C-141 or larger aircraft, and sets up to roughly the size of a small moving van. The JTAGS once in theater becomes the Joint Task Force's Ground Component Commander's asset. As such, the CINC is responsible for manning, power, and security requirements. JTAGS is dependent on a clear view to the DSP satellites in their geosynchronous orbits. The direct downlink must have a clear path to the antenna, unblocked by hills, trees, or buildings. JTAGS allows the TES to be integrated (hard wired) into theater assets including those mentioned above. Hard-wiring allows the quickest dissemination of early warning data. Based on this warning data, a voice warning over in- theater communication networks could also be set up.

TACDAR. TACDAR information is limited in that it cannot be directly downlinked into theater. Processing must occur in the CONUS and then the information relayed across the satellite broadcast network following report processing.

Questions regarding TES data, the satellite broadcast network, and TES data receivers should be addressed to USSPACECOM (J3CP/J3M), HQ USSPACECOM, PETERSON AFB CO//J33OW//, DSN 692-6987, or COML 719-554-6987.

Space-Based Infrared System (SBIRS)

SBIRS will be the DSP follow-on system for the future. SBIRS is a consolidated, flexible system that will meet U.S. infrared space surveillance needs through the next several decades.

SBIRS Mission

The SBIRS mission is to develop, deploy, and sustain space-based surveillance systems for missile warning, missile defense, battlespace characterization, and technical intelligence. The SBIR High Engineering and Manufacturing Development (EMD) contract, awarded in November 1996, will be a 10-year effort. SBIRS is intended to be an integrated "system of systems" including multiple space constellations and an evolving ground element. The integrated SBIRS architecture will provide Theater Missile Defense (TMD) track data after target acquisition to the interceptor systems and Defense Battle Manager, cueing interceptors to commit and launch earlier than autonomous radars alone. This cueing effectively extends an interceptor's range and increases its effectiveness.

SBIRS Architecture

The baseline SBIRS architecture **(Fig. 15-7)** includes four satellites in Geosynchronous Earth Orbit (GEO), a yet to be determined number of Low Earth Orbit

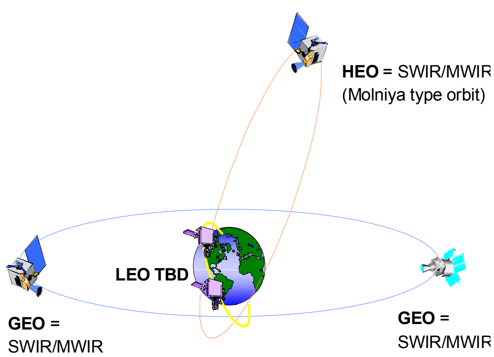

Fig. 13-7. Space Based Infra-Red System

(LEO) satellites, a set of infrared sensors hosted on two satellites in Highly Elliptical Orbit (HEO) and ground assets. The ground assets include:

- CONUS-based Mission Control Station (MCS), a backup and survivable control station
- Overseas Relay Ground Stations (RGS)
- Relocatable terminals
- Associated communications links

The SBIRS High Component element, featuring a mix of geosynchronous Earth Orbit (GEO) satellites, Highly Elliptical Earth Orbit (HEO) satellites, and a new consolidated Ground Processing station, will incrementally replace the existing DSP infrastructure over the FY99 - FY04 time frame. The first SBIRS GEO launch is scheduled for 2004. This element is the first of two planned elements that will provide an enhanced follow-on capability to the current DSP system.

The SBIRS low component is envisioned to provide a unique, precision midcourse tracking capability critical for effective ballistic missile defense as well as providing enhanced capability to support missile warning, technical intelligence and battlespace characterization.

The Common Ground Segment will be delivered incrementally. The first increment consolidates DSP and Attack and Launch Early Reporting to Theater (ALERT) mission functions at one CONUS ground station, the MCS, and is scheduled to become operational in Nov 2001. A second increment will be accepted for operation by the government around the 2004 timeframe and provides all ground segment functions necessary for high altitude space-based IR early warning elements. The ground segment has the ability to incorporate functions and equipment in a third increment necessary for the Low space element when it is deployed.

GROUND BASED WARNING SENSORS

Ballistic Missile Early Warning Systems (BMEWS)

Independent studies conducted by both the U.S. and the U.K. in the 1950s indicated the need for ballistic missile early warning facilities. The U.S. study concluded that a three radar system should be built across the northern tier. The U.K. study indicated the need for a single facility located in England. After subsequent negotiations between the two governments, the BMEWS network was born.

BMEWS Site I is located at Thule AB, Greenland (**Fig. 15-8**). Site II is at Clear AFB, Alaska and Site III is at RAF Fylingdales in the U.K. These sites originally used separate detection and tracking radars but were both upgraded to phased array technology in the late 1980s to early 1990s.

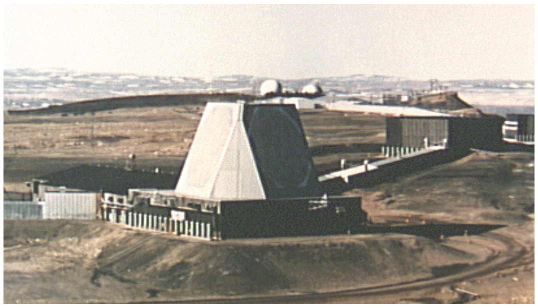

Fig. 15-8. BMEWS, Thule AB, Greenland

The 12th Space Warning Squadron (12SWS) at Thule now operates a dual face, solid state, phased-array radar (AN/FPS-123). The 13SWS at Clear operates three detection radars (AN/FPS-50s), each 400 ft long and 165 ft high. Clear also operates a tracking radar (AN/FPS-92) that is 84 ft in diameter and weighs 100 tons. Under the Clear Upgrade Program, Clear will upgrade to a dual-faced phased array radar. The project, started in FY98, will use existing equipment from El Dorado Air Station's PAVE PAWS radar (PAVE PAWS South West) since it was deactivated and has transitioned into cold storage. The new dual faced phased array radar in Alaska is scheduled to be completed by Jan 2001. Royal Air Force (RAF), Fylingdales is the site of the world's first three-faced phased array radar (AN/FPS-126). The Initial Operating Capability (IOC) was carried out in July 1992 and Joint (U.S./U.K.) Operational Capability (JSOC) in November 1992.

BMEWS provides warning of an Intercontinental Ballistic Missile (ICBM) attack on the CONUS and Southern Canada. BMEWS also provides warning of a Sea-Launched Ballistic Missile (SLBM)/ICBM attack against the U.K. and Europe. BMEWS' tertiary mission is to conduct satellite tracking as collateral sensors in the Space Surveillance Network (SSN).

PAVE PAWS

Increasing technology provided the Former Soviet Union (FSU) with the capability to launch ballistic missiles from an underwater Sea-Launched Ballistic Missile (SLBM) platform. Studies indicated the need for dedicated early warning facilities to detect such an attack. The first two sensors, Otis and Beale, came on line in 1980 with an additional two, PAVE PAWS South East (PPSE) and PAVE PAWS South West (PPSW) following seven years later. PPSE and PPSW have since been deactivated and closed (1995).

PAVE PAWS NE (**Fig. 15-9**) is located at Cape Cod AS, Massachusetts and is operated by the 6SWS. PAVE PAWS NW is at Beale AFB, California and is run by the 7SWS. Both sites operate a dual-face, phased-array radar (AN/FPS-123).

Fig. 15-9. PAVE PAWS, Cape Cod AS

The 6SWS is atop Cape Cod's Flatrock Hill. The 6SWS occupies 120-plus acres of what was once Otis Air Force Base, and is now the Massachusetts Military Reservation. The squadron receives host-tenant support from Hanscom Air Force Base, Otis Air National Guard Base and from the U.S. Coast Guard Station on Cape Cod.

PAVE is an Air Force program name while PAWS is an acronym for Phased Array Warning System.

The primary purpose of PAVE PAWS is to detect an SLBM attack, determine the potential numbers and probable destination of the missiles, then report this information to NORAD, U.S. Strategic Command (USSTRATCOM) and the National Command Authority (NCA). Additionally, PAVE PAWS provides information on the location and velocity of earth-orbiting satellites to USSPACECOM and the Space Control Center (SCC) at Cheyenne Mountain AS, Colorado.

The main difference between phased array and conventional radar is that phased array systems like PAVE PAWS are steered electronically. The phased array radar incorporates nearly 3,600 small, active antenna elements coordinated by two computers. One computer is on-line at all times and the second computer will automatically take control if the first fails. The computers feed energy to the antenna units in precise, controlled patterns, allowing the radar to detect objects at very high speeds since there are no mechanical parts to limit the speed of the radar sweep. The PAVE PAWS radar can electronically change its point of focus in milliseconds, while conventional dish-shaped radar may take up to a minute to mechanically swing from one area to another.

The PAVE PAWS main building is shaped roughly like a pyramid with a triangular base 105 feet on each side. The two radiating faces, each containing approximately 1,800 active antenna elements, are tilted back 20^{O} from the vertical. PAVE PAWS radar beams reach outward for approximately 3,000 nautical miles in a 240^{O} sweep. At this extreme range, it can detect an object the size of a small automobile. Smaller objects can be detected at closer range.

Perimeter Acquisition Radar Attack Characterization System (PARCS)

PARCS is located just 20 miles south of the Canadian border at Cavalier AS, North Dakota. PARCS (**Fig. 15-10**) was originally built as part of the Army's Safeguard Anti-Ballistic Missile (ABM) system. In 1976, the ABM system was deactivated and the sensor became available for Air Force use in December 1977. PARCS' primary mission is to provide warning and attack characterization of an SLBM/ICBM attack against the U.S. and southern Canada. Its secondary mission is to track earth orbiting objects for the Space Surveillance Network (SSN).

PARCS is a single-faced, phased array radar. The radar, communications equipment, computer and operations room are housed in a reinforced concrete building. The single-faced radar is northern looking over the Hudson Bay,

Fig. 15-10. PARC S Radar Site

and is sloped at a 25^{O} angle. Due to its initial design as part of the ABM system, it can rapidly characterize the type of missile attack for use by NORAD and the National Command Authorities. Also, due to its greater power and rapid scan rate, PARCS is one of the most valuable sensors in the SSN.

Summary

The DSP strategic ICBM processing sites, the TES tactical ballistic missile processing sites, and the host of missile warning radar sites around the globe provides the world's most sophisticated missile warning system for the National Command Authorities, Unified Commanders and the entire joint military community.

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TOC

Chapter 16

SPACE EVENT PROCESSING

Space systems have become a critical component of US military operations. Military commanders rely on navigation, communications, environmental surveillance and warning information received from or provided via space systems. Any degradation to these systems could have a significant impact on the success of a military operation. In addition, the US must protect its ground assets from intelligence collection by other countries.

OVERVIEW

The United States Space Command (USSPACECOM) was established in 1985 in order to normalize the use of space in support of US deterrence capabilities and centralize all military activity related to US space systems. USCINCSPACE advocates the space requirements of other unified commanders.

USSPACECOM conducts operations through its component commands: 14th Air Force portion of Air Force Space Command, Army Space Command and Naval Space Command.

SPACE EVENTS

A space event is an activity impacting on a US space asset or an activity involving another nation's space assets. The asset could be a satellite, a ground station or the up/down-links. Possible space events include:

- Directed energy/laser beam
- Nuclear detonations
- Electronic warfare
- Anti-satellite (ASAT) weapons systems
- Sabotage

SPACE SURVEILLANCE

A critical part of USSPACECOM's mission is space surveillance, which includes detecting, tracking, cataloging and identifying all man-made objects orbiting the earth. Some of the important roles of space surveillance are tracking present positions of space objects, detecting new satellites, and predicting when and where a space object will reenter the earth's atmosphere, thereby preventing a triggering of a false missile alarm due to a reentering space object. Additional roles include producing a catalog of all man-made space objects, determining who owns an orbiting space object and informing NASA whether or not objects may interfere with the Shuttle or the International Space Station now under construction.

SPACE EVENT PROCESSING

When a space event occurs, the USSPACECOM Space Control Center (SCC) (**Fig. 16-1**) is responsible for determining if the event is accidental, incidental or the result of a hostile action directed against the United States. The SCC gathers information from a variety of sources to make this determination.

The SCC at Cheyenne Mountain Air Station, Colorado is the focal point for all space surveillance tracking information. Naval Space Command provides the Alternate SCC (ASCC) and could take over all operations if necessary.

Once USCINCSPACE has been provided with the SCC's report, the CINC may request a Space Event Conference with the National Military Command Center (NMCC). During the Space Event Conference, USCINCSPACE describes the activity and will provide one of the following assessments:

- **NO**—An attack against a space system has not occurred nor is one in progress.

- **CONCERN—**Events are occurring that has raised the level of concern. Further assessment is necessary in order to determine the nature of the activity involved. Pending completion of the ongoing assessment, precautionary measures to enhance responsiveness or survivability are suggested.

- **YES—**A verified attack against a space system has occurred. This means that all-source data confirms the hostile event has occurred or is occurring.

Fig. 16-1. Space Control Center Operator

SATELLITE RECONNAISSANCE ADVANCE NOTICE (SATRAN) PROGRAM

USSPACECOM is tasked by Annex A of the Joint Strategic Capabilities Plan (JSCP) to provide timely notification of potential space-based reconnaissance of US forces worldwide by a foreign nation. This program is known as SATRAN and is a proven, reliable Operations Security (OPSEC) support tool that informs customers of expected foreign intelligence satellite overflights.

SATRAN reporting is site-specific and provides sufficient warning to allow recipients time to respond to a potential threat by employing cover, concealment or cessation of activity until the threat is passed.

Under JCS guidance, the Defense Intelligence Agency (DIA) is the manager for SATRAN. Operational execution of the program has been delegated to the USSPACECOM Combined Intelligence Center (CIC) at Peterson AFB, Colorado.

The Naval Space Operations Center (NAVSPOC), a component of Naval Space Command, is delegated the responsibility of providing satellite reconnaissance OPSEC support to US Navy and Marine Corps assets only.

Likewise, the US Army White Sands Missile Range (WSMR) produces satellite overflight times for users of the White Sands Ranges only.

CONCLUSION

The nature of space operations is such that its theater of operations is not normally host to the personnel affected. USCINCSPACE has no combat forces assigned. Also, all of USSPACECOM's ground facilities are located in another Commander-in-Chief's area of responsibility. As a result, when a verified attack occurs or is in progress, USCINCSPACE relies on the other unified commanders to protect US assets and, when necessary, respond to space events with force.

USSPACECOM's Space Control Center and the Combined Intelligence Center provide other unified commanders with the information necessary to avoid threats to space or ground systems.

REFERENCE

USSPACECOM REG 55-10.

Chapter 17

U.S. MISSILE SYSTEMS

This chapter covers land-based Intercontinental Ballistic Missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and (briefly) cruise missiles.

Brief History of the ICBM

Origins

The first reference to use of rockets dates from 1232 when the Chinese defenders of K'aifung-fu used “fire arrows” against attacking Mongols. Progress in rocketry was slow, at best, for the next seven centuries.

The Germans began development of a missile arsenal during the 1930s at Kummersdorf and Peenemünde, with increased emphasis during World War II. These experiments resulted in the “Vergeltsungswaffe Ein” and “Zwei,” (Revenge weapons one and two), or V-1 and V-2. The V-2 was 46 feet long and used alcohol and liquid oxygen as propellants. It reached an altitude of 50 to 60 miles, had a maximum range of 200 miles and carried a one ton warhead. The system's accuracy was two and one-half miles. The war ended before the results of research into longer-range (transatlantic) two-stage rockets called the A-9 and A-10 could be used. These weapons might have been operational by 1948.

The United States and the Soviet Union recruited as many German scientists as possible following the war. Each began their own research programs into the use of missiles as weapons. Funding and weight limitations prevented these programs from quickly advancing. It wasn't until 1954 that Air Force Secretary Talbott directed all necessary steps be taken to advance the Atlas ICBM project.

On 27 October 1955, a contract was awarded to produce another ICBM, the Titan I. The Thor and Jupiter Intermediate Range Ballistic Missile (IRBM) programs also began in December of 1955, with the highest possible priority. The Army had responsibility for all short-range (under 200 miles) surface-to-surface missiles. The Navy had control of all ship-based missiles and the Air Force got all other surface-to-surface missiles.

Fig. 17-1. Thor and Atlas I Missiles

The first U.S. IRBM was the Thor (**Fig. 17-1**). It was deployed in the United Kingdom between 1959 and 1963. The Thor was housed horizontally in an above-ground shelter. It had to be raised to the vertical position and fueled before launch. Its propellants were RP-1 (a high grade kerosene) and liquid oxygen. The Thor had a range of 1,500 nautical miles (NM) and could place a one megaton warhead within 4,600 feet of the target.

First Generation ICBMs

The first Atlas D ICBM was launched 9 September 1959 at Vandenberg AFB, California. General Thomas D. Power, CINCSAC, then declared the Atlas operational. Only six days later, a Minuteman R & D tethered launch occurred at Edwards AFB, California. This was a model with inert second and third stages and a partially charged first stage. It had a 2,000 foot nylon tether to keep the missile from going too far. On 31 October 59, the first nuclear-tipped Atlas was on alert at Vandenberg AFB. Deployment of the Atlas continued in three versions, the D, E and F models. The D model was housed horizontally in an above-ground, soft building and erected for launch (plus three D models were in soft, vertical gantries at Vandenberg AFB). It used a combination of both radio and inertial guidance.

The E model incorporated many improvements over the D model. Perhaps the most significant was the replacement of radio guidance with an all-inertial system, making the E model invulnerable to jamming. The E model was also housed horizontally, but it was in a semi-hard "coffin" launcher that was buried to reduce its vulnerability to blast and overpressure.

The F model was kept in an underground, hardened silo and raised to the surface by an elevator for launch; this was called "hard silo-lift." The silo was nearly 180 feet deep.

The Titan I was also being developed and deployed in a similar configuration as the Atlas F. Both used the same propellants and the same silo lift technique. One primary difference was in the command and control. The Atlas F system had one launch control center connected with, and in command of, one silo and missile. The Titan I system had three silos connected to the underground launch control center. Another difference was that the Titan I used a radio-inertial guidance system similar to the Atlas D. The sixth and last Titan I squadron became operational at Mountain Home AFB, Idaho on 16 August 1962. Only four months later, on 20 December, the last Atlas F squadron at Plattsburgh AFB, New York achieved operational status.

Even as these milestones were reached, the days of the first generation ICBMs were numbered. The newer Titan II and Minuteman ICBMs were more survivable and quicker reacting, along with being more economical to operate and more reliable. On 24 May 1963, General Curtis E. LeMay, Air Force Chief of Staff, announced the phaseout of the Atlas D and E and the Titan I. By its completion, that phaseout also encompassed the Atlas F, with the last Atlas F being removed from alert at Lincoln AFB, Nebraska on 12 April 1965 and shipped to Norton AFB, California for storage.

Second Generation ICBMs

The second generation of ICBMs, the Titan II and the Minuteman, shared only one characteristic--they were housed and launched from hardened underground silos. The Titan II was a large, two-stage liquid-fueled missile that carried a single warhead. Its range was about 5,500 NM. The missiles were deployed at three wings. Davis-Monthan AFB, Arizona was the home of the first operational wing. McConnell AFB, KS and Little Rock AFB, AR were the other two.

The Titan II offered five distinct advantages over the Titan I. First, its reaction time was reduced from 15 minutes to less than one minute because it used storable hypergolic propellants. Second, it used an all-inertial guidance system, a major improvement over its radio-controlled predecessor. Third, the missile carried the largest and most powerful warhead ever placed on a U.S. missile. Fourth, each launch complex contained only one missile, instead of the cluster of three used in Titan I; this separation enhanced survivability. And last, the Titan II was designed to be launched from below ground inside its silo, also to limit its vulnerability to damage, except during the earliest stages of flight.

The Minuteman is a three-stage, solid-fueled missile housed in a remote launch facility. Its range is also in excess of 5,500 NM. From the beginning, it was intended to be a simple, efficient and survivable weapon system. Its main features are reliability and quick reaction.

The first Minuteman, the Minuteman I "A," went on strategic alert during the Cuban missile crisis of October 1962. President Kennedy later referred to this missile as his "ace in the hole" during negotiations with the Soviets.

The Minuteman II became operational in 1964 and replaced many of the Minuteman Is. This system, known as the LGM30F, or more simply the "F" model, was over 57 feet long, weighed over 73,000 pounds and carried one warhead, like the Minuteman I.

The Titan crew consisted of two officers and two enlisted technicians, where the Minuteman crew is composed of only two officers. Control of a single Titan missile was done from the Launch Control Center (LCC). Minuteman uses a similar procedure, but the crew controls 10 to 50 missiles.

Because the Titan was increasingly expensive to operate and hampered by a series of accidents, the Reagan Administration announced its deactivation in October 1982. The system deactivation began in 1984, and the last Titan II wing was deactivated in August 1987. The Bush Administration began deactivation of the Minuteman II to comply with Strategic Arms Reduction Treaty (START) requirements. The last Minuteman II was removed in 1998.

Third Generation ICBMs

While Titan II missiles were deployed in only one model, the Minuteman series spanned several models. The latest, and only operational version, is the Minuteman III "G." The last Minuteman III was deployed in July 1975, so this is the oldest ICBM on alert. It is almost 60 feet tall and weighs approximately 79,000 pounds. The Minuteman III originally carried three reentry vehicles, each capa-

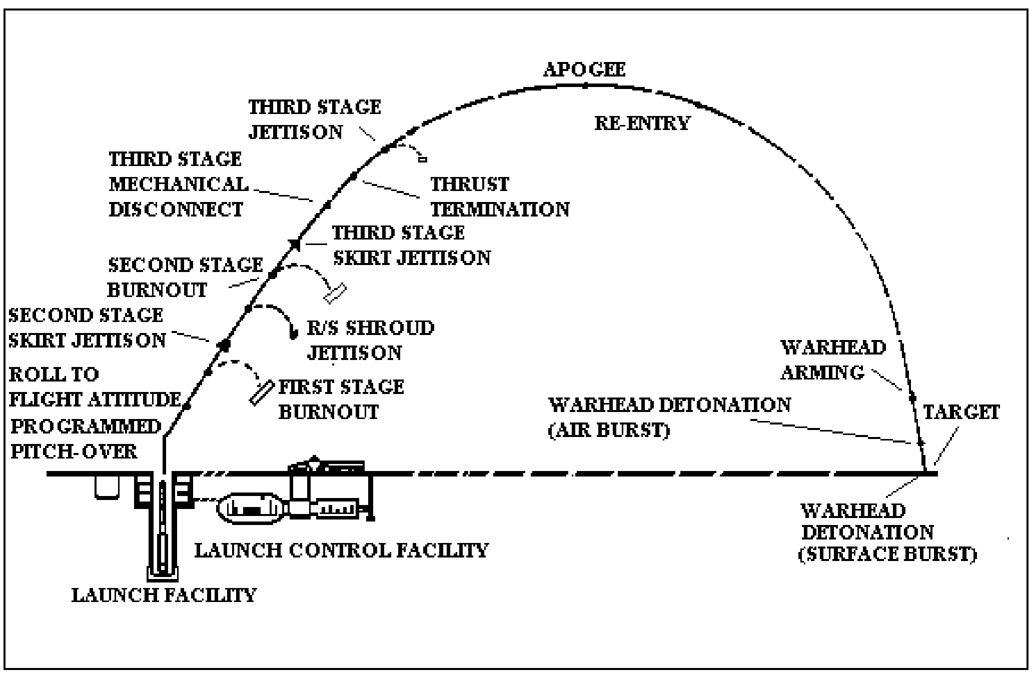

Fig. 17-2. Typical ICBM Flight Profile

ble of maneuvering to strike a different target. Upon START II entry into force, the Minuteman force will be downloaded to a single reentry vehicle.

The Minuteman is hot-launched (ignition occurs in the silo) and flies out through its own flame and exhaust. An avcoat material protects the first stage from the extreme heat generated during this process. Once ignition occurs, the missile will pass through several phases of flight, beginning with the boost phase. A typical flight profile is shown in **Figure 17-2**.

The newest U.S. ICBM is the Peacekeeper. It is a four-stage, solid-fuel missile which replaced 50 Minuteman III missiles at F.E. Warren AFB, Wyoming. These missiles are deployed in converted Minuteman silos. The first ten Peacekeeper missiles achieved operational alert status in December 1986 as part of the 400th Strategic Missile Squadron. When START II enters into force, Peacekeeper will be deactivated.

The Peacekeeper is 71 feet long and weighs 195,000 pounds--nearly three times the weight of a Minuteman III. This allows it to carry up to 12 reentry vehicles, although 10 is the operational configuration. The missile is about seven and one-half feet in diameter on all of its stages.

All four stages are protected during launch and in its flight environment by an ethylene-acrylic rubber coating. No ablative material is needed because it uses a cold-launch technique similar to the system used by the Submarine Launched Ballistic Missile (SLBM) submarines. The Peacekeeper is protected inside the canister by Teflon-coated urethane pads. Nine rows of pads are used to protect and guide the missile smoothly up and out of the canister. The pads fall away when exiting the canister.

The cold launch system uses a reinforced steel canister to house the missile. At the bottom of the canister is a Launch Ejection Gas Generator (LEGG). A small rocket motor is fired into 130 gallons of water contained in the LEGG reservoir. This creates steam pressure that pushes the Peacekeeper up and out of the canister prior to first stage ignition.

The presently deployed ICBM force consists of Minuteman III "G" and Peacekeeper missiles. They are deployed as follows:

- 200 Minuteman III, Malmstrom AFB, Montana
- 150 Minuteman III, Minot AFB, North Dakota, and
- 150 Minuteman III and 50 Peacekeeper, F.E. Warren AFB, Wyoming.

ICBM Characteristics

Mission Profile and Equipment

The ballistic missile as a weapon is often compared to an artillery cannon and its ballistic projectile. Important to the accuracy of the artillery projectile are its elevation and speed. Apart from atmospheric resistance, gravity is the only vital force operating on the projectile, causing a constant acceleration fall to earth. As the distance to the target increases, so must the elevation (angle of launch toward the target) or speed (muzzle velocity) of the projectile increase.

In order for the ballistic missile reentry vehicle (RV) to reach the target, the missile must be aimed toward the desired impact point and given a specific speed and altitude. There is one point somewhere along the missile flight path at which a definite speed must be achieved. The flight control system is responsible for getting the missile to this point.

From the moment of lift-off, the missile must stabilize in its vertical climb. It must be rolled about its longitudinal axis to the target azimuth and pitched over toward the target. The missile must be accelerated, staged and given any necessary corrections along its roll, pitch and yaw axes, and various engines must be ignited and terminated at precise times. In addition, the reentry vehicle must be armed and separated from the missile. These operations are performed by the flight control system through two basic subsystems; (1) the autopilot subsystem (or attitude control) and (2), the inertial guidance subsystem or radio.

An inertial guidance system is completely independent of ground control. It is capable of measuring its position in space, computing a trajectory taking the payload to the target. It generates (1) steering signals to properly orient the missile, (2) engine cutoff signals, and (3) the warhead prearming signals.

Reentry Vehicle Design

A "ballistic missile" is only powered for a short time during flight. The total flight time for an ICBM is about 30 minutes, but powered flight lasts only five to 10 minutes. The remainder of the time is spent "coasting" to the target. The velocity of powered flight may reach 15,000 mph, but it really is gravity that does the work of getting the payload to the target. Once the vehicle begins to encounter atmospheric drag during reentry, aerodynamic heating and braking begins. Induced drag and lift affect the reentry vehicle's trajectory. There are no control surfaces on a true ballistic reentry vehicle. It acts more like a bullet as it falls to the target.

Reentry vehicles have two types of heat shielding: heat sink and ablative. Heat sink vehicles disperse heat through a large volume of metal, while ablative vehicles have coverings that melt or burn off. Essentially, the covering absorbs the heat and sloughs off, carrying away the heat. Continued use of heat sink vehicles became impractical because of the trade-off between RV weight, booster size and range. The use of ablative vehicles reduced these problems.

Reentry is incredibly severe, with an interesting tradeoff between survivability and accuracy. In general, the steeper the reentry angle, the more accurate the ballistic vehicle. However, the steeper the angle, the higher the temperature and G-loading encountered. The problem is to design a reentry vehicle that will not vaporize when reentering the earth's atmosphere and yet maintain the needed accuracy. An intense program covering shock tests, materials research, hypersonic wind tunnel tests, ballistic research, nose cone drop tests and hypersonic flight was used during development.

There are several design requirements for an RV. Foremost is the ability to survive the heat encountered during reentry. A body reentering the atmosphere at speeds approaching Mach 20 experiences temperatures in excess of 15,000 degrees Fahrenheit. In practice, the RV never reaches this temperature because of a strong shock wave ahead of the blunt body that dissipates more than 90 percent of this energy to the atmosphere. In addition, the internal temperature must be kept low enough to allow the warhead to survive reentry. As the RV reenters the atmosphere, it encounters tremendous deceleration forces--as high as 50 Gs. All internal operational components must function under these extreme conditions and additionally, must withstand the high lateral loads and intense vibrations also encountered.

An RV may be deflected from its calculated trajectory by aerodynamic lift forces. Stability, assisted by a form of attitude control and further augmented by some means of averaging deflection, must be designed into the RV. An arming and fusing mechanism must be incorporated into the RV to prevent non-programmed weapon detonation. It also must have a sensing mechanism to indicate the proximity of the target and arm the warhead. The weight of the vehicle must be kept to a minimum to maximize range. The higher the terminal velocity, the less likely the RV will be intercepted. Higher velocity also decreases the probability of missing the target due to atmospheric deflection.

Nuclear Weapons Effects

Nuclear weapons effects are normally divided into three areas: initial, residual and long-lived. Residual effects are those which begin about one minute after the detonation and continue for about two weeks. These would include fallout and associated radiation. Long-lived effects would include the subsequent damage to the environment and some radiation concerns. It is generally the initial effects that are most germane to military matters. There are six primary nuclear weapon effects:

- Electromagnetic Pulse (EMP)
- Nuclear radiation
- Air blast
- Ground shock
- Thermal radiation
- Dust and debris.

Each of these effects can be compared to our normal phenomena. Electromagnetic pulse is similar to a lightning bolt, producing a tremendous surge of electrical current and generating huge magnetic fields – both of which affect electrical equipment. Depending on the altitude of the explosion, it can have effects thousands of miles from the detonation. Nuclear radiation is similar to a powerful X-ray and varies depending on the burst option used (**Fig. 17-3**).

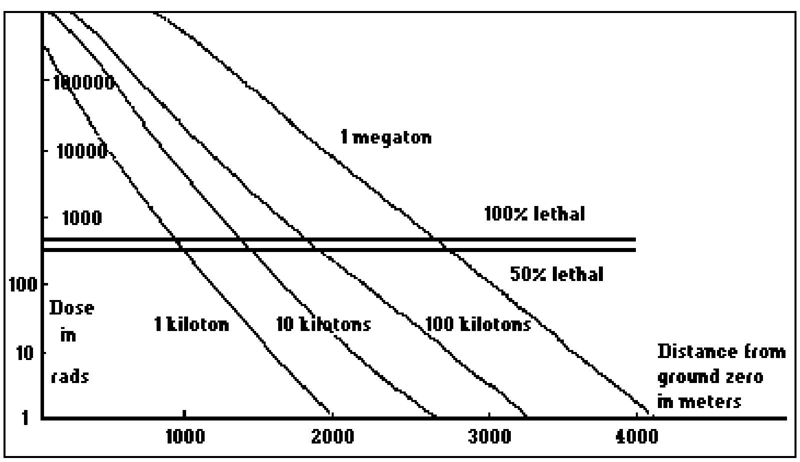

Fig. 17-3. Nuclear Weapon Effects versus Distance

Air blast is the wind generated by the detonation. These winds are ten times stronger than those found in the most powerful hurricane. They actually "slap" the earth hard enough to contribute to the ground shock at the detonation site. The ground shock is nearly 250 times worse than the greatest earthquake. The lateral accelerations are transmitted over large distances at very high speeds. Heat is another product, with the sun's thermal radiation a useful comparison. The temperatures in the fireball reach upwards of 14,000 degrees Fahrenheit. As a comparison, the sun's surface temperature is approximately 11,000 degrees.

Finally, a ground burst will generate large amounts of dust and debris. The debris can bury undamaged structures while the dust clouds can act as sandblasting equipment on aircraft and missiles flying through them.

The most familiar phenomena relating to both blast effects and target hardness is overpressure. This is measured in pounds per square inch (psi). A one cubic foot block of concrete exerts one psi on the ground beneath.

Stacking a second block on the first will increase the pressure to two psi, etc. Five Washington Monuments placed atop each other equates to 500 psi; a sonic boom registers a mere 0.3 psi.

Blast overpressure is heightened by the interaction of the primary shock wave and a reflected shock wave. The primary wave is radiated outward from ground zero and compresses the air in front of it. This wave will strike the earth and reflect upward and outward, creating the reflected wave. This reflected wave moves faster than the primary wave because the air resistance has been decreased by the passage of the first wave. The primary wave will be reinforced by the reflected wave, forming a "mach front." A drawing of this phenomenon would resemble the letter "Y" with the intersection of the "Y" termed the "Triple Point." Below the triple point, the two blast waves will strike like a single, powerful blow. Anything above the triple point is the overpressure.

Table 17-1 shows the effects of overpressures on building materials.

The power of a nuclear explosion is almost incomprehensible, but the following example may help to put it into perspective. Five million one-ton pickup trucks loaded with TNT would have the same explosive yield as a single *five megaton* nuclear weapon. A surface burst of this weapon will yield the following results at a distance 3,200 feet (0.6 miles) from ground zero:

- Fireball diameter: 2.8 miles
- 5.5 billion kW hours X-rays
- 14,000 degrees
- 250 G lateral acceleration
- 500 psi
- 3,500 mph winds
- 20 inches of debris
- Debris weighing as much as 2,000 lbs. impacting at 250 mph
- Crater: 3,000 ft wide; 700 ft deep

Table 17-1. Overpressure Sensitivities

Structural Element	Failure	Approximate Side-on Peak Overpressure (PSI)
Glass windows, large & small	Shattering, occasional frame failure	0.5 - 1.0
Corrugated asbestos siding	Shattering	1.0 - 2.0
Corrugated steel paneling	Connection failure followed by buckling	1.0 - 2.0
Wood-frame construction	Failure occurs at main connections, allowing a whole panel to be blown in	1.0 - 2.0
Concrete or cinder block wall panels, 8-12 inches thick (unreinforced)	Shattering	1.5 - 5.5
Brick wall panel, 8-12 inches thick (unreinforced)	Shearing and flexure	3.0 - 10.0

The effects on people are shown in **Table 17-2** (next page). Note: "rem" stands for Roentgen Equivalent in Man; it's a standard measurement of radiation effects on humans. A rem is the equivalent of one roentgen of high-penetration x-rays.

Table 17-2. Nuclear Radiation Effects on People			
Dose in Rems (see note above)	**Radius in feet from 20 KT Air Burst**		**Probable Effects**
	Unprotected Persons	Troops in Covered Foxholes	
0 - 80	5,550	4,200	No obvious effects. Minor blood changes possible.
80 - 120	5,250	3,900	Vomiting and nausea for about one day in 5-10% of exposed persons. Fatigue, but no serious disability.
130 - 170	4,800	3,750	Vomiting and nausea for about one day followed by some symptoms of radiation sickness in about 25% of exposed persons. No deaths anticipated.
180 - 260	4,500	3,600	Vomiting and nausea for about one day followed by some symptoms of radiation sickness in about 50% of exposed persons. No deaths anticipated.
270 - 390	4,200	3,300	Vomiting and nausea in nearly all persons on first day, followed by other symptoms of radiation sickness. About 20% deaths within two to six weeks after exposure. Survivors convalescent for up to three months.
400 - 550	3,900	3,000	The "mid-lethal dose." Vomiting, nausea, and radiation sickness symptoms. About 50% deaths within one month. Survivors convalescent for up to eight months.
550 - 750	3,750	2,850	Vomiting and nausea in all persons within a few hours, followed by other symptoms of radiation sickness. 90% to 100% deaths. The few survivors convalescent for six months.
1,000	3,600	2,550	Vomiting and nausea in all persons exposed. Probably no survivors.
5,000	3,000	2,250	Incapacitation almost immediately. All persons will die within one week.

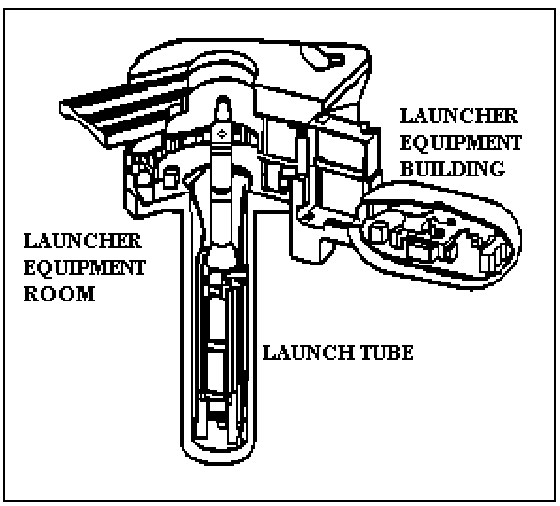

Fig. 17-4. Minuteman Launch Facility (LF)

Current ICBMs

Minuteman III (LGM-30G)

The Minuteman "G" model is a three-stage, solid-propellant, inertially guided, Intercontinental Ballistic Missile with a range of more than 6,300 miles. It employs a Multiple Independently Targetable Reentry Vehicle (MIRV) system with a maximum of three reentry vehicles. The Post Boost Control System (PBCS) provides maneuvering capability for deployment of the reentry vehicles and penetration aids. It is comprised of a Missile Guidance Set (MGS) and a Propulsion System Rocket Engine (PSRE). The "G" model is maintained on alert in a hardened, underground, unmanned Launch Facility (LF) as depicted in **Figure 17-4**, the same as the "F" model was. The LFs are at least three miles apart and three miles from the LCC. Each LF in the squadron is connected to other squadron resources by a buried cable system. This allows one LCC to monitor, command and launch its own ten missiles (called a flight) and all fifty missiles in the squadron when necessary.

Enhancements and modifications are in progress to maintain the viability of the force at least until the year 2020. On the missile itself, the first and second-stage motors are being washed out and repoured. The third stage motors are being remanufactured. A major effort is under way to test an environmentally acceptable propellant replacement. The Rapid Execution and Combat Targeting (REACT) Service Life Extension Program (SLEP) is designed to provide long-term supportability of the aging electronics components. It also modifies the launch control center allowing real-time status information on the weapons and communications nets to correct operability problems, improve responsiveness to launch directives, and provide rapid retargeting capability.

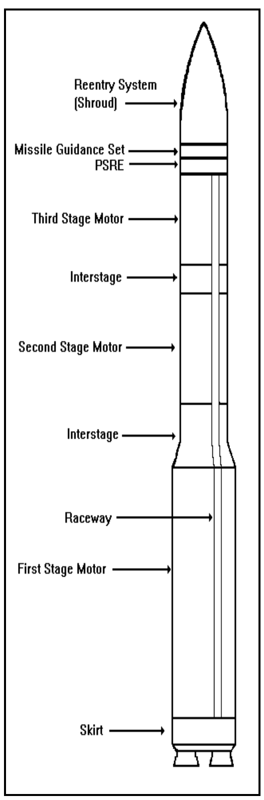

Fig. 17-5. Minuteman

Propulsion System. Three solid propellant rocket motors make up the propulsion system of the Minuteman "G" model (**Fig. 17-5**). The first stage uses a Thiokol M-55 solid propellant motor that generates 200,400 pounds of thrust. The second stage motor is built by Aerojet (SR19-AJ-1), developing 60,700 pounds of thrust. These stages are identical to the Minuteman "F" model. The third stage is larger than the "F" model and it uses a single, fixed exhaust nozzle with the Liquid Injection Thrust Vector Control (LITVC) system and roll control ports for attitude control. The third stage is a Thiokol SR73-AJ-1 motor that delivers 34,500 pounds of thrust (the third stage on the Minuteman II also uses this motor, but it only generates 17,100 pounds of thrust). Thrust termination is similar to the "F" model but there are six thrust termination ports mounted at the forward end of the third stage. These "blow out" when the desired point in space is reached to employ all weapons. The actual deployment of the reentry vehicles and penetration aids is accomplished by a "mini fourth stage," the PBCS. It fires a liquid-fueled engine periodically to maneuver throughout the deployment sequence. This process allows the "G" model to hit up to three separate targets at different ranges with great accuracy.

Airframe. The missile consists of rocket motors, interstages, a raceway assembly and the Mark 12 or 12A reentry system. The reentry system includes a payload mounting platform, penetration aids, reentry vehicles and an aerodynamic shroud. A shroud protects the reentry vehicles during the early phases of powered flight. All three stages of the "G" model are delivered preloaded from the manufacturers and emplaced into the LF as one unit. The PBCS and the reentry system are assembled on the missile in the launch tube after missile emplacement.

Peacekeeper (LGM-118A)

The Peacekeeper is a four-stage, inertially guided ICBM, with a range of more than 6,000 miles. The first three stages are solid propellant with Kevlar 49 casings. The fourth stage is liquid propelled. The Peacekeeper can carry eleven Mark 21 or twelve Mark 12A reentry vehicles. The operational deployment is ten Mark 21s. The guidance and control system is in stage four and uses a raceway with fiberoptic cabling to transmit commands to the first three stages. Peacekeeper missiles are maintained on alert in modified Minuteman LFs (**Fig. 17-6**) and commanded by modified Minuteman LCCs. Only one squadron of Peacekeeper missiles is operational and it is deployed at F.E. Warren AFB, Wyoming.

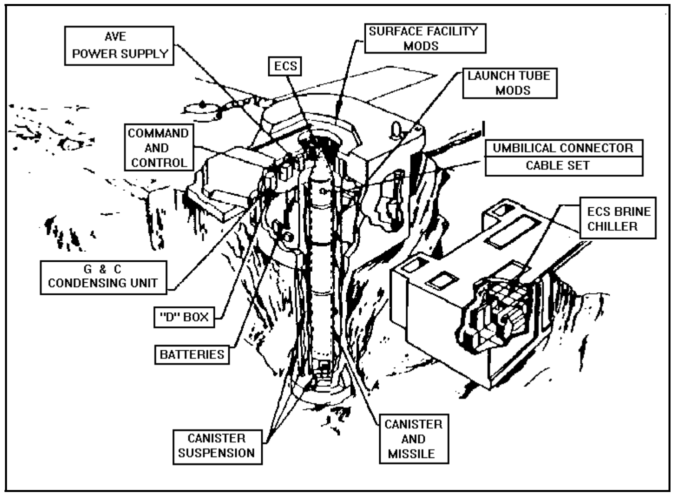

Fig. 17-6. Peacekeeper Launch Facility

Propulsion System. Unlike the Minuteman, Peacekeeper's engines do not ignite in the silo. The missile is in a canister with a Launch Ejection Gas Generator (LEGG). Like a sea-launched ballistic missile, the Peacekeeper is ejected from the canister and propelled some 80 feet into the air before the first stage engine ignites. Peacekeeper's first three stages are solid propellant with single exhaust nozzles. The first stage nozzle is movable through hydraulic actuators powered by a hot gas generator and turbine centrifugal pump. A similar gas generator turbine assembly extends the nozzles on stages two and three. These Extendable Nozzle Exit Cones (ENEC) are folded before stage ignition and extend to provide better performance characteristics without increasing stage diameter or length. The fourth stage, deployment module, guidance and control section and shroud make up the Post Boost Vehicle (PBV). The system operates like the PBCS on the Minuteman “G” model using the new Advanced Inertial Reference Sphere (AIRS) and the Missile Electronics and Computer Assembly (MECA).

Airframe. The missile consists of rocket motors, interstages, a raceway assembly, and the reentry system. The reentry system is the Post Boost Vehicle minus the fourth stage. Peacekeeper is assembled in its canister at the LF following delivery of the components from the manufacturer. Along with several special vehicles, an “air elevator” is used in this assembly process to lower the missile one stage at a time into the canister. This isn't an easy task. It's been described as “similar to stacking BBs.”

U.S. SLBMs

SLBM History

In 1955, the National Security Council requested an IRBM for the defense of the U.S. They further decided that part of the IRBM force should be sea-based. As a result, the Navy was directed to design a sea-based support system for the existing liquid-fueled Jupiter IRBM. This led to the development of the Special Projects Office (SPO) by the Secretary of the Navy. The SPO was tasked with adapting the Jupiter IRBM for shipboard launch. Originally, the Jupiter was an Army missile designed for land-based launches. Because of the unique handling and storage requirements of liquid propellants, Navy crews encountered storage and safety problems. As a result, the Navy began a parallel effort to the Air Force in the development of alternate solid-fueled rocket motors.

Breakthroughs in solid fuels, which resulted in smaller and more powerful motors, occurred in 1956. Reductions in the size of missile guidance, reentry vehicles and warheads further aided in smaller missile technology. The first solid-fueled missile incorporating this new technology was named Polaris. The first submarine launch of a Polaris occurred in July 1960 from the USS GEORGE WASHINGTON. Three hours later a second missile was successfully launched. These two shots marked the beginning of sea-based nuclear deterrence for the U.S.

Since then, the Fleet Ballistic Missile (FBM) has progressed through Polaris and Poseidon, to the Trident I and Trident II missiles of today. The Poseidon added MIRV capability while both generations of Trident increased range and accuracy.

There are other changes as well. The launcher system evolved from compressed air units to steam-gas generators. The missile guidance systems now use in-flight stellar updates. Navigation has matured from external fixes to on-board computers. The missile fire control system has developed through semiconductor and solid-state electronics to the present microchip technology.

The first SSBN was constructed by cutting a fast-attack submarine (USS SCORPION) into two pieces and inserting a 16 tube missile compartment section. Since then, several classes of submarines have been designed and built specifically for the FBM mission. The Ohio (726)-class submarine is the newest generation of SSBN. The first submarine of this class was deployed in 1981. This is the same class of submarines that carry the Trident II strategic weapon system (SWS) and missile. Currently, the United States has two different strategic weapon systems (Trident I and Trident II).

<u>Polaris</u>. The Polaris (A1) program began in 1957; later versions were called A2 and A3. Its innovations included a two-stage solid propulsion system, an inertial navigation guidance system, and a miniaturized nuclear warhead. Production ended in 1968 after more than 1,400 missiles had been built. The last version, the A3, had an increased range (2,900 miles compared with 1,700 miles for the A2 model) and multiple warhead capability. The missile was replaced by the Poseidon SLBM and later by the Trident.

<u>Poseidon</u>. The Poseidon (C3) weapon system was deployed on Poseidon (Lafayette-class) submarines. The Poseidon submarine was similar to the one that carried the Polaris. They carried 16 missiles. Poseidon submarines, now out of service (except for two converted to SSNs) were deployed from Charleston, South Carolina and Holy Loch, Scotland.

<u>Trident I</u>. The Trident I (C4) backfit weapon system was initially deployed on Poseidon submarines starting in 1979. The Trident I system consisted of the Trident I missile and updated launch and preparation equipment. The Trident I missile has increased range and accuracy over the Poseidon (C3). The updated weapon system included many improvements resulting from new technology.

The Trident I was deployed on early Ohio-class submarines in 1981; the pre-Ohio class submarines were retired in 1995. This weapon system consists of the Trident I missile and new/modified launch and preparation equipment. The modifications to the launch and preparation equipment result largely from improvements in electronics technology. The Ohio-class submarine was designed from the ground up to carry the new weapon system. It is larger, faster and quieter than the Poseidon submarine and carries 24 Trident I missiles.

Trident II. The Trident II (D5) was deployed on the later Trident (Ohio-class) submarines, starting in March 1990. This weapon system consists of Trident II missiles and a combination of new and modified preparation and launch equipment. The Trident II missile is significantly larger than the Trident I because of the increased size of the first stage motor, giving it a greater payload capability. The Trident II uses the latest electronics for improved reliability and maintainability. The launch platform is basically the same submarine that carries the Trident I. They are deployed from Naval Submarine Bases at Bangor, WA and Kings Bay, GA.

The Trident II is also provided to the United Kingdom (U.K.) which puts its own warheads on the missiles. The U.K. deploys them on Vanguard-class submarines.

Current SLBMs

Trident I C-4

The Trident I C-4 is a three-stage, solid propellant, inertial/stellar-guided, ICBM. It has a range of 4,000 nautical miles (4,600 statute miles). It carries a MIRVed system and was originally deployed on the Lafayette-class (all retired) and currently on the Ohio-class (Trident) submarines.

Propulsion Subsystem. Three solid propellant rocket motors make up the propulsion system of the C-4 missile (see **Fig. 17-7**). Each stage of the missile contains a nitroglycerin and nitrocellulose-base propellant encased in a Kevlar/epoxy rocket motor casing. Stage I is 14.75 feet long or about half the missile's length. It is six feet wide and weighs approximately 19,300 pounds. The third stage is ten feet tall, 2.6 feet wide, and weighs 4,200 pounds. Each stage is controlled by a single movable nozzle activated by a gas generator. The PBCS and RV mounting platform surrounds the third stage rocket motor. At a predetermined time, a small rocket located on the top of the third stage fires, backing it away from the PBCS. Now taking on a doughnut appearance, the PBCS fires and proceeds to the RV deployment points.

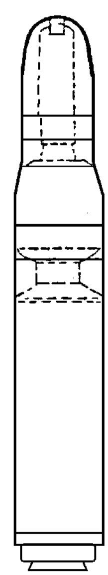

Fig. 17-7. Trident I

Airframe. The airframe of the C-4 is similar to the Poseidon C-3. The C-4 has a length of 34 feet, a diameter of about six feet, and weighs about 73,000 pounds. An aerodynamic spike (AEROSPIKE) actuates by an inertial pyrotechnic device during first stage flight. This aerospike increases missile range by reducing aerodynamic drag by about 50 percent. The nose fairing on the C-4 is also constructed of Sitka Spruce. The fairing jettisons during second stage burn.

Trident II D-5

The Trident II D-5 is a three-stage, solid propellant, inertial/stellar guided, ICBM. It has a range of over 4,000 nautical miles (over 4,600 statute miles). It carries a MIRVed re-entry system and is deployed on Ohio-class submarines.

Propulsion Subsystem. Three solid propellant rocket motors make up the propulsion subsystem of the Trident II D-5 missile (**Fig. 17-8**). Each stage of the D-5, like the C-4, contains nitroglycerin and nitrocellulose-based propellants in the motor casing. The motor casing for the first and second stages is constructed of graphite and epoxy, while the third stage of the D-5 consists of Kevlar/epoxy materials; these materials are lighter than those used in the Trident I. Stage one is approximately 26 feet long, almost seven feet wide, and weighs 65,000 pounds. Stage two is eight feet long, seven feet wide and weighs approximately 19,000 lbs. The third stage is 10 feet tall, 2.5 feet in diameter, and weighs 4,200 pounds. A single movable nozzle, actuated by a gas generator, controls each stage. Like the C-4, the third stage of the D-5 is surrounded by the PBCS and the RV mounting platform. During third stage separation, the stage slides back through the equipment section along support rails. Taking on a doughnut appearance, the PBCS fires and proceeds to the deployment points for RV release.

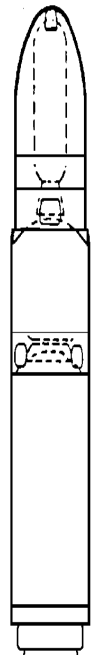

Fig. 17-8. Trident II

Airframe. The Trident II D-5 is 44 feet in length, approximately seven feet in diameter and weighs 130,000 pounds. Like the Trident I C-4, the D-5 employs an AEROSPIKE during first stage burn. The nose fairing is constructed of Sitka Spruce and jettisons during second stage burn. All other airframe characteristics of the D-5 are the same as the Poseidon C-3 and the Trident I C-4.

Ohio Class Submarine

All 18 Ohio-class submarines were operational as of 1998. Shown in **Fig. 17-9**, each is 560 feet long, 42 feet in beam and has a submerged displacement of 18,700 tons. Although over two times larger than the Franklin-class in volume displacement, the Ohio-class requires only 16 officers and 148 enlisted crew members. The Ohio-class submarine carries up to 24 Trident I or Trident II missiles.


Fig. 17-9. Ohio-class Ballistic Missile Submarine

Cruise Missile Weapon Systems

Cruise missiles are described here for comparison with the previous weapon systems. There are several major differences between ballistic missiles and cruise missiles. First is that ballistic missiles are only in powered flight for a short time (being fired hundreds of miles up, then letting gravity carry them to a target). Cruise missiles are continuously powered because they fly close to the earth. The second major difference is a consequence of the first; cruise missiles have a much shorter range. Third, cruise missiles fly at subsonic speeds while ballistic missile warheads arrive at up to Mach 20; so cruise missiles have a lot in common with unmanned aircraft.

Cruise missile weapon systems consist of the Air Launched Cruise Missile (ALCM), the Sea Launched Cruise Missile (SLCM) and the Advanced Cruise Missile (ACM). While the launch techniques used by each system are different, their airframe characteristics, guidance systems, propulsion systems and flight profiles are similar.

Airframe

Cruise missile airframes (**Fig. 17-10**) are approximately 20 feet long and 20 inches in diameter. These missiles weigh close to 3,000 pounds at launch. The guidance system in the forward portion of the missile uses two separate techniques to achieve outstanding accuracy. A Terrain Contour Matching (TERCOM) system provides periodic location updates correcting any drift or errors in the inertial guidance set. Later missiles include GPS guidance. Aft of the guidance compartment is the warhead. The ALCM and ACM carry nuclear warheads, while the SLCM may be either nuclear or conventional. Behind the warhead is the fuel tank for the turbofan engine. After the fuel tank is the midsection where the missile's wings meet the fuselage.

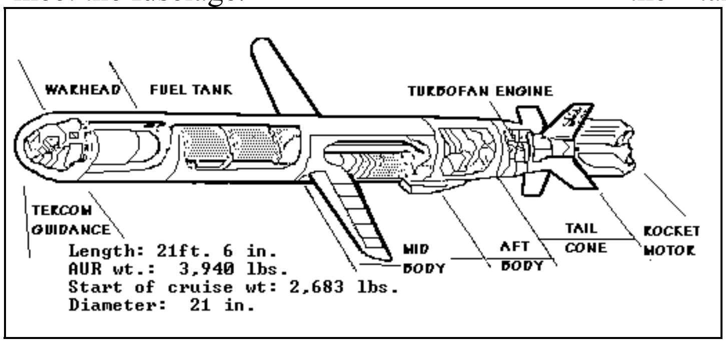

Fig. 17-10. Sea Launched Cruise Missile (SLCM)

SLCM and ACM wings are eight feet seven inches long and extend straight out from the fuselage. ALCM wings are 12 feet long and swept back 25 degrees. Aft of the midsection is the air inlet for the turbofan engine. SLCM and ACM air inlets are on the bottom of the airframe while the ALCM's is on top. SLCM and ALCM air inlets are kept retracted into the airframe until needed during flight. Immediately behind the air inlet is the tail cone section which contains an F-1017-WR turbofan engine. This engine weighs 145 pounds and produces about 600 pounds of thrust. The tail cone section also provides attachment points for the missile's tail fins. Finally, there is a solid rocket motor on the SLCM. This rocket accelerates the missile to a speed of 550 mph

Tomahawk Land Attack Missile (TLAM)

The Tomahawk is a long-range cruise missile that can be used against surface ships or land targets, employing several different types of warheads. The missile entered service in submarines in 1983, and is also launched from surface vessels. TLAMs are launched from standard 21-inch torpedo tubes and, in the later Los Angeles-class submarines, from 12 vertical launch tubes (in addition to the standard 4 horizontal tubes).

The Tomahawk is an all-weather, subsonic missile which, when launched from a submarine, rises to the surface and deploys small wings and starts a small turbofan engine which propels it toward the target. The small size of the Tomahawk gives it a low radar cross section and its low-level flight profile makes it difficult to intercept. The TLAM is launched on a preset course above the water and, as it crosses over land, switches to an inertial and Terrain Contour Matching (TERCOM) system to guide the missile to its target with an accuracy measured in feet.

TLAM warheads consist of conventional high explosives (TLAM-C) or scattering bomblets (TLAM-D). Block III TLAMs have an extended range and incorporate a Global Positioning System (GPS) receiver for improved reliability and time-of-arrival control to permit coordinated strikes between other missiles and aircraft. The GPS feature will also make it easier to retarget the missiles while at sea, thus enhancing mission planning.

ALCM Airframe

The ALCM's overall dimensions and component locations are similar to the SLCM. The ALCM (**Fig. 17-11**) differs from the other cruise missile variants in the shape of its airframe and wings, the location of its air inlet and its lack of a solid rocket motor.

Fig. 17-11. ALCM

Launch

The SLCM comes in a canister, which functions as a shipping and storage container and firing tube. A canister loaded with a warhead-equipped missile is an All-Up-Round (AUR). When a launch command is received, the SLCM's solid rocket motor fires and accelerates the missile to a speed of 550 mph. The tail fins deploy six seconds after the booster ignites. Two seconds later the turbofan sustainer engine starts and propels the missile to its Initial Timing Control Point (ITCP). Since ALCM's initial velocity is provided by its carrier aircraft, it does not need a rocket booster. The ALCM's wings, elevons and fin deploy immediately after the missile is released from the aircraft. The turbofan engine then starts and the flight control system begins. The ALCM then proceeds to the ITCP.

Flight Profile

Flight profiles from the ITCP to the target are similar for both cruise missiles. A pre-programmed path stored in its onboard computer (inertial guidance navigational system) guides the missile from the ITCP to the target. The TERCOM system compares information about the land terrain relief stored in the cruise missile's computer memory with the actual terrain it is flying over. Various altimeters collect the actual terrain relief data. The missile's position is determined and commands are sent to an automatic pilot which corrects the course. Digital maps of terrain areas are compiled by first digitizing the height of a point on the earth's surface whose coordinates are known. Adjoining points are then established, assembled into a digitized map of the area, and stored in the memory of the cruise missile's computer.

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Chapter 18

REST-OF-WORLD (ROW) SATELLITE SYSTEMS

For the longest time, space exploration was an exclusive club comprised of only two members, the United States and the Former Soviet Union. That has now changed due to a number of factors, among the more dominant being economics, advanced and improved technologies and national imperatives. Today, the number of nations with space programs has risen to over 40 and will continue to grow as the costs of spacelift and technology continue to decrease.

RUSSIAN SATELLITE SYSTEMS

In the post-Soviet era, Russia continues its efforts to improve both its military and commercial space capabilities. These enhancements encompass both orbital assets and ground-based space support facilities. Russia has done some restructuring of its operating principles regarding space. While these efforts have attempted not to detract from space-based support to military missions, economic issues and costs have lead to a lowering of Russian space-based capabilities in both orbital assets and ground station capabilities.

The influence of Glasnost on Russia's space programs has been significant, but public announcements regarding space programs focus primarily on commercial space promotion and budgetary justification of the civil and commercial space programs. Admissions of their military use of space remain infrequent, and the economic measures reported by space program managers, appear to be designed largely to avoid calls for further constraints.

Despite restructuring throughout the Russian military, the objectives of the military space programs have not changed. Military space strategy still requires sufficient capability to provide effective space-based support to terrestrial military forces and the capability to deny the use of space to other states. Maintaining this capability has, however, proved extremely difficult in post-Soviet Russia.

Missions and Operations

The satellite section of the Russian space program continues to be predominantly government in character, with most satellites dedicated either to civil/military applications (such as communications and meteorology) or exclusive military missions (such as reconnaissance and targeting). A large portion of the Russian space program is kept running by launch services, boosters and launch sites, paid for by foreign commercial companies.

The most obvious change in Russian space activity in recent years has been the decrease in space launches and corresponding payloads. Many of these launches are for foreign payloads, not Russian. This can be attributed not only to the recent breakup of the Soviet Union, but also to the fact that Russian satellites are gradually becoming more sophisticated and longer-lived. This increased operational efficiency is the mark of a more mature military space program which can reduce redundancy while accomplishing its missions. Economic problems throughout Russia have lead to many problems in building and launching these new satellites. While Russia retains the surge launch and reconstitution capabilities that are essential for military operations in crisis or conflict, money and lack of maintenance to ground facilities cast doubts on the viability of this former Soviet capability.

Space-Based Military Support

An extensive array of spacecraft was developed to support the Soviet, now Russian, armed forces and political leadership. These satellite systems conduct missions which include: imagery; electronic and radar reconnaissance; launch detection and attack warning; ocean surveillance and targeting; command, control, and communications; geodetic, navigational, and meteorological support; anti-satellite (ASAT) operations; and military R&D. Reports in 1999 indicated that Russia's military space forces had barely the resources to meet the needs of the nation's armed forces.

These systems, in turn, are supported by a tremendous infrastructure on the ground, including the Ministry of Defense (MOD) main space command, control and telemetry complex near Moscow. Improvement, maintenance and refurbishment of this infrastructure has continued despite a lower launch rate. Plans are ongoing to streamline the command and control systems, both civil and military, to optimize the networks.

Russian sources have stated that more that 70 percent of the spacecraft and ground facilities active in 1999 have outlived their guaranteed service lives.

Anti-satellite Systems

The Russian military and political leadership is fully aware of the value of military space systems. They have developed the capability to disrupt and destroy the military space systems of potential enemies. Russia built a dedicated ASAT system that probably became operational in 1971. In August 1983, Moscow announced a unilateral moratorium on the launch of ASAT weapons. However, Russia continued the testing of ASAT elements and procedures on the ground, and the associated booster, the SL-11. The SL-11 is also the same booster used to launch the ELINT Ocean Reconnaissance Satellites (EORSATs) and Radar Ocean Reconnaissance Satellites (RORSATs), although the last RORSAT launch was in 1988. The co-orbital interceptor has been launched from two separate cosmodromes; Plesetsk in Russia and Tyuratam in Kazakhstan. Due to the current political considerations between Russia and Kazakhstan, it is doubtful that Russia would launch an ASAT system from Tyuratam. No Russian ASAT has been launched since 1982.

Russia maintains a significant ASAT capability against low-earth and medium-earth orbit satellites, but capabilities against high altitude ones are limited. Future ASAT developments could include new directed energy weapons or direct-ascent non-nuclear interceptors.

In addition to the co-orbital interceptor, Russia has additional potential ASAT capabilities. These capabilities include: exo-atmospheric ABM missiles, located around Moscow, that could be used against satellites in near-earth orbit; at least one ground-based laser, that may have sufficient power to damage some unprotected satellites in near-earth orbits; and electronic warfare assets that probably would be used against satellites at all altitudes. Research and development of technologies applicable to more advanced ASAT systems continue. Areas of investigation that appear to hold promise include high energy laser, particle beam, radio frequency and kinetic technologies.

Photographic Reconnaissance

Photographic reconnaissance by satellite to gather high resolution images of military installations and activities was so clearly of value to both the East and West that its development was one of the main incentives in the early years of the space era. Russia has both the older film return systems and newer digital, near-real-time, imaging systems. As with most of its satellite programs, Russian capability here has declined since the break-up of the Soviet Union. During the 1980's the Soviet Union launched over 30 photo-reconnaissance satellites, always having at least one imagery satellite in orbit. Russia currently has not been able to maintain anything near this rate. In fact, between September 28, 1996 and May 15, 1997, there were no Russian imagery satellites in orbit.

Russia's COSMOS film return "spy" satellites (**Fig. 18-1**) normally operate in low orbits that pass over geographic areas of interest. These satellites are designed to withstand the heat of reentry so that they can be recovered. They are used mainly for military purposes, but do have civilian uses.

A current commercial venture is using older Russian film return satellites to image areas of the earth for commercial sales. The imagery is processed at a resolution of two meters and then digitized and made available for sale via Internet. This project is a joint Russian-US venture called SPIN-2 (SPace INformation - 2 meter).

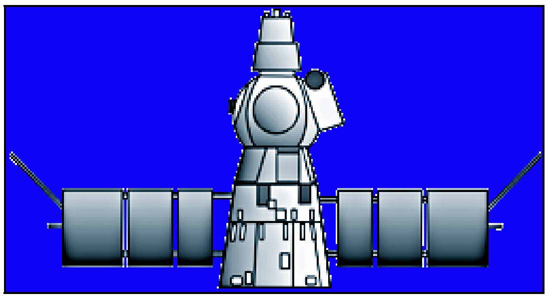

Fig. 18-1. Cosmos

Communication

Russia operates several communications satellite systems. These satellites operate in highly inclined, geostationary and low-earth orbits.

The Molniya (Lightning) satellite series orbits in a highly inclined orbit that places it over the Russian landmass for approximately eight hours of its 12 hour orbit. With satellites placed 90 degrees apart, 24 hour communications are possible. This series was first launched in 1965. The Molniya-1 series are primarily used for military and government communications (**Fig. 18-2**). The Molniya-3 series are for civil and domestic telecommunications as well as TV broadcasts.

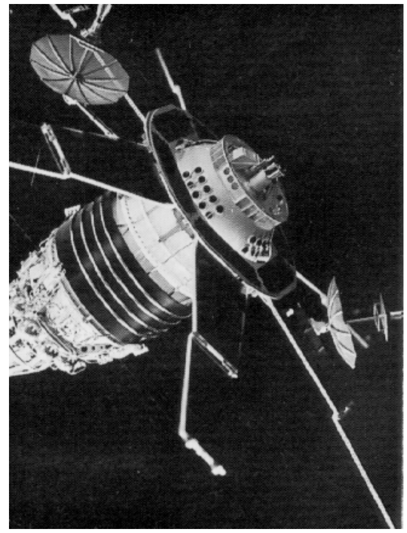

Fig. 18-2. Molniya 1 Communications Satellite

The Ekran (Screen), Gorizont (Horizon) and Raduga (Rainbow) series, were the Soviet Union's first generation of geosynchronous satellites. The Ruduga was the first system launched in 1975. This system is used primarily for military and government communications channels in addition to some domestic links.

Launched in 1976, the Ekran was the Soviet Union's first civil geostationary communications satellite, providing direct TV broadcast to Siberia.

Gorizont was the next geostationary system, first launched in 1978 (**Fig. 18-3**). This constellation is mainly used for TV distribution, telecommunications services and maritime/mobile aeronautical receivers in western regions of Russia via the Moskva system. In design, this system is very similar to the Ruduga.

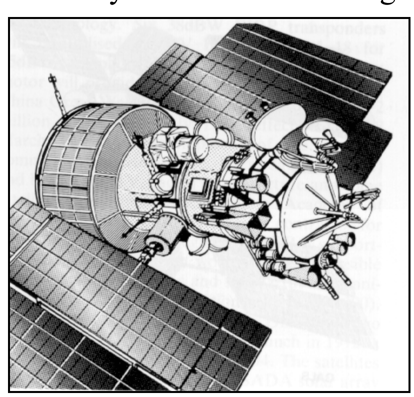

Fig. 18-3. Gorizont Communications Satellite

These systems are being replaced by newer generations of geostationary satellites. The Ekran is being replaced by the Gals series while the Gorizont follow-on is the Express system.

Russia has one additional geostationary system, a Satellite Data Relay Network (SRDN) with the satellite sometimes referred to as Luch or Loutch. This system was intended to relay communications between manned satellites and ground controllers. First launched in 1985, they were used extensively to relay communications with the MIR space station and the manned Soyuz spacecraft. It was also used to support the test flight of the Russian space shuttle Buran in 1988. In 1992, Russian press reported that MIR was operating without satellite links due to cost, leaving the station out of contact with ground control for up to 9 hours a day. Currently there is only one operational SRDN satellite in orbit. This is used by the MIR during special events, such as space walks and docking operations.

Russia also has many other communication satellites in lower orbits used primarily for military communications. There are a variety of systems, most launched in multiples of six or eight at a time. These systems often use a store and dump method of communications, receiving transmissions from locations around the world and storing the messages until over a Russian receiving station. A version of the sextet system without the military transponders was offered commercially in 1990 to foreign buyers interested in establishing their own store and forward communications networks. This system is marketed under the name Gonets.

Of all the Russian satellite systems, the communications constellations are in the best shape. These systems are, however, showing their age and those in orbit need to be replaced by current or upgraded systems. This problem was highlighted by launch failures in 1996 and 1999, to place a Raduga satellite in orbit.

Navigation

Russia maintains three satellite navigational systems: a low altitude military, a low altitude civil and a medium altitude system, GLONASS.

The low altitude military satellites, Parus (sail) provide primary navigational support to their maritime forces. The civil system has two different versions. The original version is Tsikada while a version with the Cospas/Sarsat search and rescue transponder is called Nadezhda (Hope). **(Fig. 18-4)**

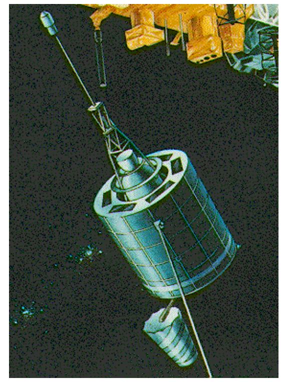

Fig. 18-4. Nadezhda

The GLONASS (Global Navigation Satellite System, Globalnaya Navigatsionnaya Sputnikovaya Sistema) system is similar to the U.S. GPS satellite navigation system. Like the GPS, GLONASS has many civil applications and commercial receivers are available (**Fig. 18-5**).

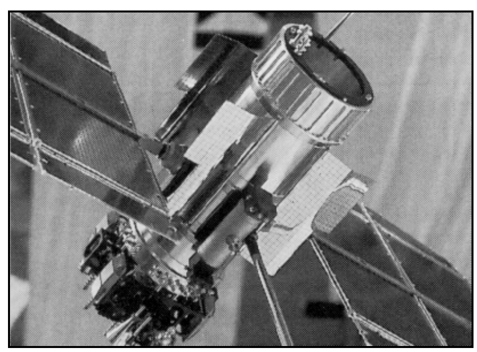

Fig. 18-5. GLONASS Navigation Satellite

While the Parus and civil systems have had regular replacements and are in good shape, the GLONASS system is not. Designed to operate with a 24 satellite constellation, first achieved in December 1995, satellites have reached the end of their operational live and have not been replaced. Currently the GLONASS system is operating with less than 15 satellites. This is barely adequate for Russian military needs but without regular replacements in the near future, the system may breakdown and be unable to perform its mission beyond the year 2001.

Meteorological and Natural Resources

Russia's weather satellites provide them with vital environmental information including cloud coverage of earth; the flow of radiation in near-earth space; and atmospheric dust formations.

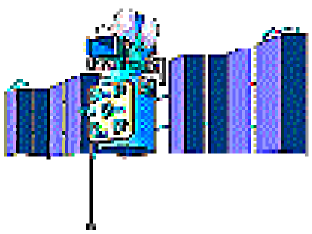

Fig. 18-6. Elektro

Russian maintains both geo-stationary (Elektro) **(Fig. 18-6)** and polar orbiting (Meteor) weather satellites. The Meteor system was first launched in 1969 while the geo-stationary Elektro was not launched until 1994.

Their natural resource satellites collect and analyze data covering a wide range of areas. These include agriculture, forestry, geology, mineral surveys, hydrology, oceanography, geography and environmental control. Natural resource data can be collected by photo-reconnaissance satellites, manned MIR missions and by oceanographic satellites.

Early Warning

Russian early warning satellites are used for detection of ballistic missile launches. The first system, Oko (eye) was placed in Molniya orbits allowing Russia to view the continental U.S. First launched in 1972, this system reached full operational capability of nine satellites in 1987. Four early warning satellites have been placed into geosynchronous orbits (1975, 1984, 1985 and 1987) to develop geo-stationary technologies and to provide coverage over ocean areas for submarine launched missiles. In 1988, a new series of early warning satellites, Prognoz**, (Fig. 18-7)** took over the geosynchronous location.

As with many of Russia's satellite systems, the early warning constellation is not fully operational. In 1999, only three of the nine Oko slots were filled. These three satellites orbit the Earth every 12 hours in highly elliptical orbits, but are unable to see the U.S. missile sites for about seven hours during each orbit. One Oko and one Prognoz are currently in geo-stationary orbit to cover the Atlantic and Pacific Ocean.

Fig. 18-7. Prognoz

ELINT Reconnaissance

Russia also has satellites to gather Electronic Intelligence (ELINT). Their task is to identify and locate military radio and radar stations, making it possible to identify command and control centers, forward battle elements, air defense units and reveal military movements. There have been several types of ELINT satellites, although only two types are thought to be currently deployed.

Ocean Reconnaissance

The primary function of ocean reconnaissance satellites is to detect, locate and target U.S. and Allied naval forces for destruction by anti-ship weapons. Two satellites that performed this mission are the ELINT Ocean Reconnaissance Satellite (EORSAT) and the Radar Ocean Reconnaissance Satellite (RORSAT - no longer active). These systems are designed to work in pairs, their combined data building a comprehensive view of surface activity. The RORSAT has an active search system which can locate ships in all weather conditions, while the EORSAT is a passive collector of transmissions from both radio and radar units.

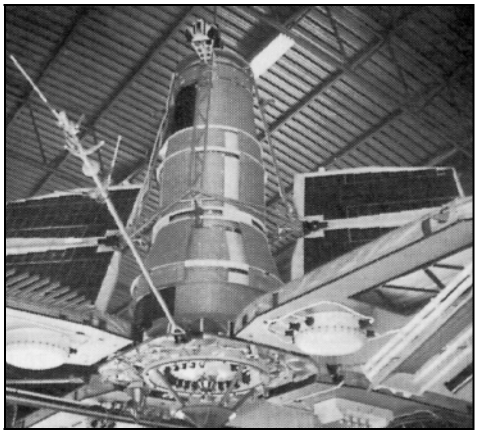

Fig. 18-8. Okean Oceanographic Satellite

A third satellite with a more civilian mission is the Okean. Its primary mission is ice and oceanographic reconnaissance (**Fig. 18-8**).

Another category includes "minor military" satellites. These satellites have missions of radar calibration, atmospheric drag measurement and spacecraft technology experimentation.

Scientific Satellites

Russia launches some scientific satellites that have instruments to study physical activity such as shock waves and solar wind. Some satellites that contain living organisms are launched to study biological conditions in space.

Man and Man-related Space Programs

Manned Russian programs include the MIR (Peace) space station (**Fig. 18-9**), whose core was launched in 1986. This complex provides a space-based science lab to conduct military and civilian experiments. The first addition to MIR was the *Kvant-1* module in 1987, containing astrophysics instruments, additional life support and attitude control equipment.

After a four month hiatus in mid-1989, the MIR space station complex was remanned and reactivated in early September. The space station was continuously occupied until 30 Aug 1999. The MIR's capabilities for military and scientific research were vastly enhanced by launching the 20-ton *Kvant-2* module in late November of 1989. As part of its equipment, the *Kvant-2* carries an external gimbaled platform outfitted with a variety of sensors. Reporting indicates that these sensors are for earth resource studies only; however, military applications are also possible. *Kvant-2* has a larger hatch for egress into space. It also delivered a manned maneuvering unit to the MIR.

Kristall, the materials technology module, was added to the MIR complex in June 1990 to facilitate the production of various materials under microgravity conditions. Such materials have civil applications as well as military.

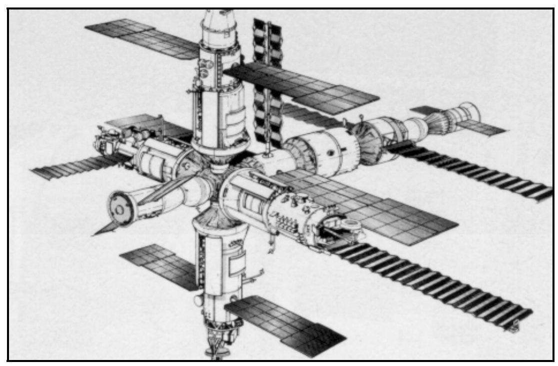

Fig. 18-9. MIR Space Station Complex

Kristall also has a docking port, originally designed as a potential means of docking the Russian space shuttle orbiter. It is now attached to the Docking Module used by the U.S. shuttle fleet.

In 1995, the *Spektr* module was added to the station. The focus for this module is Earth observation. Both Russian and American equipment are carried on-board the *Spektr*. This module also has additional solar panels to increase the power capability of the MIR space station.

With the increase in international cooperation, arrangements were made for the U.S. Space Shuttle to dock with MIR. In June 1995, the U.S. shuttle docked to MIR for the first time. However, to make that possible, the MIR configuration had to be changed. During a spacewalk, Russian cosmonauts moved the *Krystall* module to give the shuttle enough clearance to dock. The module had to be returned to its original position after the mission. In November 1995, the shuttle delivered and installed a Docking Module to the *Krystal* module.

The latest addition was the *Priroda* module in April 1996. Its primary purpose is to add Earth remote sensing capability to the station. The module also contains hardware and supplies for several joint U.S.-Russian science experiments.

With the final assembly complete in 1996, the core module had long exceeded its planned life of five years. The station also was a critical platform for developing the International Space Station.

During 1997, MIR suffered several problems with internal systems. In February, there was a fire in the oxygen-generating system that was extinguished, followed in March by additional repairs to the oxygen-generating system. Also in March 1997, the crew had a partial power outage and encountered problems with the motion control system. During April 1997, an overheated carbon dioxide remover had to be shut down and a cooling leak repaired. Potentially, the most damaging event occurred in June 1997, when a Progress resupply vehicle collided with the *Spektr* module. This collision damaged the solar panels and created a leak in the module. The crew had to seal off the *Spektr* from the rest of the station to prevent total loss of air in MIR. This rapid sealing off involved disconnecting cables from the *Spektr* to the station, resulting in a loss of 50 percent of the stations power producing capability. Further, computer problems have put the future of the MIR into serious doubt.

MIR has survived in space for over 12 years and was occupied continuously for almost 10 years. With the start of the International Space Station, ISS, in 1998, the future of MIR in unknown. While Russia would like to keep its space station in orbit, its commitments to support the ISS make it almost impossible to maintain both MIR and the ISS.

In 2000, MIRCorp, a commercial enterprise, leased the use of MIR. Made up of RSC Energia, MIRs builder and other financial groups, MIRCorp is now responsible for funding, supply, control and mission for the MIR. With private control of MIR, its future remains to be seen. Between April and June 2000 a crew was sent to the station for checkout and to return it to operational status. A paying customer is training for a flight to MIR in early 2001. Funding is still the driving issue on MIRs live span.

Russian Space Shuttle

The Russian shuttle Buran (Snowstorm) was launched in the fall of 1988 on an unmanned flight **(Fig. 18-10).** Technical and financial problems in Russia have halted this program.

Fig. 18-10. Buran

Solar System Exploration

Russia has launched numerous probes to the Moon, Venus and Mars. Collection and return of soil samples from the Moon, mapping and other scientific experiments have taken place.

Both solar system exploration and earth orbit science missions have suffered under budget constraints. No new programs have started in recent years, or are likely to, and it has been a struggle for Russian to maintain operations of some already in orbit. Some of the current programs would not survive without foreign participation.

UKRAINE SATELLITE SYSTEMS

After Russia, Ukraine has the most active space program. Several booster and satellite manufacturing companies and subcontractors exist in Ukraine. Some of the old Soviet Union's satellite and space control sites are also located in Ukraine.

Ocean Reconnaissance

Ukraine currently operates only one satellite. Based on a Soviet ocean reconnaissance satellite, this Ukraine built satellite family is used for all-weather radar ice and oceanographic surveillance by both Russia and Ukraine. This satellite family is called Okean (Ocean) by the Russians. In 1995 a joint Russian/ Ukrainian project launched an Okean which the Ukrainians took over full operational control in late 1995. This program is called Sich by Ukraine. Improved versions of the Okean are planned by Ukraine. These versions when used exclusively by Ukraine will be known as Sich-2 and Sich-3.

EUROPEAN SATELLITE SYSTEMS

The majority of the satellites produced or launched by European nations have been for scientific research or communications (including television). Many of these projects are also multi-national in construction or usage. To cover all the countries in Europe and their various national and international programs is beyond the general scope of this publication.

Communications

These European countries have communications/TV broadcast satellites:

- United Kingdom - Skynet series
- France - Telecom series
- Germany - DFS series
- Hungry - CERES
- Italy - Italsat series
- Luxembourg - Astra series
- Norway - Thor series
- Spain - Hispasat series
- Sweden - Siries

There are also several international communications satellites that Europe uses internationally:

- Eutelsat, European Telecommunications Satellite Organization, 47 members
- Inmarsat, International Mobile Satellite Organization, 79 members
- Intelsat, International Telecommunications Satellite Organization, 136 members

Earth Resources

ERS Series

The European Remote Sensing (ERS) satellite system has three different radar sensors for all-weather sensing (**Fig. 18-11**). It is intended for global measurements of sea wind and waves, ocean and

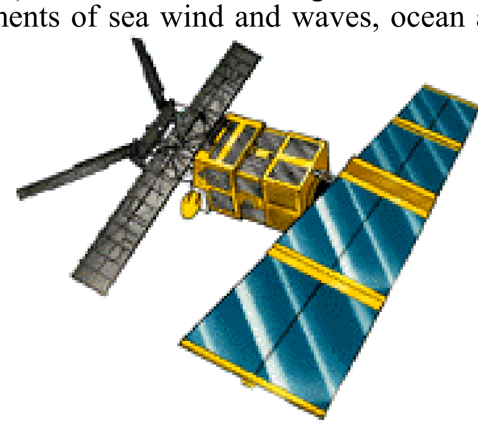

Fig. 18-11. ERS - series Satellite

ice monitoring, coastal studies and a small amount of land imagery. An ESA project, the system had contractors throughout Europe.

ERS-1 was launched in 1991, followed

Fig. 18-12. North Sea oil spill detected by ERS

by ERS-2 in 1995. Both satellites were placed in polar, low-earth orbit (LEO).

One of the first Synthetic Aperture Radar (SAR) commercial earth resource satellites, the demand for ERS-1 products exceeded the preparatory studies and surveys. The range of customers is enormous, from individual scientists to multi-institutional research groups and from small high-tech firms to multi-billion dollar firms and large public services **(Fig. 18-12)**.

FRENCH SATELLITE SYSTEMS

Within the European community, France has the most active national satellite program. These programs include both commercial and military applications. In addition to communications, France has developed, launched and now controls earth resources, military imagery and a signals intelligence testbed satellite.

Earth Resources Satellites

SPOT Series

The Satellite Probatorire d'Observation de la Terre, SPOT, is an optical earth resources satellite (**Fig. 18-13**). The satellite was designed by CNES (Centre National d'Etudes Spatiales), the French National Space Center, and developed with the participation of Sweden and Belgium. The system comprises a series of spacecraft plus ground facilities for satellite control and programming, image production and distribution.

The exploitation is managed by CNES and SPOT Image. CNES is directly responsible for on-orbit control of the satellite and the execution of the acquisition plan. SPOT Image is in charge of preprocessing the image telemetry and pro-

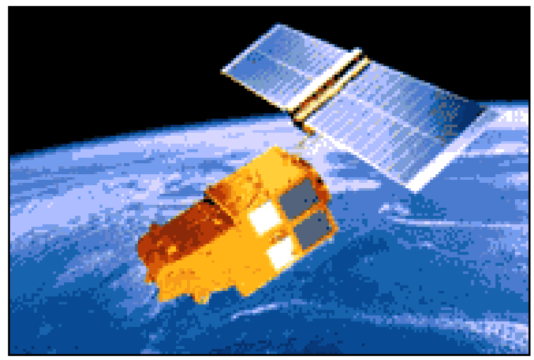

Fig. 18-13. SPOT Imaging Satellite

ducing the products. It is also responsible for the commercial exploitation of SPOT data. Receive locations for SPOT imagery are organized as two networks; a centralized network and a decentralized network (**Fig. 18-14**). The central network is comprised of the main imagery receiving stations at Toulouse, France and Kiruna, Sweden. The decentralized network consists of receive locations around the world having contracts with SPOT Image to receive SPOT imagery. The basic difference between the two networks is that the centralized stations can receive data recorded on the satellite, hence imagery of any part of the Earth. The other stations can only receive images directly from within their zone of visibility, a circle about 2,500 km around the station. This decentralized network consisted of twenty stations in 1997.

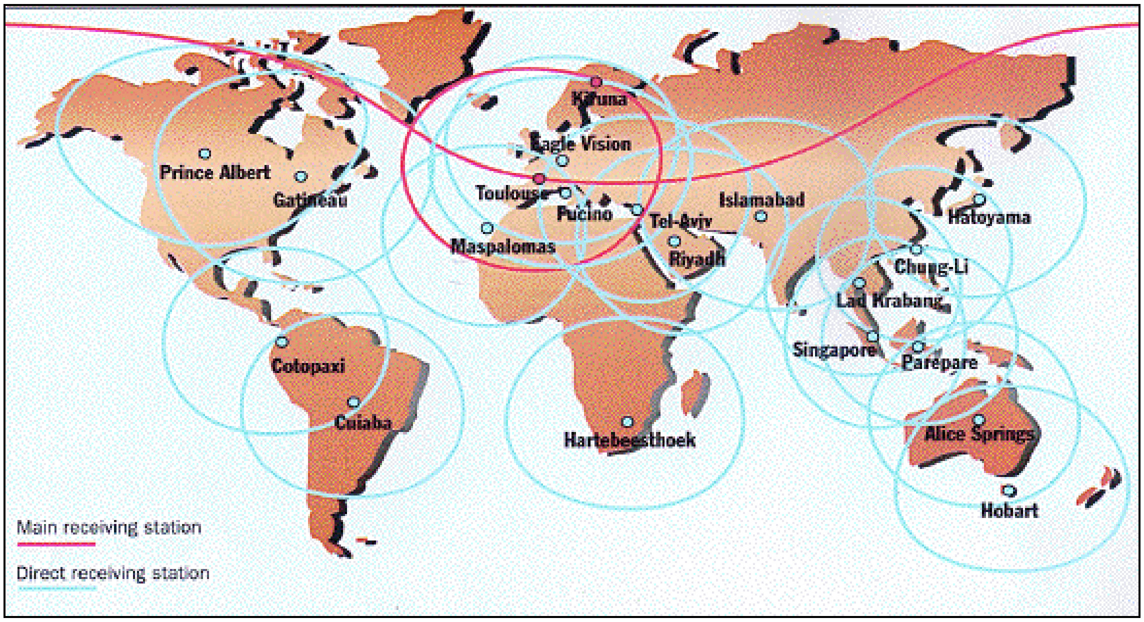

Fig. 18-14. SPOT Image Receive Stations

SPOT has two imaging modes, panchromatic and multispectral. The 10 meter resolution panchromatic (black & white image) is for applications calling for fine geometrical detail. The multispectral mode that images in three bands, green, red and near infrared, gives a color composite image. The imaging systems are capable of tilting the image viewing area to obtain stereo images.

SPOT-1 was launched in February 1986 and withdrawn from active service in December 1990. SPOT-2 was launched in January 1990 to replace SPOT-1. SPOT-3 was launched in September 1993.

Each satellite has a design life of three years; however, in the case of SPOT-1 and SPOT-2, they are proving to have a longer operational life.

In late 1996, at just over three years, SPOT-3 suffered an unrecoverable malfunction. SPOT-2 remained operational and SPOT-1 was reactivated in January 1997 to maintain SPOT coverage. Both SPOT-1 and -2 have inoperable data recorders and therefore, can only operate in the real-time acquisition mode. SPOT-4 was launched March 20, 1998. With SPOT-4 active, the SPOT system is now back to its full capability.

Military Systems

In December 1985, the French government approved the development of a military reconnaissance satellite for launch in the 1990's. The satellite would be based on the SPOT series with upgraded optics and recording systems. The development was aided by funding from Italy and Spain.

Helios

In July 1995, Helios-1A was launched into a 680 Km polar, sun-synchronous orbit. Helios provided the fourth independent military surveillance capability after those of the U.S., Russia and China. The imagery system is stated to be a multispectral, digital (near-real-time) camera with a one meter resolution.

NATO's 1999 air campaign in the Balkans has emphasized the importance of space systems. Several European nations are looking at national and joint efforts to improve European reconnaissance systems. Conditions in the Balkans also showed the need for radar and infrared reconnaissance systems. Helios-1A was the only non-US observation satellite used in the campaign. While the systems performance was publicly praised, in drove home the point of European reliance on U.S. systems. Many European governments feel they have to prepare for a time when European defense forces will be engaged in a conflict in which the United States does not take part and Europe must have its own assets. While seen as important, this development may take 10 to 15 years.

In December 1999, the second satellite of the series, Helios-1B, was launched. Work is ongoing for the follow-on, Helios-2. This satellite is planned to include an infrared imaging system as well as an optical camera. The proposed time frame for a Helios-2 is around 2002.

CERISE

In addition to military imagery, France is beginning the development of an ELINT satellite reconnaissance capability. On the same launch as Helios in July 1995, the 50 kg CERISE (Caracterisataion de l'Environnement Radioelectriqur par un Instrument Spatial Embarque) was launched to help characterize the Earth's radio environment in research that could lead to a national ELINT satellite. The technology testbed had a designed lifespan of 2.5 years (**Fig. 18-15**).

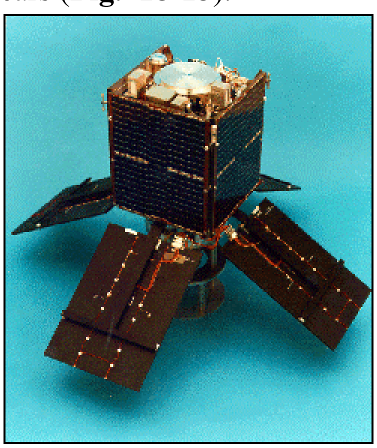

Fig. 18-15. CERISE

On 24 July 1996, ground controllers observed a sudden change in attitude of the CERISE. The satellite appeared to be tumbling rapidly end-over-end. Initial investigations suspected a collision with a piece of space debris. Subsequent observations and analysis seemed to confirm the collision of a section of a 10 year old Ariane rocket stage with the 6-meter long stabilization boom of CERISE. This is the first ever collision between two catalogued space objects. The collision is especially unusual because it was well documented by tracking systems and involved all European hardware (**Fig. 18-16**).

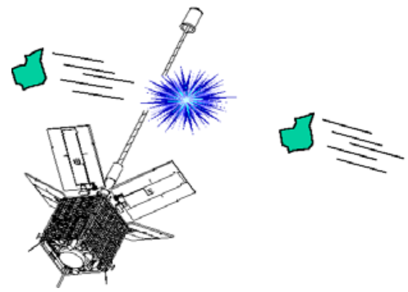

Fig. 18-16. Depiction of CERISE/Ariane collision

In December 1999, a second testbed satellite, Clemetime, was launched along with the Helios-1B imaging satellite.

ASIA/PACIFIC SATELLITE SYSTEMS

Throughout Asian and Pacific Rim countries there are many satellite programs and users. Currently, only the Peoples Republic of China, Japan and India have satellite launch capability. As in Europe, many Asian and Pacific nations use international satellite systems in addition to buying satellites and launch services to place a satellite in orbit. Most of these satellites are for communications: radio, telephone or television. As with Europe, to cover all the nations in Asia and their various national and international programs is beyond the general scope to this document.

Communications

The majority of the satellites used by Asian and Pacific nations are communications systems. These systems are generally built and launched by another country. The following Asian nations have communications/TV broadcast satellites:

- Australia - 4 Optus satellites
- Hong Kong - 3 Asiasat, 3 Apstar
- Indonesia - 4 Palapa, 1 Cakrawarta
- South Korea - 2 Mugunghua
- Malaysia - 2 Measat
- Philippines - 1 Agila
- Thailand - 3 Thaicom
- Singapore - 1 ST-1

JAPANESE SATELLITE SYSTEMS

Within Asia, Japan has the most extensive space program. Japan has the ability to build, launch and control space systems and satellites. Most Japanese launches have been Japanese scientific, communications and earth resources satellites. A major problem with the Japanese space program getting into the commercial market has been the cost of their launches.

Communications

The Japanese have several different communications corporations that own and control satellites. Most systems are located in geostationary orbits. These systems include:

- Broadcasting Satellite Systems, BSAT
  - 2 BSAT Satellites
- Japan Satellite Systems, JSAT
  - 5 JSAT Satellites
- Space Communications Corp, SCC
  - 3 Superbird Satellites
- Telecommunications Advancement Organization of Japan
  - 2 Broadcast Satellite (BS)
  - 2 N-Star

Earth Resources

Japan began Earth monitoring with weather satellites in 1977. Currently there are two Geostationary Meteorological Satellites (GMS), Himawari 4 and 5, in orbit over the Pacific Ocean. In addition to earth weather images, the satellites relay meteorological data from fixed and mobile stations within their field of view.

MOS series

Japan's first domestic earth resources satellite was the Marine Observation Satellite (MOS) launched in 1987. A second was launched in 1990. The MOS satellites were developed to acquire expertise for later operational systems. These satellites monitored atmospheric water vapor, ocean currents, sea surface temperature and ice floe distribution in addition to land applications. Sensors included a Multi-Spectrum Electronic Self-Scanning Radiometer (MESSR), a Microwave Scanning Radiometer (MSR) and a Visual and Thermal Infrared Radiometer (VTIR). Both satellites are now out of service, MOS-1B ending its mission life in May 1996.

JERS series

The Japan Earth Resources Satellite (JERS) was the second domestic remote sensing satellite and the first to operate at all-weather radar wavelengths (**Fig. 18-17**). The synthetic aperture radar (SAR) is accompanied by an optical sensor. The JERS-1 was launched in February 1992.

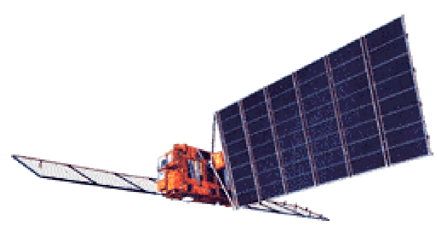

Fig. 18-17. JERS-1 satellite

The SAR system has a resolution of 18 meters and is used for monitoring land use and type, glacier extent, snow cover, surface topography, ocean currents and waves. The four band optical sensor covers the visible and near infrared region. It is used for pollution monitoring in oceans and lakes, land use classification, cloud and snow discrimination. Imagery can be stored on board and transmitted to the main processing site in

Japan or imagery of a local area can be sent real-time to other ground sites located in Asia, Europe, North America and Antarctica.

Launched in February 1992, the mission on JERS-1 was to last only two years, but it was operational and obtaining observation data on the earth for six-and-a-half years. Operation of JERS-1 was terminated on October 12, 1998 after a malfunction the day before.

ADEOS series

Japan's latest earth resources satellite is the ADEOS (Advanced Earth Observation Satellite) launched in August 1996. This satellite acquired global observation data corresponding to environmental changes, such as global warming, depletion of the ozone layer, decrease of tropical rain forests, occurrence of unusual weather and other tasks. Payload included both Japanese and foreign sensors.

In June 1997, the satellite developed major power problems and is now totally out of service with little hope of recovery. Studies are underway to determine the problem prior to the launch of ADEOS-2.

CHINESE SATELLITE SYSTEMS

The Chinese space program is developing a wide variety of satellites. Much of the development is slow, as the Chinese have limited access to Western or Russian technology. They are working on communications, earth resources/ imagery, weather, and science/space research.

Communications

STTW and DFH series

The STTW series are generally the test version of their communications satellites, the DFH series are the final. Sometimes, both designations apply after a satellite reaches orbit and is declared operational. China has successfully launched and operated both its DFH-2, a spin stabilized satellite, and the DFH-3, a three axis stabilized system.

During the mid-to-late 1990's, China had problems with both its booster and satellites. The DFH-2 series was to be replaced by the newer DFH-3. Three DFH-3 satellites were lost or became non-operational after only a short time in orbit (1994, 1996, and 1997). During this timeframe the DFH-2 satellites also were becoming non-operational. To get over the communications problems caused by the DFH-3 program, China has had to buy older satellites already on orbit or order western built systems

With the return of Hong Kong to China control in July 1997, the satellites controlled from there, APStar and AsiaSat, may in the future be included as Chinese systems. Currently these satellites are still controlled by the commercial companies that bought them. Of note is that the Chinese government owns75% of APStar.

Earth Observation

FSW series

The FSW series are recoverable satellites **(Fig. 18-18)** used primarily for imagery, military reconnaissance/earth resources starting in 1975. Since 1987, Micro-gravity experiments have also conducted using the FSW capsules. China has launched 17 of these flights, several of them containing foreign micro-gravity experiments.

Fig. 18-18. FSW capsule

FY Series

This series is China's first weather satellite attempt. The FY-1 series are polar orbiting, while the FY-2s are placed into geosynchronous orbits.

China launched two FY-1 satellites, one of which is still operational. FY-2A was launched in June 1997 but ceased operations in April 1999. FY-2B was launched in June 2000.

ZY-1 Series (CBERS)

In 1988, China and Brazil signed a cooperative program to develop two earth resources satellites. The program is called Zi Yuan (resource) in China and in Brazil and elsewhere the China-Brazil Earth Resources Satellite (CBERS) **(Fig.18-19)**. The first satellite was launched in October 1999.

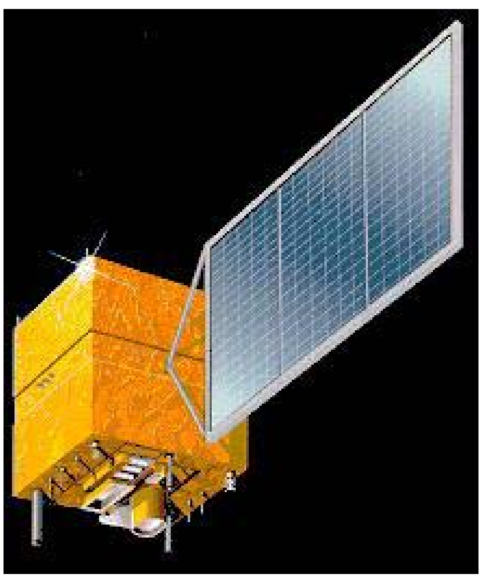

Fig. 18-19 ZY-1, CBERS

Satellite control is done mainly from China, with Brazilian control being performed only while in view of Brazil. A second CBERS is being planned.

On 1 September 2000, China launched a FY-2, remote sensing satellite. This satellite is not the second CBERS satellite, thought much of the technology may be shared. This system is though to be a Chinese only system, with possible military use.

INDIAN SATELLITE SYSTEMS

India, with more than three-quarters of its population dependent on agriculture, concentrates its space development activities on related applications satellites. The two prime goals involve operational space-based remote sensing and communications satellites.

Communications

INSAT series

India's first communications satellite was built by the U.S. and uniquely provided for simultaneous domestic communications and earth observation functions, primarily meteorology. The INSAT-1 series were launched between 1982 and 1990. INSAT-1A and 1C failed soon after launch. INSAT-1B was launched from the U.S. shuttle in 1983 and functioned until 1991. INSAT-1D is still operational in 2000.

The INSAT-2 series was built primarily by Indian companies and performs much the same functions as the INSAT-1 series. The INSAT-2A and INSAT-2B have increased communications capability from the INSAT-1. The INSAT-2C and 2D have additional communications capability but had their earth observation functions removed. Launched in July 1997, INSAT-2D failed in orbit during October 1997 due to an electrical fault. To replace this lost communications capability, India purchased already in orbit ARABSAT-1C from the Arabsat consortium in December 1997. The satellite was moved to an Indian orbital slot during the December-January time frame. The satellite was renamed INSAT-2DT and began operations in January 1998. INSAT-2E was launched in April 1999. This satellite is the last of the Indian built INSAT-2 series. In addition to the communications payload, this satellite again carries the earth observation/meteorology sensor.


Fig. 18-21. The Mall, Washington D.C. IRS-1C Panchromatic, 6-meter resolution

Earth Resources

IRS Series

The Indian Remote Sensing satellite system (IRS series) is India's first domestic dedicated earth resources satellite. The first two satellites of this system carry the Linear Imaging Self Scanning (LISS) four band multispectral scanner. These bands are excellent for vegetation discrimination and land cover mapping. This system has a spatial resolution of either 72 or 36 meters. **(Fig. 18-20)**

IRS-1A was launched in 1988 and retired from routine service in 1995. IRS-1B was launched in 1991 and is still active. Imagery from these satellites is received in India and at other ground sites around the world. Information acquired can be used for many purposes, including monitoring droughts, providing timely area on crop yield assessments, vegetation discrimination, mapping of potential ground water zones and studies for potential irrigation, land use and land cover maps.


Fig. 18-20. IRS-1B LISS-2
36 meter resolution
Chesterfield, Missouri

The next generation of satellites, the IRS-1C and 1D, carry the four band multispectral LISS-3 with a resolution of 23 meters; a panchromatic sensor with a resolution of 6 meters **(Fig. 18-21)**; and a two band Wide Field Sensor (WiFS) with a resolution of 188 meters. In addition, the 1C and 1D offer onboard recording, stereo viewing capability and more frequent revisits.

As part of developing both a satellite and launcher industry, India built multiple parts for their IRS satellites. These extra parts allowed India to gain additional expertise in satellite construction and gave them a useful payload to launch on their developmental PSLV space booster. The prime IRS-1 series would be launched on foreign boosters for safety, while the others would be part of the PSLV program. The first PSLV launch carried the IRS-1A's engineering model, refurbished and called the IRS-1E. This payload ended in the ocean when the PSLV's first launch on 20 September 1993 ended in failure.

The next PSLV test carried the IRS-P2, a demonstrator for the IRS-1C and 1D bus. This satellite was placed into orbit in October 1994. IRS-P3 was launched on the third PSLV test in March 1996. The payload included an improved three band WiFS sensor and an X-ray astronomy experiment provided by India as well as a German Modular Optoelectronic Scanner (MOS) for oceanographic applications.

In May 1999, India launched a new version of its IRS series, the IRS-P4 built for oceanographic research. This system carries the Ocean Color Monitor (OCM), an eight band spectral camera. The system collects data on chlorophyll concentration, phytoplankton blooms, atmospheric aerosols and water suspended sediments. Also on board is the Multi-frequency Scanning Microwave Radiometer (MSMR). The MSMR operates in four microwave frequencies to collect sea temperature, wind speed, atmospheric water content. Now called Oceansat-1, it joined India's four other operational IRS satellites (IRS-1B, 1C, 1D, and P-3).

Additional IRS-P series satellites are planned to develop new and improved sensors. As the technology is developed, additional satellites will be produced and launched. Some of the planned systems include an ATMOS series for atmospheric observations, CartoSat for mapping and an improved IRS-2 series.

MIDDLE EAST/NORTH AFRICAN SATELLITE SYSTEMS

Throughout the Middle East and Africa there is only one nation with a complete space capability, Israel. Most other nations in this part of the world are currently only users of satellite systems, generally as part of a consortium. Egypt recently had a satellite built and launched that they are the prime users and sole controllers.

Communications

Most of the Middle East and Africa use of satellite systems has been for communications. IntelSat and Inmarsat have served those nations in this region that use satellite communications systems. Other than communications, earth resources receive stations are present in a few countries (Israel, Saudi Arabia, South Africa), some of which also have access to weather satellite data.

ArabSat series

The Arab Satellite Communications Organization (ASCO) was formed in 1976 to meet the increasing communications needs of the Arab countries. There are currently over twenty members across the Middle East and North Africa. The satellites used by ArabSat were built in Europe and America; launched into geostationary orbits by ESA and NASA; while Japan was the prime contractor for the ground receive sites.

ArabSat-1A was launched in February 1985, followed by ArabSat-1B in June. ArabSat-1A began drifting in late 1991 and was declared out of service in March 1992. ArabSat-1B followed a year later, starting to drift in October 1992 and declared out of service early 1993.

ArabSat-1C was launched in February 1992. It supports regional television, telephone, data and fax relay. In early 1993, only ArabSat-1C was operational, raising the possibility of leasing a satellite until ArabSat-2 was ready. Canada's Anik-D2 was selected, moved to cover the Middle East in 1993 and renamed ArabSat-1D. This satellite was operational until February 1995, when it depleted its fuel and was raised above geostationary. As ArabSat-2 was still not available, ASCO leased Telstar 301 in 1994. The satellite was moved late that year and renamed ArabSat-1E. This system also provides domestic telephone, data and television.

In 1996 the ArabSat-2 series was ready, with ArabSat-2A being launched in July and ArabSat-2B following in November. Arabsat-1E has ceased operations, while Arabsat-1C was sold to India. The next generation of satellites, Arabsat-3A was launched in February 1999. This newest satellite is dedicated to Direct TV Broadcasting with 20 Ku-band transponders. This gives ASCO a constellation of three satellites.

ISRAELI SATELLITE SYSTEMS

In addition to its own satellite programs, Israel also has receive stations for earth resource imagery from SPOT and the ERS series satellites. Israel also has international projects with European and Asian countries as well as NASA.

Communications

Israel has one communications satellite for which they were the prime contractor. In addition, they are uses of the Intelsat system, in which they hold a 1.06% share.

AMOS Satellite

The AMOS-1 (Affordable Modular Optimized Satellite, also referred to as the Afro-Mediterranean Orbital System) was launched by an ESA Ariane-4 in May 1996 into geostationary orbit. The transponders are optimized to cover the Middle East and Central Europe. The system performs broadcasting services of multiple digital television channels to Cable Headends, Direct-To-Home, business data and voice transmission to include interactive learning.

Israel is currently working on the AMOS-2/CERES (Central European Regional Satellite), a joint venture with Hungry.

Ofeq series

Israel's first satellite was the Ofeq-1 technology demonstration satellite, launched in September 1988. A second test satellite, Ofeq-2, was launched in April 1990. These first-generation satellites were spin stabilized and carried only test payloads.

Ofeq-3 (**Fig. 18-22**) was the debut of the second-generation of light Israeli satellites. Launched in April 1995, this satellite was also listed as a technology demonstrator, but unlike Ofeq-1 and 2, carried an operational payload. With a 3-axis stabilization system, the satellite is being proposed and marketed to carry payloads for astronomy and remote sensing. The payload carried on the Ofeq-3 is a light-weight electro-optical scanner or Earth Resources Monitoring System, which was developed in Israel. The Israeli media reported this as their first "spy" satellite.

Fig. 18-22. Ofeq-3

In January 1998, Israel planned to launch Ofeq-4 to replace Ofeq-3, which was nearing the end of its planned operational life. This launch failed due to a malfunction of the booster soon after launch. Israel statements indicate that they will continue to develop, built, and launch earth observation/reconnaissance satellites.

Recent press reports indicate Israel is marketing Ofeq satellites and technology for commercial sales.

TechSat Series

TechSat is a collaboration to develop a simple, low cost, low power platform for technology testing. TechSat-1 contained an amateur store and forward transponder, an earth-observation digital camera, a spectroradiometer for ozone studies and an X-ray imager. This satellite was lost in March 1995 during the first attempted launch of Russia's Start booster from Plesetsk.

On July 10, 1998, TechSat-2 was launched on a Russian Zenit booster into a sun-synchronous 830 Km polar orbit. The 48 kilogram satellite contains a wide variety of experiments. They include a test of superconducting material that would allow satellites to carry more channels in a smaller space, a charged particle detector to determine frequency and damage of charged particle impacts, an ultraviolet sensor, an x-ray detector, a new stabilization system, and field test of a new horizon sensor.

In September, Israel announced that Techsat-2 had completed what is termed the first successful test of superconductive material in space.

OTHER MIDDLE EAST/AFRICAN SATELLITE USERS

EGYPT

Egypt has long been a member of the ArabSat and InmarSat communications organizations. In 1998, Egypt became the first Arab country and the first African nation to own and operate its own satellite. This TV, radio, and data transmission satellite will allow viewers throughout the Mediterranean and Middle East to have programs in a region previously dominated by Saudia Arabian and non-Arab broadcasters.

NileSat Series

NileSat 101, sometimes just NileSat-1 **(Fig. 18-23)**, was launched in April 1998. With this launch Egypt became the first Arab and African nation to own and operate its own satellite. The satellite was designed primarily for Direct-To-Home television but will also offer free and pay TV, audio (radio), data services, and other related services. With 12 transponders, the system is capable of transmitting at least 84 TV channels. NileSat 101 began transmitting programs at the end of May 1998.

Fig. 18-23. NileSat 101

Egypt also owns and operates the two Satellite Control Stations (SCS). The primary control Tracking, Telemetry and Control (TTC) station with its Satellite Control Center (SCC) is located near Cairo. A backup SCS is in Alexandria.

ESA launched NileSat-102 for Egypt on 17 August 2000. This new satellite will cover the African continent in an effort to promote cooperation among African countries in the media field.

AFRICA

Africa, long the world's most neglected satellite market, is finally being taken more seriously as a major market for all types of satellite services. No African countries have domestic satellites with the exception of Egypt, who controls a satellite built by someone else and South Africa, which controls a recently built university research satellite launched. Many African satellite users will use an upcoming Intelsat through the auspices of the Regional African Satellite Communications Organization. One dedicated satellite for Africa has been launched, which will beam radio programming directly to listeners throughout Africa.

AfriStar

Launched in October 1998, AfriStar is intended to provide high quality digital information, international news, and entertainment programs through Africa. Owned and operated by WorldSpace, a registered public charity, located in the United States. AfriStar will allow local African radio stations of all sizes to reach an audience on the whole of the continent. While the satellite will be controlled from the AfriSpace, Inc. regional operations in Washington D.C., programming can be sent to the satellite from ground stations in London, England; Toulouse, France; and Johannesburg, South Africa. Plans include the building of a studio in Africa that would be run by Africans with an African advisory board.

AfriStar is the first of three planned satellites intended by WorldSpace to provide digital audio communications to developing nations around the world. AsiaStar and AmeriStar are planned for launch in either late 1999 or in 2000.

SOUTH AFRICA

South Africa became the first African nation to have its own domestically built satellite placed in orbit. A program sponsored by the University of Stellenbosch, near Cape Town designed, built, and is controlling the satellite.

Sunsat

The Stellenbosch UNiversity SATellite or Sunsat is an educational and research project. In addition to carrying earth resources and communications payloads, the program was intended to encourage engineers and engineering in South Africa, and gain international recognition of South Africa's ability to contribute and compete in the high technology world.

The Sunsat **(Fig. 18-24)** carries both a three-color MSI imager and a commercial color video camera as earth resources systems. It also carries amateur radio gear, high school experiments, a US sponsored GPS receiver to conduct atmospheric, ionospheric and geodesic mapping, and other NASA sponsored experiments.

The 61 kilogram satellite, considered a critical milestone for the South African space program, was launched into a polar orbit in February 1999.

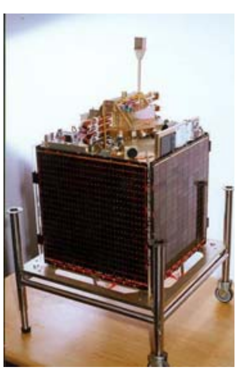

Fig. 18-24 SUNSAT

NORTH AND CENTRAL AMERICA

After the United States, Canada and Mexico are the only nations in North or Central America with any significant space capability.

Canada builds and controls its own satellites and was developing a privately funded space launch facility at Churchill, Manitoba. This launch facility has only launched sub-orbital flights to date and the private operator of the SpacePort announced it was going out of business in 1998.

Mexico is primarily a user of communications satellites. The first generation of US built satellites were the Morels series followed by the current Solidaridad series that provide telephone, data, TV distribution, and mobile services.

CANADIAN SATELLITE SYSTEMS

Telesat series

Canada has an extensive communications satellite system. The first satellite, Anik-A1 (also Telasat-1) was launched in November 1972. This satellite was followed by Anik-A2 in 1973, Anik-A3 in 1975 and Anik-B1 in 1978.

The first of the Anik-C series, C3, was launched in late 1982, followed by C2 in June 1983. Anik-C1 launched in April 1985. Both C1 and C2 were sold to Argentina in 1994 to provide interim services until a dedicated system became available. Anik-D2 was launched in 1984 and then sold in 1993 to become ArabSat-1D.

The Anik-E series has suffered several mishaps. While both satellites, E1 and E2, are active and performing their mission, both have had technical problems that have reduced their capability.

Canada's latest satellite is the MSAT-1. This satellite was launched in April 1996. The system provides mobile telephone, radio, data and positioning service to land, aviation and maritime users.

Earth Resources

Canada uses several different earth resources satellite systems. The country has ground receive stations for ERS-1, JERS-1, Landsat and SPOT. In addition, Canada has developed and controls its own radar Earth resources satellite.

Radarsat

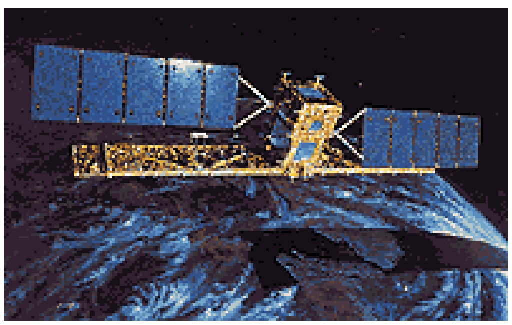

Fig. 18-25. RADARSAT

Radarsat is a cooperative program between the Canadian Space Agency (CSA), NASA and NOAA (**Fig. 18-25**). CSA built and operates the system, NASA furnished the launch vehicle and facilities. In exchange, U.S. government agencies have access to all archived Radarsat data and around 15% of the satellite's observing time.

Radarsat is a synthetic aperture radar (SAR) system with a resolution between 30 and 90 meters. The first Radarsat was launched in November 1995 into a polar orbit. It is designed to give primary coverage of Canada and the Arctic regions.

MEXICAN SATELLITE SYSTEMS

Mexico currently operates four communications satellites. Morelos-2 was launched in November 1985. Solidaridad-1 and -2 were launched in November 1993 and October 1994, respectively. The Morelos-2 provides domestic television, telephone and data services. The Solidaridad satellites provide these same services in addition to mobile and international services. Mexico's latest satellite is the SATMEX-5, which will provide a complete range of telecommunications services, direct TV broadcasting, rural telephony, distance learning and telemedicine to Mexico and Spanish-speaking communities in North and Latin America. This satellite was launched in December 1998.

SOUTH AMERICA

South America is served by a small number of dedicated satellites, however, service is also provided by a variety of trans-Atlantic, PanAmSat and other Atlantic Ocean satellites. Only Brazil and Argentina have their own communications satellites systems.

BRAZILIAN SATELLITE SYSTEMS

Brazil is the most advanced nation in South America involved in the space business. They are capable of manufacturing their own space launch vehicles and satellites and controlling them. Brazil's first space launch vehicle ended in failure 3 November 1997. One of the four strap-on engines failed to ignite and 65 seconds later, the launch controllers had to destroy it. The next launch attempt was in December 1999. This booster suffered a failure in its second stage.

Brazilsat series

Brazilsat-A1 and A2 were launched in February 1985 and March 1986, giving Brazil its own communications. The A1 satellite was sold in 1995 and the antenna re-aimed to North America. A2 is currently an on-orbit spare. These satellites carried limited television, telephone and data services.

The currently active communications satellites are the Brazilsat-B series. B1 was placed into geosynchronous orbit in August 1994, with B2 following in March 1995. This series increased the number of transponders over the Brazilsat-A series and added X-band transponders for government and military uses. Brazilsat-B3A was launched in February 1998 and B4 in August 2000.

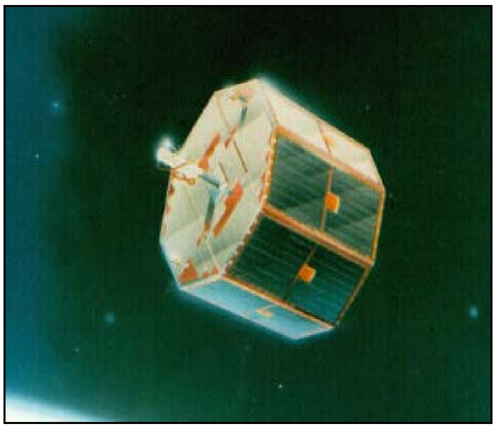

Fig. 18-26. SDC-1 Data Relay Satellite

SDC series

The SDC series of Satellite Data Collectors are the first satellites built by Brazil. SDC-1 relays data gathered by ground-based data collection platforms throughout Brazil, which is then transmitted to an acquisition station. The SDC-1 was placed into orbit in February 1993 from the Pegasus (**Fig. 18-26**).

SDC-2A was planned for the first launch of the Brazilian space booster but was destroyed when the booster failed 65 seconds into the flight. In October 1998 the second of the series, SCD-2, was launched by a Pegasus booster.

Brazil has plans for other data relay satellites and is developing its own remote sensing programs. A joint Chinese-Brazilian Earth Resources Satellite, CBERS, launched in 1999. Currently, Brazil also has ground stations to receive data from ERS-1, Landsat and SPOT.

ARGENTINE SATELLITE SYSTEMS

Argentina's space activities emphasize applications. A user of Inmarsat and Intelsat, Argentina, in 1993, signed an agreement for a South American communications satellite. Two Canadian satellites provided an interim service beginning in 1993.

Nahuel series

Nahuel **(Fig. 18-27)** will serve the southern part of the South American continent for the first time with high performance links. Launched in January 1997, the satellite provides television distribution, telephone, data and business services.

This contract also included the construction of a ground control station in Argentina. This control station is located near the capital, Buenos Aires, and was approved for operations in November 1996. Since then, over 50 technicians have been trained in satellite operations. The station is designed to control the operation of three satellites.

Fig. 18-27. Nahuel 1A

SUMMARY

The expansion of ROW countries into space will continue. Communications and Earth observations are expected to lead the way for new entries into the list of space using nations.

For emerging nations with inadequate or antiquated communications infrastructure, satellites are an ideal way of rapidly acquiring a modern communications capability.

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Chapter 19

REST OF WORLD MISSILE SYSTEMS

The ballistic missile threat posed to the U.S. from the Soviet Union during the 1950s-1960s necessitated the development of U.S. missile launch warning systems. By the 1970s, the first satellites of the Defense Support Program (DSP) were launched and placed into geo-stationary orbits to detect hostile ballistic missiles. This chapter will review the missile threat capability of the Former Soviet Union (FSU) as well as other ROW nations, focusing on those ballistic missiles which can be detected by U.S. space-based sensors.

RUSSIAN MISSILE SYSTEMS

When the Soviet Union broke up in the early 1990's, the result was four nations versus one with nuclear ballistic missiles; Russia, Ukraine, Belarus and Kazakhstan. However, by early 1997, only Russia retained a strategic nuclear missile force; the other three countries having shipped their warheads back to Russia. The Russian strategic capability revolves around a triad of Submarine Launched Ballistic Missiles (SLBMs), land-based Inter-continental Ballistic Missiles (ICBMs) as well as land-attack cruise missiles (CMs) carried on strategic bombers and nuclear attack submarines.

Despite the reductions of the Strategic Arms Reduction Treaties (START I/II), the Russian strategic offensive force will retain approximately 50 percent of its firepower deployed on land-based ICBMs. Also, these ICBMs will continue to fulfill the most important targeting require-meanest in any strategic nuclear strike.

Fourth Generation ICBMs

The Fourth Generation Soviet ICBMs, consisting of the SS-18 and SS-19, were introduced into the operational inventory in the late 1970s. This generation of missiles gave the FSU a modernized and sophisticated force.

For the first time, the FSU deployed Multiple Independently Targetable Reentry Vehicles (MIRV) technology. A MIRV-capable system can carry a number of warheads and strike different targets using just one missile. Equally important, the accuracy of these missiles gave them the capability to strike hardened targets such as U.S. ICBM silos. Additionally, the introduction of cold-launch technology gave the FSU the capability to re-launch from the same silo. The cold-launch system consists of a gas generator located at the bottom of the silo which ejects the missile out of the silo. Once clear from the silo, the main engine of the missile ignites, thus minimizing damage to the launch facility.

SS-18 (SATAN) Weapon System

The SS-18 (**Fig. 19-1**) is the centerpiece of the Russian Strategic Missile Force and of the Fourth Generation ICBM force. This system was designed to target hardened Minuteman missile silos. The SS-18, which is larger than the U.S. Peacekeeper, has been modernized many times over the life of the program. Silo (**Fig. 19-2**) conversion activity has replaced some of the older SS-18 force with the MOD 5 MIRV and the single RV MOD 6.

Fig. 19-1. SS-18

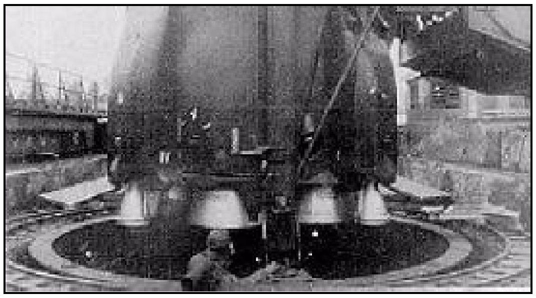

Fig. 19-2. SS-18 Silo loading

These upgrades temporarily offset the firepower losses required under the START I. START I reduces the number of allowed SS-18 to 154 and START II requires the elimination of all SS-18s by January 2003. START II also eliminates all land-based MIRV'd missiles by 2003.

SS-19 (STILLETO) Weapon System

The SS-19 is the third of the Fourth Generation ballistic missiles developed by the FSU. Unlike the SS-17 and SS-18, this missile is hot-launched from its silo. Under a special provision of START II, Russia is allowed to keep 105 single warhead versions of the SS-19.

In December 1994, the launch of an SS-19 was reported as a trial to determine the suitability of use as a civilian satellite launcher, called ROCKOT. On May 16, 2000, Russia announced the successful Commercial Demonstration Flight (CDF) of their ROCKOT launch vehicle from the Plesetsk Cosmodrome. The goal of the CDF was the commissioning of the ROCKOT as an operational launch vehicle as well as the qualification of the dedicated EUROCKOT launch facilities at Plesetsk.

Fifth Generation ICBMs

The Fifth Generation of ICBMs, introduced in the 1980s, was the result of new force objectives. During the 1970s, with the Fourth Generation of ICBMs, the Soviets acquired tremendous technological advances that gave them better accuracy (hard-target capability), MIRV technology (more targets with one missile) and a cold-launch (reload/refire) capability. However, FSU strategic planners realized that their land-based ICBM force was still threatened by a pre-emptive strike from the U.S. With this in mind, they concentrated their efforts in creating a more survivable force. The introduction of the SS-24 and SS-25 in the mid-1980s highlights the FSU's success with mobile systems (to be completely accurate, their success with mobile systems began with the deployment of the SS-20 IRBM in 1977). Furthermore, the incorporation of these systems has enhanced the survivability of the ICBM force and assures the Russians that their requirements for responsiveness and accuracy will be met. By the year 2000, the mobile ICBM segment of the inventory could account for about one third of the Russian force.

SS-24 (SCALPEL) Weapon System

The SS-24 is a solid propellant MIRV system that can be targeted against soft and semi-hardened targets. This missile has been deployed in two different modes, rail-mobile and in retrofitted SS-19 silos. The SS-24 MOD 1, a rail mobile system, was first deployed in 1987 and it is currently deployed at three launch garrisons. SS-24 missile trains reportedly have three missile launch cars, several locomotives, a power generator car, a command car, and several support cars. The rail garrisons are assessed to contain four trains each and are capable of deploying on the 145,000 km railroad system. Alert duties were cut back drastically in 1994, due to costs and security concerns.

All silo based SS-24 MOD 2s have been decommissioned. In accordance with START-II, the SS-24, rail as well as silo versions, will be phased-out and destroyed.

SS-25 (SICKLE) Mobile ICBM System

The SS-25 joined the operational inventory in 1985. This system is a road-mobile, single warhead, three-stage solid-propellant missile, comparable in size to the U.S. Minuteman ICBM. The SS-25 is carried on a seven axle-wheeled, Transporter Erector Launcher (TEL) (**Fig. 19-3**). This weapon system gives Russia a highly survivable ICBM with an

Fig. 19-3. SS-25 TEL

inherent refire capability. The garrison bases that house this system consist of garages equipped with sliding roofs for the TEL and other support buildings for critical mobile equipment (such as generators and command/control vehicles).

Production of the SS-25 has ended as this missile will be replaced by the newer SS-27. The mobile missile garrisons are constrained by START I which stipulated that in peace time, mobile units will be confined in a 25 square kilometer area around their garrison. Russia has also developed mobile satellite launchers from the SS-25 boosters, which are called "Start 1" launch vehicles after the treaty.

SS-27 *Weapons System*

The SS-27 is an evolutionary upgrade of the SS-25. This new system is a cold-launched, three stage, solid propellant ICBM that will be deployed in both silo-based and mobile versions (**Fig. 19-4**).

Development of the SS-27 began in the late 1980's with the first test launch in December 1994. Initial deployment of the silo-based version began in 1998.

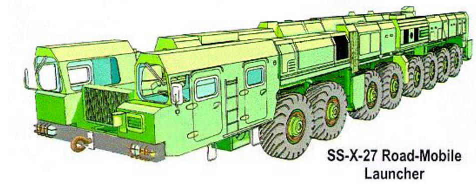

Fig. 19-4. SS-27 TEL

The road-mobile version will be fielded sometime in the near future.

Previously, in the former Soviet Union, most ICBM systems were built in the Ukraine. The SS-27 was designed so that it could be totally manufactured in Russia.

Among the Russian stated system improvements are anti-ballistic missile features and a space navigation system.

Submarine Launched Ballistic Missile Systems (SLBMs)

Russia currently has three primary SLBM platforms: the Delta III, Delta IV and the Typhoon class submarines. These nuclear powered ballistic missile submarines, referred to as SSBNs, are based on the Kola Peninsula in northern Russia and on the Kamchatka Peninsula in the Russian Far East.

Current Russian doctrine dictates that ballistic missile submarines should deploy in waters close to Russian landmass, since these patrol areas (known as bastions) can be protected by aircraft, sonar networks, surface ships and Russian attack submarines. Additionally, it should be noted that the Russian SSBN force is capable of striking most of the CONUS from pier-side, reducing the need to deploy well away from Russian shores.

Delta III/SS-N-18 (STINGRAY)

The Delta III carries the two-stage SS-N-18, the first MIRV'd Soviet SLBM. This submarine carries 16 missiles, each with three MIRV warheads.

Following implementation of START I and II, it is expected that some of the SS-N-18s will be withdrawn from service. There remain questions regarding the future size of the Russian SSBN force. A revised Russian plan suggests that the entire Delta III class may be retired in the next decade.

Delta IV/SS-N-23 (SKIFF)

A three-stage liquid-propellant SLBM was tested in 1983 from a submarine designated the Delta IV. This SLBM was designated as the SS-N-23 and is more accurate than the SS-N-18. The SS-N-23 is about 47 feet long, carries up to 10 MIRVs and has a range of 4,500 nm.

All seven Delta IV submarines (**Fig. 19-5**) are based on the Kola Peninsula, with protected bastion patrol areas in the nearby Barents Sea and easy access to the Arctic.

Fig. 19-5. Delta IV with missile hatch open

Even though the SS-N-23 has the capability to carry 10 MIRVs, it is counted as carrying four MIRVs under the START agreements. Four is the number of warheads per missile postulated for future deployment.

Typhoon/SS-N-20 (STURGEON)

The SS-N-20 SLBM was first identified in the early 1980s. The missile test program was unsuccessful during its early stages. However, following the first Typhoon submarine launch in September 1980, subsequent successful missile tests from the submarine moved the program ahead. The Typhoon's SS-N-20 weapon system was declared operational by Western sources in 1984.

The SS-N-20 is a three stage, solid-propellant missile capable of carrying between 8 to 10 RVs, with a maximum range of approximately 4,300 nm. This range gives it the capability to operate within Russian waters and still strike targets on the North American continent.

The Typhoon is the largest operational SSBN in the world. This submarine is approximately one third larger than the U.S. Ohio Class SSBN. It is estimated to have been designed to conduct missile patrols under the Arctic Ocean ice cap. Six Typhoons are estimated to be operational, each with 20 launch tubes and a total weapon capacity of 120 SS-N-20 missiles carrying 960 warheads.

A unique feature of the Typhoon is that its missile bays are located forward of the submarine's sail. All other Russian and U.S. SSBNs have their missile bay behind the sub's sail (**Fig. 19-6**).

Fig. 19-6. Typhoon-class SSBN

Borei/SS-NX-28 and Bulava-30

Reports in the early 1990's indicated that a follow-on to the SS-N-20 was being developed, the SS-NX-28. Little is known about this system, however there have been reports of numerous difficulties with the system. There have been four test launches of the SS-NX-28, the latest in November 1997. None of the launches have been successful. Like the ICBM's, much of the former Soviet SLBM systems were build in the

Ukraine, so Russia has had difficulties in building such missile systems.

A new class of SSBN was envisioned for this new missile system, the Borei. The first of these fourth generation submarines was started in 1996 but lack of funding and the SS-NX-28 problems has significantly delayed construction. Both the SS-NX-28 and Borei programs have been cancelled due to technological and economic roadblocks. Russia has announced a replacement system called the Bulava-30. A new SSBN, called the "Dolgoruky" will carry the new missile, which has a range of 8,000+ km.

Cruise Missile Systems

Russia recognizes the advantages of having a cruise missile force as part of their strategic offensive capability. Equally important, they recognize the defensive challenges inherent with these systems. With this in mind, Russian military designers and planners have pursued their own cruise missile program.

Platforms have been developed for deployment in air and on sea. Two such systems have been named by the U.S. and the North Atlantic Treaty Organization (NATO) as the AS-15 (KENT) and the SS-N-21 (SAMPSON). These systems have common characteristics, such as a small airframe, low flight profile, subsonic speed and a possible nuclear warhead. Such characteristics provide these systems with an excellent probability of penetrating defenses and successfully accomplishing their mission. These weapons systems and their related carriers cannot be detected from space under normal operating conditions.

AS-15 (KENT)

The AS-15 is a small, subsonic cruise missile capable of delivering a nuclear warhead to a maximum distance of approximately 1850 nm. This weapon system resembles the U.S. Tomahawk cruise missile.

The AS-15 is thought to be equipped

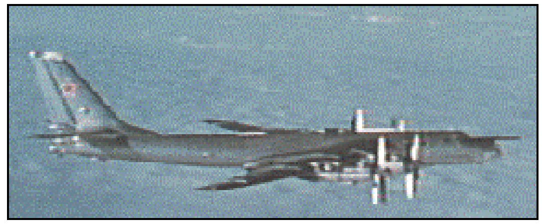

Fig. 19-7. TU-95 Bear

with a guidance system similar to our Terrain Contour Matching (TERCOM)

Fig. 19-8. TU-160 Blackjack

system. TERCOM guidance allows the system to correct any guidance errors that may occur during flight. The AS-15 is carried by the TU-95 Bear H (**Fig. 19-7**) and the TU-160 Blackjack bombers (**Fig. 19-8**).

SS-N-21 (SAMPSON)

The SS-N-21 Submarine Launched Cruise Missile (SLCM) is believed to have about the same characteristics as that of the AS-15. However, this system presents a unique detection problem. With the AS-15, we know what Russian aircraft are configured to support Air Launched Cruise Missile (ALCM) employment. However, the SS-N-21 was developed to fit in a standard Russian 53cm torpedo tube. From a detection standpoint, it will be difficult to determine when a Russian submarine is carrying SLCMs or standard torpedoes, since no externally apparent modifications are required. The SS-N-21 may be carried on the Akula fast attack submarine (**Fig. 19-9**), which is one of the quietest submarines in the world.

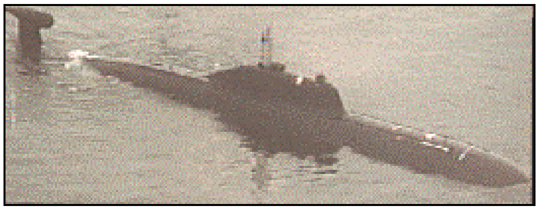

Fig. 19-9. Akula-class submarine

The Russian SLCM force could represent a significant threat against U.S./ European targets. Because of their unique flight profiles, SLCMs have the potential of being used as a surprise/first strike option against U.S. and allied airfields.

Theater Ballistic Missile Systems

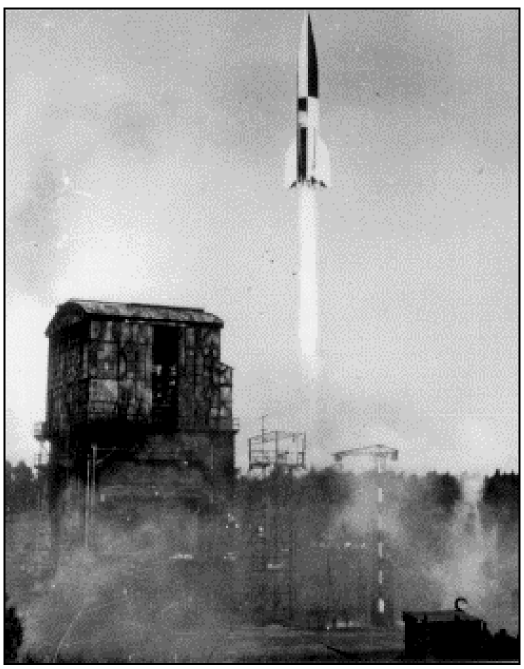

Fig. 19-10. German V-2 test launch

Also referred to as Tactical Missile systems, these missiles have ranges of up to 1,000 km. This type of missile was the first type of missile developed. During World War II, the Germans developed the first ballistic missile, the V-2 (**Fig. 19-10**). These primitive missiles had a range of 200 to 220 miles and carried a 730 kilogram high explosive warhead. In all, more than 3,000 V-2s were launched in the final months of World War II.

After the defeat of Germany, V-2 rockets, technology and specialists were taken to both the U.S. and Russia. Using this German technology and knowledge, both the U.S. and Russia began to develop their respective missile and space programs.

In Russia, work on the SS-1 series began in 1945, when Russia decided to build two versions of the V-2. Two groups worked on creating derivatives of the V-2: one group consisted of Germans captured after the war, the other was made up of Russians. Both team's missiles were successfully tested in 1948. The Russian built version was selected for development. From this first SS-1A missile, further development led to the SS-2 on through the SS-5. Versions of the SS-4/5 became the space boosters SLV-7/8, referred to as "Kosmos". Technology developed in these programs led to the development of the SS-6. As a space booster, versions of the SS-6 are still used today as the SLV-4 "Soyuz" and SLV-6 "Molniya".

SS-1 Series (SCUD)

Further development of tactical missiles led to the SS-1C, more commonly known as the SCUD-B. This weapon entered service in 1962 and in 1965 a wheeled MAZ transporter-erector-launcher (TEL) was introduced (**Fig. 19-11).**

Used by the Russian Army, the SCUD-B was also exported to various other nations. From this exportation, the current proliferation of theater ballistic missiles began, as countries resold, reverse engineered and developed the technology to initiate their own missile programs.

One of the newest developments to the SCUD missile has been the Aerofon version. This system improvement has centered on warhead improvements.

Fig. 19-11. SS-1C, SCUD-B

Unlike the earlier models, the SCUD Aerofon is reported to have its warhead separate from the engine and fuel tank assembly after engine burnout. This is done to increase the stability and accuracy of the warhead. In addition, an optical correlation device was added for digital scene matching in order to refine the aim point as the missile approaches the target area. The goal of this appears to be to increase missile accuracy to around 50 meters.

PEOPLES REPUBLIC OF CHINA (PRC) MISSILES SYSTEMS

The Peoples Republic of China is the only other non-western nation with a known strategic nuclear and missile capability. China's missile capabilities span all ranges and payloads, from tactical to intercontinental. Since their entry into the export market in the 1980s, they have actively aided several countries in missile development programs

Strategic Missile Systems

China's missile program started in the mid-1950s with help from the Soviet Union. A number of SS-2 missiles, improved adaptations of the V-2, were supplied to China. Additionally, some SS-2's were locally produced under license and designated DF-1 (Dong Feng - East Wind) by the Chinese. The first test flight of a DF-1 took place in November 1960. It appears the Chinese also had access to the Russian SS-3.

After the break with Moscow in the early 1960s, China used its existing industrial base to build its first indigenous missile, which appeared to combine aspects of the SS-2 and SS-3. This system was called the CSS-1 by the West and the DF-2 by China. One of the main shortcoming of the CSS-1 was the use of liquid oxygen for fuel. The missile could not be stored fully fueled for long periods nor launched on short notice. Recognizing this, the Chinese

Fig. 19-12. CSS-2/DF-3

started the development of a series of missiles using only storable propellants.

CSS-2/DF-3

The CSS-2 (**Fig. 19-12**) was the first truly indigenous Chinese ballistic missile. Deployed in 1971 the CSS-2 is a single stage, liquid-fueled system with a payload of 2,200 kilograms carrying one nuclear warhead in the megaton class. With a range of 2,500 km, the CSS-2 had sufficient range to attack the former U.S. bases in the Philippines.

An improved version, DF-3A, entered service in 1986 with an increased range of 3,800 km.

Despite its age, the CSS-2 may be the largest element of the PRC's nuclear force. At least 50 missiles are thought to be currently deployed. The system is believed to be transportable, with basing at permanent sites in northwest China from which targets in central and eastern Asia could be reached. (**Fig. 19-13**).

Fig. 19-13. CSS-2 Missile Convoy

Fig. 19-14. CSS-3 on parade

In 1988, China sold conventionally armed CSS-2s to Saudi Arabia as part of a multi-billion dollar deal, heightening proliferation concerns in the Middle East.

CSS-3/DF-4

The two stage CSS-3 (**Fig. 19-14**) was designed essentially in parallel with the CSS-2. It was considered a stop-gap measure until the longer range DF-5 (CSS-4), a true ICBM, could be developed. The CSS-3 incorporated essential components, including the entire 1st stage of the subsequent CSS-4. A civil version of the CSS-3 was also developed, the Long March I, China's first space launch vehicle.

Originally designed to reach the U.S. bases in Guam, the CSS-3's range capability was increased after the deterioration in relations between Russia and China. The enhanced missile was designed to strike Russian cities, in particular, Moscow.

The system is believed to have become operational in 1980 and received upgrades to improve accuracy in 1985. Main deployment for this system is in western China, an area from which targets in Russia are accessible. Between 20 and 30 missiles are thought to be deployed, primarily in caves. The missiles are prepared for launch while inside the caves then moved outside just prior to launch.

CSS-4/DF-5

The CSS-4 is currently China's only true ICBM. The missile was designed to have a range of 12,000 km in order to attack the U.S., Russia and other parts of Asia. Research started in

Fig. 19-15. LM-2C, CSS-4

1965 with the first test flights in 1979 and 1980.

The civilian version, Long March 2C (**Fig. 19-15**), is used for space launches. This launcher has been operational since 1975, some five years before the ICBM version was completed.

In 1983, improve-ments to the missile lead to the DF-5A with an increased range to 13,000 km and improved payload capacity to 3,200 kilograms. Currently, this is the only Chinese missile that can be silo launched.

Only a small number of CSS-4 missiles have been deployed, possibly to demonstrate that China could deploy a superpower-type silo-based ICBM if needed. The limited deployment might also have been planned so as not to cause major fears and reactions among the other nuclear powers and adhere to China's declared "minimum deterrence doctrine".

CSS-5/DF-21

The CSS-5 is a road mobile, two-stage solid propellant intermediate-range missile. It was derived from the sea-based CSS-N-3/JL-1 SLBM.

The development of the JL-1 began in the mid-1960s. The first test launch of the JL-1 was in 1982, while the CSS-5 was first flown in 1985. These two versions are China's first solid propellant ballistic missiles.

In 1987, the CSS-5 became the first truly mobile Chinese missile system. The system is mounted on a tractor-trailer type Transporter-Erector-Launcher, or TEL **(Fig. 19-16)**. The missile uses a cold launch technique where the missile is ejected from a container and the engines ignite while airborne. The Chinese Army uses a six-vehicle convoy to deploy the CSS-5 system.

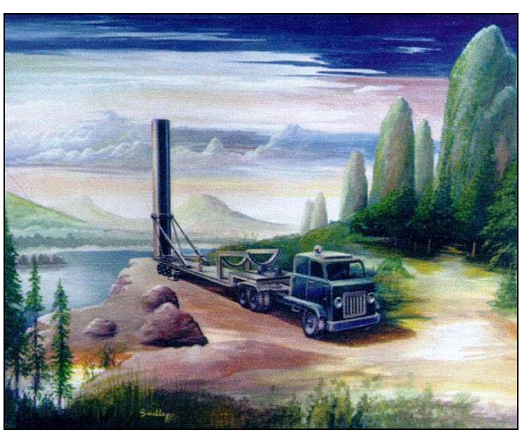

Fig. 19-16. CSS-5 TEL

Reportedly, there is a DF-21A variant. Reported improvements include range increase from 2,150 km to 2,500 km, improved accuracy through satellite navigation (GPS or the Russian GLONASS), a radar-based terminal guidance system and warhead improvements.

The CSS-5 is designated as a replacement tactical nuclear missile for the liquid-fueled CSS-1.

DF-31

The DF-31 is China's first solid-fuel ICBM. First tested in August, 1991, this three stage missile has a range of 8,000km. It is launched from a mobile TEL and carries a single nuclear warhead.

Chinese SLBMs

China currently has only one SLBM class vessel, the "Xia". The development of SLBMs and submarines to carry them has been a long process for China. The first operational Chinese ballistic missile submarine was a conventional-powered Golf II assembled from Soviet parts in 1964. The Golf tested the first Chinese SLBM and has since been used for training and a test vessel for missile crews. The Golf II can carry two missiles in the sail. Given time, the Golf

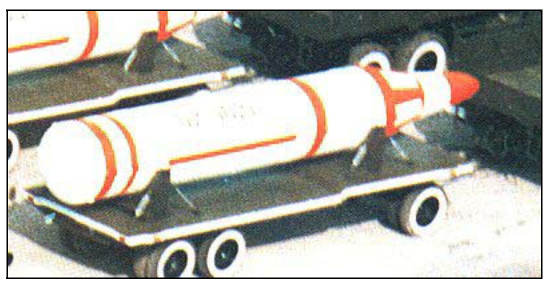

Fig. 19-17. CSS-N-3 (JL-1) SLBM

could be outfitted in a crisis and deployed with operational weapons.

Xia (CSS-N-3/JL-1)

The CSS-N-3 (**Fig. 19-17**) was developed throughout the late 1970's, with the first test firing in 1982. Initial launches were from a submerged firing pontoon, and then from China's diesel powered Golf II submarine.

The missile took about 15 years to develop, primarily due to difficulties in using solid propellant (this was China's first missile not to use liquid fuel), problems with smaller warheads, problems with underwater launching and difficulties with the Xia class nuclear powered submarine itself.

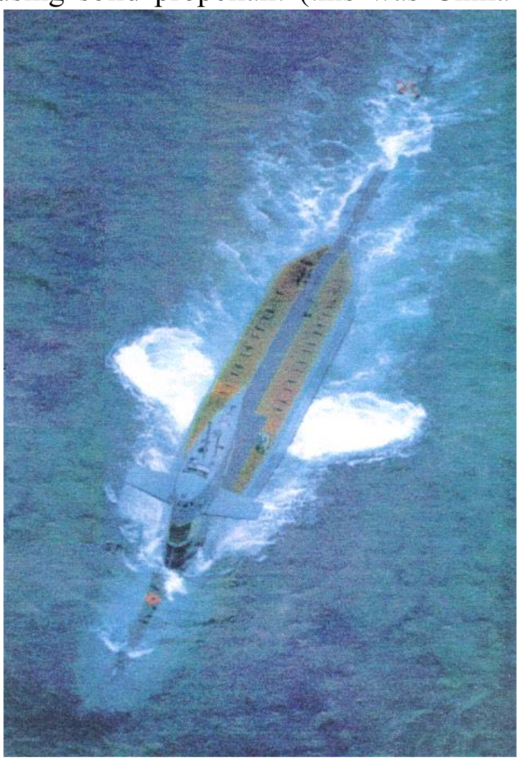

Fig. 19-18. Xia class SSBN

The CSS-N-3 has such a short range, 1,700 km, that it is limited operationally. Chinese vessels would likely deploy in home waters where they can be protected by Chinese land and naval forces, similar to the Russian concept of SSBN bastion deployments.

The development of the Xia class SSBN (**Fig. 19-18**) has also been a long process. Its production was greatly delayed by difficulties in producing a safe and reliable nuclear reactor. As a result, the vessel was in development for twenty years. Its operational debut was in 1987. The JL-1 is known to have been launched twice from the Xia, once in 1988 and again in 1990.

The submarine carries 12 CSS-N-3 SLBMs. Operational deployment is unknown but it is believed that only two Xia have been built, however only one appears to be currently in service.

China is currently working on a replacement missile system. Following the success of the JL-1/CSS-5 joint development, the follow-on JL-2/DF-31 ICBM program appears to be following a similar development strategy.

In addition to a new missile system, China is designing and building a new class of SSBN for the JL-2 series missile.

Chinese Theater Ballistic Missiles

The Chinese M-series tactical short range ballistic missiles began development in the early 1980's. There are three versions: the M-7, M-9, and M-11.

M designations are used for the export versions while the Chinese versions have DF or other Chinese designations. These systems also carry a western CSS identification.

M-7/CSS-8

The M-7, Chinese project 8610, converted the HQ-2 surface to air missile (SAM) (itself a Chinese copy of the Russian SA-2 Guideline), into a surface-to-surface ballistic missile. The original booster and sustainer motors act as the first and second stages.

The missile has a range of 150 km with a 190 kilogram high explosive warhead. It is reported that the M-7 can be launched from a tracked TEL adapted from the HQ-2 SAM launcher.

Fig. 19-19. M-9 missile

Fig. 19-20. M-9 TEL

Estimated to have entered service in 1992, this system was exported to Iran that same year.

M-9/CSS-6 DF-15

The M-9 (**Fig. 19-19**) was first flight tested in 1988 and in 1991 was operationally deployed. The M-9 is a solid fueled, single stage, road-mobile system (**Fig. 19-20**). It has a range of 600 km with a 500 kilogram high explosive warhead. Some reports indicate the Chinese have a nuclear warhead option, believed to be around 90 kilotons.

Fig. 19-21. M-9 lifting out of its TEL

Initially assessed as a single stage system, recent reports suggest that there may be a separating warhead with its own miniature propulsion system. This may indicate some type of terminal guidance. The missile currently carries an inertial guidance package, although reports indicate the Chinese are working on upgrading in the future with GPS inputs.

The M-9 is deployed on an 8x8 wheeled TEL, with the missile raised to vertical before launch (**Fig. 19-21**). The system's solid fuel gives it a launch preparation time as short as 30 minutes. The system has been advertised for sale,

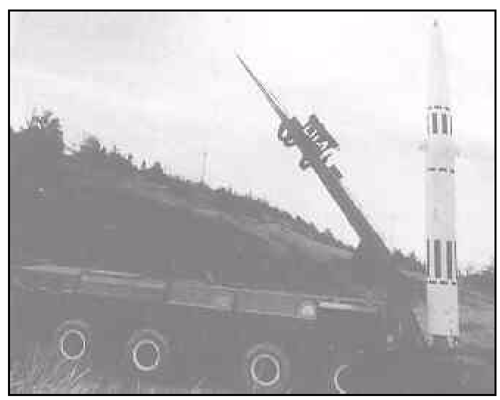

Fig. 19-22. M-11 model on TEL

with major selling points being its 30 minute reaction time and accuracy of under 600 meters.

M-11/CSS-7/DF-11

The M-11 (**Fig. 19-22**) was developed as a solid propellant, short range, road-mobile missile. Designed with external dimensions and electrical interfaces similar to the Russian SS-1C "SCUD-B" missile, it is considerably shorter and lighter. As an interchangeable version of the SCUD-B, the M-11 is capable of being launched from a SCUD TEL with a minimum of modification.

The missile is stated to have a range of 300 km with a 500 kilogram warhead. First test flights occurred in 1990 and the missile is believed to have reached operational status in the late 1990s.

NORTH KOREAN MISSILE SYSTEMS

North Korea (the Democratic Peoples Republic of Korea) has been actively pursuing a ballistic missile development program since the mid-1970's. Initially they worked with the Chinese on a 600 km-range missile. Following the demise of this program due to internal problems in China, North Korea sought to obtain SCUD missile technology in order to provide the basis for an indigenous missile production capability. Purchase of foreign missile systems followed by reverse engineering and development of indigenous capabilities has created an active missile program.

Despite a severe shortage of resources, North Korea continues to press forward with its ballistic missile programs. North Korea is among the leading nations in the proliferation of missile systems, technology and manufacturing.

SCUD System

Around 1980, North Korea obtained a small number of Russian SCUD-B's from Egypt. The Koreans reverse-engineered the system and flight tested their copy, the SCUD Mod A, in 1984. While never intended to become a production model, it provided the basis for the North Korean SCUD Mod B; usually referred to as a SCUD-B, since it is nearly identical to the Russian version. This North Korean system incorporated several production engineering improvements.

SCUD-B

North Korean improvements to the Russian SCUD-B included slightly lighter structural materials and marginally more powerful engines, increasing the range from 300 to 320 km. Like the Russian missile, it possesses poor accuracy, with a circular error probability (CEP) of 500-1000 meters at maximum range.

With the SCUD-B, North Korea also began exports of ballistic missile systems to a number of nations. They established a relationship with Iran that has continued and financial aid obtained from Iran enabled full-scale SCUD production to begin in late 1986. Iranian financial assistance has been one of the most important factors in the success of North Korea's missile program. In return, Iran has received missile systems and limited production capabilities.

SCUD-C

Development of an extended-range SCUD missile began in 1987. This system, the SCUD-C, achieves a range of 550 km through the reduction in warhead weight to 500 kilogram and a slight increase in size and thus, propellant. The SCUD-C was first tested in June 1990. Like its predecessor, this system has also been exported to Iran, Egypt, and Syria.

In addition to the Russian MAZ TEL, North Korea has developed several TEL vehicles including German MAN and Japanese Nissan tractor trailer units.

NO-DONG System

North Korea pursued a twin-track approach in its efforts to develop longer range missiles. The first method led to the SCUD-C. However, there comes a point where neither increases in fuel nor lighter airframes will increase range without greater initial thrust and substantial redesign. In order to carry a larger warhead over a greater distance, a full redesign of the 1960's vintage SCUD technology was needed. Thus, the development of the NO-DONG series was initiated by North Korea at roughly the same time as the SCUD-C program, but proceeded at a slower pace.

NODONG-1

An increase in thrust appears to have been achieved by using a cluster of four SCUD-B engines, much like the Russians did in their early SLBMs in the 1950's and the Chinese with the CSS-2. This increase in thrust is estimated to give the NO-DONG-1 a range of 1,000 km with a payload of 1,000 kilograms. The first test firing occurred in May 1993. Unlike the SCUD series, the NO-DONG warhead is believed to separate from the missile shortly before re-entry into the atmosphere.

The NO-DONG-1 is a road-mobile system. The TEL is a modified version of the Russian SCUD TEL vehicle.

Series production and deployment may have begun as early as 1996. When deployed operationally, the NO-DONGs 1,000 km range will place most of western Japan at risk.

As with the SCUD-B and C, North Korea appears to have sold the NO-DONG or its technology to various nations for their own missile programs. Pakistan and Iran appear to be the first nations to have developed missile systems based on NO-DONG-1 technology.

NODONG-2

North Korea may also be developing a 1,500 km version, the NO-DONG-2. Carrying the same 1,000 kilogram payload, the range increase may be achieved by making the main booster structure from an aluminum-magnesium alloy rather than steel. This could reduce the weight of the missile by at least one ton.

TAEPO-DONG Series

The TAEPO-DONG series consists of two systems, both with two stages. Such multi-staging represents a considerable advance for North Korea, requiring new materials and construction technologies.

TAEPO-DONG-1

The TAEPO-DONG-1 appears to use a NODONG-1 first stage and SCUD-derived second stage. This combination could give the missile a range of approximately 2,000 km with a 1,000 kilogram warhead.

On 31 August 1998, North Korea test launched the TAPEO-DONG-1 **(Fig. 19-23).** During this launch several new developments were revealed. The launch

Fig. 19-23 TAPEO-DONG-1

was claimed by North Korea to be a satellite launch and not a missile test. The system was launched in an easterly direction with the first stage landing in the Sea of Japan and, after overflying the Japanese islands, the second stage impacted in the Pacific Ocean 480 km east of the Japanese island of Honshu, some 1,500 km from its launch point.

One of the key surprise developments was the third stage. North Korea stated that this third stage was a solid fuel stage intended to place a satellite into orbit. This stage failed and the third stage along with its satellite payload landed in the Pacific Ocean south of Alaska after a flight of about 6,000 km.

This test of a staging missile system put North Korea on a par with India as the only developing nation to master "staging".

TAEPO-DONG-2

The TAEPO-DONG-2 appears to have a new first stage and a modified NO-DONG-1 second stage. Initial estimates put the TAEPO-DONG-2 range at 4,000 km with a 1,000 kilogram payload. No flight tests of this variant have been noted.

While the TAEOPO-DONG systems appear to represent a considerable advance over the SCUD-based NO-DONG series, it is clear from looking back at China's missile development program, that these advances represent the next logical steps. Nonetheless, North Korea must overcome numerous additional technical obstacles if the TAEPO-DONG series is to become a viable operational system.

Fig. 19-24. Nike-Hercules SAM

SOUTH KOREAN MISSILE SYSTEMS

North Korean missile developments were likely the impetus for the initiation of South Korean missile programs. By reverse engineering U.S. supplied missiles, South Korea produced a two-stage, solid-fuel surface to surface missile based on the Nike-Hercules surface to air missile (**Fig. 19-24**). This development took place in the late 1970's.

NHK Series

NHK-1 and NHK-2 (Nike-Hercules-Korea) are in service with South Korean forces. The systems are reportedly capable of delivering a payload of about 450 kilograms to a range of roughly 260 km.

South Korea depends on the U. S. for most of its advanced weapons. An agreement between the U.S. and South Korea bans South Korea from developing medium/long-range missiles. However, in order to counter North Korea's theater ballistic missile development programs, South Korea has just completed negotiations with the US to allow for 300 km missiles.

INDIAN MISSILE SYSTEMS

India's security environment is dominated by the mutual distrust between themselves and Pakistan, with whom it has fought three wars since 1947 (47-48, 65, 71) and have near continuous border disputes. Another factor is its competition for regional influence with China, with whom it also fought a border war in 1962. A combination of high defense spending and considerable technical expertise has made India's military-industrial base one of the best in the third world.

Like many countries, India's missile developments have been closely related to their space program. Their efforts show what a determined, developing country can do with a long-term, measured approach to the concurrent development and production of space launch vehicles and missiles.

After failing to reverse-engineer a Russian SA-2 SAM as a viable Short Range Ballistic Missile (SRBM) in the 1970's, India started its Integrated Guided Missile Development Program (IGMDP) with the aim of achieving selfsufficiency in missile production and development.

The IGMDP is comprised of five core systems. The first two are an SRBM and a Intermediate Range Ballistic Missile

Fig. 19-25. Prithvi SRBM

(IRBM) to be developed in close association with the space program. The other programs are a short and medium range SAM and an anti-tank guided missile.

Prithvi SRBM System

The Prithvi ("earth") SRBM missile design began in 1983 and was first test fired in 1988. This road-mobile, liquid fueled missile uses basic propulsion technology from the SA-2 SAM. Two versions of the Prithvi have been developed, the Prithvi-I and Prithvi-II, both believed to have entered service in 1994 or 1995.

The system is carried on a truck based eight-wheeled TEL (**Fig. 19-25**) and is raised to vertical for launch.

The Prithvi-I is an army version, having a range of 150 km carrying a 1,000 kilogram warhead, while the Air Force Prithvi-II has a range of 250 km with a 500 kilogram warhead.

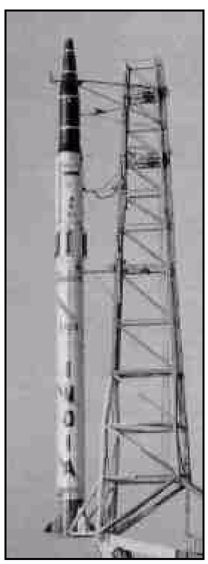

Fig. 19-26. Agni IRBM

The Prithvi class systems use a highly volatile liquid fuel and therefore, are fueled immediately prior to launch. Reports suggest that a solid propellant motor is being researched.

A naval version of the Prithvi-II called the "Dhannsh" was test launched from an Indian naval vessel in 2000. The test was not successful but the Indian Navy will likely continue testing and eventually deploy the system.

Agni IRBM System

The Agni ("fire") missile represents a much more ambitious project than the Prithvi. First conceived in 1979, the Agni (**Fig. 19-26**) is a full-fledged IRBM. This two stage system uses a solid fuel first stage, copied from the SLV-3 space booster, while the second stage is a shortened version of the liquid fueled Prithvi. Its first flight was in 1989. The system has been tested to 2,500 km with a 1,000 kilogram warhead.

India has called the Agni a technology demonstrator and not a developed weapon system. In December 1996, India announced that the Agni "technology demonstrator" program was over.

In April 1999, India tested an upgraded Agni ballistic missile. Variously called the Agni-2 Agni-II, Agni Plus, and the Agni ER (Extended Range) the missile reportedly will carry a warhead of 1,000 kilograms to a range of 2,000 km. A CEP of 40 meters was reported but is not confirmed. The missile has an advanced inertial navigation system and may have mid-course updates using GPS.

This version is expected to be India's operational IRBM. The solid fuel missile is intended to be fired from mobile launchers **(Fig. 19-27)**. This is a major upgrade from the basic Agni which had a solid first stage but a liquid fuel second stage.

Fig. 19-27. Agni-2 in Parade

With the increased range of the new Agni-II, targets in Pakistan can be reached from almost anywhere in India as well as the major cities of China, both of whom India has fought wars with in recent times.

The possibility has been raised that India may be developing an Agni-III with a range of 3,500 km.

PAKISTANI MISSILE SYSTEMS

The Prithvi threat from India spurred Pakistani efforts to acquire ballistic missiles. Pakistan started to develop the Hatf ("Deadly") series in the early 1980's. They claim to have done this without assistance; however, Chinese or some other aid is suspected. There is also evidence that China delivered unassembled M-11 missiles to Pakistan. Rumors of Chinese M-9 missile or technology have also been associated with Pakistan's missile program.

Hatf Series

The Hatf-1 and 2 were both revealed during test firings in early1989. They are short to intermediate-range, road-mobile, solid fuel systems. Little is known about the missiles or their role.

Hatf-1

The Hatf-1 is a single-stage SRBM with a range of 80 km carrying a 500 kilogram warhead. The system is a road-mobile, single stage, solid propellant missile. It is believed to have entered service in 1992.

An improved version, the Hatf-1A was reported to have entered service in 1992. This missile is reported to have an increased range to 100 km.

Hatf-2

The Hatf-2 appears to have been developed in tandem with the Hatf-1 during the early 1980's. This system appears to be a two-stage solid fuel missile. Performance is believed to be in the range of 300 km with a 500 kilogram warhead.

The Hatf-2 is reported to be a mobile system; however, when displayed, they were transported on converted World War II-era anti-aircraft gun trailers instead of a more modern transporter-erector-launcher vehicle.

Hatf-3/4

There have been numerous reports of other Pakistani missile systems under development. Little is know about these systems. Possible missile systems have been speculated with a variety of different names.

One report mentions a Hatf-3 follow on with a range of 600 km. There has been some speculation that the Hatf-3 program may be related to the Chinese M-9 or M-11 missiles.

M-11 (Chinese)

Since 1993, there have been indications that Pakistan has received unassembled M-11's from China. In August 1996, U.S. intelligence officials reported a partially completed factory that could be ready in a year or two to produce "precise duplicates" of the M-11. An engine test stand was also located nearby. In 2000 the US Government publicly stated that China had proliferated the M-11 missile to Pakistan. The M-11 is a mobile system with a range of 300 km with a 500 kilogram warhead.

Ghauri (Hatf-5) Series

Development of a longer range missile system appears to have started between 1993 and 1996. The first public reference to the missile was in 1997. After the first flight test in 1998, North Korean involvement in this missile development program appeared highly likely.

Fig. 19-28. Ghauri

Ghauri

In April 1998, Pakistan launched a missile 1,100 km with a 700 kilogram warhead. Flight time was just under 10 minutes. First identified as the Hatf-V, the missile was renamed the Ghauri **(Fig. 19-28),** after a historical Muslim who defeated the Hindu's in the 1100's.
The Ghauri missile is stated to have a range of 1500 km with a CEP of 250 meters and is assessed to be liquid fueled. The Ghauri appears to be a North Korean No Dong type missile.

Ghauri-2

In April 1999, one year after the Ghauri launch, Pakistan claimed to have launched an improved missile. The Ghauri-2 has a reported range of 2,000 km with a 1,000 kilogram warhead but was only tested to a range of 1,150 km. Flight time for this test was supposedly around 12 minutes. If there is a Ghauri-2, foreign, probably North Korean, help is suspected. However, there is no evidence other than the Pakistani press release that a Ghauri-2 missile was actually tested.

Shaheen Series

Shaheen

On April 15, 1999, one day after supposedly testing the Ghauri-2, Pakistan flight tested a new series of ballistic missile. The Shaheen (Eagle) **(Fig. 19-29)** is a solid fuel, mobile SRBM. While the system has an advertised range of 750 km with a payload of 1,000 kilograms, the four minute flight was to a distance of 600 km. A CEP of 10 meters has been cited in Pakistani reports.

Fig. 19-29. Shaheen TEL

Numerous other missile names have appeared in connection with the Pakistani missile programs. These include; Ghaznave (2,000 km), Shaheen-2 (2,300 km), Tipu (4,000 km), Babar, and Abdali.

ISRAELI MISSILE SYSTEMS

Israel has the most highly developed defense industry as well as the most advanced missile production in the Middle East. Israel has developed both a short range and a medium range ballistic missile. Both of these missiles are produced indigenously.

Jericho-1

The Jericho-1 is a short range missile based on the French MD-600 design. It can carry a 500 kilogram warhead a distance of 500 km. This solid propellant, mobile system was developed in the 1960’s. First test fired in 1968, it was deployed around 1973. The missile can be launched from a railroad flatbed car or from a wheeled TEL vehicle.

Jericho-2

It is believed that the Jericho-2 was develop-ed in tandem with Israel's Shavit space launch vehicle **(Fig. 19-30**).

The Jericho-2 improved upon the performance of its predecessor, the Jericho-1. Developed in the mid-1970s to the early 1980s, its first fight was in 1986. It entered service in 1990.

The Jericho-2 is a two-stage, solid propellant system capable of delivering a 1,000 kilogram war-head a distance of around 1,500 km. This places most of the capitals of the Middle East in range as well as southwestern Russia.

As with the Jericho-1, the system is launched from either a wheeled TEL or a railroad flatcar.

IRANIAN MISSILE SYSTEMS

Iran acquired its first SCUD launcher and missiles in 1985-1986. It is believed that these were acquired from Libya and Syria. At this time, Iran had been at war with Iraq since September 1980.

The 300 km range of the SCUD-B permitted Iran to launch strikes against Baghdad, some 130 km from the Iranian border. In 1985, Iran fired an estimated 14 SCUD-B's at Iraqi cities. In 1987 and 1988, more SCUD missiles were then obtained; this time from North Korea. Reportedly between 90 and 100 missiles were purchased. In 1988, during the "War of the Cities" Iran fired 231 SCUD-B missiles at Iraq. Since the end of the Iran/Iraq War in 1988, Iran has continued to expand its missile program.

SCUD Missile Systems (North Korea)

Iran's current inventory of over 250 SCUD-B missiles was obtained from North Korea. The extended range North Korean SCUD-C (500 km) was subsequently purchased and Iran may have over 200 of these missiles. North Korea has also aided Iran in converting a missile maintenance facility into a SCUD-C assembly plant.

M-7 (CSS-8) Missile System (China)

In 1992, Iran purchased the Chinese M-7 short-range missile. Iran has also expressed an interest in obtaining the M-9 and/or the M-11 missiles.

A recent agreement between the U.S. and China, where China agreed to terminate its missile support to Iran, should preclude Iran from building a near-term offensive missile capability against U.S. allies or other countries in the gulf region. China has more or less honored this pledge. However, the Iranians are still getting missile technology assistance from North Korea and Russia.

Shahab-3

Iran's newest missile is the Shahab-3 (Meteor) which is currently being deployed. This MRBM is a mobile system based on the North Korean No Dong. The system was tested in Iran in July 1998 and has been assessed to have a 1,300 km range **(Fig. 19-31).**

Fig. 19-31 Shahab Articulated TEL

IRAQI MISSILE SYSTEMS

Iraq received its first ballistic missiles, SUCD-B's, from the FSU in 1974. In 1985, during the Iran/Iraq War, SCUD-B missiles were launched against Iraqi cities, particularly Baghdad. Most Iranian cities were beyond the range of the Iraqi SCUD-B missiles. Tehran, the capital of Iran, is about 500 km from the Iraqi border. To overcome this deficiency, Iraq started an extensive missile program which centered on upgrading the performance of the SCUD-B.

SCUD and SCUD Modifications

While Iraq originally obtained its SCUD missiles from the FSU, Iraq has been able to develop an autonomous production capability. Using oil revenues to fund a huge missile technology procurement network, Iraq was able to obtain more advanced missile technology. During the late 1980s, the Iraqis made strides in their indigenous rocket program, apparently relying on foreign technical assistance and equipment.

Al Hussein

The first upgrade to the SCUD -B was the Al Hussein, **(Fig. 19-32)** with a range of 600 km, allowing strikes on Tehran, Iran. In 1988, during the Iraqi "War of the Cities" strikes, some 189 modified SCUDs were fired at Tehran. This resulted in a halt to Iran's small-scale missile attacks on Baghdad. Additionally, it hastened Iran's acceptance of a cease-fire in a war which was started by Iraq and had become bogged down in a World War I-style stalemate.

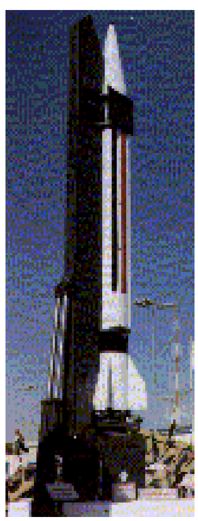

Fig. 19-32
Al Hussein

Al Hussein variants are approximately three feet longer than the standard SCUD-B and have reduced warheads, from 1,000 kilograms to 500. This reduction in payload weight and extra fuel provides for the extended range.

During the Gulf War of 1991, about 40 Al Hussein missiles were fired at Israel and around 46 were launched against Saudi Arabia.

Al Abbas

A second modification, designated Al Abbas, was tested in April 1988. This missile had an enhanced range of 900 km. However, it does not appear to have reached operational status. Only one flight test appears to have been conducted.

The extended range was obtained by reducing the warhead to around 150 kilograms and again, extending the missile body; this time by more that six feet over the original SCUD-B.

Since the Gulf War, Iraq has been prohibited from having or developing ballistic missiles with ranges over 150 km. However, they continue to test short range missiles within this limit.

SAUDI ARABIAN MISSILE SYSTEMS

Saudi Arabia obtained its first ballistic missile during the late 1980s. Although the missiles were purchased from China around 1986, it was not disclosed to the world until 1988. Currently, no other ballistic missiles are reported to be operational or under development in Saudi Arabia.

CSS-2 Missile System

Saudi Arabia is believed to have a total of approximately 12 launchers and 50 CSS-2 missiles deployed at two sites, located 100 and 500 km south of Riyadh, Saudi Arabia.

The CSS-2 can carry a 2,000 kilogram conventional warhead to a distance of 2,500 km. This range brings countries throughout the Middle East within striking range; yet, none of the Saudi CSS-2s were fired during the Gulf War.

The missile is far too inaccurate to be used against a point target with a conventional warhead. The Saudis stated that the war was against the leadership of Iraq, not its people, thereby acknowledging the missile's inaccuracy and its consequent potential for civilian causalities. Saudi Arabia has further stated that they would not obtain or use chemical or nuclear warheads on their CSS-2 missiles. In April 1988, they signed the Nuclear Nonproliferation Treaty.

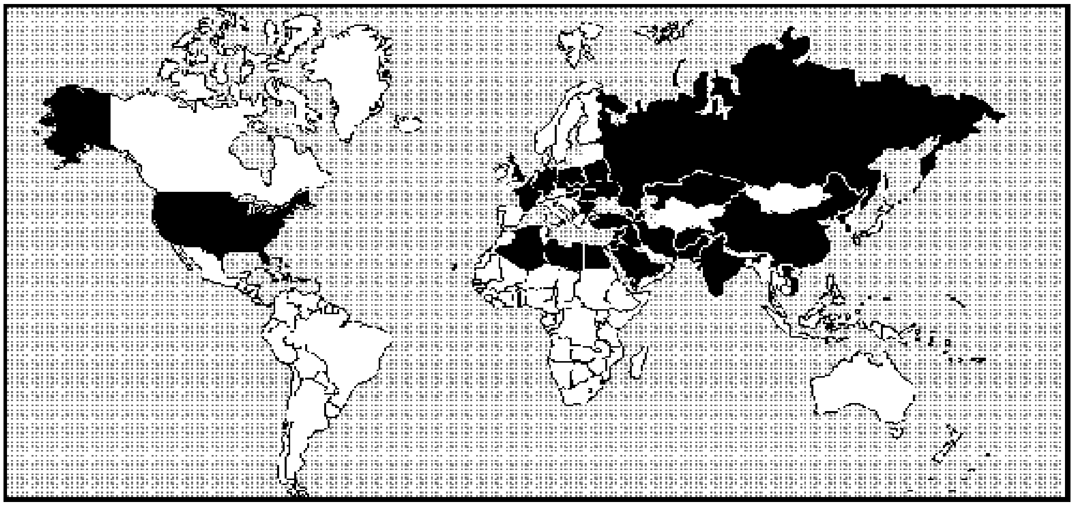

Fig. 19-33. Countries in black have, produce or are developing theater ballistic missiles

SYRIAN MISSILE SYSTEMS

Syria was one of the FSU's staunchest allies in the Middle East. Beginning in the early 1970s, Syria began receiving the SCUD-B and other battlefield missiles. It is believed that Syria has 200 SCUD-B missiles and 18 launchers. They also have more modern SS-21 solid fueled short range missiles.

LIBYIAN MISSILE SYSTEMS

Libya obtained SCUD-Bs from the FSU during the 1970s. Since then, it has attempted to purchase other new systems. Additionally, reports of an indigenous missile production program are persistent. This missile development program, Al Fatah, has been in progress since at least 1981. Despite the apparent slow progress, Libya's relative wealth allows the country to continue seeking an indigenously produced ballistic missile.

MISSILE PROLIFERATION

Theater ballistic missile proliferation is becoming an ever increasing problem in the world. Many nations possess theater ballistic missiles and some have made these systems/technology available for purchase (see **Fig. 19-33**). Today, proliferation poses a significant threat to U.S. commanders in overseas locations and this threat will continue to grow in the future.

In 1986, Libya fired two ballistic missiles at a U.S. communications installation on the Italian island of

Lampedusa. Although they missed, equally ominous was Qaddafi's boast that if Libya had possessed a missile that could reach New York City at the time of the U.S. air raid on Tripoli, he would have used it. Although that may have been an empty threat at the time, Americans cannot be overly optimistic about the prospect of missiles under the control of a volatile political leader.

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Chapter 20

REST-OF-WORLD (ROW) SPACE LAUNCH

Missiles and space have a long and related history. All the early space boosters, both U.S. and Russian, were developed from ballistic missile programs. Today, many other nations are using their missile and rocket technology to develop a space launch capability.

COMMONWEALTH AND INDEPENDENT STATES (CIS) RUSSIAN / UKRAINE / KAZAKH SPACE LAUNCH SYSTEMS

Space Launch Facilities

The breakup of the former Soviet Union (FSU) into independent states has fragmented and divided the Russian space support infrastructure. This has resulted in planning and scheduling difficulties for Russia, the main inheritor of the remains of the former Soviet space program. Ukraine has the most extensive space capability after Russia but with no space launch facility, followed by Kazakhstan with a major space launch facility but little industrial base. Other newly independent countries have some limited manufacturing capability related to the space industry. Russia's spaceports are now located in two different countries. The program's oldest and biggest spaceport, and the only site currently able to do manned launches is Baikonur Cosmodrome or Tyuratam in Kazakhstan. Within Russia, there are three spaceports. There are two from the former Soviet space program: Plesetsk Cosmodrome and Kapustin Yar Space and Missile Test Facility, and the new Russian spaceport in Siberia, Svobodny Cosmodrome. The Russian's have also developed and marketed a space booster based on a Submarine Launched Ballistic Missile (SLBM) which has launched a satellite into orbit from the Barents Sea. Counting this undersea space launch platform, Russia can use five different launch locations.

Tyuratam (TT)/Baikonur Cosmodrome

In the 1950s, the Soviet Union announced that space launch operations were being conducted from the Baikonur Cosmodrome. Some concluded that this facility was near the city of Baikonur, Kazakhstan. In truth, the launch facilities are 400 Km to the southwest, near the railhead at Tyuratam (45.9ºN, 63.3ºE). The Soviets built the city of Leninsk near the facility to provide apartments, schools and administrative support to the tens of thousands of workers at the launch facility. Sputnik, the first man-made satellite, was launched from TT in October 1957. This site has been the location of all manned and geostationary orbit Soviet and CIS launches as well as most lunar, planetary launches. Additionally, it is the only facility that supports launches of the Proton (SL-12 and SL-13), the Zenit (SL-16) and the Energia (SL-17). The climate is hot in the summer and suffers violent snowstorms and -40ºC temperatures in the winter. A unique feature of the Russian/CIS space program is its ability to launch in extremely harsh climates. Since the demise of the Soviet Union, Kazakhstan has claimed ownership of the facility. However, most of the skilled workers and the military forces protecting the site are Russian. To use the facilities at Tyruatam, Russia must pay rent to Kazakhstan.

Kapustin Yar (KY)

Kapustin Yar Space and Missile Test Center (48.4°N, 45.8°E) is located on the banks of the Volga River, about 120 Km east of Volgograd and less than 48 Km west of Kazakhstan. In 1947, this site was selected as the location for the development of the Soviet rocket and space program. Numerous German V-2 rocket launches were made from here during testing and development. The first Soviet-built rocket systems, the R-1 and R-2, were launched from here in 1948 and 1949. In the past, this facility was the site of numerous sounding rockets and small orbital payload launches using the SL-8/Kosmos. There were no space launches from Kapustin Yar from 1987 until April 1999 when a commercial launch was performed for a German satellite. Kapustin Yar's proximity to Kazakhstan now precludes eastward launches without prior approval of that government.

Plesetsk (PK) Cosmodrome

Plesetsk Cosmodrome (63.8°N, 40.7°E) is about 640 Km northeast of St. Petersburg. PK is situated in a heavily wooded area close to the Arctic Circle. It is near the town of Plesetsk on the railway line from Moscow to Archangelsk. Although used for civilian communications, meteorological and international launches; most launches from PK have military roles. The site may be considered as the Russian equivalent of Vandenberg AFB. Orbital inclinations attained from PK range from 63° to 83°. Historically, it is the port of debarkation for over 1,300 launches, or more than one third of all orbital or planetary missions from all launch sites world-wide. It typically is used to deliver most (if not all) Russian polar orbiting sensor payloads and many Molniya orbit payloads. The high inclination of the Molniya communications satellites is a natural result of an eastward launch from PK. Because the launch site is on Russian soil and the flight profile does not pass over any other countries during the boost phase, the requirement for coordination with other countries is minimal. There are launch pads for the SL-4, SL-6, SL-8, SL-14 and the SL-19 space launch vehicles. Additionally, launches of the SL-3 and SL-11 could also be conducted, if necessary. The extreme northern latitude of PK has provided the Russians with valuable experience in cold weather launch operations.

Svobodny Cosmodrome

When the breakup of the Soviet Union left Russia's largest spaceport of Tyuratum in Kazakhstan, experts concluded that Russia needed another spaceport. Svobodny Cosmodrome (51.2°N, 128.0°E) was selected in 1993 to fill this role. It is the site of a former ICBM base along the Trans-Siberian railway. Plans call for Svobodny to incrementally come on line as a spaceport. At first, the existing facilities of the former ICBM base will be used to launch Rokot and START-series vehicles. In later stages, launch facilities will be built to support the heavy Angara launch vehicle. Svobodny became Russia's fourth spaceport with the launch of a START-1 on 4 March 1997. A second START-1 was launched in December 1997 and a third in late 2000.

Barents Sea Launch Area

With the development of a space booster from an SLBM, the Russian's have demonstrated the potential ability to launch a small satellite from almost anywhere in the world. All Russian tests and its first commercial satellite from a submarine have all taken place from near Russian home waters in the Barents Sea located north of the Kola Peninsula, the homeport of Russia's ballistic missile submarine fleet. This first underwater launch of a satellite placed a German university built scientific satellite into a polar, low earth orbit.

Russian Space Launch Vehicles

The FSU developed an impressive array of SLVs, mostly derived from Intercontinental Ballistic Missiles (ICBMs). On more than one occasion, Russia has demonstrated the ability to conduct multiple launches within a short period of time. The SLV names such as Proton used in this chapter are Russian. The "SL-#" designation is assigned by DOD. The letter-number designation, such as "A-1", was developed by Dr. Charles Sheldon, U.S. Congressional Research Service, to differentiate between launch vehicle families and their variants. This system is no longer used but is still found in some publications. Since the break-up of the Soviet Union, many FSU countries and companies have been marketing former Soviet booster for international and commercial space lift. This trend has lead to the increased use of the Russian names for these boosters in press releases and news reports. **Table 20-1** at the end of this SLV section is a matrix providing a list of all three types of names.

Soyuz Series (A-Class, Soyuz, Molniya)

The Soyuz class of launch vehicles is based on the original Soviet ICBM, the SS-6 Sapwood (**Fig. 20-1**), which was first tested as a missile on 2 August 1957. Its first use as a space vehicle was only two months later, suggesting concurrent development as an ICBM and SLV. This ICBM has provided, in various forms, the initial stages of a whole family of SLVs including the operational Vostok, Soyuz and Molniya SLVs.

Fig. 20-1. SS-6

The original version, the A vehicle (or SL-1/2) is classified as a one and one-half stage vehicle. It consists of a central core with four strap-on boosters. The Russians classified this as a two-stage assembly, but since the engines of the strap-ons and the central sustainer ignite simultaneously at lift off, this parallel staging arrangement is generally regarded as a one and one-half-stage vehicle. This vehicle launched the first three Sputnik satellites in 1957 and 1958. The third and largest Sputnik had a mass of 1327 Kg and was delivered to a 122 by 1016 nm orbit. All three A launches were conducted from TT.

To satisfy the need to launch bigger payloads, the Vostok (A-1/SL-3) (**Fig. 20-2**) was introduced in 1959.

With an SS-6 first stage, the Vostok has a second stage attached by a trellis-like structure. The initial version of the A-1 vehicle was used to launch the Luna moon payload. The payload fairing was

Fig. 20-2. SL-3 Vostok

then enlarged to launch the manned Vostok as well as the first-generation recoverable Kosmos satellites. With a larger and more sophisticated payload fairing used on the Vostok, the overall length of the booster increased to 38m from about 34m. Initially the Vostok was launched from TT and later from PK. PK no longer launches the Vostok, although the capability still exists. There have been about 150 successful Vostok launches.

The Soyuz (A-2/SL-4) premiered in 1963, with the development of a more powerful core second stage. This SLV has been the workhorse of the Soviet rocket program (**Fig. 20-3**). Since 1964, all Soviet manned missions have relied on the SL-4. However, the largest program it supports is military and civilian photographic reconnaissance flights. It is used today to launch the Soyuz, Progress

Fig. 20-3. SL-4 Soyuz

and Biosats, as well as Kosmos observation satellites. It also launched the Voskhod manned vehicles. Over 900 Soyuz have been flown successfully from TT and PK. Normally launched 40-50 times a year, the Soyuz is by far the most launched SLV in the world.

During the 1960s, the Molniya SLV (A-2-e/SL-6) supported all Soviet planetary missions and most lunar flights, such as Luna, Zond and Venera payloads. It differs from Soyuz mainly with the addition of a core third stage. Today, this SLV supports Molniya communications satellite and Kosmos early warning satellite programs, which require highly elliptical, semi-synchronous orbits. The Molniya rocket was initially flown out of TT but is now flown from PK.

The Soyuz SLVs have dominated the Russian space program, having performed about 60% of the all launches. Since 1957, A-class boosters have placed more than 1,300 payloads into earth orbit.

The most recent versions of the Soyuz family are the SL-22, Soyuz/Ikar **(Fig. 20-4)** and the SL-26, Soyuz/Fregat. These boosters were modified from the original Soyuz by the addition of a new upper stage, either the Ikar or the Fregat. Both boosters are a commercial venture between France and Russia to perform commercial launches with versions of the SL-4 Soyuz. Depending on the satellite payload requirements, different upper stages may be used or special purpose built.

Fig. 20-4. SL-22 - Soyuz-Ikar

Launch Processing. Three or four weeks before the launch, the components of the A-class SLV are delivered to the Space Vehicle Assembly Building (MIK) assembly complex in up to seven parts (4 strap-on boosters, first, second and third stages). In a few days, the separate parts are horizontally mated. After a successful integration test, the entire SLV, with its payload, is carried on a rail transporter-erector car to the launch pad, then tilted up to sit on a stand over a huge flame deflector pit.

The payload or satellite is also delivered to the launch facility by rail. The prospective satellite first goes to the MIK for initial pre-launch check-out. It is then carried by a special transport to the fueling facilities several kilometers from the launch site. Once fully fueled, the spacecraft is transported back to the MIK for horizontal mating with the SLV and final pre-pad checkout.

The launch structure for the vehicle employs four releasable support beams which accept the weight of the SLV. The SLV is suspended over the gas deflecting trough with its tail portion 7m below the level of the platform.

After ignition, the four support beams are initially held in place by the weight of the booster. Counterweights cause these four beams to fall back and allow the climbing SLV to clear the structure.

The A-class SLVs are normally brought to the pad less than 48 hours before liftoff. They are capable of launching in severe weather conditions including dense fog, wind, rain and snow.

Flight Sequence. The following table shows the sequence of a Soyuz Manned LEO Mission Launch:

MIN:SEC	
0:00	Lift Off
1:58	Strap-on boosters separate
2:40	Escape system jettison command
5:00	1st stage separation 2nd stage ignition
9:00	2nd stage shutdown
9:43	Spacecraft orbital injection

Kosmos Series (C-Class SLVs, Kosmos)

The Kosmos (C-1/SL-8) (**Fig. 20-5**) was first launched in 1964. It is a two-stage, storable propellant SLV with the capability to place 1350 Kg into low-earth orbit (LEO). This bridged the payload gap between the older SL-7 (B-1) booster, which was capable of placing 600 Kg into LEO and the A-class boosters capable of placing 4730 Kg to LEO. As with earlier SLVs, a missile, in this case the SS-5 Skean, was used as the first stage.

Kosmos' first use launched the triple payload of Kosmos 38, 39 and 40 out of TT. Launching multiple small payloads with a single Kosmos has remained a common mission. Initially launched from TT, PK has been the launch site since 1966. Today, nearly all Kosmos launches are conducted at PK, although a few were conducted from KY. Kosmos is the first and only SLV to date that has been launched from three operational launch sites.

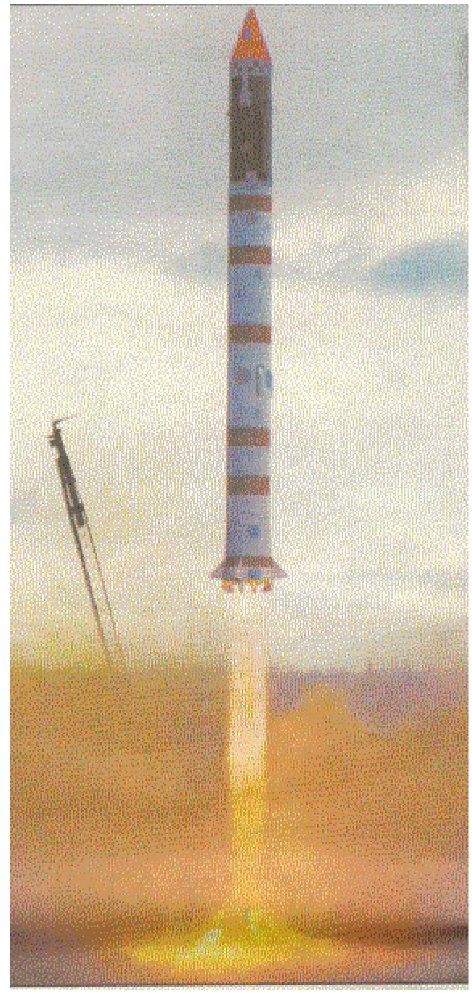

Fig. 20-5. SL-8 Kosmos

In 1983 and 1984, Kosmos launched four BOR-4 lifting bodies under the names Kosmos 1374, 1445, 1517 and 1614. These sub-scale space plane missions were conducted for the Buran space shuttle program to test heat resistant reentry materials and gather additional transonic aerodynamic data. The four space missions were successful, culminating in recoveries in the Indian Ocean or the Black Sea.

Today, Kosmos has replaced the B-1 SLV. Its annual flight rate has dropped to pre-1970 levels and many of its payloads have been transferred to the more capable and more modern Tsyklon booster. Primary payloads are low-altitude navigation satellites and store/ dump communications satellites.

Launch Processing. Launch processing is the same as A-class SLVs, with payload check-out and fueling done prior to mating horizontally with the SLV and being moved to the pad for launch. However, different launch sites and pad structures are used.

Proton Series (D-Class, Proton)

Until the 1987 launch of the Energia, for over 20 years, the Proton was the largest operational booster. However, not until the launch of the two Vega probes to Halley's comet in December 1984 did the world receive its first complete view of the Proton SLV.

Additional data has since been made available as a result of Glasnost and the Russian/CIS effort to compete in the commercial world market.

There are three variants of the Proton; a two, three or four stage SLV. The first three stages of the Proton were designed in the early 1960's by the design bureau headed by V.H. Chelomey. It was the first Soviet SLV design not based on an existing ballistic missile.

The original version of the Proton is known in the west as the D or SL-9 SLV (**Fig. 20-6**). It consists of two stages; the first with a cluster of six engines and the second with a cluster of four. No longer in use, the original D SLV was only used four times in 1965 and 1966 to launch Proton 1 through 4 satellites, thus naming the booster. The payloads were 12,000 Kg; well below what the SLV was capable of placing into orbit.

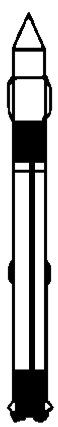

Fig. 20-6. SL-9 Proton

The next two versions of the Proton, still in operation today, are the D-1 (SL-13) and the D-1-e (SL-12) (Fig. 20-7). The D-1 consists of the D's first two stages plus a new third stage. This SLV, first flown in 1968, has flown LEO payloads including all of the Soviet space stations from Salyut 1 in 1971 to the Mir in 1986.

The D-1-e consists of the D-1's three stages plus a fourth stage for orbit transfer or escape. This SLV, first flown in 1967, has flown geosynchronous communication satellites like the Ekran, Raduga and Gorizont, and interplanetary satellites like the Zond and Luna missions to the Moon, Venera to Venus, Vega to Haley's comet and Mars and Phobos to Mars. Nearly 90% of Proton launches used the D-1-e variant.

Fig. 20-7. SL-12 Proton

In December 1968, before the Apollo 8 mission, the Soviets scheduled a Zond mission on a Proton to carry Aleksei Leonov and Oleg Makarov around the moon and back to earth. That mission was scrubbed when an unmanned Zond 6 suffered cabin decompression the month before. There are no current plans to man-rate the Proton for cosmonauts. All Proton launches are conducted from TT.

Flight rate of the Proton **(Fig. 20-7)** steadily grew from an initial six launches in 1970 to a peak of 14 in 2000. The Proton SLV was considered operational in 1970 despite failing on seven out of nine missions in 1969. Between 1983 and 1986, the Proton had its longest string of consecutive launch successes, totaling

43. Recently, about 10% of all CIS launches are Proton launches.

The Proton SLV can deliver 20,000 Kg to LEO, 5,700 Kg to lunar transfer trajectories, 5500 Kg to geo-transfer orbit and 2,800 Kg to sun-synchronous polar orbits.

The newest version of the Proton is the SL-25. This booster has a new upper stage, the Breeze. This new stage allows for improved performance placing satellite in orbit.

Launch Processing. The special, technical and launching complexes for the Proton SLV are at the Baikonur Cosmodrome or TT. The technical complex is equipped with railroad spurs and engineering service lines that are used to transport the SLV and its payload through-out the complex.

Fig. 20-8 Proton

The main building of the technical complex is the integration and testing facility. Assembly and integration of the Proton booster stages **(Fig. 20-8)** are carried out in the horizontal position. Special jigs and assembly mating trolleys are used to accomplish these functions. The jig, used for the SLVs first stage assembly, is the most important.

The central block of the launch vehicle is fixed horizontally on the jig and can be rotated around the x-axis. One of the first stage lateral strap-on blocks is brought under the bottom of the central block by the assembly-integration trolley and is attached to the core vehicle. Next the trolley is removed, and the central core is rotated to the desired angle and the next of six lateral strap-ons is attached.

As soon as the central core and strap-ons are assembled into a single unit, they are removed from the jig by a bridge crane to the assembly integration erector trolley. Here the various units are mated to the next stage, after which the integration test of the assembled launch vehicle is carried out. Up to three Proton SLVs can be assembled in this facility in about 21 days and the assembly building can accommodate as many as six boosters at one time.

Once the spacecraft and the fourth stage are assembled and encapsulated in the satellite preparation building, (**Fig. 20-9**) they are transported to the Proton SLV horizontal assembly building located 6.5 Km from the Sputnik/Soyuz satellite technical zone.

Fig. 20-9. Satellite encapsulation

There the satellite is installed on the launch vehicle under the nose fairing and rolled out horizontally to be erected on the pad into a vertical position. Satellite thermal control is provided by an air conditioning system feeding air under the nose fairing.

There are two Proton launch complexes. Each complex consists of two launch pads located 600 meters apart.

The SLV is not suspended on the launcher system like the Soyuz SLV. It is erected directly on the supporting fixtures on the launch pad (**Fig. 20-10**). It takes four hours to erect and install the Proton on the pad. Normally the launch happens three to four days after installation on the pad. If a scrub were to occur, it would require 12 hours to de-fuel the booster and lower it to a horizontal position for the roll back to the assembly building.

Fig. 20-10. SL-12 Lift to launch pad

Launch is controlled from a special complex located 1.6 Km from the launch complex. At the moment of liftoff, the service mechanism rises with the SLV and tracks for the first few fractions of a second. The SLVs azimuth guidance is provided by its control system which can correct the rocket at the initial phase of flight to the calculated angle. This mechanism is then separated and withdrawn by a pneumatic accelerator and is secured behind an armored steel firewall cover. This steel cover helps to form part of the launch pad flame deflector.

Tsyklon Series (F-Class, Tsyklon)

As a SLV, Tsyklon was initially introduced as the F-1 booster. The SLV F-1-r (SL-10) was introduced in 1966 and followed a year later by the F-1-m (SL-11) (**Fig. 20-11**). Tsyklon is a derivative of the SS-9 SCARP ICBM.

The F-1 has been used mainly for military purposes; first for offensive weapons such as the Fractional Orbital Bombardment System (FOBS), then as an anti-satellite (ASAT) interceptor. Further, it has launched electronic/radar ocean reconnaissance satellites (EORSAT/ RORSAT). The FOBS version is often referred to as F-1-r, with the r standing for "retro-rocket" stage. This portion is actually part of the payload used to place the entire payload into a reentry trajectory. Similarly, the ASAT and the EORSAT/ RORSAT SLV is referred to as the F-1-m. The ***m*** stands for "maneuverable" stage, which is part of the payload.

The F-2 (SL-14) introduced in 1977, is an F-1 with an added small third stage. It performs a number of missions previously flown on the Kosmos and Vostok. These include launching communications, meteorology, remote sensing, science, geodesy, electronic intelligence and minor military payloads. The F-2 is launched from PK at a highly automated launch complex, placing payloads into orbits with inclinations between 73.5º and 82.5º.

Fig. 20-11. SL-11

The name "Tsyklon" (Cyclone), identified as part of the F-class of medium boosters, appeared first in 1987. Named by Glavkosmos, the Russian organization that markets space hardware on a commercial basis, the F-2 was offered as a commercial launch vehicle capable of delivering 4,000 Kg payloads into a circular orbit with a 200 Km altitude. The Tsyklon is comprised of three tandem-arranged stages and a shroud. It is fueled by nitrogen tetroxide and asymmetric dimethylhydrazine. The third stage and the payload are enclosed within the shroud.

The first stage has six thrust chambers and four verniers for thrust. The second stage has two thrust chambers and four verniers for thrust. The F-2 can boost several spacecraft into orbit simultaneously. It also can subsequently inject them into their individual orbits by using up to three low-thrust engines firing from the third stage. The third stage sustainer engine can be restarted twice under weightless conditions, permitting spacecraft placement in various orbits required for specific space missions. Typically, a single starting of the third stage sustainer is used for payload injection into orbits ranging from 200-250 Km in altitude;

double starting of the engine is used for injection into orbits higher than 250 Km. Russian documents indicate that out of the first 75 F-2s launched, 73 were successful. The Tsyklon **(Fig. 20-12)** was one of the boosters that was built in the Ukraine during the Soviet era and now be being built

Fig. 20-12. SL-14 Tsyklon

and marketed by Ukraine.

Launch Processing. The Tsyklon is assembled, mated with the spacecraft and transported to the pad in the horizontal position. Once the rocket is placed vertically on the launch pad, manual access to the SLV is lost. The ground servicing system of the Tsyklon provides for a high degree of automation of prelaunch and launch operations. This ground automation reduces the need for personnel at the launch pad and contributes to pad safety.

Zenit Series (J-Class, Zenit)

Zenit (J-1/SL-16) (**Fig. 20-13**) is another booster that the Ukraine built during the period of the Soviet Union. This system first appeared in 1985 launching two sub-orbital and two orbital tests, was the first totally new Soviet launch vehicle in 20 years. In May 1989, it was officially acknowledged as "Zenit" by vehicle designer Yuri A. Smetanin of the Soviet space agency Glavkosmos.

The SLV is a two stage, liquid oxygen/kerosene booster. The first stage is virtually identical to the Energia strap-on booster described below. The second stage has one sustainer engine and one four-chamber vernier powered by the same propellant. The two stage SLV can place a payload into a 1,500 Km orbit. A three stage version (Zenit-3) is also available. The third stage is similar to a Proton fourth stage (Block D). All launches of the Zenit occur from Baikonur Cosmodrome.

Currently, the Zenit supports a small military Electronic Intelligence (ELINT) program as well as remote sensing, scientific satellites and possible photo reconnaissance platforms.

Fig. 20-13.
SL-16 Zenit

A modified three stage Zenit has been developed for use by an international commercial launch corporation. This new booster, the SL-23 or Zenit-3SL is for use by the SeaLaunch International Corporation. A new upper, third stage was developed as well as improved electronics for the first and second stage.

The first launch of this booster **(Fig. 20-14)** was in May 1999.

Fig. 10.14 SL-23 Zenit-3SL

Energia Series (K-Class, Energia)

The history of the Energia (Energy) SLV (K-1/SL-17) and the Buran (Snowstorm) space shuttle dates back to the unsuccessful Soviet moon program planned to be flown on the N-1 (SL-15/G-1-e) heavy lift vehicle.

Begun in the 1970s, the Energia/Buran program design of this SLV was placed under the direction of NPO Energia. NPO Energia's direct predecessor was an enterprise headed by Sergei Korolev, who designed the first Sputniks and Vostok as well as the N-1. The Energia **(Fig. 20-15)** is designed with four strap-on liquid oxygen and kerosene boosters attached to a large diameter core that is capable of delivering 88,000 Kg to LEO with a kick stage. The core uses four liquid oxygen and liquid hydrogen propellant engines, the first cryogenic engines of their kind in the CIS fleet. Payloads are side mounted and are either an unmanned cargo carrier or the Buran orbiter. The Energia is only launched out of Baikonur Cosmodrome from pads associated with the N-1 moon launcher. At liftoff, the 60m tall Energia generates 7.8 million pounds of thrust.

The introduction of the Energia and Buran at Baikonur Cosmodrome required the construction of a very large infrastructure. The work began in 1978 with the construction of a landing strip for the shuttle. The landing strip is also used by the world's largest aircraft to bring in the Energia parts. The first parts of the Buran were delivered to Baikonur in 1982.

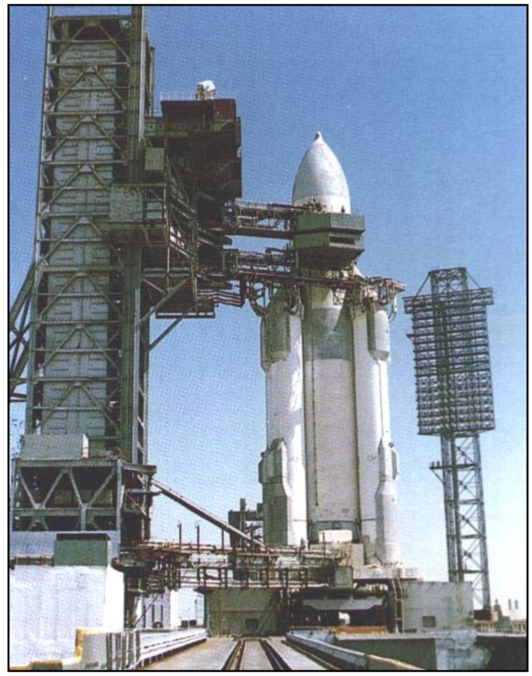

Fig. 20-15. SL-17 Energia

In 1985, the Zenit was successfully launched on its maiden launch. This was significant since the Zenit first stage is used as one of the four strap-ons of the Energia. Numerous successful launches of the Zenit and a successful ground test program enabled the decision to be made for the first Energia launch.

In 1987, the Energia was ready for launch. General Secretary Gorbachev visited Leninsk and the Baikonur Cosmodrome from 11 to 13 May. The report from his visit stated the Baikonur Cosmodrome was preparing to launch of a new all-purpose carrier rocket. News of the actual launch did not appear until the following day providing a launch time of 1730 GMT on May 15. The launch was conducted from a static test stand that was pressed into service for this first test launch. The announcement said the first stage landed in Soviet territory as planned. The second stage followed the flight plan precisely delivering the payload, a full size and weight mock-up of a satellite, to the calculated position. At the time of separation from the payload, the second stage fell into the pre-planned area in the Pacific Ocean.

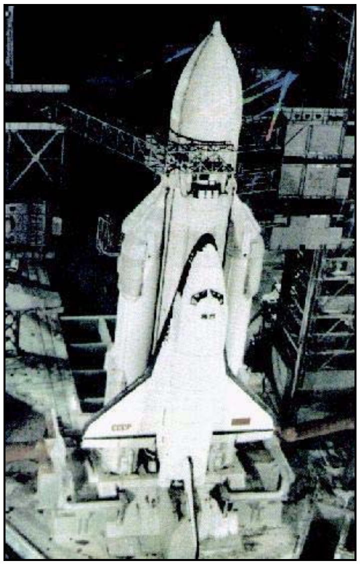

Fig. 20-16. SL-17 with Buran Space Shuttle

Apparently, the payload should have injected itself into orbit by means of its own engine. However, because of a malfunction of its onboard systems, it failed to do so and also fell into the Pacific Ocean. Although the mission was something less than a success, the launch announcement claimed that "the aims and objectives of the first launching have been fully met."

Although the Buran program was publicly denied and decried as economically unjustified, it was no longer a secret in the spring of 1983. At the Paris Air Show that year, Cosmonaut Igor Volk announced that the Soviets were building a space shuttle, the dimensions of which were approximately the same as those of the U.S. Space Shuttle (**Fig. 20-16**). The most complicated problems in developing the Buran were associated with its thermal protection system for the aluminum structure and landing system for a wide range of weather conditions.

As stated earlier, valuable data on heat resistant reentry materials and transonic aerodynamics was gathered during four flights of the BOR-4 sub-scale space plane between 1982 and 1984, which were launched by the Kosmos SLV. Experience with the Buran's handling capability during the final atmospheric flight portion was obtained in an experimental orbiter. This orbiter was equipped with jet engines which allowed it to take off from a normal airfield. Overall, 18 of the 24 flights performed by this experimental orbiter were fully automatic.

The only space flight of the Buran was on 15 November 1988. This flight was fully automated with no cosmonauts on board. After two orbits the unmanned spacecraft landed at Tyuratam's 4.5 Km long runway. Ironically, at this moment of triumph, the entire Soviet space effort was on the verge of huge cutbacks and cancellations due to the collapse of the Communist system.

New Systems

Despite current problems in the their space program, the Russians are continuing to design and develop new space boosters. Currently, new SLVs have been developed by converting ballistic missiles into launch systems.

Fig. 20-17 Start-1 SLV

Start Series

Start (SL-18)

The Start-1 SLV (**Fig. 20-17**) is based on the three stage SS-25 road-mobile ICBM. Start-1 consists of the SS-25's three solid motor stages plus an additional fourth solid motor stage. The system also employs a small liquid-propellant postboost stage to increase the accuracy of the final orbit injection. The first commercial launch of the Start-1 was in March 1997 and was also the initial launch from the Svobodny Cosmodrome **(Fig. 20-18)**

Fig. 20-18 SL-18 launch

Start (SL-20)

Like the Start-1 booster, the SL-20 Start SLV is also based on the three stage SS-25 road-mobile ICBM. By essentially inserting a duplicate second stage between the Start-1 second and third stage, the SL-20 Start is transformed into a five stage configuration. The first attempted launch of the Start was made March 1995, but was unsuccessful. To date, no additional launches of this booster have taken place.

Rokot Series (SL-19)

The Rokot SLV **(Fig. 20-19)** is based on the SS-19 ICBM. Due to the deactivation of numerous SS-19's because of arms reduction treaties, Russia decided to convert many of these highly reliable missiles into SLVs. Using SS-19 first and second stages with a newly designed third stage the SL-19 can place 1,900 kilogram satellites into low-earth orbit. The Breeze third stage is re-ignitable and has small thrusters for fine tuning of the final orbit maneuvers. An enlarged payload fairing containing a double launch system, "DOLASY," allows two satellites to be launched on one Rokot.

Fig. 20-19 SL-19 Rokot

There were three successful test flights of the Rokot system, two sub-orbital and one orbital, between 1990 and 1994. The first launch of the Rokot was in May 2000 with a test satellite from the Plesetsk Cosmodrome. This commercial launch is contracted by a joint German-Russian venture, EUROCKET. Several launches from at least three different sources have been contracted by EUROCKET.

Shtil (SL-21)

The SL-21 is a converted SS-N-23 liquid-fuel sea-launched ballistic missile. It was proposed for satellite launches by its builder, Makeyev of Russia. Since 1991, Makeyev has marketed and tested several SLBM's as satellite launchers. The Shtil ("Calm Sea") is the first to have been successfully marketed.

This SLV is capable of launching small satellites in place of its normal warhead. While advertised as being able to lift around 400 kilograms to LEO, the Shtil's first satellite payload was only ten kilograms. Makeyev plans to demonstrate the capability of its converted sea-launched ballistic missiles in order to attract potential customers. The first launch of the Shtil was in July 1998 **(Fig. 20-20).**

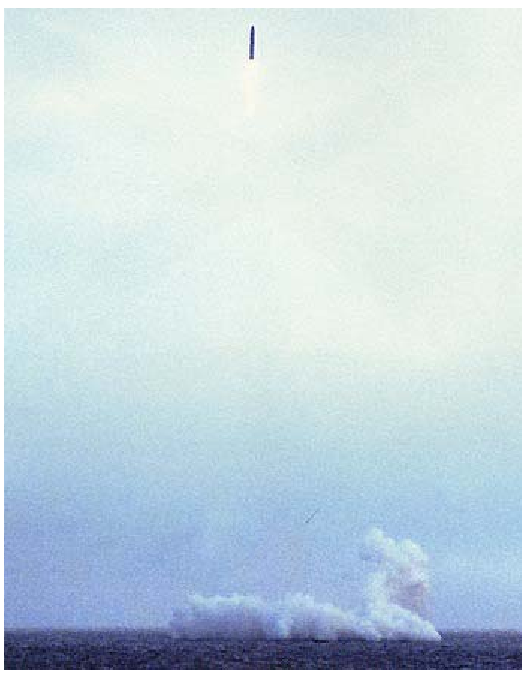

Fig. 20-20 SL-21 launch

One of the unique features of this system is that the launch platform is an active duty Russian Delta-VI ballistic missile submarine **(Fig. 20-21)**. Payment for this launch was reported to be directly to the Russian Navy. The launch of a German university satellite was the first ever launch of a satellite from a submerged submarine at sea.

Fig. 20-21. Delta-IV

Dnepr Series (SL-24)

The *Dnepr* SLV's boosters are based on the SS-18 ICBM **(Fig. 20-22).** As with the SL-19, Russia is required to eliminate its SS-18 by 2007 and has elected to convert them into space boosters. This requires the help of Ukraine, which designed and built the SS-18 in the former Soviet Union. The booster is essentially identical to the SS-18, with the missile's post-boost vehicle serving as a small orbital insertion stage. The small size of this third stage limits the basic version to delivering satellites to relatively low-earth orbits.

Fig. 20-22. SS-18 ICBM

An improved *Dnepr* may employ the same third stage of the Tsyklon (SL-14) in place of the SS-18 third stage, providing increased performance to higher circular and elliptical orbits.

This booster is marketed by a joint Ukrainian/Russian company. The first commercial, in fact the first launch, of the *Dnepr* was in April 1999 with a British built satellite.

RESEARCH AND DEVELOPMENT SYSTEMS

Russia is currently working several new boosters to replace many of their older Soviet era systems. One of the goals of this program is to have these new boosters built totally in Russia. During the Soviet era some of the design and building of booster or their components was done in other former republics.

Soyuz-2 (Rus)

The Soyuz-2 is the conversion of an upgraded A-class vehicle to replace the current Soyuz (SL-4) and Molniya (SL-6) boosters. The Soyuz-2 will preserve the basic A-class configuration. The strap-ons and core first stage will remain externally unchanged, although the engines will reportedly be modified. The core second stage is to be upgraded with a modern guidance system for improved accuracy. The Molniya core third stage will be replaced by a slightly larger stage.

The term "Rus," commonly reported as the name of the upgraded A-class launch vehicle, actually refers to the upgrade program, not the vehicle itself.

It appears that much of the development of this new version of the Soyuz family is being sponsored by Starsem. This joint French-Russian company markets the Soyuz booster for international launches. New, improved booster would improve the marketability of the company and its boosters.

Angara Series

The Angara is a space booster family designed for injecting satellites into low, middle, high circular and elliptical orbits, including both geo-stationary as well as interplanetary trajectories. This all-new Russian built booster is expected to replace the Ukrainian built Zenit and possibly the Russian built Proton.

Fig. 20-23. Angara model

The system is designed around a common core center stage. Changes to the upper stage give different capabilities to the basic version, producing the 1.1 and 1.2 boosters. Heavier payloads can be lifted by add additional common core stages to the first stage. This system allows for the 3.0 version with two additional stages and the 5.0 version with four additional cores **(Fig. 20-23).** All the components are sized for rail transport to the cosmodromes at Plesetsk and Svobodny

Lift goals for the Angara booster are stated as 26,000 kilograms to LEO and 4,500 kilograms to geosynchronous transfer.

There are several other existing or planned launcher projects such as follow-ons of the SL-21 "Shtil", new upper stages for older boosters and other totally new projects like the "Arkc" spaceplane and "Burlak" air-launched booster, about which little is known .

Table 20-1. Russian/CIS Space Launch Systems

Russian/CIS Name	DOD Designation	Sheldon Designation
Vostok	SL-3	A-1
Soyuz	SL-4	A-2
Molniya	SL-6	A-2-e
Kosmos (Interkosmos)	SL-7	B-1
Kosmos	SL-8	C-1
Tsyklon	SL-11	F-1
Proton (Gorizont)	SL-12	D-1-e
Proton	SL-13	D-1
Tsyklon (Meteor)	SL-14	F-2
Zenit	SL-16	J-1
Energia	SL-17	K-1
Start-1	SL-18	N/A
Rokot	SL-19	N/A
Start	SL-20	N/A
Shtil	SL-21	N/A
Soyuz-Ikar	SL-22	N/A
Zenit-3SL	SL-23	N/A
Dnepr-1	SL-24	N/A
Proton (Breeze)	SL-25	N/A
Soyuz-Fregat	SL-26	N/A

EUROPEAN SPACE PROGRAM

The idea of creating an independent space power in Europe goes back to the early 1960s. In 1962, Belgium, France, Germany, Italy, the Netherlands, the United Kingdom and Australia formed the European Launcher Development Organization (ELDO) to develop and build a launcher system.

In the same year, these countries plus Denmark, Spain, Sweden and Switzerland formed the European Space Organization (ESRO) to develop satellite programs. Ten years later these partners merged the activities of the two separate bodies into a single organization and laid down the foundation for the European Space Agency (ESA).

In 1975, Ireland applied to join these ten countries and become a member of ESA. On 30 October 1980, the final signature ratifying the Convention gave legal existence to ESA. Since then, the founding members have also been joined by Austria, Norway and Finland.

Each country has their own space program and organization, but the members cooperate on various launcher, satellite, control and subsystems that are of interest or benefit to their own country.

ESA Space Launch Facility

ESA has one operational spaceport located near Kourou, French Guiana in South America (5.2°N, 52.8°W). The site at Kourou (see **Fig. 20-24**) was chosen by the French space agency (CNES) in 1964.

This was to replace its former launch site in Algeria, which was closed in 1967 as part of the Algerian independence agreement. The geographical location of the site is exceptionally good. Because of its proximity to the equator, the site enables launchers to take full advantage of the Earth's rotation and also avoids the need for costly maneuvers after launch to achieve the equatorial orbit required for geostationary positions.

The Guiana Space Center (CGS) became operational in 1968 and the first orbital launch was in 1970. Since then, there have been more that 100 launches from Kourou using a variety of launch vehicles. Due to lack of obstacles both to the East and North, orbital inclinations attained from Kourou, range from 5 degrees to 100 degrees. This permits launches into equatorial, polar and sun-synchronous orbits. There are two active launchpads at the site. They are the second Ariane facility, ELA-2, used for the

Fig. 20-24. ESA Locations/Facilities

Ariane-4 series SLV and the newest, ELA-3, (**Fig. 20-25**) used for the Ariane-5 SLV. Earlier pads for the Europa and Diamant as well as the first Ariane launch facility, ELA-1, are no longer used.

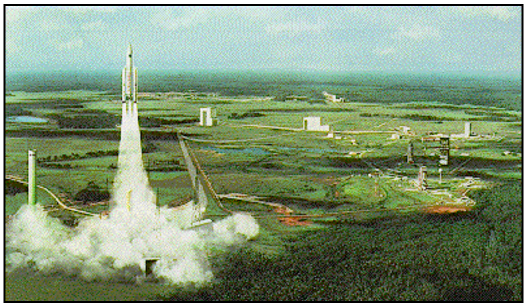

Fig. 20-25. ELA-2/ELA-3

ESA Space Launch Vehicles

The first ESA launcher was the Diamant. Initially part of an earlier French program, it was used between 1965 and 1975. Launches between 1965 and 1967 were from the French launch site in Hammaguir, Algeria. The first Diamant launch from Kourou was in March 1970. The Diamant had six successful launches out of a total of eight attempts. The Europa launcher was a joint British, French and German booster tested between 1964 and 1971. Five of the 11 launch attempts made with the Europa booster were successful. Only the last launch of this series was made from Kourou, all the rest being launched from Woomera, Australia.

In 1973, the nations who subsequently formed the European Space Agency, chose the Ariane program as their launch vehicle. This program was based on proven know-how and technologies gained in various national programs. One of the defining concepts of the Ariane launcher was it had to be able to subsequently evolve. Ideas about how it should evolve took shape early in the program.

The first Ariane booster flew on 24 December 1979. Since then, the Ariane family of boosters has become a prime commercial satellite launcher used by many countries.

Ariane-1/2/3

The Ariane-1 was flown 11 times between 1979 and 1986. The three-stage launcher was capable of placing a 1,850 Kg payload into a geostationary transfer orbit (GTO).

Derived from the Ariane-1, both the Ariane-2 and 3 had an improved third stage, while the Ariane-3 also mounted two strap-on boosters. Payload lifting ability to GTO was improved to 2,175 Kg and 2,700 Kg, respectively. There were a total of 17 launches of the Ariane-2/3 series between 1984 and 1989. To increase the utility of the Ariane booster, a system was developed to launch two satellites on the same booster. The Ariane Dual Launch System or Systeme de Lancement Double Ariane (SYLDA) had one satellite sitting on top while it served as a shroud for the second satellite.

Ariane-4

In 1982, ESA embarked on the development of the Ariane-4 program. Having become a leading commercial launching company, ESA needed to be able to adapt to a variety of payloads in the commercial market. The Ariane-4 program gave rise to a true family of launchers. The core stage of the Ariane-4 is longer than Ariane-3, with an increased capacity for propellant. Various combinations of solid or liquid propellant boosters are strapped to this core section, providing a total of six possible versions.

The satellite payload fairings are also developed in different sizes. Short, long or extra-long versions are available and may be combined with the SYLDA or a new dual satellite launch structure (SPELDA) which also comes in three different lengths.

All Ariane-4 boosters are launched from the ELA-2 launch pad. Nine to twelve Ariane-4's in many combinations/configurations can be launched per year.

Fig. 20-27. Ariane-42P

Ariane-40

This is the basic core vehicle for the entire Ariane-4 family of Space Launch Vehicles. The launcher consists of three stages with no strap-on boosters. It is capable of lifting 4,600 Kg to LEO, 2,705 Kg to sun-synchronous orbit or 1,900 Kg to GTO. While the first launch of an Ariane-4 series launcher was in 1988, the Ariane-40 version did not have its first flight until January 1990.

Ariane-42L

The Ariane-42L (**Fig. 20-26**) consists of the core vehicle with two liquid fuel strap-on boosters. It can lift 7,270 Kg to LEO or 3,200 Kg to GTO. The first launch of this version was May 1993.

Ariane-42P

This version of the Ariane-4 family (**Fig. 20-27**) adds two solid fuel strap-on boosters to the core vehicle. The "P" is for Powder to indicate solid fuel. The lift capability of the Ariane-42P is 6,000 Kg to LEO and 3,000 Kg to GTO. The first flight of the Ariane-42P was in November 1990.

Fig. 20-26. Ariane-42L Liftoff from ELA-2

Fig. 20-28. Ariane-44L

Ariane-44L

The Ariane-44L version (**Fig. 20-28**) has four liquid strap-on boosters around the core vehicle. Lift capacity is 9,590 Kg to LEO (the most for any of the Ariane family) and 4,200 Kg to GTO. The initial launch for this version was in June 1989.

Ariane-44P

Four solid fuel strap-on boosters are added to the core vehicle to produce the Ariane-44P variant. This configuration can lift 6,500 Kg to LEO or 3,400 Kg to GTO. The first flight of this version was in November 1990.

Ariane-44LP

The Ariane-44LP (**Fig. 20-29**) was the first of the Ariane-4 family to fly. Its configuration is two solid fuel and two liquid fuel strap-on boosters to the core vehicle. Payload lift capability for this versions is 8,300 Kg to LEO or 4,200 Kg to GTO (the most GTO lift for the Ariane-4 family). The first flight of this version and the inaugural flight of the Ariane-4 series were June 1988. The first seven launches of the Ariane-4 series were Ariane-44LP versions.

Fig. 20-29. Ariane-44LP

Ariane-5

ESA adopted the Ariane-5 program in 1987 and development began in 1988. The program is more than just a follow-on from the Ariane-1 through Ariane-4 launchers; its goal is to establish the premier space transport system by developing a launcher that is even more powerful, more reliable, more economical and better matched to the 21st century payloads.

With an architecture that is radically different from earlier Ariane launchers, the Ariane-5 (**Fig. 20-30**) is a new-generation family of boosters geared for launching satellites in the early 2000s. For reliability and flexibility, the Ariane-5 comes in two sections; a "lower composite" which will be the same for all missions and an "upper composite" matched to the mission and payload.

The initial design of the Ariane-5 was to lift 18,000 Kg. to LEO, 12,000 Kg to Polar LEO, 6,800 Kg to GTO (single payload) or 5,900 Kg to GTO (duel payload). Like the Ariane-4, the ability to lift two major satellites into orbit with

Fig. 20-30. Ariane-5 on ELA-3

one launch was a prime consideration in the overall design. Due to the increasing weight of communication satellites, improvements are already being worked on to increase the lift capability of the Ariane-5.

The initial launch attempt of the Ariane-5 was in June 1996 (**Fig. 20-31**). Flight 501 failed when the booster exploded 32 seconds into the launch. Investigations revealed that some Ariane-4 software commands were loaded into the on-board computer. The differences between the Ariane-4 and Ariane-5 launch profiles were such that the computer was unable to identify and handle the launch when it tried to correct the Ariane-5 launch profile based on Araine-4 data. Software corrections and other improvements were incorporated into the next Ariane-5. Flight 502 was successfully launched on 30 October 1997 and injected two separate payloads into orbit. The third launch of the Ariane-5 was in October of 1998. This mission launched a mock-up satellite demonstrator and the European Atmospheric Reentry Demonstrator, (ARD). The knowledge gained from the ARD will assist ESA in work on the Crew Rescue Vehicle for the International Space Station, (ISS).

Following this flight the Ariane-5 was declared commercially ready. The first commercial launch, Flight 504, occurred in 1999.

Launch Processing. Assembly of the Ariane series boosters takes place at Kourou. Satellite and booster sections are either flown in or brought in by ship.

Fig. 20-31. First attempted launch of the Ariane-5

The Araine-4 and Ariane-5 systems have separate assembly areas and each is connected to its respective launch pad.

The payload preparation complex, also called the spacecraft preparation room, is designed to house both launch customers and their satellites. This provides customers the ability to make final satellite preparations before the satellite is mated to the launcher during the final assembly phase. Simultaneous processing of up to five satellites is possible. A satellite "campaign" takes three to six weeks, and the satellites "appointment" with its launcher is set for only eight days prior to launch.

The Ariane-4 complex (**Fig. 20-32**) physically separates the assembly and launch zones. This arrangement allows for considerable flexibility in launch campaigns, reducing the time between launches to as little as three weeks.

The Ariane-5 launch complex (**Fig. 20-33**) is also divided into two zones, launcher preparation and launch pad. Facilities at the launch site also include manufacturing plants for both solid boosters and cryogenic propellants (liquid hydrogen and oxygen plant). The Araine-5 complex is designed to support a launch rate of eight launches per year.

Italy - San Marco Project

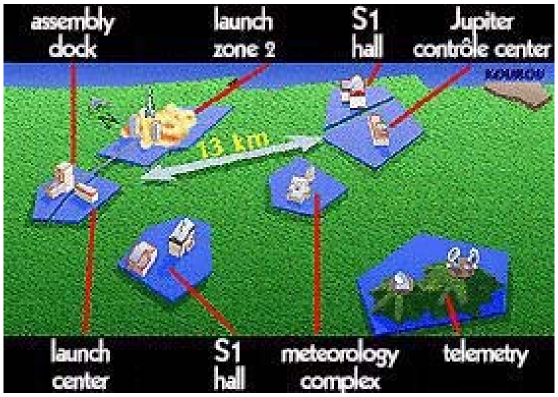

Fig. 20-32. Ariane-4 ELA-2 Complex

In 1962, the University of Rome and NASA created the San Marco Project as a joint space research project. The project was approved by the U.S. and Italian governments. Italy's portion of funding provided the University of Rome the ability to promote and initiate space research. The project activities concerning satellite

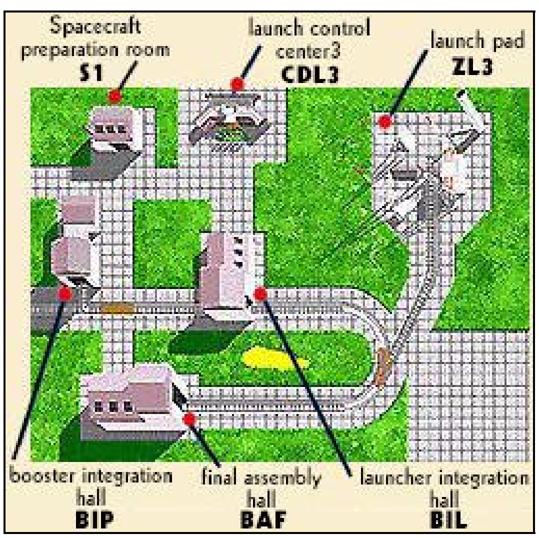

Fig. 20-33. Ariane-5 ELA-3 Complex

design, building and testing were performed in Rome. Space launches and satellite telemetry support was performed in Kenya from San Marco Equatorial Range (SMER). The project has developed and maintained active, fruitful and mutually advantageous cooperation between NASA and ESA.

San Marco Equatorial Range (SMER)

The SMER is located near the town of Malindi on Kenya's Indian Ocean coast at 3° South latitude. The launch area consists of three "off-shore-type" platforms standing on steel legs above the ocean floor **(Fig. 20-34)** and include the San Marco platform for booster assembly, test and launch; the Santa Rita platform for communications, telemetry and commanding; and the Santa Rita II platform for radar. The platforms have been certified up to year 2014. The main support area is located on land and contains telemetry stations, support facilities, housing, administration offices and machine shops.


Fig. 20-34. SMER Launch Platform

Between 1967 and 1988, nine launches were made using U.S.-supplied Scout boosters to place small satellites into LEO. Launches included Italian, NASA and U.K. scientific payloads.

The Scout has a lift capability of 560 lbs to LEO. The last Scout rocket was launched in 1994.

CHINESE SPACE PROGRAM

In 1956, the People's Republic of China laid the foundations for its astronautics industry. As a developing nation, the country recognized the need to develop space technology for its own purposes. Research and development on launch vehicles began in the early 1960's.

As a result of this effort, the first version of the Long March family of SLVs was developed. The Long March (LM) family is also known as Chang Zheng (CZ). In 1969, China launched its first vehicle, marking the country's entry into the space age. On 24 April 1970, China's first satellite, Dong Fang Hong 1, was placed into a low-earth orbit using the first CZ-1. This event highlighted China's capability to develop its own launch technology using Chinese materials.

Fig. 20-35. Chinese Launch Sites

Launch Sites

China's growing indigenous space industry has built three major launch complexes **(Fig. 20-35**). By Western standards, the facilities are austere and make limited use of advanced technologies; however, they are functional and adequate to support current Chinese space programs. Each site generally launches satellites into specific orbits based on safety, geographic or political constraints. Between them, the three launch complexes currently have six active launch pads.

Shuang Cheng-tzu (also called Jiuquan)

Shuang Cheng-tze, China's first launch site (40.6°N/99.9°E), is located in the Gobi desert, 1,000 miles west of Beijing in northwest China. There are two primary launch pads located about 300 meters apart. Long March 1 and 2 SLV's have been launched from this facility. The first space launch attempt on 1 November 1969 was a failure. It was followed by a successful sub-orbital flight on 10 January 1970. The first successful orbital launch was on 24 April 1970. Historically, orbital missions are launched to the Southeast to avoid overflying Mongolia and Russia. In 1999, China test launched its first man-rated system from a new launch facility.

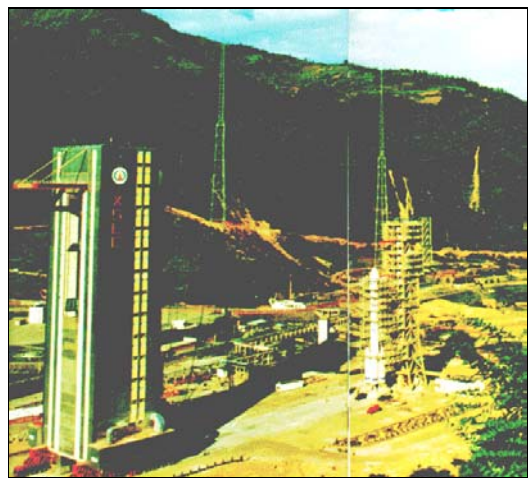

Fig. 20-36. Xichang Launch Complex

Xichang

Xichang, **(Fig. 20-36)** China's second launch site, is located in a mountainous area 40 miles northwest of Xichang City in south China (28°N/102°E). It became operational in 1984 and is used for launching CZ-2 and CZ-3 SLV's. Xichang is China's primary site for geostationary launches. There are three launch pads; the original pad, now inactive, built for the CZ-3 series; and two newer pads, built between 1989 and 1990, capable of handling a CZ-2E or

CZ-3A. China's first commercial launch mission, the Hong Kong AsiaSat 1, was launched from Xichang in April 1990.

Taiyuan

Taiyuan is China's newest launch facility. This site is located 270 miles southwest of Beijing (38°N/112°E) in eastern China. The facility is used to launch CZ-4 SLVs in a southward direction in order to place satellites into polar orbits. Its first use was to place a Chinese weather satellite into orbit on 6 September 1988.

Launch vehicles

The China Academy of Launch Vehicle Technology (CALT), under the Ministry of Aerospace Industry of China, is responsible for the development, production and testing of launch vehicles. The Shanghai Bureau of Astronautics (SBA), also known as the Shanghai Academy of Spaceflight Technology (SAST), is also involved in the development and building of space boosters. Certain versions of the Long March family have been designed by either CALT or SBA, while other versions have been produced jointly.

Successive improvements since the first CZ-1 include stage upgrading, new motors, addition of third stages (solid, storable liquid and cryogenic fuels) and strap-on boosters.

Fig. 20-37. CZ-1D

Long March 1 (CZ-1) Series

The CZ-1 was derived from the CSS-3 IRBM. Development began in 1965 with the only two known launches occurring in 1970 and 1971. Several improvements had been proposed or developed for the SLV incorporating improve-ments to the third stage. The CZ-1C was to have a liquid-propelled third stage while the CZ-1M was to have an Italian solid propellant third stage. Neither of these are now expected to reach operational status.

The only improved version of the CZ-1 considered operational and being offered as a launcher is the CZ-1D (**Fig. 20-37**). Although data is limited, it is estimated that the booster has improved capabilities over the original CZ-1. The Chinese did launch a single CZ-1D on a sub-orbital test flight. The Chinese appear to be waiting for a civilian contract before they launch another CZ-1D. The CZ-1D is designed to place small payloads (around 750 kilograms) into LEO.

Long March 2 (CZ-2) Series

Development of a successor for the CZ-1 began in 1970 with the parallel development of the two stage CSS-4 ICBM. The first launch of the CZ-2 in 1974 ended in failure after a few seconds. Based on lessons learned, the control system design was modified. Quality control during production and functional checkout was also improved. In addition,


Fig. 20-38. CZ-2C Long March

payload capability was increased and the modified launch vehicle was designated as the CZ-2C (**Fig. 20-38**).

CZ-2A was the original designation for what became the CZ-4 class of boosters. CZ-2B was the original designation for what became the CZ-3 series of boosters.

The first launch of the CZ-2C was on 26 November 1975. The flight was a complete success, with China's first recoverable satellite being placed into orbit. Since then, the CZ-2C has become the most utilized Chinese launcher. The CZ-2C has been commercially available for launch services since 1976.

The CZ-2C is offered principally for low-earth orbit and/or sun-synchronous launches. The booster is capable of lifting over 2,000 kilograms to low-earth orbit or in conjunction with the Chinese FSU recoverable microgravity platform, returning 150 kilogram payloads to earth. A version with an extended 2nd stage is being developed for GTO.

One of the most active versions of the CZ-2C is the CZ-2C/SD or Smart Dispenser version. This newly designed upper stage is indented for the duel launch requirements of Iridium satellites.

CZ-2D

The CZ-2D is an improved CZ-2C and serves as the basis for the CZ-4 class of boosters. The CZ-2D was designed as a three stage booster with stages one and two being a Chinese liquid-propelled booster and the third stage a McDonnell Douglas PAM-D (Payload Assist Module).

Only two launches have been performed, both launching the FSW-2 recoverable platform. These launches were in 1992 and 1994. Chinese statements in 1989 indicated that the CZ-2D was only a design study.

CZ-2E

The CZ-2E is the most powerful of the CZ-2 family (**Fig. 20-39**). Its subsystems are essentially the same as the subsystems of the CZ-2C using the first and second stages of the CZ-3, including engines, propellant feeding systems, guidance system and main structures. In addition, four liquid propellant strap-on boosters are added to the first stage. First launched on 16 July 1990, commercial flight operations began in August 1992 with an Australian payload launch.

Fig. 20-39. CZ-2E

The CZ-2E can lift about 8,800 kilograms into LEO or over 3,400 kilograms into GTO, depending on the perigee kick motor (PKM) used.

CZ-2F

The CZ-2F is a follow-on to the -2E and is upgraded and man-rated. One test flight was conducted in November 1999 and one in January 2000. Few details are available on the booster.

Long March 3 (CZ-3) series

Beginning in 1975, studies were made for the development of a cryogenic (very cold, liquefied gases) propellant. A program for upgrading the third stage of the CZ-2 into a GEO-class launcher using this propellant began in 1977. The booster was initially referred to as the CZ-2B, but later renamed the CZ-3.

The CZ-3 first and second stage boosters were developed on the basis of the CZ-2C. The third stage was a newly developed liquid oxygen and liquid hydrogen engine with a restart capability.

In January 1984, the CZ-3's debut established China as only the third user of cryogenic propulsion, after the U.S. and ESA. The second launch on 8 April 1984 produced China's first GEO satellite.

Fig. 20-40. CZ-3A

The CZ-3 has a payload capability of placing around 1,400 kilograms into GEO. Offered for commercial launches in 1986, the first commercial launch was on 4 April 1990.

CZ-3A

The CZ-3A incorporates a stretched, upgraded first stage and an improved cryogenic third stage that almost doubles the basic CZ-3's GTO lifting capability. Originally scheduled to be commercially avail-able in 1992, Chinese officials stated in 1990 that its introduction had been delayed until 1994. On 8 February 1994, the first CZ-3A was launched (**Fig. 20-40**). This improved version can lift 2,300 kilograms to GEO.

CZ-3B

The CZ-3B was created by adding the strap-on boosters of the CZ-2E to the CZ-3A launcher (**Fig. 20-41**). Although initial designs included an improved CZ-2E, the CZ-2E/HO, that would use the cryogenic third stage of the CZ-3A, this version was never developed.

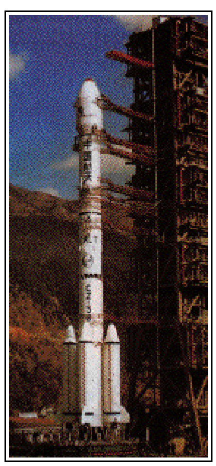

Fig. 20-41. CZ-3B

The configuration of the CZ-3B created the most powerful launch vehicle in the Chinese inventory. The first launch attempt took place on 14 February 1996 but ended in failure, destroying the IntelSat 708 payload. Since then, China has successfully launched four CZ-3B boosters, two each in 1997 and 1998.

The design lift of the CZ-3B is 4,800 Kg to GTO. The booster is also designed to launch planetary missions.

CZ-3C

China is currently working on another version of the CZ-3 booster. The CZ-3C will have only two strap-on boosters vice the CZ-3B's four. The design lift is 3,800 Kg to GTO.

Long March 4 (CZ-4) Series

The CZ-4 is an outgrowth of the development of the CZ-2C and CZ-3A programs. The first and second stages have enlarged CZ-3A fuel tanks for additional fuel. The third stage uses a new storable propellant optimized for sun-synchronous payloads.

CZ-4A

The first launch of the CZ-4A booster (**Fig. 20-42**) was 6 September 1988 and the second was 3 September 1990. Currently the CZ-4A has only been launched two times. Both launches placed satellites into sun-synchronous orbits.

Advertised lift capability is 2,500 kilograms to sun-synchronous orbit and 4,000 kilograms to low-earth orbit.

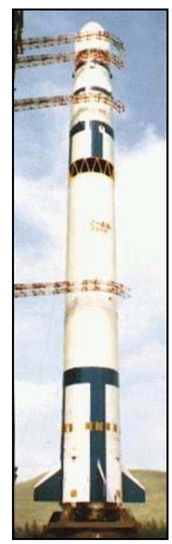

Fig. 20-42. CZ-4A

CZ-4B

In May 1999, China launched an improved CZ-4 Series, the CZ-4B for the first time. The CZ-4B has an enhanced third stage and fairing. This first launch placed two Chinese built satellites into sun-synchronous orbits. Payload capacity is stated at 1,500 kilograms.

Launch processing

Most of the knowledge concerning Chinese payload and launch processing has been gained from observation at the Xichang launch site, their main commercial facility. Processing at the other sites is believed to be very similar.

Long March stages are shipped to the launch facility generally via rail or by a river/rail combination **(Fig. 20-43).**

Fig. 20-43. CZ-2E en route to launch site

A booster will spend several weeks at the launch vehicle checkout hanger in a horizontally mated position for checkout **(Fig. 20-44).** After checkout, the booster is disassembled and transported in stages to the launch pad. Boosters are reassembled vertically on the launch pad **(see Fig. 20-45).** Integrated checkout of the vehicle and payload is also done on the pad.

Fig. 20-44. CZ-4B undergoing checkout

China's man-rated booster, the CZ-2F appears to use a more western method. A vertical assembly building has been built at Jiuquan. After vertical assembly in the facility, the booster is transported erect to the launch pad.

There is a payload preparation building for nonhazardous assembly, integration and testing operations of spacecraft and upper stages, if required by the mission. Another building is for processing hazardous assembly operations, spacecraft propellant fueling and pressurization, solid motor integration and other hazardous testing. The satellite is taken to the launch pad inside an environmentally controlled payload container or inside the launch fairing.

At the launch area, the tasks of mating, testing and checkout, direction orientation, propellant filling, and launching are done.

The China Great Wall Industry Corporation (CGWIC) is the company responsible for marketing and negotiating launch services and contract execution. CGWIC is the primary interface with customers, undertaking all coordination between the customer and the other elements of the launch services organization.

Fig. 20-45. CZ-3 being stacked

A comparison of the China's Long March boosters is in **Figure 20-46**. This chart includes active, retired and developmental launchers.

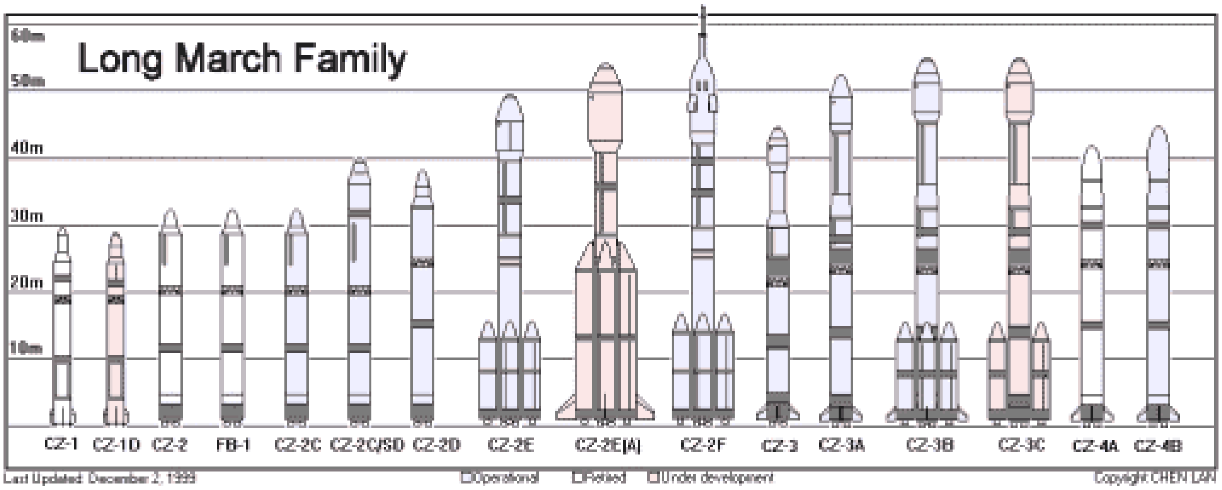

Fig. 20-46. PRC Long March Launch Vehicles (to scale)

JAPANESE SPACE PROGRAM

The Space Activities Commission (SAC) is Japan's most senior space advisory group. Established in 1968, its purpose is to unify the space activities of various government agencies and actively promote them. SAC formulates plans, deliberates, makes decisions on space matters and submits its opinions to the Prime Minister for adjudication.

The Science and Technology Agency (STA) plans and promotes basic space-related policy, conducts the overall coordination of space activities among government agencies and performs research and development activities through the National Aerospace Laboratory and the National Space Development Agency (NASDA).

National Space Development Agency (NASDA)

NASDA was established in October 1969 as the central body responsible for the development of space technology in Japan and the promotion of space activities solely for peaceful purposes. The main tasks of NASDA are to develop satellites and launchers; to launch and track satellites; to promote the utilization of space technology; and to devise methods, facilities organizations in accordance with the Space Development Program.

Institute of Space and Astronautical Science (ISAS)

Directly under the auspices of the Ministry of Education, Science, Sports and Culture is ISAS, a central institute for space and astronautical science in Japan. ISAS conducts scientific research using space vehicles. For this purpose, it develops and operates sounding rockets, satellite launchers, scientific satellites, planetary probes and scientific balloons.

In late 1999, NASDA suffered several partial and total failures of their primary launch vehicle, followed in early 2000 by ISAS having a major in flight failure of their primary booster. These events have lead to an on-going study over the future and direction of the space program.

Launch Centers

Japan maintains two launch centers. Each agency maintains and operates their own complex. Both sites are located in the southern islands of Japan.

Launch windows are a major concern as launches from both sites are normally restricted to two 45-day windows; January/February and August/September. This restriction is because of range safety and an influential fishing lobby. Japanese space officials want to extend the launch window to minimum of 140 days a year and a maximum of 200 days a year in the near future.

Tanegashima Space Center (NASDA)

The Tanegashima Space Center is NASDA's largest facility (**Fig. 20-47**). It is located on the southeast tip of Tanegashima Island (30.4°N/130.9°E), some 1,000 Km southwest of Tokyo. There are three launch areas at the center; Yoshinobu complex, Osaki range and Takesaki range.

The Yoshinobu complex is dedicated to the servicing and launching of the H-2 booster. It contains launcher and payload processing facilities, a Vehicle Assembly Building (VAB) with its mobile platform, first stage engine test facility, a non-destructive test facility for the solid rocket boosters and the launch pad. Currently, the facility can support two annual launches; increasing this rate would require an additional mobile platform, as a minimum. The Osaki range includes pads for the J-1 and H-1 booster and was used to launch the H-2 prior to construction of the Yoshinobu complex. The Takesaki range handles sounding rockets, provides facilities for the H-2 solid booster static firing and contains the H-2 Range Control Center.

Kagoshima Space Center (ISAS)

The Kagoshima Space Center (**Fig. 20-48**) is run by ISAS. It is primarily a sounding rocket site, but handles some scientific satellites. The center is 50 Km north of Tanegashima on the southern tip of Kyushu Island, the southern most major island of Japan (31.2°N/131.1°E). Kagoshima is restricted by government directive to all-solid propellant launch vehicles.

Launch facilities at Kagoshima consist of numerous sites built on leveled hilltops. The first sounding rockets and suborbital flights of the Japanese space program were launched from here. In 1970, Japan's first orbital launch was conducted from this center on the M3-SII booster.

The M3-SII was retired in 1995 and the facility has been upgraded to support the next generation solid booster, the M-5. A satellite processing facility is linked with the "M" pad and assembly area.

Fig. 20-47. Osaki J-1/H-1 launch pad (Front) Yoshinobu H-2 VAB and launch pad (Back)

Fig. 20-48. Kagoshima SC "M" launch pad (right)

Launch Vehicles

NASDA and ISAS continue the operation of two distinct launcher types; ISAS is constrained to science missions and solid propellant boosters, while NASDA provides the national capability for launching applications satellites aboard liquid boosters of increasing capabilities. NASDA's goal is an indigenous vehicle for two-ton GTO and LEO applications, with a view to commercialization.

NASDA launchers

"N" Series. Development of orbital launchers began with the "N" series of launchers. The N-1 and N-2 launchers provided the initial expertise, but they were based on the McDonnell Douglas Delta booster built under license. This license prohibited orbiting of third-party payloads without U.S. approval. The N-1 was a version of the Thor-Delta launcher. It was a two-stage launcher with three solid motor strap-on boosters. Its lift capability was 1,200 kilograms to LEO or 130 kilograms to GEO. The N-2 was very similar to the N-1, with nine strap-on solid boosters, first stage tank extended, second stage engine improvements and an inertial guidance system. This version had a payload capacity of 2,000 kilograms to LEO or 350 kilograms to GEO. All seven N-1 launches and eight N-2 launches have been successful.

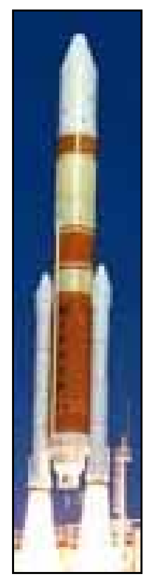

Fig. 20-49. H-1 Rocket

"H" Series. The H-series of launchers were designed for Japan to enter the commercial market with their own booster. The H-1 (**Fig. 20-49**) was very similar to the N-2 launcher. It employed a new cryogenic second stage, improved inertial guidance system and solid upper stages; all Japanese built. The N-2's first stage and solid strap-ons were retained for the H-1. Eight launches of the H-1 were performed and all were successful. The lift capability of the H-1 booster was 3,200 Kg to LEO or 550 Kg to GEO. The H-series significantly enhanced Japan's capability in design and SLV use.

H-2

Based on experience gained through the H-1, NASDA developed the H-2 launch vehicle entirely with Japanese technology. The H-2 is designed to serve as NASDA's workhouse in the 1990's. Freed from U.S. licensing restrictions experienced under the "N" series, the H-2 is offered for commercial launch.

The launcher consists of a cryogenic first and second stage and a pair of solid strap-on boosters. The H-2 **(Fig. 20-48)** can also mount twin solid sub-boosters when mandated by mission requirements.

Fig 20-48 H-2 at Tanegashima

The first launch of the H-2 was on 4 February 1994. Lift capability for the H-2 is 10,500 kilograms to LEO or 2,200 kilograms to GEO.

The H-2 has not been a commercial success for the Japanese. The cost of H-2 launches for commercial customers has been almost twice the price of equivalent U.S. or ESA launches. NASDA is developing the H-2A, an improved launcher, to be its commercial launcher after the year 2000. To aid in reducing the cost of H-2 launches and orders for H-2A launches, a consortium of Japanese companies formed the Rocket Systems Corporation (RSA).

"J" Series**.** NASDA began developing the J-1 solid propellant launcher to lift payloads too small for the H-2 launcher (**Fig. 20-49**). Minimum development cost and risk were obtained by adapting existing hardware. The J-1 booster uses a H-2 solid strap-on booster for the first stage and ISAS developed M3-SII rocket stages for the second and third. Lift capability was 870 Kg to LEO. The first flight was on 12 February 1996. For numerous reasons, including cost and suitable payloads, the future of the J-1 is in doubt. Plans to scrap the J-1 in favor of a remodeled version have been made by NASDA. The new version's goal is to develop a highly reliable, advanced J-1 rocket capable of launching a one ton payload at commercially competitive prices. This advanced version is currently referred to as the J-1A.

Fig. 20-49. J-1

ISAS launchers

"L" Series. Launchers produced by ISAS are all solid-fuel rockets; the first developed was the L-4S, a modified sounding rocket. The first successful launch of the L-4S was in February 1970. This launch gave the Japanese the confidence to continue in SLV development. To orbit larger payloads, a new vehicle design was needed.

"M" Series. The first of the "M" series (sometimes referred to as "Mu") was the M-4S. This booster was a four stage, solid-fuel vehicle capable of lifting 180 kilograms to LEO.

To expand launch capabilities, the M-3C was designed. This booster retained the M-4S first stage, but improved the second and third stages. It could lift 195 kilograms to LEO.

The next improved version was designated the M-3H. This booster increased the size of the first stage core motor by one third. The capability of the M-3H was twice that of the M-3C, lifting 290 kilograms to LEO.

The next improvement in the M-series was the M-3S. Similar to the M-3H, the

M-3S incorporated a first stage guidance and control capability.

In 1981, research and development began on the M-3SII (**Fig. 20-50**), built primarily for the Haley's Comet mission. This was the first Japanese interplanetary flight. Unlike the previous M-series step-by-step improvement approach, signifi-cant enhancement to the launch capa-bility was required. Only the first stage was inherited for the M-3S.


Fig. 20-50. M-3SII

The size and thrust of the second and third stages were increased. The eight small strap-on motors of the M-3S were replaced by two much larger strap-ons. These modifications enabled the launch of 780 kilogram payloads to LEO, which is 2.7 times the performance of the M-3S.

The first two M-3SII launches, with an added optional fourth stage, injected the initial Japanese interplanetary probes on 7 January 1985. Since then, it has become the main launch vehicle for scientific satellites from Japan.

To keep up with the increasing demand on payload capability and en-able anticipated inter-planetary missions, ISAS initiated the M-V launcher pro-gram in 1989.

The M-V (**Fig. 20-51**) is a three-stage solid-propel-lant system, with an optional kick stage for high-energy missions. It is the largest solid propellant rocket ever built in Japan. The design calls for a lift capability of 1,800 kilograms to LEO or 300-400 kilograms for planetary missions. To achieve this payload, all the stages of the M-V had to be newly developed with no direct heritage from the M-3SII series. The first launch of the M-V was on 12 February 1997.

Launch Preparation

The facilities used for the M-series launch preparation include the Satellite Preparation Building (SPB), the Mu Assembly Building (MAB) and the Mu Launch Complex (MLC) at Kagoshina Space Center.

The various booster elements, such as the stage motors, fins, nose fairings and payload are transported to the launch facility by road. Inspection of the stages and payload fairing take place within the MAB. Most assembly takes place at the MLC. After satellite checkout in the SPB, the satellite, payload fairing and the third stage are assembled in the MAB prior to transport to the MLC.


Fig. 20-51. M-V

Vehicle integration is carried out inside the assembly tower of the MLC. The launcher is built vertically starting with the first stage, then the solid strap-on, the second stage followed by the third stage with the satellite in place.

INDIAN SPACE PROGRAM

India's space program is an outgrowth of a concerted effort to develop an indigenous scientific and technological base in the country. This effort was established to ensure that India would be able to find solutions within the country and not have to rely on outside assistance to satisfy its needs. India has one of the most accomplished and capable space programs among developing nations. India's space program began in 1963; the Indian Space Research Organization (ISRO) was established in 1969; and a national framework created in 1972 with the Space Commission and Department of Space. ISRO is the primary developer of launchers and satellite hardware, complemented by separate communications and remote sensing agencies.

In July 1980, India was the seventh nation to achieve orbit capability. It has concentrated its space activities on developing various applications satellites, communications and remote sensing, and launcher technology. India wishes to be self sufficient in both satellite manufacturing and domestic space launchers around the year 2000.

Launch Center

SHAR Center (Sriharikota Range)

SHAR Center, (13.7^{o}N/080.2^{o}E.) located on Sriharikota Island off the eastern coast of India, is ISRO's only satellite launching facility. Currently there are two launch facilities; however, a third is under construction. The complex also includes a solid propellant booster plant, static test and evaluation complex (STEX), vehicle integration building (VIB), and is tied into ISRO's Telemetry, Tracking & Command Network (ISTRAC).

ISRO's Range Complex (IREX), headquartered at SHAR, is responsible for space launch operations as well as sounding rocket operations at SHAR, Thumba and Balasore.

Launch Vehicles

Although launcher and propulsion development represent ISRO's largest single area of expenditure, the relatively modest sums have dictated a gradual evolution of space launch vehicles. Early emphasis was on sounding rockets, which led to the first Indian Space Launch Vehicle (SLV).

SLV-3

The SLV-3 was an all solid booster developed in the late 1970s. This launcher was capable of lifting 42 kilograms to LEO. The first attempted launch on 10 August 1979 was unsuccessful due to a second stage thrust failure. The next three flights were all successful, placing test payloads and imaging systems into orbit.

ASLV

The Augmented SLV (ASLV) was developed largely by adding strap-on boosters derived from the SLV-3 first stage. This raised the lift ability to 150 kilograms to LEO. The first attempted launch of the ASLV on 24 March 1987 failed when the second stage failed to ignite. The second launch was also a failure due to insufficient control gain in the first stage. The first successful launch was 20 May 1992; however, insufficient spin stabilization for the satellite caused a low perigee and short life span. The last launch of the ASLV was a total success on 4 May 1994.

PSLV

The Polar SLV (PSLV) represents India's first attempt in acquiring launcher autonomy for applications satellites. Designed for placing one ton earth resources satellites into 900 kilometer sun-synchronous orbits from SHAR, the PSLV also offers growth potential as the follow-on Geo-synchronous SLV (GSLV) to handle 2.5 tons to GTO.

The PSLV (**Fig. 20-52**) employs an unusual combination of liquid and solid stages. An Indian liquid fuel system is used for the second and fourth stages as well as the clustering of six ASLV strap-ons around the solid fuel first stage. The third stage is also a solid fuel booster.

The initial attempted PSLV launch on 20 September 1993, failed due to a software error that prevented orbit from being obtained. The next two developmental launches in 1994 and 1996 respectively, were both successful.

In October 1994, the government of India approved the procurement of six additional PSLVs. India eventually plans to offer the PSLV for commercial launches.

Fig. 20-52. Indian PSLV

Current lift capability of the PSLV is 3,000 kilograms to LEO, 1,000 kilograms to sun-synchronous orbit and 450 kilograms to GTO. The PSLV booster is capable of lifting larger payloads, but geographical and range safety issues limit launches. Without these limitations, capacity would raise to 1,600 kilograms for a sun-synchronous orbit.

Geosynchronous SLV (GSLV)

The latest Indian SLV under development is a geosynchronous launcher capable of handling 2.5 ton satellites. The GSLV uses proven technology from the PSLV as well as new technology. The GSLV booster replaces the six solid strap-ons of the PSLV with four liquid boosters around the solid first stage and substitutes cryogenic boosters for the second and third stages. The first cryogenic motors will be Russian until India can perfect its own cryogenic technology. Projected payload lift is 5,000 kilograms to LEO and 2,500 kilograms to GTO.

Launch Preparation

The ASLV launcher is integrated in the Vehicle Preparation Building (VIB) and completed by the addition of the strap-on boosters on the launch pad within a Mobile Service Structure.

The Vehicle Assembly, Static Test and Evaluation Complex (VAST) and the Solid Propellant Space Booster Plant (SPROB), used for casting and testing PSLV solid motors, are located at SHAR.

PSLV booster assembly is done vertically on the launch pad using a Mobile Service Tower (MST). All solid motors are processed in the Solid Motor Preparations Facility (SMPF) prior to transfer to the MST. Liquid stage fueling is remotely controlled on the pad from the Launch Control Center (LCC).

Satellite Preparation (SP) and integration is done in three SP cleanroom facilities. SP-1 at the LCC provides satellite inspection, subsystem tests, Reaction Control System leak tests and solar panel deployment testing. SP-2 is used for satellite fueling and PSLV adapter compatibility. SP-3 is located within the MST for integrating payloads with the launcher.

ISRAELI SPACE PROGRAM

The Israeli space program began with university-based research in the early 1960's. The Israel Academy of Sciences and Humanities formally established the National Committee for Space Research in 1963. In the early 1980s, Israel set its sights on developing an industrial and scientific infrastructure required for full-fledged membership in the "Space Community." The Israel Space Agency (ISA) was established in 1983 and charged with the coordination of the nation's space program. On September 19, 1988, Israel became the eighth nation to fully enter the space age. With the advent of the Ofeq satellite program, Israel has developed, produced, and launched from their own country, a satellite of their own with a locally developed launcher.

Launch Site

Palmachim Air Force Base

Israel has one launch facility located near Palmachim Air Force Base (31.0^{O} N /035.0^{O} E) south of Tel Aviv near the town of Yavne. Facilities are classified, although they are reportedly visible from the coast road. The site is restricted to retrograde (westward) launches for range safety and to avoid overflying Arab countries. Due to the need to launch into a retrograde orbit, the payload weight is reduced because of the increased fuel required.

Launch Vehicle

Shavit

Israel currently has only one launch vehicle, the solid-fuel, three-stage Shavit (**Fig. 20-53**) developed by Israel Aircraft Industries (IAI). This vehicle is believed to be derived from or duel-developed with the Jericho II ballistic missile. The Shavit is able to lift 155 kilograms into a retrograde low-earth orbit. Calculations indicate that if launched from Cape Kennedy, the Shavit would lift up to 600 kilograms to LEO and if launched from Vandenberg AFB, it would lift up to 450 kilograms to polar orbits. There have been three successful launches of the Shavit; one each in 1988, 1990 and 1995. Although never acknowledged by the Israeli space program, a possible fourth launch was attempted in 1994, but it was believed to have been a failure. A confirmed launch failure occurred in January 1998.

Fig. 20-53. Israeli Shavit

Beginning around 1997, IAI began negotiations with the U.S. firm Coleman Research and France's Matra Marconi Space on adapting the Shavit for launches from the U.S. or Europe's Kourou launch site. This joint venture is being marketed under the name "LeoLink" and the upgraded boosters are referred to as LK-1 and LK-2.

LK-1 advertised payload is 340 Kg to LEO. First launch is planned for late 2001. LK-2, using a U.S. built Castor 120 motor as the first stage, will be capable of placing 1,000 Kg into a LEO polar orbit. This booster will be offered for launch from the end of the year 2000.

Launch Preparation

Little information is available regarding Shavit launch procedures. If Israel obtains commercial launch contracts, more information on launch procedures should be available.

Advertising for "LeoLink" states that the LK series uses a mobile stage assembly/transporter/erector facility and a launch preparation van that makes site operations flexible and short.

BRAZILIAN SPACE PROGRAM

Brazil is poised to become the ninth nation to achieve an indigenous space program. They have the ability to build and command their own satellites, have a space launch complex under development, and are developing their own booster. As a developing country, Brazil recognizes the need to emphasize and develop space technologies in order to address its unique problems. These include its large land mass, under-populated land borders, a huge coastline and the extensive natural resources still to be surveyed in its territory. Another goal of the space program is to progress toward an independent space launch capability.

The National Institute for Space Research (INPE, Instituto Nacional de Pesquisas Espaciais) was formed in 1971 and is responsible for the development of ground/space segments of applications satellite programs.

In 1994, the Brazilian Space Agency (AEB, Agencia Espacial Brasilera) was established to coordinate and plan Brazil's space program.

Launch site

Alcantara

Brazil is upgrading its sounding rocket facility at Alcantara into a space launch facility. The Alcantara Launch Center **(Fig.20-54)** (CLA, Centro Lancamentos de Alcantara) is on Brazils northern coast (2.2°S /044.2°W). The formal opening of Alcantara, as a sounding rocket facility, was in February 1990. Due to its location, Alcantara can launch from near geostationary to polar or retrograde orbits (from 2 to 100 degrees). The first space launch attempt was in November 1997 and their second in December 1999.

Launch Vehicle

VLS

Brazil is developing its own space launch vehicle, based on the Sonda series

Fig. 20-54 Alcantara (CLA)

of sounding rockets. The VLS (Veiculo Lancador de Satelites) is a three stage booster with strap-ons, propelled by solid fuel. It is designed to place a 200 kilogram payload into LEO or a sun-synchronous orbit. The first and second stages as well as the strap on boosters are derived from the Sonda-4 series. The third stage is newly developed.

A 1/3 scale VLS was launched in 1989 to demonstrate strap-on separation. In 1993, the VS-40 version made a 24 min-

Fig. 20-55. First VLS launch attempt

ute flight test of the VLS's second and third stages.

The first orbital launch from Alcantara was attempted on 2 November 1997 using the VLS. Controllers were forced to destroy the booster 65 seconds after lift-off when one of the four strap-on engines failed to ignite **(Fig. 20-55).** A second launch was attempted December 1999. This VLS had a second stage failure.

AUSTRALIAN SPACE PROGRAM

In 1946, a joint United Kingdom and Australian test range was established in southern Australia for ballistic missiles and sounding rockets. Australia hoped that this test range would lead to a future satellite launch center. During the 1960s, development was done at this range on the British Blue Streak as the first stage of the European "Europa" rocket. However, a number of factors led to the demise of the range. First, a number of Europa launch failures occurred. Additionally, France preferred to develop its own center at Kourou as the European launch facility. In addition, it was decided that the Australian site was not suitable for equatorial launches. Finally, Britain announced that there would be no more work after 1976. Only two satellites were launched into orbit from Australia.

In 1987 the range was reopened for a scientific sounding rocket launch.

An Australian National Space Program was established in 1985 to provide a base for participation in the world space industry, followed by the formation of the Australian Space Office in 1987 as the focus for space-related activities. In 1993 the Australian Space Council (ACS) was established to support an Integrated National Space program with programmed funding. A major task was to formulate a five-year plan to set new directions for the National Space Plan and determine priorities. The ACS recommended the development and demonstration of a light launch capability. These would be the vehicles for carrying Australian-built demonstrations satellites, leading to the development of Earth observation and communications payloads. A goal of this program is for Australia to secure a share of the Asian space business in launches, small satellites and space-based services.

Launch Sites

Australia's only current space launch facility is at Woomera in South Australia (31.1^{O}S/136.8^{O}E). Both orbital launches from this site were on modified sounding rockets; the U.S.-built Redstone launched the first Australian satellite, the WRESAT, on 29 November 1967; and a British Black Arrow launched the British weather technology satellite Prospero on 28 October 1971. In 1997, the Japanese space agency, NASDA, used the facilities at Woomera for drop and test flights of its ALFLEX (Automatic Landing Flight Experiment). These tests suggest substantial progress in the revitalization of Woomera as a center for space-related activity

Studies are being conducted to address the feasibility of upgrading Woomera to an active space launch facility. In addition, other studies have been under taken to look at other locations in Australia for launch sites. Currently studies have been done for the Australian territory or Christmas Island in the Indian Ocean.

NORTH KOREA

On 31 August 1998, North Korea announced that it had launched a satellite. The expected first launch of the Taepo-Dong 1 ballistic missile was instead an apparent attempt to orbit a satellite. No independent confirmation of the event has been obtained, so it appears that the attempt was not successful.

Launch Site

Little is known of the North Korean launch site reported in Musudan-ri near the northeastern coast **(Fig 20-56).** Recent imagery of this site was obtained by a commercial satellite imaging company. Their pictures show an austere site with a single launch pad and limited infrastruc-

Fig. 20-56 Musudan-ri launch site

ture.

Launch Vehicle

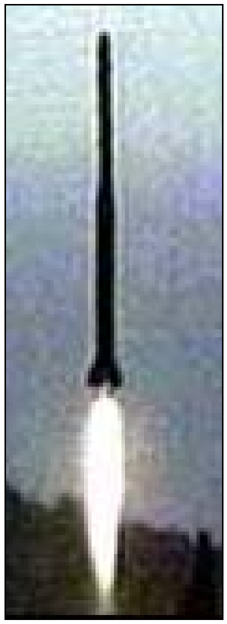

Fig. 20-57. Taepo-Dong-1

The booster used for this launch attempt appears to be a version of the Taepo-Dong 1 ballistic missile **(Fig. 20-57).** The missile is assessed to be a two stage system. The SLV version seen in August appears to have three stages or two stages and an orbital insertion motor. The first stage booster landed in the Sea of Japan while the second landed in the Pacific Ocean off the east coast of Japan. Reports indicate that the third stage or the failed satellite impacted in the Pacific Ocean south of Alaska, some 6,000 Km from North Korea.

INTERNATIONAL SPACE PROGRAMS

The International Space University is an interdisciplinary, intercultural and international institution which prepares individuals to respond to the current needs and the increasing and evolving demands of the space sector in a rapidly changing world. The University announced during its 1997 international symposium that:

"Space is no longer the special, protected domain that it was in the past, but is becoming integrated with the mainstream of economic activity."

Indeed, many new international commercial enterprises are being established to support the growing space market for expanding communications, earth resources and imaging systems. This includes a number of launch ventures.

International Launch Services (ILS)

International Launch Services was established in 1995 to market the American-built Atlas and the Russian-built Proton. ILS was formed by a joint venture between Lockheed Martin's Commercial Launches Services Company (LMCLS), Khrunichev Enterprise, and RSC Energia of Russia forming Lockheed-Khrunichev-Energia International (LKEI).

As of June 1999, ILS had launched 63 payloads, 11 on Proton and 52 on Atlas boosters. The Company has future commitments for an additional 30 Atlas and 16 Proton launches. These numbers are close to the launch commitment totals for ESA's Ariane booster.

Starsem

Starsem is a joint venture announced in July 1996, between Aerospatiale and Arianespace of France, the Russian Space Agency and Samara Space Center (makers of the Soyuz booster) to market the Soyuz launch system around the world.

Starsem is a contraction of "Space Technology Alliance, based on the R-7 SEMyorka" launch vehicles. Semyorka is the Russian name for SL-4 system. Starsem's SL-22 an SL-26 boosters are developments of the SL-4 with new upper stages and satellite dispensers. The partnership stems from Arianespace's need to respond to the launch demand for small satellites for which its Ariane-5 is not ideally suited.

In October 1996, Starsem announced its first launch order for three launches of the Globalstar system. A total of six launches for Globalstar were done in 1999. In addition, ESA has contracted for three launches, two launches for the

Cluster-II series in 2000 and one launch of ESA's Mars Express interplanetary probe.

Eurocket

In 1995, the joint Eurocket Launch Services company was formed between Germany’s Daimler-Benz Aerospace Corporation and Russia’s Khunichev Space Center to market the Russian Rocket, SL-19, booster. Formed to meet the need for small satellite launch services. Eurocket’s first test launch was of two dummy satellites in May 2000. Eurorocket contracts include two launches for six E-SAT data satellites. The German Space Agency and NASA have also contracted for a launch in 2001.

Sea Launch

The Sea Launch venture was formed in April 1995 in response to a growing market for a more affordable, reliable, capable and convenient commercial satellite launch service. Engineering and market studies determined that a sea-based launch system could competent favorably with incumbent service providers. A partnership was formed between Boeing Commercial Space Company, RSA Energia of Russia, NPO Yuzhnove of the Ukraine and Kvaerner of Norway to build and market a sea launch facility. Long Beach, California was selected as the home port and ground breaking for facilities began in August 1996.

Two unique ships form the marine part of Sea Launch. The Assembly and Command Ship is an all-new, specially designed vessel that will serve as a floating rocket assembly factory as well as provide crew and customer accommodations and mission-control facilities at sea.

The Launch Platform is a modified ocean oil drilling platform (**Fig. 20-58**)

Fig. 20-58. SeaLaunch Lift-off

and is a self-propelled, semi-submersible launch complex which houses the integrated launch vehicle in an environmentally controlled hanger during transit to the launch site.

Chosen to capitalize on the Earth’s rotation, the launch location maximizes Sea Launch’s performance. The primary launch site will be along the Equator in international waters of the Pacific Ocean about 1,000 miles south of Hawaii.

The selected booster for Sea Launch is the Ukrainian/Russian Zenit-35L, the SL-23. Modified to a three stage configuration, the Zenit was selected due to its highly automated launch procedures.

Hughes Space and Communications Company has ordered 13 launches from Sea Launch. The first launch from this platform was an instrumented satellite simulator in March 1999. SeaLaunch's first commercial launch occurred in October 1999. In March 2000 the SL-23 booster suffered an in flight failure. Launch operations resumed in July 2000. Currently there are a total of 19 launch commitments through 2003.

Cosmos International

A joint German-Russian venture, Cosmos International markets the SL-8 Kosmos booster, for commercial launches.

The first launch of this new provider was in April

1999, with a German and an Italian satellite. A second launch was performed in June 2000.

LeoLink

LeoLink is a joint venture between Israeli Aircraft Industries, Coleman Research of the U.S. and Matra Marconi Space-France. The venture is marketing improved versions of the Israeli Shavit booster. While the company has not yet launched any of it LK boosters, they were one of two companies to win NASA's light launcher competition.

Other International Launch Providers

Other international launch providers are attempting to market Russian launchers. Numerous companies are studying many other possibilities. These and other launch projects have no confirmed launch orders to date.

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Chapter 21

SPACE SURVEILLANCE THEORY AND NETWORK

The Space Surveillance Network (SSN) is a combination of optical and radar sensors used to support the Space Control Center (SCC) and its mission, which is to detect, track, identify and catalog all *man-made* objects in earth orbit. This chapter looks at the various components of the SSN, its sites and how they combine to support the space surveillance mission. This chapter also contains a description of the radar and optical sensors, which are the two primary technologies used by the SSN.

SPACE SURVEILLANCE THEORY

Although referred to as a network, the SSN was not originally envisioned as such. As various sensors became available, their particular capabilities were used to support the space surveillance mission.

The current sensors use numerous technologies. Each sensor in the SSN and the methods by which the SCC uses (tasks) the SSN to sustain the space surveillance mission are also described in this chapter.

A description of the space surveillance principles includes their associated technologies. A review of the Space Object Identification (SOI), a specific application of optical and radar sensors, will also be provided.

Doppler Effect

When a source of sound moves toward or away from a listener, the pitch (frequency) of the sound is higher or lower than when the source is at rest with reference to the listener. A common example is the rise and fall of the pitch of a locomotive's whistle as it approaches and recedes from the listener. Similar results are obtained when the listener approaches or withdraws from a stationary source of sound. This phenomenon is referred to as the Doppler effect, named after the Australian scientist, Christopher Johann Doppler, who predicted in 1842 that the color of a luminous body would change in a similar manner, due to the relative motion of the body and the observer.

Simply stated, the Doppler effect applies to all types of waves and can further be described by the following sequence. When a source of sound approaches the listener, the waves in front of the source are crowded together so the listener receives a larger number of waves in the same time than would have been received from a stationary source. This process raises the pitch the listener hears. Similarly, when the source moves away from the listener, the waves spread farther apart and the observer receives fewer waves per unit of time, resulting in a lower pitch.

The Doppler effect is significant in optics. Due to the velocity of light, pronounced effects can only be observed for astronomical or atomic bodies possessing velocities exceeding normal values. The effect is seen in the perceived shift in the wavelengths of light emitted by moving astronomical bodies. The perceived shift to longer wavelengths of light emitted from distant galaxies indicates they are receding and hence, supports the concept of an expanding universe. Radiation from hot gases shows a spread of wavelengths (Doppler broadening), because the emitting atoms or molecules move at varying speeds in different directions as measured by the observing instrument.

The Doppler effect has many uses in science as well as a variety of practical applications. For example, measurements of shifts of radio waves from orbiting satellites were used in maritime navigation; the effect is also utilized in radar surveillance.

Radar

Radar is actually an acronym for Radio Detection and Ranging, a name given to an electronic system utilized during World War II, whereby radio waves were reflected off an aircraft to detect its presence and location. Numerous researchers have aided in the development of devices and techniques of radar. The earliest practical radar system is usually credited to Sir Robert Watson-Watt.

Operation

A radio transmitter generates radio waves which radiate from an antenna that "illuminates" the air or space with radio waves. A target, such as an aircraft, which enters this space scatters a small portion of this radio energy back to a receiving antenna. This weak signal is amplified by an electronic amplifier and displayed on a Cathode-Ray Tube (CRT), where it is examined by a radar operator. Once detected, the object's position, distance (range) and bearing can be measured. As radio waves travel at a known constant velocity -- the speed of light (300,000 km/sec or 186,000 mi/sec) -- the range may be found by measuring the time it takes for a radio wave to travel from transmitter to the object and back to the receiver. For example, if the range was 186 miles, the time for the round trip would be (2 x 186)/186,000 = two-thousandths of a second, or 2,000 microseconds. In pulse radar, the radiation is not continuous, but is emitted as a succession of short bursts, each lasting a few microseconds. This radio-frequency pulse is emitted on receipt of a firing signal from a trigger unit that simultaneously initiates the time-base sweep on the CRT. The electronic clock is started and when the echo signal is seen on the tube, the time delay can be measured to calculate the range. The pulses are emitted at the rate of a few hundred per second so that the operator sees a steady signal.

Modern radar also provides excellent moving-target indication by use of the Doppler shift in a frequency similar to a radio wave when it is reflected from a moving target. Target detection is hindered by "clutter" echoes rising from backscatter from the ground or raindrops. Today's radars have higher transmitter powers and more sensitive receivers, which cause pronounced clutter so that even flocks of birds may show up on the screen. Antenna design can reduce these effects and the use of circularly polarized waves reduces rain echoes.

The WWII wartime radar operator interpreted the mass of data displayed. Simultaneously tracing the histories of many targets, which is essential to modern systems, requires the incoming radar data to be electronically processed to make information more accessible to the operator/controller. Progress towards satisfying this need had to await the arrival of large-scale integrated circuits, charge-coupled devices and the development of the technology for processing digital signals. Another important advance has been the development of computerized handling of video data, as in automatic plot extraction and track formation.

SSN Radar Sensor Systems

Radar sensors used by the SSN are divided into three categories: tracking, detection and phased array.

<u>Tracking Radars (TR)</u> **(Fig. 21-1)**, or mechanical trackers, are the oldest type used by the SSN and are employed to follow or track a target throughout the radar's coverage. Basic radar technology is used to transmit a single beam of radar energy out toward the target. The energy is then reflected off the target and returned to the radar receiver for measurement. The transmitter sends out another beam of radar energy and the cycle repeats itself as the radar follows the target throughout its coverage. The TR is a good system for tracking near earth ob-

jects because it can acquire a large number of data points on a target. It is very precise in predicting the trajectory of that target. The main limitation of the TR is its inability to track more than one object at a time. It cannot "search" for targets very efficiently because it sends out only a single beam of radar at a time.

Fig. 21-1. Kwajalein Tracking Radar

Detection Radars (DR) send out radar energy to form a fan out in space. This fan literally "blankets" an area with radar energy. The radar simply waits for a target to break this fan. Unlike the TR, a DR gives only a single data point at the location where the object breaks the radar's fan. The DRs used to support the SSN usually transmit two separate fans of energy. This allows for two data points to be collected on an object, which limits the accuracy. DRs are always collocated with at least one TR. When an object is detected by the DR, the TR is then used to lock onto the object, giving more accurate positional data.

Phased Array Radar (PAR) is the newest radar technology used within the Space Surveillance Network. Rather than move the antenna mechanically, the radar energy is steered electronically. In a PAR there are many thousands of small Transmit/Receive (T/R) antennas placed on the side or face of a large wedge-shaped structure. If the signals from the separate T/R are released at the same time and in phase, they form a radar beam whose direction of travel is perpendicular to the array face.

To detect objects that do not lie directly in front of the array face, time delay units, or phase shifters, are used. This phase-lag steering is a computer procedure where the radiating elements are delayed sequentially across the array, causing the wave front to be at an angle to the perpendicular. This controls the direction of the beam. Since these radars have several thousand T/R antenna elements, multiple beams can be formed at the same time. A PAR is capable of simultaneously tracking several hundred targets, since a computer calculates the proper time delays of these beams. There are several advantages of this type of radar: it can track many different objects at the same time and it can put up search patterns, by volume, or detection fans similar to DRs. However, there are two disadvantages of a PAR: the high cost of building it and complex maintenance.

Optical Sensor Systems

Optical sensors are very basic. They simply gather light waves reflected off an object to form an image. This image can then be measured, reproduced and analyzed. However, these sensors are limited due to their reliance on light; they cannot track during the day or under overcast sky conditions. The objects tracked must also be in sunlight and have some reflective qualities. *Electro-optical* sensors are the only optical sensors used operationally today to support the space surveillance mission.

Electro-optical refers to the way the sensor records the optical image. Instead of being imprinted on film, the image is changed into electrical impulses and recorded onto magnetic tape. This is similar to the process used by video recorders. The image can also be analyzed in real-time.

The primary electro-optical sensors used in the SSN are part of the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) System. These telescopes are extremely powerful.

Space Object Identification (SOI)

SOI analyzes signature data, both optical and radar, to determine satellite characteristics. More specifically, the size, shape, motion and orientation of the satellite. With optical sensors, the SOI information depends on the clarity of the satellite pictures. There are two types of radar SOI: wideband and narrowband. Two sensors (Haystack and the Advanced Research Projects Agency (ARPA) Lincoln C-Band Observable Radar (ALCOR)) have the capability of providing wideband SOI. Wideband SOI provides a detailed radar picture of the satellite. Most other radar sensors can provide narrowband SOI, which is a depiction of the radar energy charted as an amplitude versus time. SOI information is used to determine the operational status of various payloads and may forecast maneuvers or deorbits. The process of using SOI data, in conjunction with other intelligence resources to determine the nature of unidentified payloads, is called mission payload assessment.

THE SPACE SURVEILLANCE NETWORK (SSN)

All sensors in the SSN are responsible for providing space surveillance and SOI to the SCC located at Cheyenne Mountain AS (CMAS), Colorado. The sensors in the network are categorized primarily by their availability for support to the SCC. There are three active sensor categories (dedicated, collateral and contributing) plus the passive sensors which collectively comprise the SSN.

Dedicated Sensors

A dedicated sensor is a U.S. Space Command (USSPACECOM) operationally controlled sensor with a primary mission of space surveillance support. Dedicated sensors include: GEODSS, Naval Space Surveillance (NAVSPASUR), and the AN/FPS 85 Phased Array Radar (PAR).

GEODSS

GEODSS has the mission to detect, track and collect SOI on deep space satellites in support of the SCC. Each GEODSS site **(Fig. 21-2**) is controlled and operated by the 21st Space Wing and the 18th Space Surveillance Squadron (SPSS). There are currently three detachments operating GEODSS sensors: Det. 1, Socorro, New Mexico, Det. 2, Diego Garcia, British Indian Ocean Territories, and Det. 3, Maui, Hawaii. The GEODSS sites provide near real-time deep space surveillance capability.

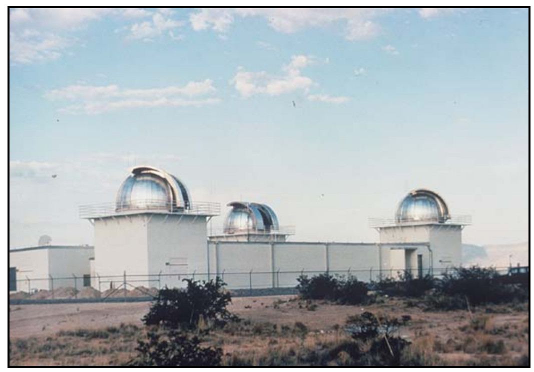

Fig. 21-2. GEODSS Site

To perform its mission, GEODSS brings together three proven technologies: the telescope, low-light television, and computers. Each site has three telescopes: two main and one auxiliary (with the exception of Diego Garcia, which has three main telescopes). The main telescopes have a 40-inch aperture and a two-degree field of view. The system only operates at night, when the telescopes are able to detect objects 10,000 times dimmer than the human eye can detect. Since it is an optical system, cloud cover and local weather conditions influence its effectiveness.

The telescopes move across the sky at the same rate as the stars appear to move. This keeps the distant stars in the same positions in the field of view. As the telescopes slowly move, the GEODSS cameras take very rapid electronic snapshots of the field of view. Four computers then take these snapshots and overlay them on each other.

Star images, which remain fixed, are electronically erased. However, man-made space objects do not remain fixed and their movements show up as tiny streaks which can be viewed on a console screen. Computers measure these streaks and use the data to calculate the positions of objects, such as satellites in orbits from 3,000 to 22,000 miles. This information is used to update the list of orbiting objects and is sent nearly instantaneously from the sites to CMAS. The GEODSS system can track objects as small as a basketball more than 20,000 miles in space.

MOSS

The Moron Optical Space Surveillance (MOSS) system was fielded at Moron AB, Spain during the first quarter of Fiscal Year (FY) 1998. MOSS will operate in conjunction with the existing GEODSS network. The GEODSS network called for an additional site in the Mediterranean to provide contiguous geosynchronous coverage. Air Force Space Command (AFSPC) is fielding MOSS to provide this critical geosynchronous belt metric and Space Object Identification (SOI) coverage.

MOSS consists of one high resolution electro-optical telescope and the MOSS Space Operations Center (MOSC) van. The telescope has a nominal aperture of 22 inches and a focal length of 51 inches (f 2.3). The camera houses a 1024 x 1024 MIT/LL charge-coupled device (CCD) focal plane array. The telescope is housed in a dome structure and is positioned by an Uninterruptible Power Supply (UPS) and backed up by a diesel generator.

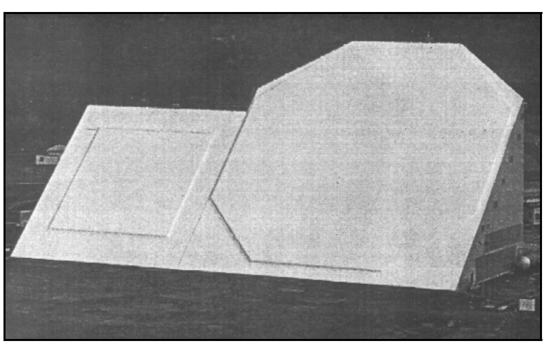

Fig. 21-3. AN/FPS-85 PAR at Eglin AFB

NAVSPASUR

Naval Space Command (NAVSPACE) has the oldest sensor system in the SSN: NAVSPASUR, whose mission is to maintain a constant surveillance of space and to provide satellite data as directed by the Chief of Naval Operations and higher authorities to fulfill Navy, USSPACECOM and national requirements. NAVSPASUR uses three transmit antennas and six receive antennas, all geographically located along the 33rd parallel of the U.S. The transmitters send out a continuous wave of energy into space, forming a “detection fence” which covers 10 percent of the Earth’s circumference and extends 15,000 miles into space.

When a satellite passes through the fence, the energy from the transmitter sites “illuminates” it and a portion of the energy is reflected back to a receive station. When the reflected energy is acquired by at least two receive sites, an accurate position of the satellite can be determined through triangulation.

NAVSPACE has the additional mission of being the Alternate Space Defense Operations Center (ASPADOC) and the Alternate Space Control Center (ASCC).

AN/FPS 85 PAR

Located at Eglin AFB, Florida, the AN/FPS-85 PAR is operated by Air Force Space Command (AFSPC), 21st Space Wing, 20th Space Surveillance Squadron (SPSS). The 20 SPSS operates and maintains the only phased array space surveillance system dedicated to tracking space objects. It is one of the earliest PARs, built in the mid-1960s, and became operational in December 1968.

The radar is housed in a wedge-shaped building **(Fig. 21-3)**, 318 feet long and 192 feet high (receiver side), and 126 feet high (transmitter side). Unlike other PARs, Eglin has separate transmitter and receiver arrays (antennas). The transmitter array has about 5,200 transmitter elements, while the receiver array has roughly 4,600 receiver elements. The transmitter and receivers are set in their respective antenna faces on the south side of the building, which is inclined at a 45 degree angle. It has the capability to track both near-earth and deep-space objects simultaneously. The previous primary mission at Eglin was Submarine- Launched Ballistic Missile (SLBM) warning. Once the southeast radar at Robins AFB, GA, known as PAVE PAWS (Phased Array Warning System) became operational, the SLBM warning coverage was redundant and Eglin's mission changed in 1988 to dedicated space surveillance. The PAR at Eglin tracks over 95 percent of all earth satellites daily.

Collateral Sensors

A collateral sensor is a USSPACECOM operationally controlled sensor with a primary mission other than space surveillance (usually, the site's secondary mission is to provide surveillance support). Collateral sensors include the Maui Optical Tracking and Identification Facility (MOTIF), Maui Space Surveillance System (MSSS), Ballistic Missile Early Warning System (BMEWS), PAVE PAWS, the Perimeter Acquisition Radar Attack Characterization System (PARCS), Antigua, Ascension and Kaena Point. MSSS was once part of 18th SPSS Det 3 but AFSPC transitioned it to AFRL on 1 Oct 00.

MOTIF

MOTIF performs near-earth/deep space surveillance and SOI. It uses photometric, visual imaging, and also a Long Wave Infra-red (LWIR) data generation system. It is an optical sensor very similar to the GEODSS sites, in addition to its LWIR capability.

MOTIF consists of a dual telescope system on a single mount **(Fig. 21-4)**. One telescope is used primarily for infrared and photometric (light intensity) measurements. The other is used for low-light-level tracking and imagery. Both use video cameras to record data. MOTIF has identified objects as small as 8 cm in geosynchronous orbit.

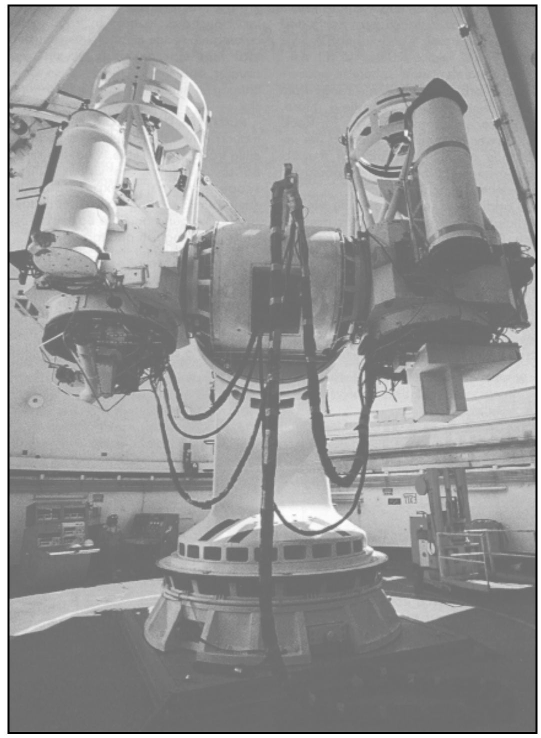

Fig. 21-4. MOTIF

BMEWS

BMEWS is a key radar system developed to provide warning and attack assessment of an Intercontinental Ballistic Missile (ICBM) attack on the CONUS and southern Canada from the Sino-Soviet land mass. BMEWS III also provides warning and attack assessment of a SLBM/ICBM attack against the United Kingdom and Europe. BMEWS' tertiary mission is to conduct satellite tracking as collateral sensors in the space surveillance network. BMEWS consists of three sites: Site I is located at Thule AFB, Greenland; Site II is at Clear AFB, Alaska; and Site III is at Royal Air Force Station Fylingdales, United Kingdom.

Site I, Thule **(Fig. 21-5**), is operated by the 12th Space Warning Squadron (SWS), a unit of AFSPACECOM's 21st Space Wing. Site I's initial operations began in October 1960. Its original equipment consisted of four Detection Radars (DRs) and a single Tracking Radar (TR). After more than 26 years of continuous operation, the DRs and TR were replaced with a phased array radar. The upgraded radar became operational in June 1988.

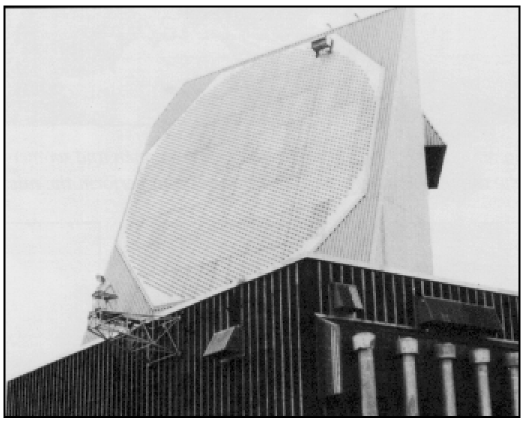

Fig. 21-5. PAR at Thule AB

The 13 SWS at Clear AFB, Alaska began operations in 1961 with three DRs (AN/FPS-50s), each 400 ft long and 165 ft high, and a TR (AN/FPS-92) that is 84 ft in diameter and weighs 100 tons. **(Fig. 21-6)** The DRs provide most of the data by surveying a fixed volume of space and providing the basic measurements to estimate the trajectory of any missile or satellite detected. Clear has been upgraded with a dual faced phased array radar similar to Thule and the PAVE PAWS sites.

The Royal Air Force at Fylingdales operates a three-faced phased array radar. Fylingdales' original configuration consisted of three tracking radars that have since been dismantled. It searches the sky for possible missile threats with a full 360^0 coverage.

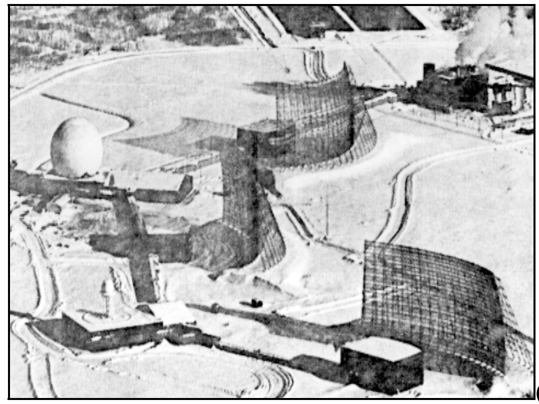

Fig. 21-6. Clear AFB, AK Prior to Phased Array Radar Upgrade

PAVE PAWS

Increasing technology provided the former Soviet Union the capability to launch ballistic missiles from submarines.

Studies indicated the need for early warning facilities to detect such an attack. The PAVE PAWS mission is to provide warning and attack assessment of a SLBM attack against the CONUS and southern Canada. PAVE PAWS also provides warning and attack assessment of an ICBM attack against North America from the Sino-Soviet land mass. The final tertiary mission, like BMEWS, is to provide satellite tracking data as collateral sensors in the space surveillance network.

The first two sensors came on line in 1980, while the other two (located at Robins AFB, Georgia and Eldorado AFS,

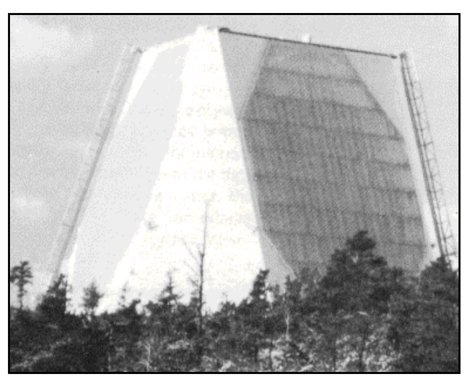

Fig. 21-7. PAVE PAWS Site

Texas) followed seven years later. The latter two sites were closed in mid-1995.

PAVE PAWS currently consists of the initial two sites: Site I **(Fig. 21-7)** is located at Cape Cod AFS, Massachusetts and run by the 6 SWS; Site II is at Beale AFB, California and operated by the 7 SWS. Both sites operate a dual-faced, phased array radar (AN/FPS-115). The computer hardware and software was upgraded in the mid-1980s, when the other two sites were built.

The PAVE PAWS phased array antenna, as with any other directional antenna, will receive signals from space only in the direction in which the beam is aimed. The maximum practical deflection on either side of antenna center of the phased array beam is 60 degrees. This limits the coverage from a single antenna face to 120 degrees. To provide surveillance across the horizon, the building housing the entire system and supporting antenna arrays is constructed in the shape of a triangle. The two building faces supporting the arrays, each 120 degrees, will monitor 240 degrees of azimuth. The array faces are also tilted back 20 degrees to allow for an elevation deflection from three to 85 degrees above the horizon. The lower limit provides receiver isolation from signals returned from ground clutter and for environmental microwave radiation hazard protection of the local area.

The PAVE PAWS system is capable of detecting and monitoring a great number of targets that would be consistent with a massive SLBM attack. The system must rapidly discriminate between vehicle types, calculating their launch and impact points in addition to the scheduling, data processing and communications requirements. The operation is entirely automatic, requiring people for system monitoring, maintenance, and as a final check on the validity of warnings. Three different computers communicating with each other form the heart of the system which relays the information to CMAS.

PARCS Sensor

PARCS is operated by the 10 SWS, located just 15 miles south of the Canadian border at Cavalier AS, North Dakota **(Fig. 21-8)**. The PARCS sensor was originally built as part of the Army's Safeguard Anti-Ballistic Missile (ABM) system. It was operational for one day (1 October 1975). The ABM system was shut down in 1975 by Congress. It later was modified by the Air Force in 1977 for use as a missile warning/space surveillance sensor, a role it continues to do extremely well.

PARCS' mission is to provide warning and attack characterization of an SLBM and ICBM attack against the CONUS and southern Canada. It is one of the workhorses, along with Eglin, providing surveillance, tracking, reporting and SOI data. PARCS uses a single-faced phased array radar (AN/FPQ-16). The radar, computer, communications equipment and operations room are housed in a reinforced concrete building, originally designed to ride out a missile attack as part of the Safeguard ABM system. The single-faced radar looks due North and slopes from the side of the building at a 25^0 angle. This site is considered a "CONUS remote."

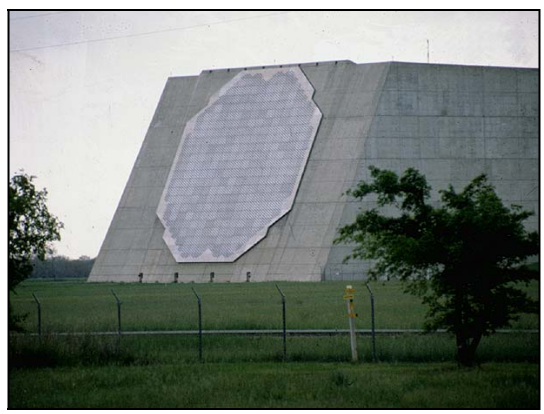

Fig. 21-8. PARCS, Cavalier AS, ND

Antigua and Ascension

The radars located on Antigua and Ascension Islands in the Atlantic Ocean are tracking radars. They are part of the Eastern Range, playing a secondary role in supporting the SCC.

Contributing Sensors

The contributing sensors are those owned and operated by other agencies, but provide space surveillance upon request from the SCC. They are: Millstone/Haystack, the ARPA Long-Range Tracking and Identification Radar (ALTAIR), ALCOR and AMOS.

Millstone/Haystack

The Millstone/Haystack Complex is owned and operated by Lincoln Laboratories of the Massachusetts Institute of Technology (MIT). Millstone Hill Radar **(Fig. 21-9**) and Haystack Long Range Imaging Radar are both located in Tyngsboro, Massachusetts.

Fig. 21-9. Haystack Radar

Millstone is a deep space radar that contributes 80 hours per week to the SCC. Haystack is a deep space imaging radar that provides wideband SOI tracks to the SCC. Haystack provides this data one week of every six of Millstone operations. USSPACECOM may recall Haystack off schedule twice in a fiscal year.

ALTAIR and ALCOR

ALTAIR and ALCOR are located in the Kwajalein Atoll in the western Pacific Ocean. Operated by the Army, they are primarily used for ABM testing in support of the Western Range and support the space surveillance mission when possible. ALTAIR is a near-earth and deep-space tracking radar. Due to its proximity to the equator, ALTAIR alone can track one-third of the geosynchronous belt. ALCOR is a near-earth tracking radar, and is the only other radar besides Haystack that can provide wideband SOI.

Kaena Point

Kaena Point is a tracking radar **(Fig. 21-10**) located on Oahu, Hawaii. It is part of the Western Range and supports the SCC with satellite tracking data.

Fig. 21-10. Kaena Point Tracking Radar

AMOS

The last contributing sensor is AMOS, which is a GEODSS-type optical sensor collocated with the GEODSS and MOTIF sensors on Maui. The research and development facility uses a 1.6-meter telescope owned by Air Force Materiel Command.

Both the AMOS and MOTIF systems at the MSSS will be upgraded in the near future.

Passive Space Surveillance System

The U.S. passive space surveillance system locates and tracks man-made objects in space via a new generation of radio frequency technology. Passive space surveillance units include the Deep Space Tracking System (DSTS).

Deep space tracking involves tracking objects with orbits that take more than 225 minutes to rotate the earth (geosynchronous). DSTS antennas are at the 3rd

Space Surveillance Squadron (3 SPSS), Misawa AB, Japan, and the 5 SPSS, RAF Feltwell, U.K.

The 4 SPSS, Holloman AFB, New Mexico **(Fig. 21-11)** performs mobile space surveillance communications and space data relay.

This passive system supports USSPACECOM and theater warfighters' requirements through continuous all-weather, day-night surveillance of on-orbit satellites.

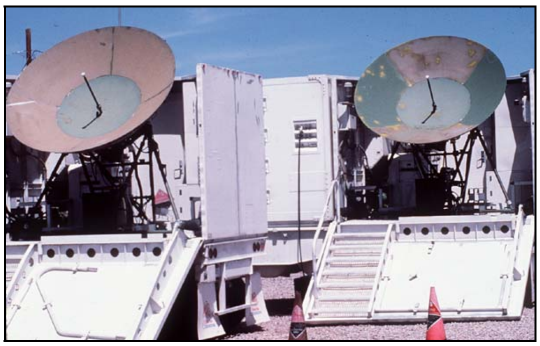

Fig. 21-11. Holloman Mobile Communications Antennas

SPACE SURVEILLANCE SENSOR TASKING

Because of the limits of the SSN which include number of sensors, geographic distribution **(Fig. 21-12)**, capability and availability, every satellite cannot be continuously tracked. To maintain a data base of where all man-made objects in earth orbit are, the SCC uses a tracking cycle which starts with a prediction. The SCC makes an assumption as to where a newly launched object will be, then sends out this postulation in the form of an element set (ELSET) to the sensors. Subsequently, the sensor uses this ELSET to search for the object. If the assumption is close, the sensor will detect-and-track the object. The sensor then collects observations from the track, which are sent back for processing and analysis.

The SCC uses this information to compute a new ELSET, or prediction, which is then sent to the next sensor to track it. This cycle repeats 24 hours a day, seven days a week.

Another tool used by SCC to efficiently distribute the limited tracking capabilities of the SSN, is prioritized sensor tracking. A NORAD/USPACECOM regulation defines categories of priority and specific data collection instructions (categories and suffixes); assigned according to each satellite's type and orbit. Generally, satellites with high interest missions or unstable orbits (objects about to decay) will have higher priority and data collection requirements than other satellites.

SUMMARY

We have covered the different sensor technologies used to track satellites and identify them, and then looked at the Space Surveillance Network (SSN) and all the sensors that make up the SSN. Finally, we looked at how the SCC processes sensor information to maintain its database for over 9,000 objects.

A listing of acronyms used in this chapter is included on the next page.

A listing of space surveillance sites is detailed on the two pages following the acronym listing (Table 21-1).

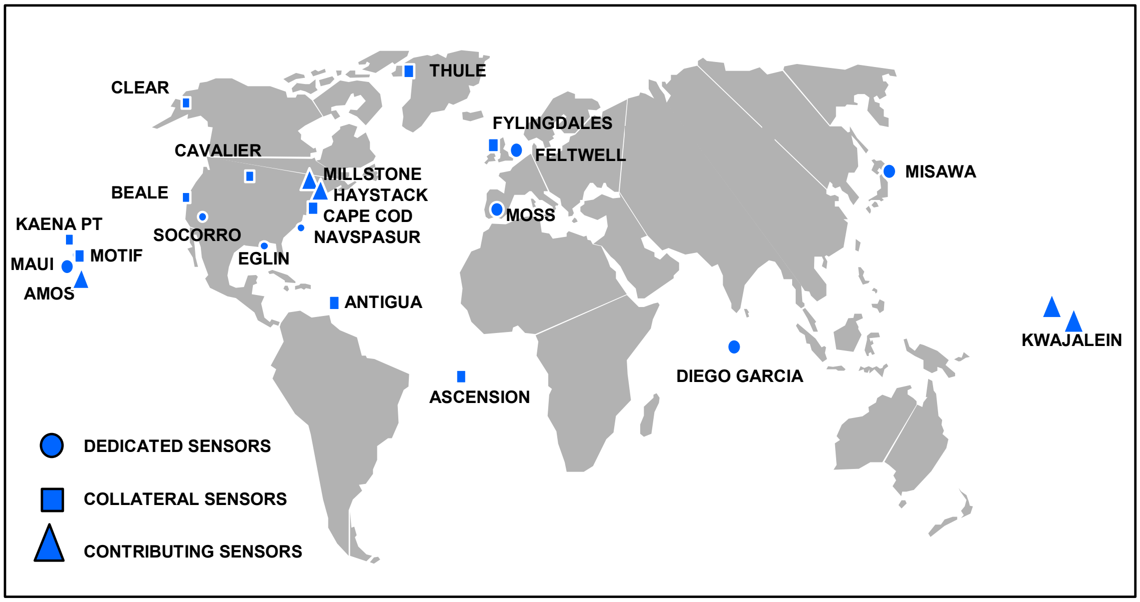

Fig. 21-12. Space Surveillance Network

SSN ACRONYMS

ABM – Anti-Ballistic Missile

ALCOR – ARPA Lincoln C-band Observable Radar (Wideband)

ALTAIR – ARPA Long-range Tracking and Identification Radar

AMOS – ARPA Maui Optical Station (Imaging)

ARPA – Advanced Research Projects Agency

ASPADOC – Alternate Space Defense Operations Center (at NAVSPACE)

ASCC – Alternate Space Control Center (Dahlgren, VA)

BMEWS – Ballistic Missile Early Warning System

CRT – Cathode Ray Tube

DSTS – Deep Space Tracking System

ELSET – Element Set (SOI positioning tool format)

GEODSS – Ground-based Electro-Optical Deep Space Surveillance

Haystack – Wideband (X-band) deep space tracking radar at Tyngsboro, MA

LWIR – Long Wave Infra-red (data generation system)

Millstone – Lincoln Lab L-band deep space tracking radar at Tyngsboro, MA

MOSS - Moron Optical Space Surveillance

MOTIF – Maui Optical Tracking and Identification Facility

NAVSPASUR – Naval Space Surveillance (system)

PAR – Phased Array Radar (also known as the AN/FPS-85)

PARCS – Perimeter Acquisition Radar Attack Characterization System (AN/FPQ-16)

PAVE – Major command nickname for project acquisition

PAWS – Phased Array Warning System (AN/FPS-115)

SOI – Space Object Identification

SSN – Space Surveillance Network

SCC – Space Control Center in Cheyenne Mountain Air Station, Colorado

Table 21-1. Space Surveillance Sites

SITE NAME	TYPE	TRACK	INTEL	LOCATION	FREQ	CATEGORY	REMARKS
ALCOR	TR	NE	WB/C	Kwajalein Atoll, Pacific	C-band	Contributing	WB imaging
ALTAIR	TR	NE/DS	NB/C	Kwajalein Atoll, Pacific	UHF/VHF	Contributing	
AMOS	PHOTO	NE/DS	PHOTO	Mt. Haleakala, HI	LWIR	Contributing	AF Maui Optical Site-Imaging
Antigua	TR	NE	NB/NC	British West Indies	C-band	Collateral	
Ascension	TR(2)	NE	NC/NC	Ascension Island, South Atlantic	X-band	Collateral	
Beale AFB	PHASED ARRAY	NE	NB/NC	California	UHF	Collateral	PAVE PAWS
Cape Cod AS	PHASED ARRAY	NE	NB/NC	Massachusetts	UHF	Collateral	PAVE PAWS
Cavalier AS	PHASED ARRAY	NE	NB/NC	North Dakota	UHF	Collateral	PARCS
Clear AS	PHASED ARRAY	NE	NB/NC	Alaska	UHF	Collateral	BMEWS II
Diego Garcia	GEODSS	DS	PHOTO-METRIC	British Indian Ocean Territory	Optical	Dedicated	
Eglin AFB	PHASED ARRAY	NE/DS	NB/NC	Florida	UHF	Dedicated	

C – Coherent DS – Deep Space NB – Narrow Band NC – Non-Coherent NE – Near Earth RF – Radio Frequency TR – Tracking Radar WB – Wideband

SITE NAME	TYPE	TRACK	INTEL	LOCATION	FREQ	CATEGORY	REMARKS
Feltwell	PASSIVE	DS	RF	Feltwell, England	0.5 - 18 GHz	Dedicated	Primary - Space Intel
RAF Fylingdales	PHASED ARRAY	NE	NB/NC	United Kingdom	UHF	Collateral	BMEWS III SSPAR
Haystack Auxiliary	TR	NE/DS	- - -	Tyngsboro, MA	X-band	Contributing	
Haystack	TR	DS	WB/C	Tyngsboro, MA	X-band	Contributing	
Kaena Point	TR	NE	NB/NC	Oahu, HI	C-band	Collateral	
Maui	GEODSS	DS	PHOTO	Mt. Haleakala, HI	Optical	Dedicated	
Millstone	TR	DS	NB/C	Tyngsboro, MA	L-band	Contributing	
Misawa AB	PASSIVE	DS	RF	Misawa, Japan	0.5 - 18 GHz	Dedicated	Primary - Space Intel
MOTIF	PHOTO/ LWIR	NE/DS	PHOTO	Mt. Haleakala, HI	LWIR	Collateral	
NAVSPASUR	CW FENCE	NE	- - -	Dahlgren, VA (HQ)	UHF	Dedicated	3 Transmitters 6 Receivers
Socorro	GEODSS	DS	PHOTO	New Mexico	Optical	Dedicated	
Thule, AB	PHASED ARRAY	NE	NB/NC	Greenland	UHF	Collateral	BMEWS I - SSPAR

C – Coherent DS – Deep Space NB – Narrow Band NC – Non-Coherent NE – Near Earth RF – Radio Frequency TR – Tracking Radar WB – Wideband

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Chapter 22

SPACE SYSTEMS SURVIVABILITY

"You know, if we really wanted to hurt you, we would set off an atomic weapon at high altitude above your country and produce an EMP that would destroy your entire electrical power grid, computer, and telecommunications infrastructure."

Member of the Russian Duma

Throughout this orientation of satellite operations, you have been exposed to the modern world's dependence on space systems. This dependence varies from simple commercial long distance calls to the implementation of a nation's strategic offensive and defensive forces. Furthermore, the United States Government and military forces require space systems support, such as early warning, navigation, intelligence, and communications, to maintain and formulate policies during and after a nuclear conflict.

The threat to space systems from nuclear weapons and Electro Magnetic Pulse (EMP) weapons exploded at high altitudes is real, yet largely ignored. Concerns about the proliferation of nuclear weapons and the possession of such weapons by rogue nations, make the discussion of problems associated with EMP and the magnitude of those problems a most timely topic.

Fig. 22-1. Nuclear Burst

NUCLEAR THREAT

The environmental effects of a nuclear explosion have been divided into three categories: Electromagnetic Pulse (EMP), transient nuclear radiation and thermal radiation. As for the success of a nuclear strike, it depends on three basic factors: the type of warhead (e.g., thermal nuclear, enhanced radiation and yield); the altitude of the detonation and the distance of the burst from its intended target. The altitude of a nuclear burst (**Fig. 22-1**) will depend on the mission of the weapon system. For example, if the objective is to produce maximum physical damage, a surface burst would be used.

Surface Burst

A surface burst is defined as a burst taking place between the surface and two kilometers (km) in altitude. This burst will produce the largest amount of debris, as the fireball will touch the surface and vaporize rocks, soil and other material. In addition, ground shock waves, over pressure (air blast) and EMP are present.

Low Altitude Burst

A low altitude burst is defined as a burst between two and 30 km in altitude. This burst will produce EMP, air blast and disruption in communications, such as scintillation (the distortion of radio waves) and absorption/ blackout (the denial of any communications within the affected area).

High Altitude Burst

A high altitude burst takes place at altitudes greater than 30 km. The high-altitude burst will produce EMP, scintillation and absorption and direct-radiation exposure to satellite systems. However, one effect that is common with an air and surface burst, the fireball, is not present in a high-altitude detonation. This is due to the lack of oxygen (the atmosphere is less dense at higher altitudes), which is needed to produce the fireball. The generation of EMP effects is present in any nuclear detonation, regardless of the altitude.

Electromagnetic Pulse (EMP)

The EMP threat is unique in two respects. First, its peak field amplitude and rise rate are high. These features of EMP will induce potentially damaging voltages and currents in unprotected electronic circuits and components. Second, the area covered by an EMP signal can be immense. As a consequence, large portions of extended power and communications networks, for example, can be simultaneously put at risk. Such far-reaching effects are peculiar to EMP. Neither natural phenomena nor any other nuclear weapon effects are so widespread.

Within nanoseconds (billionths of a second) of a nuclear detonation, any electrical system is threatened by EMP. Because of the potential damage by EMP, let's briefly look at how it is produced.

EMP is caused by the rapid release of gamma radiation from a nuclear detonation. The release of these particles at the speed of light (300,000,000 meters per second) will produce regions of negative/positive charges as atmospheric molecules are stripped of their electrons. These charges will propagate (travel) through the air at the speed of light and can have significant effects on all electromagnetic signals within line of sight of the nuclear detonation (NUDET).

The energy generated by the nuclear burst and its propagation towards the earth is characterized as an EMP waveform. The waveform has been broken down into three segments:

- The first is called early-time EMP and is the most devastating segment of the waveform. During early-time EMP, maximum levels of energy are produced in a very short time. Because of the intensity of the energy and the speed of the waveform, unprotected circuitry will be damaged or destroyed.
- The succeeding segment is called the intermediate-time portion of the waveform. This section is superseded in systems effects by the early-time and late-time EMP, as early-time EMP effects will overwhelm equipment and late-time EMP will expose long communications lines with continued low-level EMP.
- The final segment is called late-time EMP (also known as magneto-hydrodynamic EMP). Late-time EMP will occur at about one second after generation and can last up to 1000 seconds. During late-time EMP, low levels of energy are induced into the varying magnetic fields in the earth, which results in electrical fields being determined by the earth's surface resistance. This energy can pose a threat to long land lines such as telephone, power and submarine cables.

One significant factor in EMP effects is the amount of coverage desired. The area of exposure will depend on the size of the yield and the altitude of the burst. Based on the line of sight factor, the higher the burst altitude, the greater its coverage. Because of this factor, High-altitude Electromagnetic Pulse (HEMP) is the highest concern, as the entire electronic spectrum could be affected.

High-Altitude Electromagnetic Pulse (HEMP)

The gamma rays produced from a high-altitude nuclear burst will travel rapidly outward from the burst. The gamma rays traveling toward the earth will collide with the atmosphere at altitudes between 20 and 40 km. This collision will produce a gamma deposition layer, or EMP source region, where gamma energy is converted to a downward moving electromagnetic wave. A high-altitude burst can produce large-amplitude EMP fields over thousands of kilometers. Peak energy fields can reach levels of 50 kilovolts per meter. The peak levels can be reached very quickly and will have a large broad-band frequency coverage extending from Direct Current (DC) to 100 MHz frequencies. It is assessed that a nuclear burst at an altitude of approximately 500 kilometers can affect electromagnetic transmissions within the continental United States (CONUS).

While HEMP field strengths can be significant out to the tangent radium, the exact field strengths, as a function of ground position, can vary. Burst observer geometry is significant because HEMP is produced by an electron motion transverse to the earth's magnetic field. Other factors involved are the height of burst, weapon yield (particularly gamma yield) and geomagnetic field. The Earth's magnetic field strength is weaker and the orientation will vary near the equator. Therefore, peak EMP fields will be smaller and the field strength will be different.

EMP Protection Program

EMP is a critical issue in the survivability of all weapon systems and all three services have established regulations and organizations to examine and develop procedures to neutralize this threat. Such programs examine technology requirements, procedures and training programs for implementation.

From a technology standpoint, shielding a ground-control facility is required for EMP survivability. The ideal shielding would be made of steel and completely enclose the facility. However, this is an unrealistic method, as operations would not be possible. To create an EMP survivability facility, it should be shielded as much as possible. Furthermore, all openings to the facility need to be filtered and protected. The facility also needs to be isolated from any external electric EM propagation in the earth.

The effects of a nuclear detonation on a satellite system will also interfere with communication transmissions that are required for the maintenance of the satellite constellation. Effects, which would interfere with communications, are scintillation and absorption/blackout. Both have the effect of preventing or interrupting any communications between a ground station and the spacecraft.

Other Nuclear Effects

The effects of scintillation on a radio frequency are the disruption or breakup of the signal. For example, when the signal is transmitted through the contaminated area, characters in the transmission will be lost and only part of the message will be received. As for absorption/blackout, the layers of charged electrons trapped will prevent the transmission of the signal through the layer. However, these effects are frequency dependent. Disruption can last from just seconds to days. The lower end of the radio frequency spectrum will be affected by absorption and the higher level will encounter scintillation effects. HF communications can be affected the most, as potential outages may last for hours to days (depending upon reflection off the ionosphere). Mitigation techniques being currently used are avoidance, crosslink and signal manipulation.

Avoidance, as the word implies, means not using the satellite and ground control station within the affected area. This technique can be used with large constellations and worldwide ground-control networks. Crosslink capability allows the constellation to communicate with a satellite that is within the contaminated area via another satellite. Signal manipulation is designed to compensate for the loss of signal characters during the transmission. This is accomplished by inserting extra characters in the transmission.

Effects on Space Assets

Perhaps a more threatening challenge to our commercial satellite constellations is that from enhanced trapped radiation that results from delayed nuclear effects. These enhanced effects depend on a number of factors: the yield and number of bursts and, to a certain extent, the details of the bomb design; the latitude (and to a lesser extent the longitude); and height of the burst(s) and, of course, the "kind" of orbit the satellite is in-low earth orbit (Landsat, Teledesic, and Iridium, for example), medium earth orbit (Global Positioning Satellite (GPS) and Odyssey, for example) or geosynchronous earth orbit (Anik, Galaxy, and GOES, for example).

Direct radiation or thermal radiation effects are greater at altitudes above 40 km. Because of the lack of atmosphere, energy that would be converted to blast and shock (normally about 50% of the energy) is converted to thermal radiation (about 85% of the energy). The effects of this energy on a satellite are dependent on the distance of the spacecraft from the NUDET. Damage could range from simple computer logic changes to total destruction.

Prompt radiation can be described just like early-time EMP; it hits the satellite very quickly with maximum levels of energy. This charge of energy can be devastating to the satellite's health. Skin-charge effects are like intermediate EMP; they destabilize the energy fields and lead to the generation of internal EMP, which is similar to late-time EMP. The generation of internal EMP is the result of the satellite attempting to equalize the energy fields within itself. These charges collect on the cables, and high voltages are sent to various components, causing effects ranging from simple logic changes or circuitry disruptions to total component burnout.

Ground Segment Attack

Physical attacks and/or sabotage can be used against the critical ground facilities associated with US space systems in an effort to disrupt, deny, degrade, or destroy the utility of the space system. Satellite communications, data reception, command and control, launch, and assembly facilities, and their supporting infrastructures, are all potential targets. In cases where the neutralization of a single site effectively negates an entire space service, this method is more appealing; however, where there are many targets, this technique is less appealing. Many fixed US satellite communications, data reception, and control facilities are described in open source materials.

Once located, facilities deployed in a military theater can be attacked using conventional military assets, including aviation, cruise and ballistic missiles, special operations forces, and conventional ground forces. Facilities inside the United States or in a large, friendly country can be attacked by long-range bombers, submarine-launched ballistic missiles, intercontinental ballistic missiles, special operations forces and agents, and terrorists and paramilitary groups. Space launch facilities are also susceptible to attack or sabotage. A single incident or a small number of incidents could impact our space systems for years. Sabotage of satellite subsystem hardware or software could also be employed at the assembly plant or the location of a subcontractor.

Electronic Attack

US space systems could be functionally neutralized by jamming or spoofing the electronic equipment on the satellites or at their ground facilities. Jammers usually emit noise-like signals in an effort to mask or prevent the reception of desired signals, while spoofers emit false but plausible signals, for deception purposes, that are received and processed along with desired signals. All military and commercial satellite communication systems are susceptible to uplink and downlink jamming or spoofing. However, the jammer must operate in the same radio band as the system being jammed. Downlink jammers have a significant range advantage over the space-based emitter, so they can often be much less powerful and still be effective.

The targets of downlink jammers are ground-based satellite data receivers, ranging from large, fixed ground sites to handheld GPS user sets. Downlink jamming is generally easier than uplink jamming since very low power jammers are often suitable, though their effects are local (from tens to hundreds of miles, depending on the power of both the jammer and downlink signal).

On the other hand, the targets of uplink jammers are the satellites' radio receivers, including their sensors and command receivers. Uplink jamming is more difficult, since considerable jammer transmitter power is required. However, its effects may be global, since the satellite or space system would be impaired for all users. Furthermore, if false commands can be inserted into a satellite's command receiver (spoofing), they could cause the spacecraft to destroy itself.

Space Segment Attack

There are attacks other than nuclear that can target the space segment. Antisatellite (ASAT) systems can exploit a number of susceptibilities to disrupt, deny, degrade, or destroy satellites. For example, kinetic impact weapons cause structural damage by impacting the target with one or more high-speed masses-either warhead fragments or the ASAT itself. Chemical weapons (surface coating or reacting) can damage thermal control materials, surfaces, optical sensors, solar panels, and antennas. Laser fluence can damage exposed surfaces through heating or mechanical (pulsed laser only) effects. Lasers can also damage electro-optical sensors. Intense radio-frequency energy can couple to and disable sensitive satellite electronic components. What makes this all the more threatening is that technologies applicable to the development of some ASAT weapons are proliferating. An adversary only needs intent to use this capability.

Another area in the ASAT arena is interceptors, which can be divided into two currently basic categories-ground or air. Low-altitude direct-ascent ASAT interceptors are launched on a booster from the ground or from an aircraft into a suborbital trajectory that is designed to intersect that of a low Earth orbit (LEO) satellite. Low-altitude co-orbital ASAT interceptors are launched from the ground into an orbit from which they maneuver to intercept a low Earth orbit. High-altitude, short-duration ASAT interceptors are launched from a large space launch vehicle into a temporary parking orbit, from which an interceptor maneuvers to engage a high-altitude (MEO, GEO, or HEO) satellite, typically within 1-12 hours. Finally, long-duration orbital ASAT interceptors are launched into a storage orbit, where they await the command to engage a target satellite.

Directed energy ASAT weapons tend to be more sophisticated than ASAT interceptors. The directed-energy weapon's greatest advantage is that it can engage multiple targets, whereas interceptors tend to be single-shot systems. Ground-based high-power lasers could damage the thermal control, structural, and power generation components of the satellite. Additionally, they may also affect electro-optical sensors. Low-power antisensor lasers could blind or damage specific satellite-borne electro-optical sensors. Airborne high-power lasers could also damage components on LEO satellites. What gives the airborne laser an advantage over the ground-based laser is the airborne platform allows the ASAT to operate above inclement weather, which can shut down a ground-based laser.

CONCLUSION

In this chapter we have reviewed the effects of a nuclear burst on a satellite system, and how these effects can threaten all three segments of satellite systems. Equally important, we know that the technology to assure survivability exists; however, DOD personnel need to be more aware of the importance of maintaining facility-hardened levels for EMP. Since modern warfare and governmental duties are dependent on the availability of these systems for day-to-day operations, it is imperative that all possible means are employed to ensure survivability. We have also looked at other threats against our space systems. These have been broken down into the ground segment, link segment, and space segment.

The United States has three ongoing efforts to address the EMP threat that are underway as part of the DOD's Reliance program. The Science and Technology (S&T) directorate of the Office of the Under Secretary of Defense for Acquisition and Technology (OUSD (A&T)) established the Reliance program as a mechanism for coordinating and integrating DOD-wide S&T programs, reducing redundant capabilities, and eliminating unwarranted duplication. Although Nuclear Technology investments are addressed in the Defense S&T Reliance processes, the nuclear technology programs are unique in the level of integration built into the program. Currently all DOD Nuclear Technology S&T programs are accomplished under a single DOD component, the Defense Threat Reduction Agency (DTRA), which began operations on October 1, 1998. DTRA's establishment was one of the primary actions directed by the Defense Reform Initiative in November 1997.

The nuclear threat against our space systems has always been a primary concern because of the massive amount of damage that it would cause. However, our ground segment is more vulnerable because of the easier availability. Ground systems are much easier to attack than space systems. Moreover, the electronic attack against the link segment is a much more technologically achievable target than a nuclear explosion in space for many of our potential adversaries. In conclusion, our space systems must be regarded as a system made up of multiple parts-ground segment, link segment, and space segment, which are all integral to the accomplishment of the space mission.

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Appendix A

Annex N – Space

INTRODUCTION

Operations Plans (OPLANs) are the theater Combatant Commander key planning component for his Area of Responsibility (AOR). The OPLAN defines tasks and responsibilities of the AOR COMBATTANT COMMANDER and each supporting COMBATTANT COMMANDER, administration and logistics requirements and command and control of forces. The OPLANs are used both for long-term planning and for responding to crises within the AOR.

A theater Combatant Commander OPLAN is a key component of the deliberate planning process. OPLANs contain plans for responding to potential crises within the AOR. Development and execution of the OPLAN is in several phases.

- Phase I - Pre-hostilities
- Phase II - Lodgment
- Phase III - Military operations and stability
- Phase IV - Follow-through
- Phase V - Post-hostilities

Part of the OPLAN is the Annex N or the Space Annex that covers what contributions space assets will bring to the fight. OPLAN Annex N's cover space operations contributions to the Combatant Commander mission (friendly space systems) and enemy space capabilities which may threaten mission accomplishment.

Annex N resulted from a review of DESERT STORM operations which revealed that space systems were not integrated into OPLANs because operators were not aware of space system capabilities nor how to access or request space system support. This also led to the generation of Space Support Teams (SSTs) and STRATCOM support plans and the resultant direction from the CJCS to incorporate space system education into all professional and technical military education curriculums.

Annex N is tied into the interservice operation planning and execution system, which is the principal system within DOD for translating NCA policy decisions into the interservice combatant commander's air, land and sea operations. It does this by precisely defining DOD war planning and execution policies, designating specific procedures and format, and providing ADP support to convert NCA decisions into interservice operation plans. Campaign planning is the responsibility of the combatant commander and is not a structured, formal process but facilitates a transition from deliberate planning to crisis action planning.

JOINT OPERATION PLANNING AND EXECUTION SYSTEM (JOPES)

JOPES is a system which includes a set of publications and documents which guide the development of OPLANs and OPORDs, an operation planning process which develops deliberate plans (OPLANs) and operations orders (OPORDs), and an ADP support system for data processing support.

These can all be used to support Crisis Action Planning and the Campaign Plan. However, in today's world, we often face adversaries that we have never faced before or thought of as "enemies". Thus we may not have an OPLAN or even Contingency Plans (CONPLANs) for a particular crisis or area and may have to develop one quickly.

The primary space support plan for all theaters and contingencies comes from STRATCOM. It is a *capabilities-based* plan vice a requirements-based plan. That means that the plan discusses capabilities within Space Command's means to control and operate assets in space.

The plan provides tasks and responsibilities for both the supported commander and STRATCOM.

The supported commander may request space support team assistance, reconfiguring or repositioning of on-orbit satellites to provide him with better and longer coverage and reconfiguring of ground stations for improved C2 and data relay or processing. Additionally, the supported commander may specify known or anticipated shortfalls in COMSAT availability (including bandwidth and frequency limitations).

Responsibilities for STRATCOM (through AFSPACE/14AF) include: providing voice and data missile warning information to combatant commanders, adjusting GPS unencrypted signals for selective availability when desirable, providing communications support, identifying space threats to both satellites and ground systems, providing information on status of protection of space assets and furnishing space support teams when requested to assist the supported commander in defining his space support requirements.

STRATCOM is also responsible for negating hostile space assets through the Satellite Reconnaissance Advance Notice (SATRAN) program which informs theater commanders of when enemy or other country's reconnaissance satellites are capable of seeing ground activity in their area. The satellite vulnerability (SATVUL) program provides notices on threats to US Satellites.

STRATCOM reviews satellite posture and if replenishment is needed, recommends a prioritized, accelerated launch schedule to JCS. On-orbit assets can be repositioned to improve or increase support to battlefield commanders.

ANNEX N

- Outlines how to obtain and coordinate space support;
- Describes nature of space support;
- Lists operational constraints and shortfalls; and
- Describes command relationships.

The Annex N provides planning guidance concerning space-related support for the deployment and employment of the Combatant Commander forces. Space assets support several crucial areas that enable the Combatant Commander forces to conduct military operations.

Annex N is the Space Annex that is included in the OPLANs of theater Combatant Commander. Annex N provides guidance to U.S. forces in theater for obtaining, coordinating, and using space support to enhance "navigation, communications, warning (of missile attack), environmental monitoring, surveillance and reconnaissance, NUDET reporting and space control".

Space assets provide the following six capabilities:

- Theater Warning
  - *Provides attack warning detection and notifications capabilities*
- Navigation
  - *Provides terrestrial navigation capabilities from the Global Positioning System (GPS) and other navigation satellites.*
- Communications
  - *Provides satellite communications support*
- Environmental Sensing
  - *Provides environmental and weather satellite support*
- Intelligence, Surveillance and Reconnaissance (ISR)
  - *Military and civilian satellites which can support surveillance and intelligence gathering*
- Space Control
  - *Assures continued operation of space systems for advantage in information warfare and battlefield awareness*

Annex N addresses *planning* in these areas:

- Each of the six space capabilities for potential enemies in the AOR.
- Each of the six space capabilities for friendly/Allied forces in the AOR.
- Planning assumptions under which these capabilities would be used include:
  - shortfalls;
  - limiting factors;
  - world situation; and
  - ability to replace on-orbit assets.

DEVELOPING A THEATER ANNEX N

Attached is an notional Annex N developed for instructional purposes only. Before developing an Annex N, it is necessary to determine your and the enemy's space assets. To do that, you first need to ask some basic questions.

Q: What ***kinds*** of **space support** are required to support a warfighting COMBATTANT COMMANDER?

A: Communications, navigational/positional support, intelligence, surveillance, imagery, attack warning, weather and multi-spectral imagery (MSI). Navigation/positional support should include search and rescue (SAR).

A: Environmental monitoring information should include weather and multispectral imagery (MSI) for terrain/water depth analysis, map updates and ground cover classification.

As the campaign evolves and deployment to a theater nears, more specific questions need to be discussed and resolved.

For example:

- What are in-theater system capabilities? Can theater units receive downlinked information from satellites properly and in a timely manner? Is additional equipment needed?
- What are area and target coverage requirements? Pin-point target imagery or wide area coverage?
- What is response time of various satellite systems? How do we get data in real-time or near real-time to the theater?
- What is the resolution and accuracy of satellite information?
- What is availability and survivability of space systems?

Next we'll need to know specific, unique theater requirements.

These include:

- Do they have the proper terminal or receiver equipment to obtain the needed support data and information;
  (Example: weather terminals and tactical data processors)
- Has connectivity and interoperability among the service components (and allies) been determined and resolved;
  (Example: SHF vs UHF communications; imagery dissemination)
- Has maintenance support, especially of dissimilar equipment, been addressed and resolved; and,

- Has training and exercise space support to the theater been practiced so that deployments do not present personnel with new situations or unknown systems. Allies also need to be knowledgeable in what US systems there are and how they can be used to maximum advantage.

INTEGRATING SPACE INTO OPLANS

Annex N is only one part of the overall effort but it is a critical part. In order to be fully effective, space support and thinking must be integrated throughout as many of the JOPES annexes as possible. Of prime importance are the intelligence, operations, and communications annexes. The execution checklists must also contain information showing what space support to expect at various times.

Most planners consider space as a separate entity, much like operations or communications. This thinking has to be turned around and space incorporated as an integral part of all we do. And the hardest part will be integrating space into joint operations.

As theater COMBATTANT COMMANDER staffs are populated with increasing numbers of Space Weapons school graduates, they will assume greater responsibility for authoring their theater's Space Operations annex.

Attached is a notional Annex N which shows, paragraph by paragraph, what kinds of data are included in an Annex N. Because of the change in the types of enemies and areas of the world the US fights in today and in the future, many of the Theater Annex N's are becoming more 'generic', focusing on threats within the region rather than on specific countries.

Copy no___ of ___copies
Issuing Headquarters
Place of Issue
Date/Time Group when signed

ANNEX N (SPACE OPERATIONS) to OPLAN or OPORD nnn-yy - Issuing Headquarters

(X) References: List ANNEX N of the next higher commands OPLAN or OPORD and other documents, maps, overlays and SOPs that provide guidance and information for use with this annex.

(X) Time Zone Used Throughout the Order:

1. (X) **SITUATION**

a. (X) **General.** Describe planned and available space support to the OPLAN. Explain how to obtain and coordinate space support. List operational constraints and shortfalls. Describe relationships between supporting and supported organizations. Refer to other annexes or provide enough information about the overall situation to give subordinate and supporting units a clear understanding of the operations contemplated which require space operations support.

b. (X) **Enemy.**

(1) (X) Describe enemy space capabilities, how they will be used and their value to the enemy.

(a) (X) Estimate the impact of enemy space capabilities on friendly operations. Describe notification or warning reports to friendly units of enemy space activities to include enemy reconnaissance, surveillance and target acquisition of friendly forces by manned and unarmed space systems. Discuss the enemy's ability to use friendly space systems to support operations. Refer to Annex B, Intelligence, for amplifying information.

(b) (X) Identify enemy space weaknesses and vulnerabilities such as inadequate coverage, poor resolution, inability to launch new or replacement systems and inability to counter the capabilities of friendly space systems.

(2) (X) Describe what the enemy is capable of doing and probably will do with space, air, surface or subsurface assets to interfere with friendly space systems and space operations that support the missions and tasks envisioned in this plan. Notice of hostile space activities that deny unrestricted friendly access to space , deny the full capabilities of friendly space assets, or restrict friendly surface resources required by these space assets. Refer to Annex B, Intelligence, for amplifying information.

c. (X) **Friendly.** In numbered sub-paragraphs, state the capabilities of external commands, units, forces or agencies to provide space support for the operation such as USSPACECOM, ARSPACECOM, DISA, DIA, NOAA, NASA, etc. Include non-U.S. agencies and systems such as INTELSAT, INMARSAT, ESA, EUMETSAT, etc. Identify systems available for communications, environmental, navigation, surveillance, tactical warning, space control, nuclear detonation detection or other application categories. Identify friendly space weaknesses and vulnerabilities. Describe changes or modifications to established procedures, MOAs or MOUs that may be in effect. Use appendix for detailed information. Refer to the ANNEX N of the next higher command and adjacent commands.

d. (X) **Assumptions.** State any assumptions, not included in the basic plan, relating to friendly, enemy or third party capabilities and operations that may affect, negate or compromise space capabilities. If any assumptions are critical to the success of the plan, indicate alternative courses of action.

2. (X) **MISSION**

State in concise terms the space tasks to be accomplished in support of the operations in the basic plan and describe desired results in support of this OPLAN

3. (X) **EXECUTION**

Space activities may range from satellite communication and intelligence support to space control operations. The functions required may vary greatly within the area of operations or between phases of the operation. This paragraph may, therefore, require considerable detail and possibly alternative courses of action to accomplish the mission. Appendixes should be used as necessary to provide detailed guidance.

a. (X) **Concept of Operations.**

(1) (X) **General.** State the general concept of space operations required to support the forces in the task organization of the OPLAN and briefly describe how space operations fit into the entire operation or refer to the basic plan. Emphasize the aspects of the basic plan that will require space support and that may affect space capabilities. State OPSEC planning guidance for tasks assigned in this annex, and cross-reference other OPSEC planning guidance for functional areas addressed in other annexes.

(2) (X) **Employment.** If the operation is phased, discuss the employment of space assets during each phase. Include discussion of priorities of access, usage and capabilities in each phase. Discuss ability to launch new or replacement space systems.

b. (X) **Space Support.** Identify space support and procedures that will support the OPLAN. Include the following areas or add additional areas, as applicable:
Use Appendixes for detailed discussion and information.

(1) (X) **Communications.** Describe space systems that will support communications plans as described in Annex K. List military and commercial satellites and ground systems that will provide support. If any satellites are not in geostationary orbit, provide orbital data sufficient to determine the time and duration of their availability. Include procedures for obtaining additional SATCOM space and ground assets and allocations. Refer to Annex K, Command, Control and Communications Systems, for amplifying information.

(2) (X) **Environmental.** Describe meteorologic, oceanographic, geodetic and other environmental support information provided by space assets. List receivers and processors that are available to receive DNEP and civil weather satellite data. Describe availability of data from the various weather satellites based on transmission schedules, orbital parameters, etc. Describe capabilities, products and availability of multi-spectral satellite data. Describe provisions to acquire, receive or gain access to data from weather, multi-spectral and other satellites that cannot be received by systems in the theater of operations. Describe provisions to deny the enemy access to data from civil weather satellites. Refer to Annex K Environmental Services for amplifying information

(3) (X) **Navigation.** Describe the capabilities of space based navigation systems that will aid the position location and navigation of ships, vehicles, personnel or spacecraft. Describe types of GPS receivers available to subordinate units. Identify which receivers are not able to compensate for selective availability. Quantify the error caused by selective availability. Discuss requirements to increase, decrease or turn off GPS selective availability. If continuous 3-D coverage is not available, describe outage periods or times of reduced coverage. Describe requirements to jam or spoof GPS receivers that may be in use by the enemy. Describe requirements for differential GPS.

(4) (X) **Reconnaissance, Intelligence, Surveillance and Target Acquisition (RISTA).** Describe capabilities available to friendly forces to include IMINT, SIGINT, MASINT, NUDET, multi-spectral and others. Describe inter-theater and intra-theater dissemination architecture and procedures.

Describe which systems can be used and the type of information they provide. Describe availability of multi-spectral data, its processing and products. Discuss availability and requirements for TENCAP systems. Refer to Annex B, Intelligence, for amplifying information.

(5) (X) **Tactical Warning.** Describe the capabilities of space systems to detect enemy ballistic missile, attack by space-based weapons or other enemy activities. Describe the capabilities of systems such as Tactical Event Reporting System (TERS). Describe coordination and channels needed to disseminate warnings quickly. Identify additional resources needed. Describe linkage and coordination with ground and air based radar systems. Identify whether tactical warning data will be passed to allied military forces and civil agencies and the channels to do so. Refer to Annex B, Intelligence, for amplifying information.

(6) (X) **Space Control.** Describe actions performed by space, air or surface assets to ensure friendly forces access to space or deny enemy forces unrestricted use of space and space assets. Include planned or anticipated actions in response to the enemy's use of space or denial of friendly access to space and space systems.

c. (X) **Tasks and Responsibilities.** In numbered paragraphs, assign individual tasks and responsibilities to each applicable subordinate unit, supporting command or agency that provides support to the plan. For each of these tasks, provide a concise statement of the mission to be performed in further planning or execution of the overall plan, providing sufficient detail to ensure that all elements essential to the operational concept are described properly.

d. (X) **Coordinating Instructions.** Provide necessary guidance common to two or more components, subdivisions or agencies. Describe liaison requirements, if any.

4. (X) **ADMINISTRATION AND LOGISTICS**

Provide broad guidance concerning administrative and logistic support for space operations. Address support of mobile or fixed space system assets within the area of operations or refer to another annex where this information is available. Describe support needed and who will provide it for any space related ground stations supporting the command. Describe resupply procedures for cryptological supplies. Refer to Annex D, Logistics, or pertinent command directives for amplifying information.

5. (X) **COMMAND AND CONTROL**

a. (X) **Command and Control.** Indicate the difference, if any, between the command channels for the conduct of space activities and the command relationships established in Annex J. If applicable, state requirements for augmentation of appropriate headquarters with space operations personnel. Refer to the appropriate section of Annex J, Annex K or the basic plan for general C^2 support of space activities.

b. (X) **Command, Control, and Communications Systems.** Summarize requirements for general C^2 systems support of space activities. Refer to appropriate sections of Annex K.

/t

General/COMBATTANT COMMANDER

Appendices:
1 - Communications
2 - Environmental
3 - Navigation
4 - Reconnaissance, Surveillance and Target Acquisition
5 - Tactical Warning
6 - Space Control

7 - Space Support

(Complete Appendixes only as required for amplifying details)

Hints on preparation of Annex N and supporting Appendixes:

1. Focus on unique space capabilities and their application to the operation.
2. Refer to the ANNEX N of the next higher command's OPLAN/OPORD.
3. Cross-reference to other Annexes. Avoid unnecessarily repeating information contained in other Annexes.

Appendix B

SPACE GLOSSARY AND ACRONYMS

ω	Argument of Perigee
Ω	Ascending Node
Δv	delta-v

A

a	Semi-Major Axis
A/MWC	Alternate Missile Warning Center
AA	Attack Assessment
ABM	Anti-Ballistic Missile
ACC	Air Combat Command
ACMS	Alternate Master Control Station
ACS	Attitude Control Subsystem
ADRG	Arch Digitized Raster Graphics
ADSI	Air Defense Systems Integrator
AEPDS	Advanced Electronic Processing and Dissemination System
AFCC	Air Force Communications Command
AFM	Air Force Manual
AFSATCOM	AF Satellite Communications
AFSCN	Air Force Satellite Control Network
AFSPACE	Air Force Space Command
AFSPC	Air Force Space Command
AFSPC/CC	Commander, Air Force Space Command
AFSST	AF Space Support Team
AIRS	Advanced Inertial Reference Sphere
Al	Aluminum
ALCM	Air-Launched Cruise Missile
ALCOR	ARPA Lincoln C-Band Observable Radar
ALERT	Attack and Launch Early Reporting to Theater
ALTAIR	ARPA Long-Range Tracking and Identification Radar
AMCSS	AFSAT Modulation Compatibility Sub System
AMOS	ARPA Maui Optical Site
AOC	Aerospace Operations Center
AOC	Auxiliary Output Chip
APT	Automatic Picture Transmission
ARC	Advanced Research Center
ARPA	Advanced Research Projects Agency
ARSPACE	Army Space Command
ARSPACE FWD	Army Space Command Forward
ARSST	Army Space Support Team
ARTS	Automated Remote Tracking Station
A-S	Anti-Spoofing

ASARS-2	Advanced Synthetic Aperture Radar System-2
ASAT	Anti-Satellite
ASCC	Alternate Space Control Center
ASDP	Army Space Demonstration Program
ASEDP	Army Space Exploitation Demonstration Program
ASIS	Army Space Initiatives Study
ASPADOC	Alternate Space Defense Operations Center
ASPO	Army Space Program Office
ATACMS	Army Tactical Missile System
ATO	Air Tasking Order
ATV	Automated Transfer Vehicle
AU	Distance of Earth from the sun
AUTONAV	Autonomous Navigation
AVHRR	Advanced High Resolution Radiometer
AWACS	Airborne Warning and Control System
AWACS	Airborne Warning and Control System
AWN	Automated Weather Network
AZA	Auroral Zone Absorption

B

BIOT	British Indian Ocean Territory
BMD	Ballistic Missile Defense
BMEWS	Ballistic Missile Early Warning System
BOA	Battlefield Ordnance Awareness

C

c	Linear Eccentricity
C/A	Course Acquisition
C2	Command and Control
CACS	Command and Control Squadron
CACS	Command and Control Squadron
CALCM	Conventional Air Launched Cruise Missile
CANR	Canadian NORAD Region
CCD	Camouflage, Concealment and Deception
CCIS	Civil/Commercial Imagery System
CCS	Constellation Control Station
CCS	Constellation Control Station
CDF	Commercial Demonstration Flight
CEP	Circular Error Probability
CGS	CONUS Ground Station
CIC	Combat Intelligence Correlator
CIC	Combined Intelligence Center
CINC	Commander-in-Chief
CINC	Commander in Chief

CINC-NORAD	Commander-in-Chief CINC of NORAD
CIO	Central Imagery Office
CIR	Color Infrared
CIRA	Cospar International Reference Atmosphere
CM	Cruise Missile
CMAS	Cheyenne Mountain Air Station
CME	Coronal Mass Ejection
CMOC	Cheyenne Mountain Operations Center
CMR	Communication by Moon Relay
CNA	Computer Network Attack
CND	Computer Network Defense
CNO	Chief of Naval Operations
CO_2	Carbon Dioxide
COF	Columbus Orbital Facility
CONOPS	Concept of Operations
CONUS	Continental United States
COTS	Commercial-off-the-Shelf
CRT	Cathode-Ray Tube
CSEL	Combat Survivor/Evader Locator
CSIL	Commercial Satellite Imagery Library
CSPE	Communications Systems Planning Element

D

D	Distance
DAGR	Defense Advanced GPS Receiver
DAMA	Demand Assigned Multiple Access
DARO	Defense Airborne Reconnaissance Office
DARPA	Defense Advanced Research Projects Agency
dB	Decibels
DC	Direct Current
DCSOPS	Deputy Chief of Staff for Operations
DDC	Data Distribution Center
DEM	Digital Elevation Model
DEW	Distant Early Warning
DGPS	Differential GPS
DIA	Defense Intelligence Agency
DISA	Defense Information Systems Agency
DISN	Defense Information Systems Network
DMA	Defense Mapping Agency
DMS	Defense Message System
DMSP	Defense Meteorological Satellite Program
DOD	Department of Defense
DR	Detection Radar
DRC	Data Reduction Center
DSCS	Defense Satellite Communication System

DSCSOC	DSCS Operations Center
DSN	Defense Switched Network
DSP	Defense Support Program
DSTS	Deep Space Tracking System
DTED	Digital Terrain Elevation Data
DTRA	Defense Threat Reduction Agency
DTS	Diplomatic Telecommunications Service
DWSW	Deployable Weather Satellite Workstation

E

e	Eccentricity
EAC	Echelon Above Corps
EAM	Emergency Action Message
EC	Earth Coverage
EDGE	Exploitation of DGPS for Guidance Enhancement
EELV	Evolved Expendable Launch Vehicle
EGS	European Ground Station
EHF	Extremely High Frequency
EIRP	Effective Isotropic Radiated Power
ELSET	Element Set
EM	Electromagnetic
EMD	Engineering and Manufacturing Development
EMP	Electromagnetic Pulse
ENEC	Extendable Nozzle Exit Cone
EOSAT	Earth Observation Satellite
EPDS	Electronic Processing and Dissemination System
ERS-1	European Remote Sensing Satellite
ERTS-A	Earth Resources Technology Satellite-A
ESA	European Space Agency
ESSA	Environmental Science Service Administration
ET	External Tank
ET	Extra-Terrestrial
ETM+	Enhanced Thematic Mapper Plus
ETRAC	Enhanced Tactical Radar Correlator
ETUT	Enhanced Tactical User Terminal
EUV	Extreme Ultraviolet
EVA	Extravehicular Activity

F

FAST	Forward Area Support Terminal
FAST	Forward Space Support in Theater
FBM	Fleet Ballistic Missile
FDMA	Frequency Division Multiple Access
FEP	FLTSAT EHF Package

FLTSAT	Fleet Satellite
FLTSATCOM	Fleet Satellite Communications
FNMOC	Fleet Numerical Meteorological and Oceanographic Center
FOSIC	Fleet Ocean Surveillance Information Center
FOV	Field-Of-View
FSSC	Fleet Surveillance Support Command
FSU	Former Soviet Union

G

GATS	B GPS-Aided Targeting System
GBS	Global Broadcast Service
GCCS	Global Command and Control System
GCN	Ground Communications Network
GCNU	Ground Communications Network Upgrade
GCSS	Global Combat Support System
GDA	Gimbaled Dish Antenna
GEO	Geosynchronous Earth Orbit
GEODSS	Ground-based Electro-Optical Deep Space Surveillance
GMF	Ground Mobile Forces
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOTS	Government-off-the Shelf
GPS	Global Positioning System
GPS MCS	GPS Master Control Station
GSD	Ground Sampling Distance
GSSC	Global SATCOM Support Center
GSUs	Geographically Separated Unit
GTO	Geosynchronous Transfer Orbit

H

H_2O	Hydrogen Dioxide (Water)
HEMP	High-Altitude Electromagnetic Pulse
HEO	Highly Elliptical Orbit
HELSTF	High Energy Laser System Test Facility
HF	High Frequency
HRPT	High Resolution Picture Transmission
HRV	High Resolution Visible
HSD	High Speed Data
HSI	Hyperspectral Imagery
HSMP	High Speed Message Processor
HSS	High Speed Stream
HST	Hubble Space Telescope

I

ICBM	Inter-Continental Ballistic Missile
ISR	Intelligence, Reconnaissance and Surveillance
ITW	Integrated Tactical Warning
ITW/AA	Integrated Tactical Warning and Attack Assessment
IUS	Inertial Upper Stage

i	Inclination
ICBM	Intercontinental Ballistic Missile
ICDB	Integrated Communications Database
IDSCP	Initial Defense Communications Satellite Program
IFOV	Instantaneous Field of View
IG	Intelligence Group
IGMDP	Integrated Guided Missile Development Program
IGY	International Geophysical Year
IMF	Interplanetary Magnetic Field
INMARSAT	International Maritime Satellite
INS	Inertial Navigation System
INSAT	Indian National Satellite
Intelsat	International Telecommunications Satellite
IOC	Initial Operating Capability
IPL	Integrated Priority List
IPO	Integrated Program Office
IR	Infrared
IRBM	Intermediate Range Ballistic Missile
IRS	Indian Remote Sensing Satellite
I_{sp}	Specific Impulse
ISS	International Space Station
ITAC	Intelligence and Threat Analysis Center
ITOS	Improved TIROS Operational Satellite
IUS	Inertial Upper Stage

J

JASSM	Joint Air-to-Surface Standoff Missile
JBS	Joint Broadcast Service
JCS	Joint Chiefs of Staff
JDAM	Joint Direct Attack Munition
JEM	Japanese Experiment Module
JIOC	Joint Information Operations Center
JITI	Joint In-Theater Injection
JNTF	Joint National Test Facility
JRSC	Jam Resistant Secure Communications
JSCP	Joint Strategic Capabilities Plan
JSIPS	Joint Services Imagery Processing System
JSOW	Joint Stand Off Weapon

JSTARS/GSM	Joint Surveillance Target Attack Radar System/Ground Support Module
JTAGS	Joint Tactical Ground Station
JTF-CND	Joint Task Force - Computer Network Defense
JTFST	Joint Task Force Satellite Terminal

K

K	Kelvin
KE	Kinetic Energy
km	Kilometer
kW	Kilowatt
kW/s	Kilowatts per Steradian

L

LAAS	Local Area Augmentation System
LASS	Low-Altitude Space Surveillance System
LCC	Launch Control Center
LDR	Low Data Rate
LEGG	Launch Ejection Gas Generator
LEO	Low Earth Orbit
LF	Launch Facility
LF	Low Frequency
LH	Liquid Hydrogen
LITVC	Liquid Injection Thrust Vector Control
LLV	Lockheed Launch Vehicle
LMLV	Lockheed-Martin Launch Vehicle
LOC	Line of Communication
LOX	Liquid Oxygen
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LPS	Large Processing Station
LPSU	Large Processing Station Upgrade
LS	Light Smooth
LSD	Low Speed Data
LSMP	Low Speed Message Processor
LSTT	Light-Weight STT
LUF	Lowest Useable Frequency
LWIR	Long Wave Infra-red

M

m	Mass
MAGR	Miniaturized Aircraft GPS Receiver
MAJCOM	Major Command
MBA	Multiple Beam Antenna

MC&G	Mapping, Charting and Geodesy
MCC	Mission Control Center
MCS	Master Control Station
MCS	Mission Control Station
MDM	Mission Data Message
MDR	Medium Data Rate
MECA	Missile Electronics and Computer Assembly
MGS	Missile Guidance Set
MGS	Mobile Ground System
MI	Military Intelligence
MIES	Modernized Imagery Exploitation System
MILSATCOM	Military Satellite Communications
MIRV	Multiple Independently Targetable Reentry Vehicle
MIT	Massachusetts Institute of Technology
MITT	Mobile Integrated Tactical Terminal
MLRS	Multiple Launch Rocket System
MOC	Milstar Operations Center
MOL	Manned Orbiting Laboratory
MOS/PIM	Multiple Orbit Satellite/Program Improvement Module
MOTIF	Maui Optical Tracking and Identification Facility
MPSOC	Multi-Purpose Satellite Operations Center
M_R	Mass Ratio
MRBM	Medium Range Ballistic Missile
MSF	Milstar Support Facility
MSI	Multispectral Imagery
MSIP	MSI Processor
MSS	Mobile Service System
MSS	Multispectral Scanner
MSTS	Multi-Source Tactical System
MT	Megaton
MUF	Maximum Useable Frequency
MWIR	Medium Wave Infrared

N

NAVSPACECOM	Naval Space Command
NAVSPASUR	Naval Space Surveillance Center
NCA	National Command Authority
NIPC	National Infrastructure Protection Center
NOAA	National Oceanic Atmospheric Administration
NORAD	North American Aerospace Defense
NRO	National Reconnaissance Office
NSWCDD	Naval Surface Warfare Center, Dahlgren Division
NWS	North Warning System
NACA	National Advisory Committee on Aeronautics

NASA	National Aeronautics and Space Administration
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVASTROGRU	Navy Astronautics Group
NAVSOC	Naval Satellite Operations Center
NAVSPACE	Naval Space Command
NAVSPACECOM	Naval Space Command
NAVSPASUR	Naval Space Surveillance
NAVSPOC	Naval Space Operations Center
NAVSTAR GPS	Navigation Satellite Timing and Ranging Global Positioning System
NAVWAR	Navigation Warfare
NCA	National Command Authority
NDI	Non-Developmental Item
Ni-Cad	Nickel-Cadmium
Ni-H_2	Nickel-Hydrogen
NIMA	National Imagery and Mapping Agency
NIR	Near Infrared
NITF	National Imagery Transmission Format
NM	Nautical Mile
NMCC	National Military Command Center
NNSS	Navy Navigation Satellite
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NPIC	National Photographic Interpretation Center
NPOESS	National Polar Orbiting Operational Environmental Satellite System
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSD	National Security Directive
NSDD	National Security Decision Directive
NSPC	National Space Council
NSPD	National Space Policy Directive
NSST	Naval Space Support Team
NSTC	National Science and Technology Council
NTR	Nuclear Thermal Rocket
NUDET	Nuclear Detection

O

O	Oxygen molecule
O&M	Operations and Maintenance
O_2	Oxygen (gas)
OC	Operations Center
OCC	Operations Control Center
OGS	Overseas Ground Station
OLS	Operational Linescan System

OMS	Orbital Maneuvering System
OPCON	Operational Control
OPSEC	Operations Security
OSC	Orbital Sciences Corporation
OTH-B	Over-the-Horizon Backscatter
OUSDA&T	Under Secretary of Defense for Acquisition and Technology

P

PAR	Phased Array Radar
PARCS	Perimeter Acquisition Radar Attack Characterization System
PBCS	Post Boost Control System
PBV	Post Boost Vehicle
PCA	Polar Cap Absorption
PCM	Phase-Change Material
P-code	precision code
PD	Presidential Directive
PDD	Presidential Decision Directive
PE	Potential Energy
PEC	Photoelectric Cell
PLGR	Precision Lightweight GPS Receiver
PMT	Photo Multiplier Tube
POES	Polar Orbiting Environmental Satellite
PPS	Precise Positioning Service
PPSE	PAVE PAWS South East
PPSW	PAVE PAWS South West
PR	Production Requirement
PRC	Peoples Republic of China
PRD	Presidential Review Directive
psi	per square inch
PSRE	Propulsion System Rocket Engine
PUP	Peripheral Upgrade Program

Q

QDR	Quadrennial Defense Review
QPSK	Quadra Phase Shift-Keyed

R

R&D	Research and Development
RAF	Royal Air Force
RAOC	Region Air Operations Center
RCMP	Royal Canadian Mounted Police
RDS	Real-time Data Smooth
REACT	Rapid Execution and Combat Targeting

RFI	Radio Frequency Interference
RGS	Relay Ground Stations
RISTA	Reconnaissance, Intelligence, Surveillance, and Target Acquisition
RMS	Remote Manipulator System
ROCC	Region Operations Control Center
ROTHR	Relocatable Over-the-Horizon Radar
ROW	Rest-of-World
RSC	Reaction Control System
RSSC	Regional SATCOM Support Center
RTC	Real-Time Command
RTD	Real-time Data Fine
RTG	Radioisotope Thermoelectric Generator

S

S&T	Science and Technology
SA	Selective Availability
SAA	Satellite Access Authorization
SAASM	Selective Availability Anti-Spoofing Module
SAGE	Semi-Automatic Ground Environment
SAM	Surface-to-Air Missile
SAMT	state-of-the-art Medium Terminal
SAOC	Sector Air Operation Center
SAR	Satellite Access Request
SAR	Search and Rescue
SAR	Support Assistance Request
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communications
SATCON	Satellite Control
SATRAN	Satellite Reconnaissance Advance Notice
SBIRS	Space Based Infrared System
SCC	Space Control Center
SCG	Security Classification Guide
SCI	Sensitive Compartmented Information
SCIS	Survivable Communications Integration System
SCT	Single Channel Transponder
SDIO	Strategic Defense Initiative Organization
SDS	Satellite Data System
SED	Sensor Evolutionary Development
SEON	Solar Electro-Optical Network
SEP	Spherical Error Probable
SEU	Single Event Upset
SG	Space Group
SHF	Super High Frequency
SID	Sudden Ionospheric Disturbance
SIDEARM	Secondary Imagery Dissemination Environment and Resource Manager

SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground and Air Radio System
SIOP	Single Integrated Operations Plan
SLBM	Sea-Launched Ballistic Missile
SLCM	Sea-Launched Cruise Missile
SLCM	Submarine-Launched Cruise Missile
SLEP	Service Life Enhancement Program
SLGR	Small Lightweight GPS Receiver
SLS	Space Launch Squadron
SMABC	Space and Missile Applications Basic Course
SMDBL	SMDC Battle Lab
SMDC	Space and Missile Defense Command
SOC	Satellite Operations Center
SOC	Space Operations Center
SOCC	Satellite Operations Control Center
SOH	State of Health
SOI	Space Object Identification
SOM	Satellite Operations Manager
SOPS	Satellite Operations Squadron
SOPS	Space Operations Squadron
SPAWAR	Space and Naval Warfare
SPC	Stored Programs Command
SPIN	SATCOM Planning Information Network
SPO	Special Projects Office
SPOT	Satellite Pour L'Observation de la Terre
SPS	Simplified Processing Station
SPS	Standard Positioning Service
SPSS	Space Surveillance Squadron
SRBM	Short Range Ballistic Missile
SRM	Solid-Rocket Motor
SRMU	Solid Rocket Motor Upgrade
SRS	Satellite Readout Station
SRSU	SRS Upgrade
SSB	Solar Sector Boundary
SSBN	Nuclear Capable Submarine
SSC	Space Surveillance Center
SSDC	Space and Strategic Defense Command
SSE	SATCOM System Expert
SSM/I	Special Sensor Microwave Imager
SSMA	Spread Spectrum Multiple Access
SSN	Space Surveillance Network
START	Strategic Arms Reduction Treaty
STO	Space Tasking Order
STS	Space Transport System
STS	Space Transportation System
STT	Small Tactical Terminal

SWC	Space Warfare Center
SWF	Short Wave Fade
SWIR	Shortwave Infrared
SWO	Space Weather Officer
SWS	Space Warning Squadron
SWS	Strategic Weapon System

T

T	Thrust
T/R	Transmit/Receive
TACDAR	Tactical Detection and Reporting
TACSAT	Tactical Satellite
TACSATCOM	Tactical Satellite Communications
TACTERM	Tactical Terminal
TAOS	Technology for Autonomous Operational Survivability
TASR	Tactical Automated Situational Receiver
TAT-1	Transatlantic Telephone (first cable)
TBM	Tactical Ballistic Missile
TCF	Technical Control Facility
TDDS	Tactical Data Dissemination System
TEC	Topographic Engineering Center
TEC	Total Electron Content
TEL	Transporter-Erector-Launcher
TENCAP	Tactical Exploitation of National Capabilities
TERCAT	Terrain Categorization
TERCOM	Terrain Contour Matching
TES	Theater Event System
TIBS	Tactical Information Broadcast Service
TIROS	Television and Infrared Operational Satellite
TLAM	Tomahawk Land Attack Missile
TM	Thematic Mapper
TMD	Theater Missile Defense
TOMS-EP	Total Ozone Mapping Spectrometer-Earth Probe
TOS	TIROS Operational System
TR	Tracking Radar
TRADOC	Training and Doctrine Command
TS	Thermal Smooth
TSS	Tri-band SATCOM Sub-system
TT&C	Telemetry, Tracking and Commanding
TVC	Thrust Vector Control

U

UCP	Unified Command Plan
UDMH	Unsymmetrical Dimethyldrazine
UE	User Equipment

UHF F/O	UHF Follow-On
UHF	Ultra-High Frequency
UN	United Nations
USA	US Army
USAF	US Air Force
USCENTCOM	US Central Command
USCINCSPACE	CINC, United States Space Command
USMC	US Marine Corps
USSPACECOM	US Space Command
USSTRATCOM	US Strategic Command
UTC	Coordinated Universal Time
UV	Ultraviolet

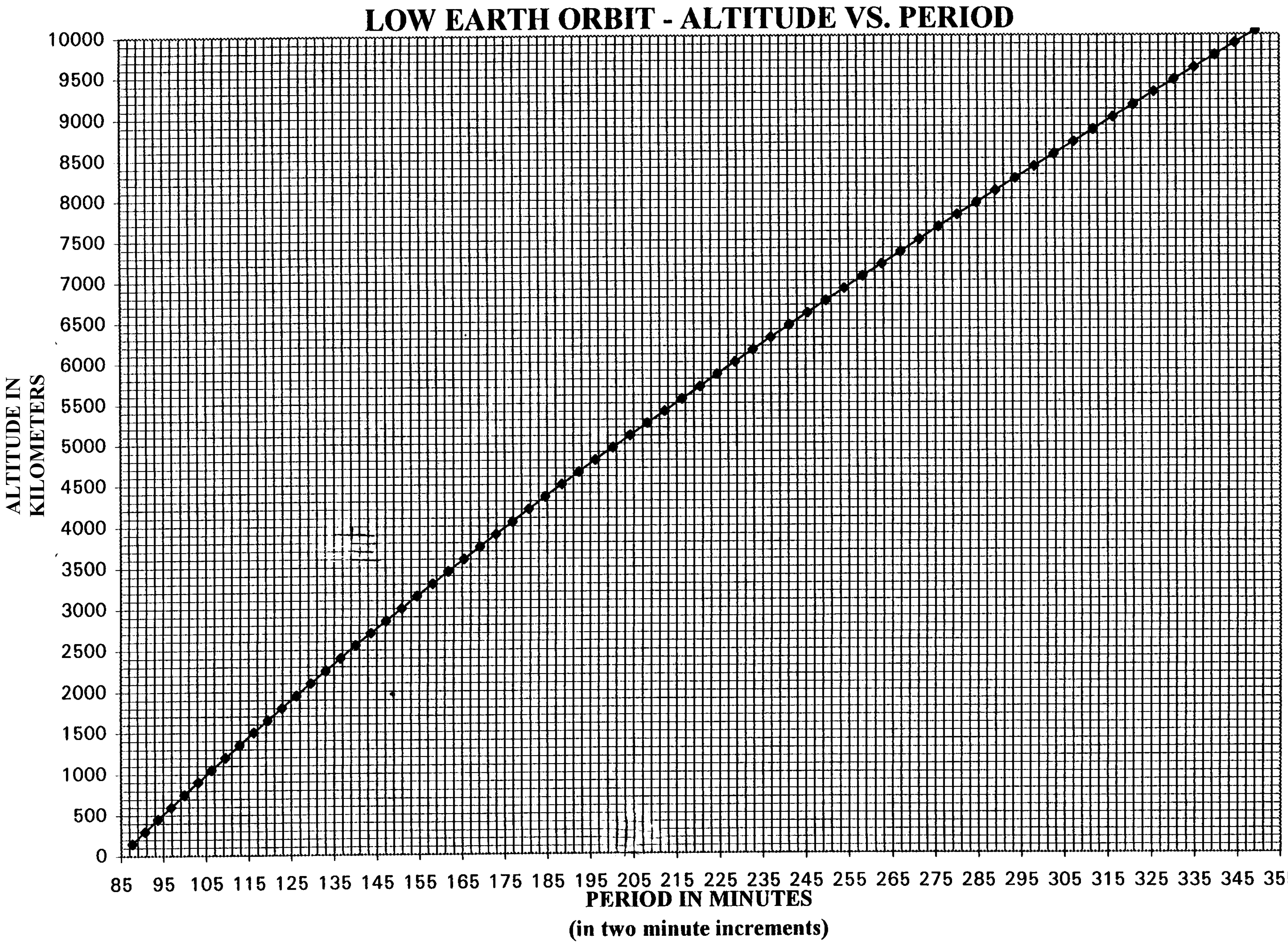
V

VHF	Very High Frequency
VLF	Very-Low Frequency

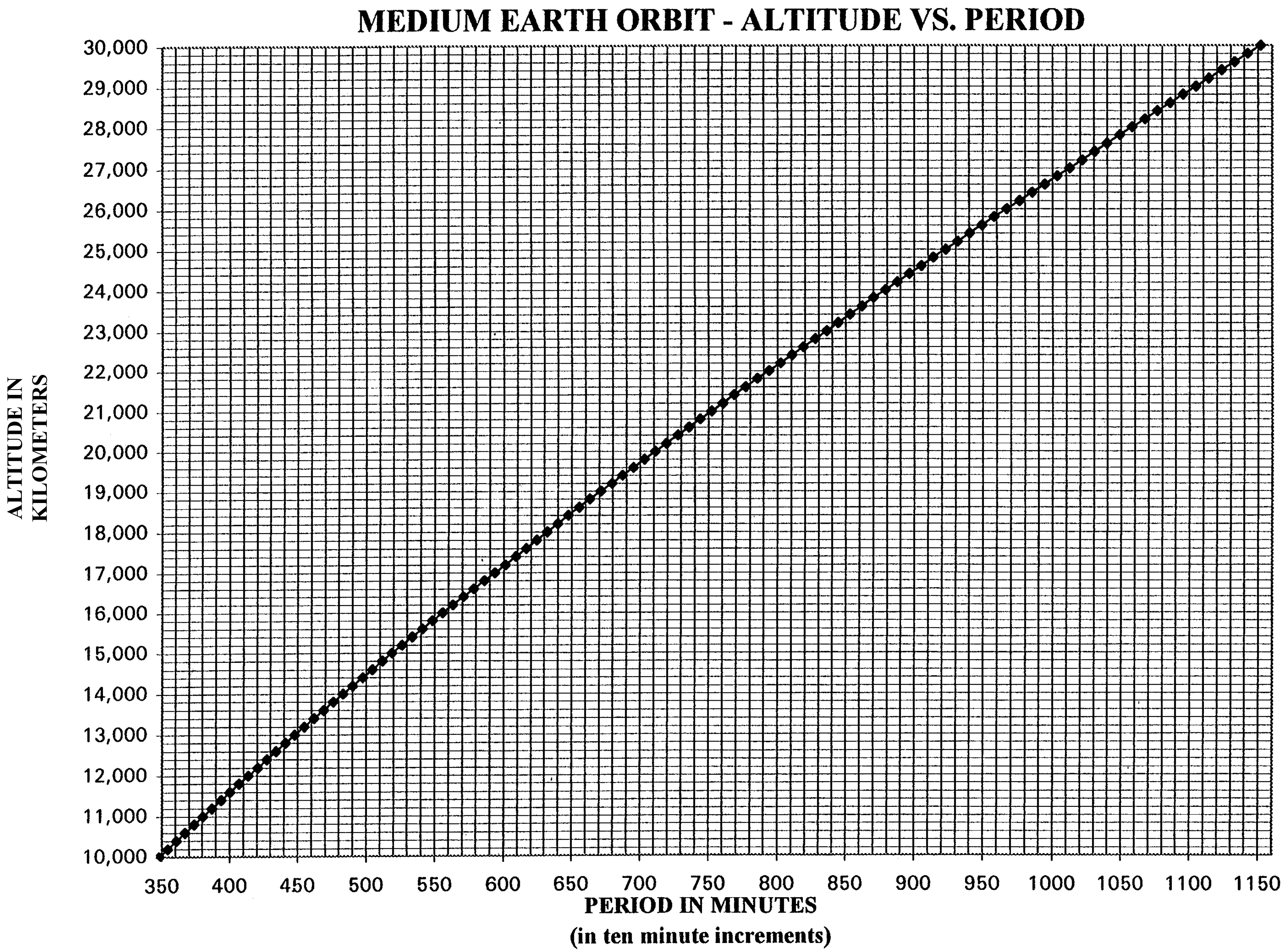
W

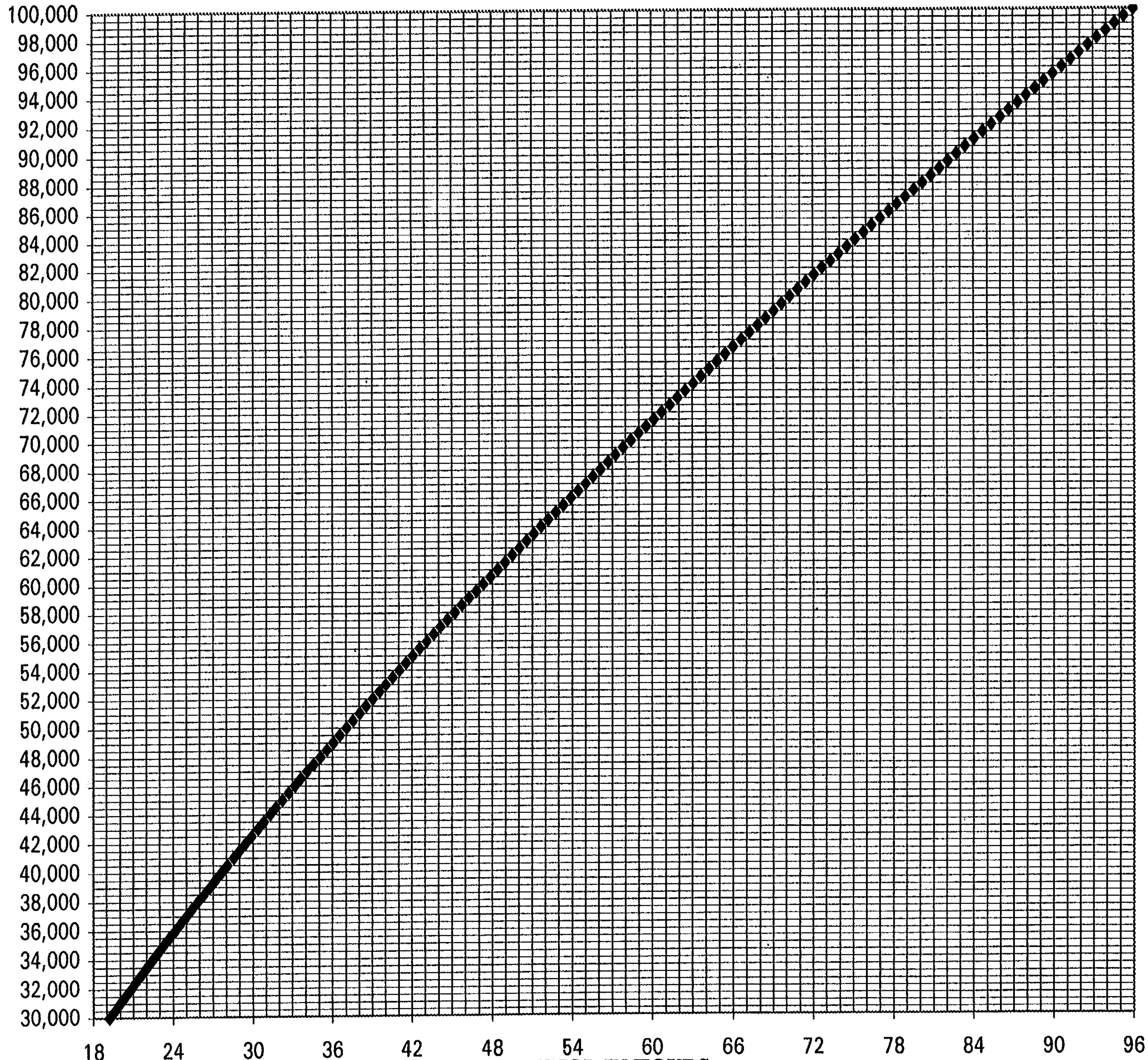
WAAS	Wide Area Augmentation System
WAGE	Wide Area GPS Enhancement
WEFAX	Weather Facsimile
WSMR	White Sands Missile Range

TOC



LOW EARTH ORBIT - ALTITUDE VS. PERIOD
ALTITUDE IN KILOMETERS
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
85 95 105 115 125 135 145 155 165 175 185 195 205 215 225 235 245 255 265 275 285 295 305 315 325 335 345
PERIOD IN MINUTES
(in two minute increments)


MEDIUM EARTH ORBIT - ALTITUDE VS. PERIOD
ALTITUDE IN KILOMETERS
30,000
29,000
28,000
27,000
26,000
25,000
24,000
23,000
22,000
21,000
20,000
19,000
18,000
17,000
16,000
15,000
14,000
13,000
12,000
11,000
10,000
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100
1150
PERIOD IN MINUTES
(in ten minute increments)



PERIOD IN HOURS

(in one hour increments)

DISTANCE CONVERSION FACTORS

STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS
100	86.90	160.94	260	225.93	418.43	580	504.01	933.43
105	91.24	168.98	270	234.62	434.53	600	521.39	965.62
110	95.59	177.03	280	243.31	450.62	620	538.77	997.81
115	99.93	185.08	290	252.00	466.72	640	556.14	1,029.99
120	104.28	193.12	300	260.69	482.81	660	573.52	1,062.18
125	108.62	201.17	310	269.38	498.90	680	590.90	1,094.37
130	112.97	209.22	320	278.07	515.00	700	608.28	1,126.55
135	117.31	217.26	330	286.76	531.09	720	625.66	1,158.74
140	121.66	225.31	340	295.45	547.18	740	643.04	1,190.93
145	126.00	233.36	350	304.14	563.28	760	660.42	1,223.12
150	130.35	241.40	360	312.83	579.37	780	677.80	1,255.30
155	134.69	249.45	370	321.52	595.46	800	695.18	1,287.49
160	139.04	257.50	380	330.21	611.56	820	712.56	1,319.68
165	143.38	265.54	390	338.90	627.65	840	729.94	1,351.87
170	147.73	273.59	400	347.59	643.75	860	747.32	1,384.05
175	152.07	281.64	410	356.28	659.84	880	764.70	1,416.24
180	156.42	289.69	420	364.97	675.93	900	782.08	1,448.43
185	160.76	297.73	430	373.66	692.03	920	799.46	1,480.61
190	165.11	305.78	440	382.35	708.12	940	816.84	1,512.80
195	169.45	313.83	450	391.04	724.21	960	834.22	1,544.99
200	173.80	321.87	460	399.73	740.31	980	851.60	1,577.18
205	178.14	329.92	470	408.42	756.40	1,000	868.98	1,609.36
210	182.49	337.97	480	417.11	772.49	1,020	886.36	1,641.55
215	186.83	346.01	490	425.80	788.59	1,040	903.74	1,673.74
220	191.17	354.06	500	434.49	804.68	1,060	921.11	1,705.93
225	195.52	362.11	510	443.18	820.78	1,080	938.49	1,738.11
230	199.86	370.15	520	451.87	836.87	1,100	955.87	1,770.30
235	204.21	378.20	530	460.56	852.96	1,120	973.25	1,802.49
240	208.55	386.25	540	469.25	869.06	1,140	990.63	1,834.67
245	212.90	394.29	550	477.94	885.15	1,160	1,008.01	1,866.86
250	217.24	402.34	560	486 63	901.24	1,180	1,025.39	1,899.05

DISTANCE CONVERSION FACTORS

STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS
1,200	1,042.77	1,931.24	2,800	2,433.13	4,506.22	6,000	5,213.86	9,656.18
1,250	1,086.22	2,011.70	2,900	2,520.03	4,667.15	6,200	5,387.65	9,978.05
1,300	1,129.67	2,092.17	3,000	2,606.93	4,828.09	6,400	5,561.45	10,299.93
1,350	1,173.12	2,172.64	3,100	2,693.83	4,989.03	6,600	5,735.24	10,621.80
1,400	1,216.57	2,253.11	3,200	2,780.72	5,149.96	6,800	5,909.04	10,943.67
1,450	1,260.02	2,333.58	3,300	2,867.62	5,310.90	7,000	6,082.83	11,265.54
1,500	1,303.46	2,414.05	3,400	2,954.52	5,471.84	7,200	6,256.63	11,587.42
1,550	1,346.91	2,494.51	3,500	3,041.42	5,632.77	7,400	6,430.42	11,909.29
1,600	1,390.36	2,574.98	3,600	3,128.31	5,793.71	7,600	6,604.22	12,231.16
1,650	1,433.81	2,655.45	3,700	3,215.21	5,954.65	7,800	6,778.01	12,553.04
1,700	1,477.26	2,735.92	3,800	3,302.11	6,115.58	8,000	6,951.81	12,874.91
1,750	1,520.71	2,816.39	3,900	3,389.01	6,276.52	8,200	7,125.61	13,196.78
1,800	1,564.16	2,896.85	4,000	3,475.90	6,437.45	8,400	7,299.40	13,518.65
1,850	1,607.61	2,977.32	4,100	3,562.80	6,598.39	8,600	7,473.20	13,840.53
1,900	1,651.05	3,057.79	4,200	3,649.70	6,759.33	8,800	7,646.99	14,162.40
1,950	1,694.50	3,138.26	4,300	3,736.60	6,920.26	9,000	7,820.79	14,484.27
2,000	1,737.95	3,218.73	4,400	3,823.50	7,081.20	9,200	7,994.58	14,806.14
2,050	1,781.40	3,299.20	4,500	3,910.39	7,242.14	9,400	8,168.38	15,128.02
2,100	1,824.85	3,379.66	4,600	3,997.29	7,403.07	9,600	8,342.17	15,449.89
2,150	1,868.30	3,460.13	4,700	4,084.19	7,564.01	9,800	8,515.97	15,771.76
2,200	1,911.75	3,540.60	4,800	4,171.09	7,724.95	10,000	8,689.76	16,093.64
2,250	1,955.20	3,621.07	4,900	4,257.98	7,885.88	10,200	8,863.56	16,415.51
2,300	1,998.65	3,701.54	5,000	4,344.88	8,046.82	10,400	9,037.35	16,737.38
2,350	2,042.09	3,782.00	5,100	4,431.78	8,207.75	10,600	9,211.15	17,059.25
2,400	2,085.54	3,862.47	5,200	4,518.68	8,368.69	10,800	9,384.94	17,381.13
2,450	2,128.99	3,942.94	5,300	4,605.57	8,529.63	11,000	9,558.74	17,703.00
2,500	2,172.44	4,023.41	5,400	4,692.47	8,690.56	11,200	9,732.53	18,024.87
2,550	2,215.89	4,103.88	5,500	4,779.37	8,851.50	11,400	9,906.33	18,346.74
2,600	2,259.34	4,184.35	5,600	4,866.27	9,012.44	11,600	10,080.12	18,668.62
2,650	2,302.79	4,264.81	5,700	4,953.16	9,173.37	11,800	10,253.92	18,990.49
2,700	2,346.24	4,345.28	5,800	5,040.06	9,334.31	12,000	10,427.71	19,312.36

DISTANCE CONVERSION FACTORS

STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS	STATUTE MILES	NAUTICAL MILES	KILOMETERS
12,500	10,862.20	20,117.04	28,000	24,331.33	45,062.18	60,000	52,138.57	96,561.81
13,000	11,296.69	20,921.73	29,000	25,200.31	46,671.54	62,000	53,876.53	99,780.54
13,500	11,731.18	21,726.41	30,000	26,069.29	48,280.91	64,000	55,614.48	102,999.27
14,000	12,165.67	22,531.09	31,000	26,938.26	49,890.27	66,000	57,352.43	106,218.00
14,500	12,600.16	23,335.77	32,000	27,807.24	51,499.63	68,000	59,090.38	109,436.72
15,000	13,034.64	24,140.45	33,000	28,676.22	53,109.00	70,000	60,828.34	112,655.45
15,500	13,469.13	24,945.14	34,000	29,545.19	54,718.36	72,000	62,566.29	115,874.18
16,000	13,903.62	25,749.82	35,000	30,414.17	56,327.72	74,000	64,304.24	119,092.90
16,500	14,338.11	26,554.50	36,000	31,283.14	57,937.09	76,000	66,042.19	122,311.63
17,000	14,772.60	27,359.18	37,000	32,152.12	59,546.45	78,000	67,780.15	125,530.36
17,500	15,207.08	28,163.86	38,000	33,021.10	61,155.82	80,000	69,518.10	128,749.09
18,000	15,641.57	28,968.54	39,000	33,890.07	62,765.18	82,000	71,256.05	131,967.81
18,500	16,076.06	29,773.23	40,000	34,759.05	64,374.54	84,000	72,994.00	135,186.54
19,000	16,510.55	30,577.91	41,000	35,628.03	65,983.91	86,000	74,731.96	138,405.27
19,500	16,945.04	31,382.59	42,000	36,497.00	67,593.27	88,000	76,469.91	141,623.99
20,000	17,379.52	32,187.27	43,000	37,365.98	69,202.63	90,000	78,207.86	144,842.72
20,500	17,814.01	32,991.95	44,000	38,234.95	70,812.00	92,000	79,945.81	148,061.45
21,000	18,248.50	33,796.63	45,000	39,103.93	72,421.36	94,000	81,683.77	151,280.18
21,500	18,682.99	34,601.32	46,000	39,972.91	74,030.72	96,000	83,421.72	154,498.90
22,000	19,117.48	35,406.00	47,000	40,841.88	75,640.09	98,000	85,159.67	157,717.63
22,500	19,551.97	36,210.68	48,000	41,710.86	77,249.45	100,000	86,897.62	160,936.36
23,000	19,986.45	37,015.36	49,000	42,579.84	78,858.81	102,000	88,635.58	164,155.08
23,500	20,420.94	37,820.04	50,000	43,448.81	80,468.18	104,000	90,373.53	167,373.81
24,000	20,855.43	38,624.73	51,000	44,317.79	82,077.54	106,000	92,111.48	170,592.54
24,500	21,289.92	39,429.41	52,000	45,186.76	83,686.91	108,000	93,849.43	173,811.27
25,000	21,724.41	40,234.09	53,000	46,055.74	85,296.27	110,000	95,587.39	177,029.99
25,500	22,158.89	41,038.77	54,000	46,924.72	86,905.63	112,000	97,325.34	180,248.72
26,000	22,593.38	41,843.45	55,000	47,793.69	88,515.00	114,000	99,063.29	183,467.45
26,500	23,027.87	42,648.13	56,000	48,662.67	90,124.36	116,000	100,801.24	186,686.17
27,000	23,462.36	43,452.82	57,000	49,531.65	91,733.72	118,000	102,539.20	189,904.90
27,500	23,896.85	44,257.50	58,000	50,400.62	93,343.09	120,000	104,277.15	193,123.63

THE SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301 1000

JUL 09 1999

MEMORANDUM FOR SECRETARIES OF THE MILITARY DEPARTMENTS
CHAIRMAN OF THE JOINT CHIEFS OF STAFF
UNDER SECRETARIES OF DEFENSE
DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING
ASSISTANT SECRETARIES OF DEFENSE
GENERAL COUNSEL OF THE DEPARMENT OF DEFENSE
INSPECTOR GENERAL OF THE DEPARTMENT OF DEFENSE
ASSISTANTS TO THE SECRETARY OF DEFENSE
DIRECTORS OF DEFENSE AGENCIES

SUBJECT: Department of Defense Space Policy

Introduction

For over forty years, the United States has led the world in the national security uses of outer space. The last major revision of DoD Space Policy, however, was in 1987 during the Cold War. Major changes have taken place since that time which warrant a significant update to reflect new priorities and the nation's evolving space policies and guidance. The increasing importance of space activities to the security and defense of the United States requires a comprehensive and coherent space policy. Such a policy is necessary to maintain the nation's leadership role in space into the next century and achieve U.S. national security objectives. Accordingly, DoD Space Policy is updated by this memorandum and the issuance of DoD Directive 3100.aa, "Space Policy."

Objectives of this Update

This update accomplishes several important objectives. Specifically, it does the following:

1. Incorporates new policies and guidance promulgated since the last update. This includes the National Space Policy issued by the President in 1996.

2. Addresses the major changes that have taken place since the last update. This includes: the transformation of the international security environment; the promulgation of new national security and national military strategies; changes in the resources allocated to national defense; changes in force structure; lessons learned from the operational employment of space forces; the global spread of space systems, technology, and information; advances in military and information technologies; the growth of commercial space activities; enhanced intersector cooperation; and increased international cooperation.

3. Establishes a comprehensive policy framework for the conduct of space and space-related activities. This framework will help to articulate the need for capabilities, guide the allocation of resources, and direct programmatic activities.

Themes of this Update

National Interest. Space is a medium like the land, sea, and air within which military activities will be conducted to achieve U.S. national security objectives. The ability to access and utilize space is a vital national interest because many of the activities conducted in the medium are critical to U.S. national security and economic well-being. The globally interdependent information- and knowledge-based economy as well as information-based military operations make the information lines of communication to, in, through, and from space essential to the exercise of U.S. power.

Strategic Enabler. Space power is as important to the nation as land, sea, and air power. It is a strategic enabler of the National Military Strategy and Joint Vision 2010. Space forces support the execution of strategy and the realization of doctrine by enabling information superiority through domination of the collection, generation, and dissemination of information. The command, control, communications, intelligence, surveillance, and reconnaissance (C3ISR) capabilities provided by space forces are necessary to maintain military readiness, enable implementation of the operational concepts of dominant maneuver, precision engagement, focused logistics, and full dimensional protection, and support the planning and conduct of military operations.

Information Superiority. Space forces provide significant capabilities to help integrate and deliver C3ISR support to U.S. military forces and, if directed, deny such support to an adversary. They help enable Combatant Commanders and operational forces to synthesize information and dictate the timing and tempo of operations. Achieving space and information superiority will help to counter an adversary's ability to command and control its forces. Access to and use of space will help enable the United States to establish and sustain the battlespace dominance and information superiority necessary to achieve success in military operations.

Deterrence. Space forces are integral to the deterrent posture of the U.S. armed forces. They help to ensure that preparations for and initiation of hostile actions will be discovered in a timely manner. Effective use of space forces will support the credible threat of force and its application in response to aggression. Space forces thus may introduce an element of uncertainty into the minds of potential adversaries about whether they can achieve their aims. Space forces are critical to the ability of the United States to ensure the costs of the threat or use of force against our interests are unacceptable to potential aggressors. The deterrence of aggression and the defense of the United States and its allies will be strengthened by ensuring that an adversary can not obtain an asymmetric advantage by countering our space capabilities or using space systems or services for hostile purposes.

Defense. Space forces contribute to the overall effectiveness of U.S. military forces in the event deterrence fails. The high technology force multipliers provided by space systems enhance the combat power of military forces. The capability to control space, if directed, will contribute to achieving the full dimensional protection, battlespace dominance, and information superiority necessary for success in military operations. Similarly, the ability to perform space force application in the future could add a new dimension to U.S. military power. Space forces thus will enable the United States to compel an adversary to cease and desist from the pursuit of its aims through the use of necessary and proportional force.

Freedom of Space. Ensuring the freedom of space and protecting U.S. national security interests in the medium are priorities for space and space-related activities. U.S. space systems are national property afforded the right of passage through and operations in space without interference. In this regard, space is much like the high seas and international airspace. The political, military, and economic value of the nation's activities in space, however, may provide a motive for an adversary to counter U.S. space assets. Purposeful interference with U.S. space systems will be viewed as an infringement on our sovereign rights. The U.S. may take all appropriate self-defense measures, including, if directed by the National Command Authorities, the use of force, to respond to such an infringement on our rights.

Integration. Space capabilities and applications will be integrated into the strategy, doctrines, concepts of operations, education, training, exercises, and operations and contingency plans of U.S. military forces. Space force structure, missions, capabilities, and applications will be incorporated into Professional Military Education as well as Joint and Service training and exercises to ensure appropriately educated and trained personnel are provided to all levels of military staffs and forces. A space-literate military with the necessary understanding of space operations and the ability to exploit fully space applications is critical to achieve national security objectives.

Defense-Intelligence Cooperation. Management of national security space activities will focus on improving the coordination and, as appropriate, integration of defense and Intelligence Community space activities. An integrated national security space architecture will minimize unnecessary duplication, achieve efficiencies in acquisition and future operations, and thereby improve support to military operations.

Intersector Cooperation. The establishment of partnerships between the defense space sector and the intelligence, civil, and commercial space sectors will enable the leveraging of scarce resources and reduce the cost of acquiring, operating, and supporting operational space force capabilities. Such partnerships will help to free scarce resources to focus defense investments on areas where there are limited incentives for the U.S. intelligence, civil, or commercial space sectors to pursue as well as sustain a robust U.S. space industrial base.

International Cooperation. Space forces provide a national advantage to the United States and are an important element within coalition strategy where America can contribute unique capabilities for international security. Although the U.S. will maintain the ability to act independently, coalition military operations are increasingly the norm. Deploying forces in cooperation with those of other countries increases the importance of interoperability. Space systems are capable of performing missions that place a premium on interoperability by providing access to common user systems, processes, and information. They enable military forces to operate in a combined environment in a more efficient and effective manner. Space forces enhance forward presence by providing the means to support commitments while minimizing risk to U.S. personnel. Integrating space capabilities into combined operations through cooperative activities will strengthen the defense relationships and alliance structures that help to underpin U.S. national security.

Purposes of the Document

DoD Directive 3100.aa, "Space Policy," establishes policy and assigns responsibilities for space and space-related activities. It implements PDD-NSC-49/NSTC-8, "National Space Policy" and supersedes the February 4, 1987, Secretary of Defense Memorandum, "Department of Defense Space Policy," and DoD Directive 3500.1, "Defense Space Council."

Attachments:
a/s

cc: Director of Central Intelligence

Department of Defense
DIRECTIVE

NUMBER 3100.10
July 9, 1999

ASD(C3I)

SUBJECT: Space Policy

References: (a) PDD-NSC-49/NSTC-8, "National Space Policy (U)," September 14, 1996
(b) Secretary of Defense Memorandum, "Department of Defense Space Policy" (U), February 4, 1987 (hereby canceled)
(c) DoD Directive 3500.1, "Defense Space Council," December 29, 1988 (hereby canceled)
(d) The White House, "A National Security Strategy for a New Century," October 1998
(e) through (nn), see enclosure 1

1. PURPOSE

This Directive:

1.1. Establishes policy and assigns responsibilities for space and space-related matters within the Department of Defense.

1.2. Implements reference (a), supersedes references (b) and (c), and supports and amplifies references (a) and (d) through (nn).

1.3. Authorizes publication of additional DoD issuances consistent with this Directive and references (a) and (d) through (nn).

2. APPLICABILITY AND SCOPE

2.1. This Directive applies to the Office of the Secretary of Defense, the Military Departments (including the Coast Guard when it is operating as a Military Service in the Department of the Navy), the Chairman of the Joint Chiefs of Staff, the Combatant Commands, the Inspector General of the Department of Defense, the Defense Agencies, and the DoD Field Activities (hereafter referred to collectively as "the DoD Components"). The term "Military Services," as used herein, refers to the Army, the Navy, the Air Force, and the Marine Corps.

2.2. The scope of this Directive includes the policy, requirements generation, planning, financial management, research, development, testing, evaluation, acquisition, education, training, doctrine, exercise, operation, employment, and oversight of space and space-related activities within the Department of Defense.

3. DEFINITIONS

Terms used in this Directive are defined in enclosure 2.

4. POLICY

It is DoD policy that:

4.1. Space is a medium like the land, sea, and air within which military activities shall be conducted to achieve U.S. national security objectives. The ability to access and utilize space is a vital national interest because many of the activities conducted in the medium are critical to U.S. national security and economic well-being.

4.2. Ensuring the freedom of space and protecting U.S. national security interests in the medium are priorities for space and space-related activities. U.S. space systems are national property afforded the right of passage through and operations in space without interference, in accordance with reference (a).

4.2.1. Purposeful interference with U.S. space systems will be viewed as an infringement on our sovereign rights. The U.S. may take all appropriate self-defense measures, including, if directed by the National Command Authorities (NCA), the use of force, to respond to such an infringement on U.S. rights.

4.3. The primary DoD goal for space and space-related activities is to provide operational space force capabilities to ensure that the United States has the space power to achieve its national security objectives, in accordance with reference (d). Contributing goals include sustaining a robust U.S. space industry and a strong, forward-looking technology base.

4.3.1. Space activities shall contribute to the achievement of U.S. national security objectives, in accordance with reference (a), by:

4.3.1.1. Providing support for the United States' inherent right of self-defense and defense commitments to allies and friends.

4.3.1.2. Assuring mission capability and access to space.

4.3.1.3. Deterring, warning, and, if necessary, defending against enemy attack.

4.3.1.4. Ensuring that hostile forces cannot prevent the United States' use of space.

4.3.1.5. Ensuring the United States' ability to conduct military and intelligence space and space-related activities.

4.3.1.6. Enhancing the operational effectiveness of U.S. and allied forces.

4.3.1.7. Countering, if necessary, space systems and services used for hostile purposes.

4.3.1.8. Satisfying military and intelligence requirements during peace and crisis as well as through all levels of conflict.

4.3.1.9. Supporting the activities of national policy-makers, the Intelligence Community, the NCA, Combatant Commanders and the Military Services, other Federal officials, and continuity of Government operations.

4.4. Mission Areas. Capabilities necessary to conduct the space support, force enhancement, space control, and force application mission areas shall be assured and integrated into an operational space force structure that is sufficiently robust, ready, secure, survivable, resilient, and interoperable to meet the needs of the NCA, Combatant Commanders, Military Services, and intelligence users across the conflict spectrum.

4.5. Assured Mission Support. The availability of critical space capabilities necessary for executing national security missions shall be assured, in accordance with references (a) and (e) through (h). Such support shall be considered and implemented at all stages of requirements generation, system planning, development, acquisition, operation, and support. Assured mission capability shall be assessed and taken into account in determining tradeoffs among cost, performance, resilience, lifetime, protection, survivability, and related factors. Access to space, robust satellite control, effective surveillance of space, timely constellation replenishment/reconstitution, space system protection, and related information assurance, access to critical electromagnetic frequencies, critical asset protection, critical infrastructure protection, force protection, and continuity of operations shall be ensured to satisfy the needs of the NCA, Combatant Commanders, Military Services, and the intelligence users across the conflict spectrum.

4.6. Planning. Planning for space and space-related activities shall focus on improving the conduct of national security space operations, assuring mission support, and enhancing support to military operations and other national security objectives. Such planning shall also identify missions, functions, and tasks that could be performed more efficiently and effectively by space forces than terrestrial alternatives.

4.6.1. Long-range planning objectives for space capabilities are to:

4.6.1.1. Ensure U.S. leadership through revolutionary technological approaches in critical areas.

4.6.1.2. Develop a responsive, customer-focused architecture that simplifies operations and use.

4.6.1.3. Ensure civil and commercial capabilities are used to the maximum extent feasible and practical (including the use of allied and friendly capabilities, as appropriate), consistent with national security requirements.

4.6.1.4. Provide assured, cost-effective, responsive access to space.

4.6.1.5. Contribute to a comprehensive command, control, communications, intelligence, surveillance, and reconnaissance architecture that integrates space, airborne, land, and maritime assets.

4.6.1.6. Ensure space systems are seamlessly integrated within a globally accessible and secure information infrastructure.

4.6.1.7. Provide appropriate national security space services and information to the intelligence, civil, commercial, scientific, and international communities.

4.6.1.8. Provide space control capabilities consistent with Presidential policy as well as U.S. and applicable international law.

4.6.1.9. Protect national security space systems to ensure mission execution.

4.6.1.10. Explore force application concepts, doctrine, and technologies consistent with Presidential policy as well as U.S. and applicable international law.

4.6.1.11. Promote a trained, space-literate national security workforce able to utilize fully space capabilities for the full spectrum of national security operations.

4.6.2. Architectures. An integrated national security space architecture, including space, ground, and communications link segments, as well as user interfaces and equipment, shall be developed to the maximum extent feasible. Such an integrated architecture shall address defense and intelligence missions and activities to eliminate unnecessary vertical stove-piping of programs, minimize unnecessary duplication of missions and functions, achieve efficiencies in acquisition and future operations, provide strategies for transitioning from existing architectures, and thereby improve support to military operations and other national security objectives.

4.6.2.1. Space architectures shall be structured to take full advantage, as appropriate, of defense, intelligence, civil, commercial, allied, and friendly space capabilities. Such architectures shall also include, as appropriate, system, operational, and technical architecture descriptions. Joint technical standards drawn from widely accepted commercial standards, consistent with national security requirements, shall provide the basis for new system integration where appropriate. Appropriate interoperability and standards mandates shall be observed to enable the interoperability of space services.

4.6.2.2. Space architectures should be designed for appropriate levels of mission optimization, availability, and survivability in all aspects of on-orbit configurations and associated infrastructure. Planning shall emphasize the need for responsiveness and the elimination of vulnerabilities that could prevent mission accomplishment.

4.7. Augmentation. Requirements, arrangements, and procedures, including cost sharing and reciprocity arrangements, for augmentation of the space force structure by civil, commercial, allied, and friendly space systems shall be identified in coordination with the Director of Central Intelligence, as appropriate, and shall be planned and implemented in accordance with reference (a).

4.8. Mobilization and Preparedness. Space forces and their supporting industrial base shall be integrated into the defense mobilization planning process. Specific programs, facilities, and personnel shall be identified and incorporated into relevant critical assets and items lists, in accordance with references (e), (g), (i) and (j).

4.9. Support to Commercial Space Activities. Stable and predictable U.S. private sector access to appropriate DoD space-related hardware, facilities, and data shall be facilitated consistent with national security requirements, in accordance with references (a) and (k). The U.S. Government's right to use such hardware, facilities, and data on a priority basis to meet national security and critical civil sector requirements shall be preserved.

4.10. Translating Operational Needs into Programs. Space programs and activities shall be responsive to mission area shortfalls, validated operational needs, and operational requirements. Requirements, resources, and acquisition activities, where applicable, shall be documented in the requirements generation system, the acquisition management system, and the planning, programming, and budgeting system. Space shall be considered as a medium for conducting any operation where mission success and effectiveness would be enhanced relative to other media.

4.10.1. Cost as an Independent Variable. Cost, as an independent variable, shall be applied in all architecture development processes to ensure requiring organizations understand cost drivers and weigh all requirements against their associated costs.

4.10.2. Acquisition. Acquisition strategies shall usually include: an overview of the system's capabilities and concept of operations desired for the full system; a flexible overall architecture, which includes a process for change; an emphasis on open systems design, flexible technology insertion, and rigorous technology demonstrations; rapid achievement of incremental capability in response to time-phased statements of operational requirements; and close and frequent communications with users. At program initiation, the acquisition strategy submitted for the cognizant acquisition authority's approval shall describe whether an evolutionary approach is appropriate, and, if so, how the program manager will implement the approach. Progression to an additional level of capability beyond the first increment requires the cognizant acquisition authority's approval and shall be based on a review of evolving requirements and technology development.

4.10.3. Preference for Commercial Acquisition. Lengthy mission specifications shall be balanced against opportunities for technology insertion, taking into consideration commercial-off-the-shelf solutions for national security items, non-developmental items, and national security adaptations of commercial items. Acquisition of national security-unique systems shall not be authorized, in general, unless suitable and adaptable commercial alternatives are not available. Such cooperation should be based on the principles of reciprocity and tangible mutual benefits and should be pursued in a manner that reasonably protects and balances U.S. national security and economic interests.

4.10.4. Science and Technology. Leading-edge technologies that address identified mission area deficiencies shall be investigated. Investments for such technology shall feature a suitable mix of theoretical research and scientific exploration and applications which support the joint vision for military operations and other national security objectives.

4.10.5. Demonstration and Experimentation. Technology applications that address mission area deficiencies shall be demonstrated. Such demonstrations shall involve both the developmental and operational elements of the DoD Components and shall be pursued to identify the value of emerging technology to the warfighter and the national security community.

4.10.6. Research and Development. Commercial systems and technologies shall be leveraged and exploited whenever possible. Research and development investments shall focus on unique national security requirements which have no known potential, or insufficient potential, for civil or commercial sector exploitation or which require protection from disclosure. Forecasts of long-term needs shall guide investments using sound business criteria to ensure they have reasonable internal rates of return compared with alternatives.

4.10.7. Test and Evaluation. Test and evaluation programs shall be structured to provide essential information to decision-makers, assess attainment of technical performance parameters, and determine whether systems are operationally effective, suitable, and survivable for intended use. Operational test and evaluation activities shall plan and conduct operational tests, report results, and provide evaluations of effectiveness and suitability.

4.10.8. Modeling and Simulation. Models and simulations shall be used to reduce the time, resources, and risks of the acquisition process and increase the quality of the systems being acquired. Space capabilities and applications shall be integrated into campaign-level and other models and simulations. Models and simulations shall focus on demonstrating the military worth and other value of both friendly and adversary space capabilities and applications to mission accomplishment.

4.10.9. Sustainment. Production procurement decisions for space systems shall be based on careful analysis of the advantages of multi-year procurements and high order quantity buys against the disadvantage of technology obsolescence, threat changes, and cost to store and maintain launch readiness of satellites. For a given satellite program, such sustainment acquisitions shall store no more than the number of satellites authorized for the particular constellation plus adequate attrition reserves. Production rate decisions shall be based on retention of critical industrial base and space system readiness maintenance.

4.10.10. Partnerships with Industry. Partnerships with industry shall be pursued to research, develop, acquire, and sustain space systems and associated infrastructure.

4.10.11. Outsourcing and Privatization. Opportunities to outsource or privatize space and space-related functions and tasks, which could be performed more efficiently and effectively by the private sector, shall be investigated aggressively, consistent with the need to protect national security and public safety. Clear lines of accountability to Combatant Commanders shall be demonstrated and documented in the employment of such resources.

4.10.12. Electromagnetic Spectrum Management. Assured access to the electromagnetic spectrum is a critical factor in spacecraft system design, acquisition, and operations and shall be an important consideration in the development and procurement of a space system. Electromagnetic spectrum for space systems, once chosen, shall be legally authorized for use in accordance with references (l) and (m) as well as national and applicable international policies.

4.11. Operations. Space capabilities shall be operated and employed to: assure access to and use of space; deter and, if necessary, defend against hostile actions; ensure that hostile forces cannot prevent U.S. use of space; ensure the United States' ability to conduct military and intelligence space and space-related activities; enhance the operational effectiveness of U.S., allied, and friendly forces; and counter, when directed, space systems and services used for hostile purposes.

4.11.1. Integration. Space capabilities and applications shall be integrated into the strategy, doctrine, concepts of operations, education, training, exercises, and operations and contingency plans of U.S. military forces. Space support to the lowest appropriate level, including the lowest tactical level, shall be emphasized and optimized to ensure that all echelons of command understand and exploit fully the operational advantages which space systems provide, understand their operational limitations, and effectively use space capabilities for joint and combined operations.

4.11.2. Education, Training, and Exercises. Information about space force structure, missions, capabilities, and applications shall be incorporated into Professional Military Education as well as Joint and Service training and exercises to provide appropriately educated and trained personnel to all levels of joint and component military staffs and forces. Space missions and capabilities, the ability to operate under foreign surveillance or against an adversary enhanced by space capabilities, and the ability to compensate for capability loss shall be integrated into appropriate Joint and Service exercises.

4.11.3. National Guard and Reserve Forces. A total force approach shall be used in structuring and resourcing space force capabilities and ensuring interoperability among active, National Guard, and Reserve forces.

4.11.4. Military Personnel-in-Space. The unique capabilities that can be derived from the presence of humans in space may be utilized to the extent feasible and practical to perform in-space research, development, testing, and evaluation as well as enhance existing and future national security space missions. This may include exploration of military roles for humans in space focusing on unique or cost-effective contributions to operational missions.

4.11.5. Space Debris. The creation of space debris shall be minimized, in accordance with reference (a). Design and operation of space tests, experiments, and systems shall strive to minimize or reduce the accumulation of such debris consistent with mission requirements and cost effectiveness.

4.11.6. Spacecraft End-of-Life. Spacecraft disposal at the end of mission life shall be planned for programs involving on-orbit operations. Spacecraft disposal shall be accomplished by atmospheric reentry, direct retrieval, or maneuver to a storage orbit to minimize or reduce the impact on future space operations.

4.11.7. Spaceflight Safety. All DoD activities to, in, through, or from space, or aimed above the horizon with the potential to inadvertently and adversely affect satellites or humans in space, shall be conducted in a safe and responsible manner that protects space systems, their mission effectiveness, and humans in space, consistent with national security requirements. Such activities shall be coordinated with U.S. Space Command, as appropriate, for predictive avoidance or deconfliction with U.S., friendly, and other space operations.

4.11.8. Nuclear Power Sources in Space. Space nuclear reactors shall not be used in Earth orbit without the approval of the President or his designee, in accordance with references (a) and (n). Requests for such approval shall take into account public safety, economic considerations, treaty obligations, and U.S. national security and foreign policy interests.

4.12. Intersector Cooperation. Enhanced cooperation with the intelligence, civil, and commercial space sectors shall be pursued to ensure that all U.S. space sectors benefit from the space technologies, facilities, and support services available to the nation. Such cooperation shall share or reduce costs, minimize redundant capabilities, minimize duplication of missions and functions, achieve efficiencies in acquisition and future operations, improve support to military operations, and sustain a robust U.S. space industry and a strong, forward-looking space technology base. Improvement of the coordination and, as appropriate, integration of defense and intelligence space activities shall be a priority. Procedures shall be established for the timely transfer of DoD-developed space technology to the private sector consistent with the need to protect national security, in accordance with reference (a).

4.13. International Cooperation. International cooperation and partnerships in space activities shall be pursued with the United States' allies and friends to the maximum extent feasible, in accordance with reference (a), Section 104(e) of reference (o) and references (p) through (s). Such cooperation shall forge closer security ties with U.S. allies and friends, enhance mutual and collective defense capabilities, and strengthen U.S. economic security. It shall also strengthen alliance structures, improve interoperability between U.S. and allied forces, and enable them to operate in a combined environment in a more efficient and effective manner. Such cooperation shall be based on the principles of reciprocity and tangible, mutual benefit and shall take into consideration U.S. equities from a broad foreign policy perspective. Such cooperation shall be pursued in a manner, which protects both U.S. national security and economic security and is consistent with U.S. arms control, nonproliferation, export control, and foreign policies.

4.14. Intelligence Support. A high priority shall be placed on the collection, analysis, and timely dissemination of intelligence information to support space and space-related policy-making, requirements generation, research, development, testing, evaluation, acquisition, operations, and employment. Requirements for such intelligence support shall be identified, prioritized, and submitted through established processes to produce timely, useful intelligence products, in accordance with reference (t).

4.15. Arms Control and Related Activities. Space and space-related activities shall comply with applicable presidential policies as well as applicable domestic and international law. Space forces planning shall include the provision of appropriate responses to possible breakouts from existing arms control treaties and agreements. The President shall be advised on the military significance of potential space arms control agreements and other related measures being considered for international implementation. Positions and policies regarding arms control and related activities shall preserve the rights of the United States to conduct research, development, testing, and operations in space for military, intelligence, civil, and commercial purposes, in accordance with reference (a).

4.16. Nonproliferation and Export Controls. The Missile Technology Control Regime is the primary tool of U.S. missile nonproliferation policy, in accordance with references (a) and (u). Space systems, technology, and information that could be used in a manner detrimental to U.S. national security interests shall be protected. Measures shall be taken to protect technologies, methodologies, information, and overall system capabilities and vulnerabilities, which sustain advantages in space capabilities and continued technological advancements. Measures shall also be taken to maintain appropriate controls over those technologies, methodologies, information, and capabilities, which could be sold or transferred to foreign recipients. Other countries' practices, U.S. foreign policy objectives, and encouragement of free and fair trade in commercial space activities shall be taken into account when considering whether to enter into space-related agreements.

4.17. Trade in Space Goods and Services. The national security implications of decisions related to the trade of U.S.-manufactured space goods and services, as well as frequency spectrum and landing rights, shall be identified and assessed. Such decisions shall seek to balance concerns about the proliferation of critical technologies and information with national security space applications and the interests of the U.S. space industry and U.S. foreign policy.

4.17.1. The commercial value of intellectual property developed with U.S. Government support shall be protected. Technology transfers resulting from international cooperation shall not undermine national security or industrial competitiveness, in accordance with reference (a).

4.17.2. Foreign military sales of U.S. space hardware, software, and related technologies may be used to enhance security relationships with strategically important countries subject to overall U.S. Government policy guidelines.

4.18. Security. Security measures shall be implemented to protect all classified aspects of space and space-related activities, in accordance with references (a) and (v) through (x) and other applicable security directives. Space missions shall be conducted in a manner intended to prevent unauthorized knowledge of and use of capabilities for countering specific missions or systems. The status and capabilities of on-orbit and terrestrial elements of the space force structure, deployment and replenishment strategies, planned, programmed, and operational objectives, and launch dates shall be classified, as appropriate, taking into account the value of needed protection for national security interests as compared with the public interests that would be served by release of such information. Technology transfer, including the direct or indirect sharing of information and resources with foreign governments or foreign-owned or -controlled contractors, shall be subject to reference (x) and other relevant security policies.

4.19. Public Affairs. Public affairs activities shall be conducted to provide general information to the public about space and space-related activities consistent with the need to protect national security information. Publication of unclassified information about the contributions of space forces to national security and other national interests shall be encouraged. Specific guidance for public affairs release shall be structured, as necessary, to protect the identity, mission, and associated operations of classified space and space-related activities.

5. RESPONSIBILITIES

Consistent with Section 105 of reference (o) and reference (y):

5.1. The Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD(C3I)), in accordance with reference (z), shall:

5.1.1. Serve as the principal staff assistant and advisor to the Secretary and Deputy Secretary of Defense and focal point within the Department of Defense for space and space-related activities.

5.1.2. Develop, coordinate, and oversee the implementation of policies regarding space and space-related activities and, in coordination with the Under Secretary of Defense for Policy, ensure that space policy decisions are closely integrated with overall national security policy considerations.

5.1.3. Oversee the development and execution of space and space-related architectures, acquisition, and technology programs, in coordination, as appropriate, with the Under Secretary of Defense for Acquisition and Technology.

5.1.4. Oversee the Director of the National Security Agency's compliance with this Directive in accordance with reference (aa).

5.1.5. Oversee the Director of the Defense Intelligence Agency's compliance with this Directive in accordance with references (bb) and (cc).

5.1.6. Oversee the Director of the National Reconnaissance Office's management and execution of the National Reconnaissance Program to meet the U.S. Government's needs through the research, development, acquisition, and operation of spaceborne reconnaissance systems in accordance with references (dd) and (ee).

5.1.7. Oversee the Director of the National Imagery and Mapping Agency's compliance with this Directive in accordance with reference (ff).

5.1.8. Oversee the Director of the Defense Information Systems Agency's compliance with this Directive in accordance with reference (gg).

5.1.9. Oversee the National Security Space Architect's compliance with this Directive in accordance with reference (hh).

5.2. The Under Secretary of Defense for Acquisition and Technology, in accordance with reference (ii), shall serve as the Acquisition Executive for space programs that are designated Major Defense Acquisition Programs and, in coordination with the ASD(C3I), oversee space and space-related acquisition and technology programs.

5.3. The Under Secretary of Defense for Policy, in accordance with reference (jj), shall:

5.3.1. Ensure that space policy decisions are closely integrated with overall national security policy considerations, in coordination with the ASD(C3I).

5.3.2. Review all Combatant Commander operations and contingency plans to ensure proposed employment of space forces are coordinated and consistent with DoD policy and the National Military Strategy.

5.4. The Under Secretary of Defense, Comptroller (USD(C)) shall comply with this Directive in accordance with reference (kk).

5.5. The General Counsel of the Department of Defense shall provide legal advice and assistance to the Secretary and Deputy Secretary of Defense, and, as appropriate, other DoD Components on all aspects of space and space-related activities, including the application of all applicable statutes, directives, regulations, and international agreements, in accordance with reference (ll).

5.6. The Director of Operational Test and Evaluation shall comply with this Directive in accordance with reference (mm).

5.7. The Secretaries of the Military Departments shall comply with this Directive in accordance with reference (y) as well as integrate space capabilities and applications into all facets of their Department's strategy, doctrine, education, training, exercises, and operations of U.S. military forces.

5.8. The Chairman of the Joint Chiefs of Staff (CJCS), in accordance with reference (y), shall:

5.8.1. Establish a uniform system for evaluating the readiness of each Combatant Command and Combat Support Agency to carry out assigned missions by employing space forces.

5.8.2. Develop joint doctrine for the operation and employment of space systems of the Armed Forces and formulate policies for the joint space training of the Armed Forces and for coordinating the space military education and training of the members of the Armed Forces.

5.8.3. Integrate space forces and their supporting industrial base into the Joint Strategic Capabilities Plan mobilization annex and formulate policies for the integration of National Guard and Reserve forces into joint space activities.

5.8.4. Provide guidance to Combatant Commanders for planning and employment of space capabilities through the joint planning process.

5.9. The Combatant Commanders shall:

5.9.1. Consider space in the analysis of alternatives for satisfying mission needs as well as develop and articulate military requirements for space and space-related capabilities.

5.9.2. Integrate space capabilities and applications into contingency and operations plans as well as plan for the employment of space capabilities within their Area of Responsibility.

5.9.3. Provide input for evaluations of the preparedness of their Combatant Command to carry out assigned missions by employing space capabilities.

5.9.4. Coordinate on Commander in Chief of U.S. Space Command campaign plans and provide supporting plans as directed by the CJCS.

5.9.5. Plan for and provide force protection, in coordination with the Commander in Chief of U.S. Space Command, for space forces assigned, deployed, and operating in their Area of Responsibility.

5.9.6. The Commander in Chief of U.S. Space Command, in accordance with reference (nn), shall:

5.9.6.1. Serve as the single point of contact for military space operational matters, except as otherwise directed by the Secretary of Defense.

5.9.6.2. Conduct space operations, including support of strategic ballistic missile defense for the United States.

5.9.6.3. Coordinate and conduct space campaign planning through the joint planning process in support of the National Military Strategy.

5.9.6.4. Advocate space (including force enhancement, space control, space support, and force application) and missile warning requirements of other Combatant Commanders.

6. EFFECTIVE DATE

This Directive is effective immediately.

Secretary of Defense

Enclosures - 2
- E1. References, continued
- E2. Definitions

E1. ENCLOSURE 1

REFERENCES, continued

(e) PDD-NSC-63, "Critical Infrastructure Protection," May 22, 1998
(f) PDD-NSC-67, "Enduring Constitutional Government and Continuity of Government Operations (U)," October 21, 1998
(g) DoD Directive 5160.54, "Critical Asset Assurance Program (CAAP)," January 20, 1998
(h) DoD Directive 3020.26, "Continuity of Operations Policy and Planning," May 26, 1995
(i) E.O. 12919, "National Defense Industrial Resources Preparedness," June 6, 1994
(j) E.O. 12656, "Assignment of Emergency Preparedness Responsibilities," November 18, 1988
(k) DoD Directive 3230.3, "DoD Support for Commercial Space Launch Activities," October 14, 1986
(l) DoD Directive 4650.1, "Management and Use of the Radio Frequency Spectrum," June 24, 1987
(m) DoD Directive 3222.3, "Department of Defense Electromagnetic Compatibility Program," August 20, 1990
(n) National Security Council Memorandum, "Revision to NSC/PD-25, dated December 14, 1977, entitled Scientific or Technological Experiments with Possible Large Scale Adverse Environmental Effects and Launch of Nuclear Systems into Space," May 17, 1995
(o) National Security Act of 1947, as amended
(p) DoD Directive 2000.9, "International Co-Production Projects and Agreements Between the United States and Other Countries or International Organizations," January 23, 1974
(q) PDD-NSC-23, "U.S. Policy on Foreign Access to Remote Sensing Space Capabilities (U)," March 9, 1994
(r) PDD-NSTC-2, "Convergence of U.S. Polar-Orbiting Operational Environmental Satellite Systems," May 5, 1994
(s) PDD-NSTC-6, "U.S. Global Positioning System Policy," March 28, 1886
(t) DoD Directive 5240.1, "Intelligence Activities," April 25, 1988
(u) PDD-NSC-13, "Nonproliferation and Export Controls (U)," September 27, 1993
(v) E.O. 12958, "Classified National Security Information," April 12, 1995
(w) E.O. 12951, "Release of Imagery Acquired by Space-Based National Intelligence Reconnaissance Systems," February 22, 1995
(x) E.O. 12829, "National Industrial Security Program," January 6, 1993

(y) Title 10, United States Code

(z) DoD Directive 5137.1, "Assistant Secretary of Defense for Command, Control, Communications, and Intelligence (ASD(C3I))," February 12, 1992

(aa) DoD Directive 5100.20, "National Security Agency and the Central Security Service," December 23, 1971

(bb) DoD Directive 5105.21, "Defense Intelligence Agency (DIA)," February 18, 1997

(cc) DoD Instruction 5105.58, "Management of Measurement and Signature Intelligence (MASINT)," February 9, 1993

(dd) DoD Directive TS-5105.23, "National Reconnaissance Office (U)," March 27, 1964

(ee) Secretary of Defense and Director of Central Intelligence, "Agreement for the Reorganization of the National Reconnaissance Program (U)," August 11, 1965

(ff) DoD Directive 5105.60, "National Imagery and Mapping Agency," October 11, 1996

(gg) DoD Directive 5105.19, "Defense Information Systems Agency (DISA)," June 25, 1991

(hh) Secretary of Defense and Director of Central Intelligence, "Memorandum of Understanding for National Security Space Management," July 1998

(ii) DoD Directive 5134.1, "Under Secretary of Defense for Acquisition and Technology (USD(A&T))," June 8, 1994

(jj) DoD Directive 5111.1, "Under Secretary of Defense for Policy," March 22, 1995

(kk) DoD 7000.14-R, "Department of Defense Financial Regulations, Volume 1: General Financial Management Information, Systems, and Requirements," January 1999

(ll) DoD Directive 5145.1, "General Counsel of the Department of Defense," December 15, 1989

(mm) DoD Directive 5141.2, "Director of Operational Test and Evaluation," April 2, 1984

(nn) Unified Command Plan (U)

E2. ENCLOSURE 2

DEFINITIONS

E2.1.1. Force Application. Combat operations in, through, and from space to influence the course and outcome of conflict. The force application mission area includes: ballistic missile defense and force projection.

E2.1.2. Force Enhancement. Combat support operations to improve the effectiveness of military forces as well as support other intelligence, civil, and commercial users. The force enhancement mission area includes: intelligence, surveillance, and reconnaissance; tactical warning and attack assessment; command, control, and communications; position, velocity, time, and navigation; and environmental monitoring.

E2.1.3. Space Control. Combat and combat support operations to ensure freedom of action in space for the United States and its allies and, when directed, deny an adversary freedom of action in space. The space control mission area includes: surveillance of space; protection of U.S. and friendly space systems; prevention of an adversary's ability to use space systems and services for purposes hostile to U.S. national security interests; negation of space systems and services used for purposes hostile to U.S. national security interests; and directly supporting battle management, command, control, communications, and intelligence.

E2.1.4. Space Forces. The space and terrestrial systems, equipment, facilities, organizations, and personnel necessary to access, use, and, if directed, control space for national security.

E2.1.5. Space Power. The total strength of a nation's capabilities to conduct and influence activities to, in, through, and from the space medium to achieve its objectives.

E2.1.6. Space Superiority. The degree of dominance in space of one force over another, which permits the conduct of operations by the former and its related land, sea, air, and space forces at a given time and place without prohibitive interference by the opposing force.

E2.1.7. Space Support. Combat service support operations to deploy and sustain military and intelligence systems in space. The space support mission area includes launching and deploying space vehicles, maintaining and sustaining spacecraft on-orbit, and deorbiting and recovering space vehicles, if required.

E2.1.8. Space Systems. All of the devices and organizations forming the space network. These consist of: spacecraft; mission package(s); ground stations; data links among spacecraft, ground stations, mission or user terminals, which may include initial reception, processing, and exploitation; launch systems; and directly related supporting infrastructure, including space surveillance and battle management/command, control, communications, and computers.

Appendix E

ROCKET THEORY

Rocketry encompasses a wide range of topics, each of which takes many years of study to master. This chapter provides an initial foundation toward the study of rocket theory by addressing the physical laws governing motion/propulsion, rocket performance parameters, rocket propulsion techniques, reaction masses (propellants), chemical rockets and advanced propulsion techniques.

PROPULSION BACKGROUND

Rockets are like other forms of propulsion in that they expend energy to produce a thrust force via an exchange of momentum with some reaction mass in accordance with Newton's Third Law of Motion. But rockets differ from all other forms of propulsion since they carry the reaction mass with them (self contained) and are, therefore, independent of their surrounding environment.

Other forms of propulsion depend on their environment to provide the reaction mass. Cars use the ground, airplanes use the air, boats use the water and sailboats use the wind. The rockets we are most familiar with are chemical rockets in which the propellants (reaction mass) are the fuel and oxidizer. With chemical rockets, the propellants are also the energy source. A conventional chemical rocket is a type of internal combustion engine burning fuel and oxidizer in a combustion chamber producing hot, high pressure gases and accelerating them through a nozzle. In electric and nuclear rockets, the propellant is essentially an inert mass.

According to Newton's Second Law, the thrust force is equal to the rate of change of momentum of the ejected matter, which depends on both how much and how fast propellants are used (mass flow rate) and the propellant's speed when it leaves the rocket (effective exhaust velocity).

Like other forms of transportation, rockets consist of the same basic elements such as a structure providing the vehicle framework, propulsion system providing the force for motion, energy source for powering the vehicle systems, guidance system for direction control and last and most important (indeed the reason for having the vehicle at all), the payload. Examples of payloads are passengers, scientific instruments or supplies. When a rocket is used as a weapon for destructive purposes, we call it a *missile*; its payload is a warhead.

Fig. 5-1. Sir Isaac Newton

ROCKET PHYSICS

Sir Isaac Newton (**Fig. 5-1**) set forth the basic laws of motion; the means by which we analyze the rocket principle. Newton's three laws of motion apply to all rocket-propelled vehicles. They apply to gas jets used for attitude control, small rockets used for stage separations or for trajectory corrections and to large rockets used to launch a vehicle from the surface of the Earth. They apply to nuclear, electric and other advanced types of rockets as well as to chemical rockets. Newton's laws of motion are stated briefly as follows:

Newton's 1st Law
(Inertia)

Every body continues in a state of uniform motion in a straight line, unless it is compelled to change that state by a force imposed upon it.

Newton's 2nd Law
(Momentum)

When a force is applied to a body, the time rate of change of momentum is proportional to, and in the direction of, the applied force.

Newton's 3rd Law
(Action—Reaction)

For every action there is a reaction that is equal in magnitude but opposite in direction to the action.

In relating these laws to rocket theory and propulsion, we can paraphrase and simplify them. For example, the first law says, in effect, that the engines must develop enough thrust force to overcome the force of gravitational attraction between the Earth and the launch vehicle. The engines must be able to start the vehicle moving and accelerate it to the desired velocity. Another way of expressing this for a vertical launch is to say that the engines must develop more pounds of thrust than the vehicle weighs.

When applying the second law, we must consider the summation of all the forces acting on the body; the accelerating force is the net force acting on the vehicle. This means if we launch a 200,000-lbf vehicle vertically from the Earth with a 250,000-lbf thrust engine, there is a net force at launch of 50,000-lbf—the difference between engine thrust and vehicle weight. Here the force of gravity is acting opposite to the direction of the thrust of the engine.

As the rocket operates, the forces acting on it change. The force of gravity decreases as the vehicle's mass decreases, and it also decreases with altitude. As the rocket passes through the atmosphere, drag increases with increasing velocity and decreases with altitude (lower atmospheric density).[1] As long as the thrust remains constant, the acceleration profile changes with the changing forces on the vehicle. The predominate effect is that the acceleration increases at an increasing rate as the vehicle's mass decreases.[2]

Figure 5-2 shows the general acceleration and velocity profiles during powered flight. The acceleration and velocity are low at launch due to the small net force and high vehicle mass at that time. Both acceleration and velocity

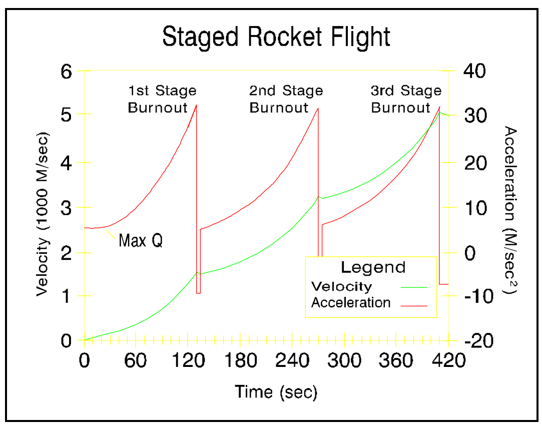


Fig. 5-2. Acceleration and Velocity

increase rapidly as the engine burns propellants (reducing vehicle mass and increasing the net force).

At first stage burnout, the acceleration drops (the acceleration at this point is due to the environment: gravity and drag) and is generally opposite the direction of

[1]The term "Max Q" refers to the highest structural pressure due to atmospheric drag.
[2]As the net force on the vehicle increases and the mass decreases, the acceleration increases at an increasing rate.

motion. With second stage ignition, acceleration and velocity will increase again. As the upper stage rocket engine(s) burn more propellants, rapid increases in acceleration and velocity occur. When the vehicle reaches the correct velocity (speed and direction) and altitude for the mission, it terminates thrust. Acceleration drops as the net force on the vehicle is due to the environment, mainly gravity, after thrust termination, or burnout, and the vehicle begins free flight. For vehicles with three, four or more stages, similar changes appear in both the acceleration and velocity each time staging occurs. Staging a vehicle increases the velocity in steps to the high values required for space missions.

Once a vehicle is in orbit, we say it is in a "weightless" condition. In fact, the vehicle is continually in free-fall, always accelerating toward the center of the Earth. The acceleration still depends on the summation of the forces acting on the vehicle (or the net force).

In a free-fall condition, we don't have to continually counter act the force of gravity, the vehicle's momentum accomplishes this task.[3] In this "weightless" condition, even a very small thrust (0.1 pound) operating over a long period of time can accelerate a vehicle to great speeds, escape velocity and more for interplanetary missions.

To relate Newton's third law, or "action-reaction law" to rocket theory and propulsion, consider what happens in the rocket motor. All rockets develop thrust by expelling particles (mass) at high velocity from their nozzles. The effect of the ejected exhaust appears as a reaction force, called thrust, acting in a direction opposite to the direction of the exhaust. The rocket is exchanging momentum with the exhaust.

It is his Third Law of Motion that explains the working principle of all propulsion systems.

A rocket engine is basically a device for expelling small particles of matter at high speeds producing thrust through the exchange of momentum. When liquid or solid chemicals are used as propellants, the exhaust consists of gas molecules. Recent scientific advances have involved experimental and theoretical work on rocket engines using *ions* (charged atomic particles), *nuclear particles* and even beams of light (photons) as "propellants."

Two items are necessary for propulsion: matter and energy. Matter is the *reaction mass* and is the source of momentum exchange. The reaction mass begins with the same momentum as the rocket vehicle, but as the rocket expels this mass, the rocket and all remaining propellants receive an equal increase in momentum in the opposite direction.

It takes energy to accelerate the reaction mass (impart momentum). The faster propellants are accelerated, the more propulsive force achieved; however, it also takes more energy.

ROCKET PERFORMANCE

There are several rocket performance parameters that, when taken together, describe a rocket's overall performance: 1) Thrust, 2) Specific Impulse, and 3) Mass Ratio.

Thrust *(T)*

The thrust is the amount of force an engine produces on the rocket (and on the exhaust stream leaving the rocket, conservation of momentum). The amount of thrust, along with the rocket mass, determines the acceleration. The mission profile will determine the required and acceptable accelerations and thus, the required thrust. Launching from the Earth typically requires a thrust to weight ratio of at least 1.5 to 1.75. Once the vehicle is in orbit and the vehicle's momentum balances the gravitational

[3] When the vehicle's orbit doesn't intersect the Earth's surface, we say the gravitational force is balanced by the inertial force.

force, smaller thrust forces are usually sufficient for any maneuvering.

Specific Impulse *(I_{sp})*

Specific impulse is a measure of propellant efficiency, and numerically is the thrust produced divided by the weight of propellant consumed per second (ending up with units of *seconds*).

So, I_{sp} is really another measure of a rocket's exhaust velocity. Specific impulse is the common measure of propellant and propulsion system performance, and is somewhat analogous to the reciprocal of the specific fuel consumption used with conventional automobile or aircraft engines. The larger the value of specific impulse, the better a rocket's performance.

We can improve specific impulse by imparting more energy to the propellants (increasing the exhaust velocity), which means that more thrust will be obtained for each pound of propellant consumed. We can think of specific impulse as the number of seconds for which one pound of propellant will produce one pound of thrust. Or, we can think of it as the amount of thrust one pound of propellant will produce for one second.

Mass Ratio *(M_R)*

Since the rocket engine is continually consuming propellants, the rocket's mass is decreasing with time. If the thrust remains constant, the vehicle's acceleration increases reaching its highest value at engine cut-off; *for example,* the space shuttle reaches 3 Gs just before main engine cut-off.

The purpose of a rocket is to place a payload at specified position with a specific velocity. This position and velocity depends on the mission. We can equate the energy needed to do this to the change in velocity (or *delta-v*, Δv) the rocket imparts to the satellite. For a rocket, the ideal Δv gain depends on the I_{sp} (exhaust velocity, v_e) and the *mass ratio*.

The more propellant the vehicle can carry with respect to its "dry" weight, or weight without propellant aboard, the faster it will be able to go. Mass ratio is an expression relating the propellant mass to vehicle mass; the higher the mass ratio, the higher the final speed of the rocket. Therefore, a rocket vehicle is made to weigh as little as possible in its "dry" state. Increasing the weight of the vehicle payload results in decreasing the mass ratio, and therefore cutting down the maximum altitude or range. For example, the addition of one pound of payload to a high-altitude sounding rocket may reduce its peak altitude by as much as 10,000 feet.

PROPULSION TECHNIQUES

From our previous discussion of rocket performance parameters, we see that we would like to be as efficient as possible in developing thrust. To develop thrust, we have to exchange momentum with some reaction mass (propellant). Any way that we can do this is a valid propulsion option. We would like to choose the option that decreased the overall mission cost while still providing for mission success.

We are most familiar with chemical rocket systems, however, there are other ways we can produce rocket propulsion. The two main ways of accelerating a propellant to provide thrust are: *thermodynamic expansion and electro-static/ magnetic acceleration*. The methods for providing the thermal energy for thermodynamic expansion, or electricity for electrostatic acceleration, can come from chemical, nuclear, or solar sources.

Thermodynamic Expansion

Thermodynamic expansion is the mechanism we are most familiar with. All of our chemical systems use this method to accelerate the propellants. However, we can also use nuclear or electrical energy to heat the propellant.

In thermodynamic expansion, we heat the propellant to turn it into a high pressure, high temperature gas. We then allow that gas to expand in a controlled way to turn the thermal potential energy into directed kinetic energy, which produces thrust. The basic device used to create these large volumes of gas and to harness their heat energy is extremely simple and often contains no moving parts.

The rocket engine using thermodynamic expansion creates a pressure difference between the thrust chamber (combustion chamber) and the surrounding environment. It is this pressure difference that accelerates the gases.

A rocket engine usually operates at what the gas dynamist calls *supercritical conditions*—high chamber pressure exhausting to low external pressure. The Swedish engineer Carl G.P. De Laval showed that for supercritical conditions gases should be ducted through a nozzle that converges to a throat (section of smallest area) and then diverges to transform as much of the gases' thermal energy into kinetic energy.

Nozzles

There are a number of nozzle types; **Figure 5-3** depicts four of them. The conical nozzle is simple and easy to fabricate and provides adequate performance for most applications; however. it also has off axis exhaust velocity components which reduces the efficiency. The radial velocity components cancel and don't contribute to the overall thrust, therefore the energy going into the radial velocity is wasted. The contoured or bell-shaped nozzle provides for rapid early expansion producing shorter (less massive) nozzles, and redirects the exhaust toward the axial direction near the nozzle exit. The plug and expansion-deflection type nozzles are much shorter than a conventional conical nozzle with the same expansion ratio.

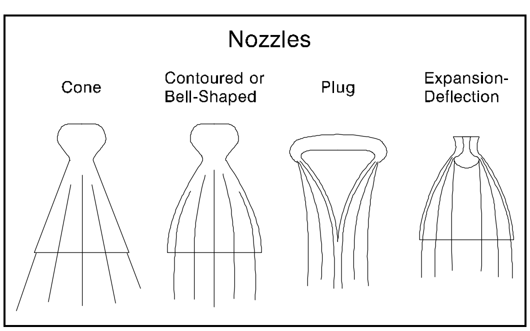


Fig. 5-3. Nozzle Types

These nozzles have a center body and an annular chamber. The plug changes the direction of the gas flow from the throat during expansion from radial to an axial direction. The expansion of exhaust gas is determined by ambient pressure. A variation of the plug nozzle is the aerospike, which uses radial auxiliary combustion chambers around the exit to the main combustion chamber. The exhaust plumes from the auxiliary chambers expand to form a "nozzle" for the gases escaping from the engine. Over expansion and under expansion can be largely compensated for by increasing or decreasing the thrust of the auxiliary chambers.

Chemical Rockets

Chemical rockets are unique in that the energy required to accelerate the propellant comes from the propellant itself, and in this sense, are considered energy limited. Thus, the attainable kinetic energy per unit mass of propellant is limited primarily by the energy released in chemical reaction; the attainment of high exhaust velocity requires the use of high-energy propellant combinations that produce low molecular weight exhaust products. Currently, propellants with the best combinations of high energy content and low molecular weight seem capable of producing specific impulses in the range of 400 to 500 seconds or exhaust velocities of 13,000 to 14,500 ft/sec.

Chemical rockets may use liquid or solid propellants or, in some schemes, combinations of both. Liquid rockets may use one (*monopropellant*), two (*bipropellant*) or more propellants. Bipropellants consist of a combination of a fuel (kerosene, alcohol, hydrogen) and an oxidizer (oxygen, nitric acid, fluorine). The liquids are held in tanks and fed into the combustion chamber where they react and then expand through the nozzle.

In contrast, solid propellants are an intimate mixture containing all the material necessary for reaction. The entire block of solid propellant, called the *grain*, is stored within the combustion chamber. Combustion proceeds from the surface of the propellant.

A chemical rocket engine is little more than a gas generator. The rapid combination (combustion) of certain chemicals results in the release of energy and large volumes of gaseous products. The gas molecules generated have considerable energy in the form of heat. In ordinary chemical rocket engines, the temperature of the resulting gases can rise higher than 5,500 degrees Fahrenheit.

For chemical systems in general, liquid propellants provide higher specific impulses than solid propellants. We call liquid Hydrogen (LH) and liquid Oxygen (LOX) high energy propellants because of the large energy release during combustion and the high transfer of thermal energy into directed kinetic energy of the exhaust stream.

An efficient LH/LOX burning engine produces around $\boldsymbol{I_{sp}}$ = 390-430 sec. on average.[4] Solid propellant motors produce around $\boldsymbol{I_{sp}}$ = 265-295 sec.

The total impulse of a rocket is the product of thrust and the effective firing duration. A typical shoulder launched short-range rocket may have an average thrust of 660 pounds for an effective duration of 0.2 seconds, giving a total impulse of 132 lbf-sec. In contrast, the Saturn rocket had a total impulse of 1.14 billion lbf-sec.

Nuclear Rockets

The nuclear rocket is an attempt to increase specific impulse by using nuclear reaction to replace chemical reaction as the energy source. The nuclear reactor generates thermal energy and heats the propellant which is then expanded through a conventional nozzle.

Compared to the chemical rocket, the nuclear rocket has some advantages. The energy released in a nuclear reaction is very much larger than that of a chemical reaction (on the order of a million times larger), and since the energy source is separate from the propellant, we have a larger latitude for propellant choice. Thus, hydrogen would be a good propellant because it has the lowest atomic weight, and would provide the highest exhaust velocities for a given chamber pressure and temperature.

We might think that the abundant energy in nuclear rockets would mean that we could employ indefinitely high chamber temperatures. This is definitely not the case, however, since the heat is transferred from a solid reactor to the propellant. Thus the structural components within the nuclear rocket, unlike those in a chemical rocket, *must be hotter than the propellant*, and the temperature cannot exceed the limiting temperature of the structure or the reactor material. The attainable temperatures in nuclear rockets to date are considerably below the temperatures attained in some chemical rockets, but the use of hydrogen as the propellant more than offsets this temperature disadvantage. Thus, as far as specific impulse is concerned, the increased performance of nuclear rockets is entirely due to the use of a propellant with a low atomic weight. The nuclear fission rocket offers roughly twice the specific impulse of the best chemical rocket (about 800-1,000 seconds), while delivering fairly high thrusts for long periods of time.

One theoretical improvement is a high-density reactor using fast neutrons. This type of reactor is expected to produce higher performance levels in a smaller

[4]The $\boldsymbol{I_{sp}}$ of any particular engine depends upon its design altitude. The Space Shuttle Main Engines (SSME) produce $\boldsymbol{I_{sp}}$ = 363.2 @ sea level, and 455.2 @ vacuum.

package than the thermal (or slow) reactors. Another improvement is a gas core reactor in which the operating temperature could be much higher. This increase in temperature would occur because of the elimination of the solid core of fuel elements used in slow and fast reactors. These structural elements are temperature limited.

NASA's Lewis Research Center is pursuing a concept for a reusable vehicle propelled by a nuclear thermal rocket (NTR) to take astronauts to the Moon and back (**Fig. 5-4**). With the addition of modular hardware elements, the lunar transit vehicle would become the core of a spacecraft to land astronauts on Mars early in the 21st century.

Specific impulse has reached about 850 seconds in nuclear engines, while the best

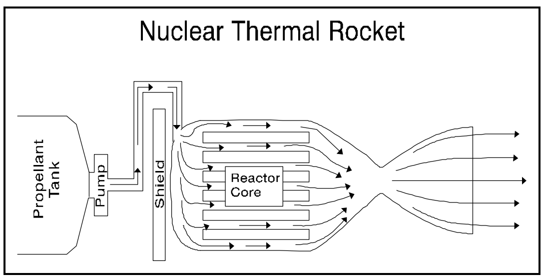


Fig. 5-4. Reusable Rocket

liquid oxygen/liquid hydrogen combustion engines only approach 475 seconds (in a vacuum). Such a system could decrease transit times to Mars from 9-15 months down to 4-6 months, leaving more time for exploration. Of course nuclear rockets have drawbacks. Nuclear reactors are not only heavy, but while in operation, produce large amounts of radiation. The mass and radiation hazard prohibit its use as a launch vehicle. However, once in space the benefits on long range missions would more than offset the extra mass.

Electrothermal Rockets

Another method using thermodynamic expansion is the *arcjet*. The arcjet is an *electrothermal* rocket because it uses electrical energy to heat a propellant. In this method, an annular arc is created in the chamber and the propellant is heated to high temperatures as it interacts with the arc. After the heating, the propellant is expanded through a conventional nozzle (**Fig. 5-5**).

This type of propulsion takes advantage of using hydrogen as a propellant, and, like nuclear rockets, experiences a similar performance gain in

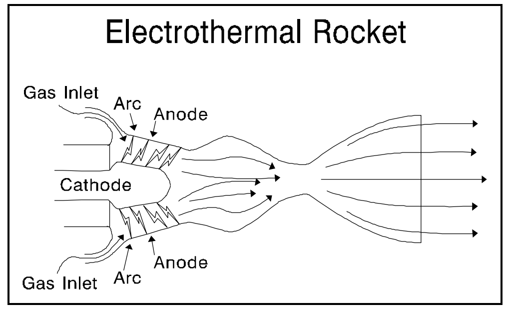


Fig. 5-5. Conventional Nozzle

specific impulse (up to 1,200 seconds). Unlike nuclear rockets, arcjets are small, producing little more than several pounds of thrust.

Electrical Propulsion

Electrical and electromagnetic rockets fundamentally differ from chemical rockets with respect to their performance limitations. Chemical rockets are *energy-limited*, since the quantity of energy is limited by the chemical behavior of the propellants. If a separate energy source is used, much higher propellant energy is possible. Further, if the temperature limitations of solid walls could be made unimportant by direct electrostatic or electromagnetic propellant acceleration without necessarily raising the fluid temperature, there would be no limit to the kinetic energy we could add to the propellant. However, the rate of conversion from nuclear or solar to electrical energy and then to propellant kinetic energy is limited by the mass of the conversion equipment. Since this mass is likely to be a large portion of the total mass of the vehicle, the electrical rocket (including electrothermal/static/ magnetic) is essentially *power-limited*.

Electrostatic/magnetic rockets convert electrical energy directly to propellant kinetic energy without necessarily raising the temperature of the working fluid. For this reason the specific impulse is not limited by the temperature limitations of the wall materials, and it is possible to achieve very high exhaust velocities, although at the cost of high power consumption.

Because of the massive energy conversion equipment, electrical rockets have low thrust, perhaps only one-thousandth of vehicle weight in the Earth's gravitational field. For this reason, they are mainly restricted to space missions during which the gravitational forces are very nearly balanced by inertial forces. Low accelerations are quite acceptable, since the journeys are of long duration.

The propellant of an electrical rocket consists of either discrete charged particles accelerated by electrostatic forces, or a stream of electrically conducting fluid (plasma) accelerated by electromagnetic forces.

Electrostatic Rockets

These are commonly called *ion rockets*. Neutral propellant is converted to ions and electrons and withdrawn in separate streams. The ions pass through a strong electrostatic field produced between acceleration electrodes. The ions accelerate to high speeds, and the thrust of the rocket is in reaction to the ion acceleration (**Fig. 5-6**).

It is also necessary to expel the electrons in order to prevent the vehicle from acquiring a net negative charge. Otherwise, ions would be attracted back to the vehicle and the thrust would vanish. They remove these excess electrons by re-injecting them back into the exhaust ion beam.

Ion rockets offer very high specific impulses (a typical figure being 10,000 seconds with values ranging up to 20,000 seconds), but very low thrust, one-half pound being high. It has been estimated that an ion rocket employing cesium propellant would require over 2,000 kW of electrical power per pound of thrust.

The propellant for ion engines may be any substance that ionizes easily. Unlike thermodynamic expansion, the size of the molecules is not a primary factor. The most efficient elements are mercury, cesium or the noble gases.

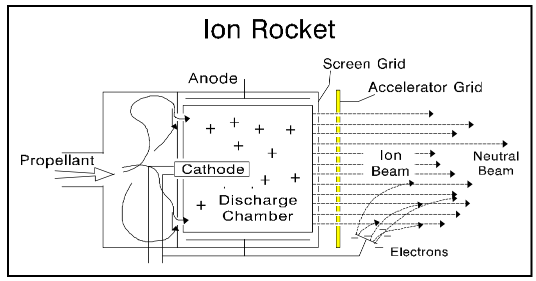


Fig. 5-6. Ion Acceleration

Electromagnetic Rockets

There are three major types of electromagnetic rockets: *magnetogas-dynamic*, *pulsed-plasma* and *traveling-wave*. All methods use a plasma with crossed electric and magnetic fields to accelerate the plasma.

A plasma is an electrically conducting gas. It consists of a collection of neutral atoms, molecules, ions, and electrons. The number of ions and the number of electrons are equal so that, on the whole, the plasma is electrically neutral. Because of its ability to conduct electrons, the plasma can be subjected to electromagnetic forces in much the same way as solid conductors in electric motors.

<u>Magneto-gas-dynamic Drive</u>.

Strong external electric and magnetic fields direct and accelerate the plasma stream, imparting high exhaust velocity. The performance is limited due to non-perpendicular currents flowing in the plasma at high field strengths. The specific impulse is lower than ion rockets but still very high (around 10,000 seconds). The mass flow rate is restricted so the thrusts remain low.

Pulsed-Plasma Accelerators.

One of the disadvantages of the steady crossed-field accelerators is that they require a substantial external field and therefore, a massive electromagnet. It is possible to make an accelerator for which an electromagnet is unnecessary by using the plasma current itself to generate the magnetic field, which gives rise to the accelerating force. Whereas the crossed-field accelerator is analogous to a shunt motor (which has separate current circuits for the electric and magnetic fields), the analog of this type of accelerator is the series motor in which the magnetic field is established by the same current which interacts to establish the crossed field force.

Traveling-Wave

A third type of plasma accelerator, sometimes called the magnetic-induction plasma motor, offers potential advantages over both the foregoing accelerators. It requires neither magnets or electrodes, and relies on currents being induced in the plasma by a traveling magnetic wave.

If the current in a conductor surrounding a tube containing a plasma increases, the magnetic field strength in the plane of the conductor will increase. Then an electromotive force will be induced in any loop in this plane. If the conductor current increases rapidly enough, the induced electric field will establish a substantial plasma current. The induced magnetic field and plasma current then interact to cause a body force normal to both, which tends to compress the plasma toward the axis of the tube and expel it axially.

A traveling-wave accelerator makes use of a number of sequentially energized external conductors along the tube. As the switches are fired in turn, the magnetic field lines move axially along the tube, interacting with induced currents and imparting axial motion to the plasma.

The inward radial force on the plasma in this accelerator appears to offer an advantage in keeping the high temperature plasma away from the solid walls of the tube. The fact that no electrodes are needed is also an attractive feature.

STAGING

Currently, the only practical method we have for launching satellites is with chemical systems. As we found out in the rocket performance section, specific impulse and mass ratio limit our chemical systems' performance.

What does this mean in terms of satellites and space probes? A rocket has to provide enough energy, essentially 25,000 ft/sec (17,500 mph), to orbit the Earth as a satellite and 36,700 ft/sec (25,000 mph) to escape the Earth's gravitational field and become a planetoid circling the Sun.

A body must attain a velocity of nearly 35,000 ft/sec to hit the Moon. No practical rocket of one stage can reach the critical velocities for satellites or space probes.

A solution to this problem is to mount one or more rockets on top of one another and to fire them in succession at the moment the previous stage burns out. For example, if each stage provides about 9,000 ft/sec in velocity when fired as above, it would take three stages to put a satellite in orbit, or four stages to reach the moon or go beyond it into space as a deep space probe orbiting the sun.

Staging reduces the launch size and weight of the vehicle required for a specific mission and aids in achieving the high velocities necessary for specific missions.

Multistage rockets allow improved payload capability for vehicles with a high Δv requirement, such as launch vehicles or interplanetary spacecraft. In a multistage rocket, propellant is stored in smaller, separate tanks rather than a larger single tank as in a single-stage rocket. Since each tank is discarded when empty, energy is not expended to accelerate the empty tanks, thereby achieving a higher total $\Delta \boldsymbol{v}$. Alternatively, a larger payload mass can be accelerated to the same total $\Delta \boldsymbol{v}$. The separate tanks are usually bundled with their own engines, with each discardable unit called a stage.

The same rocket equation describes multistage and single-stage rocket performance, but it must be applied on a stage-by-stage basis. It is important to realize that the payload mass for any stage consists of the mass of all subsequent stages plus the ultimate payload itself. The velocity of the multistage vehicle at the end of powered flight is the sum of velocity increases produced by each of the various stages. We add the increases because the upper stages start with velocities imparted to them by the lower stages.

A multistage vehicle with identical specific impulse, payload fraction and structure fraction for each stage is said to have *similar stages*. For such a vehicle, the payload fraction is maximized by having each stage provide the same velocity increment. For a multistage vehicle with dissimilar stages, the overall vehicle payload fraction depends on how the $\Delta \boldsymbol{v}$ requirement is partitioned among stages. Payload fractions will be reduced if the $\Delta \boldsymbol{v}$ is partitioned suboptimally.

ROCKET PROPELLANTS

The type of rocket engine determines the corresponding type of propellant storage and delivery systems. In the case of chemical rocket engines, the propellants may be either liquid or solid.

Rocket engines can operate on common fuels such as gasoline, alcohol, kerosene, asphalt or synthetic rubber, plus a suitable oxidizer. Engine designers consider fuel and oxidizer combinations having the energy release and the physical and handling properties needed for desired performance. Selecting propellants for a given mission requires a complete analysis of mission, propellant performance, density, storability, toxicity, corrosiveness, availability and cost; size and structural weight of the vehicle; and payload weight.

Liquid Propellants

The term “liquid propellant” refers to any of the liquid working fluids used in a rocket engine. Normally, they are an oxidizer and a fuel, but may include catalysts or additives that improve burning or thrust. Generally, liquid propellants permit longer burning time than solid propellants. In some cases, they permit intermittent operations. That is, combustion can be stopped and started by controlling propellant flow.

Many combinations of liquid propellants have been investigated. However, no combination has all these desirable characteristics:

- Large availability of raw materials and ease of manufacture
- High heat of combustion per unit of propellant mixture
- Low freezing point (wide range of operation)
- High density before combustion (smaller tanks)
- Low density after combustion (higher γ)
- Low toxicity and corrosiveness (easier handling and storage)
- Low vapor pressure, good chemical stability (simplified storage)

Liquid-propellant units can be classified as monopropellant, bipropellant or tripropellant in nature (**Fig. 5-7**). A monopropellant is a single liquid possessing the qualities of both an oxidizer and a fuel. It may be a single chemical compound, such as nitromethane, or a mixture of several chemical compounds, such as hydrogen peroxide and alcohol. The compounds are stable at ordinary temperatures and pressures, but decompose when heated and pressurized, or when a catalyst starts the reaction.

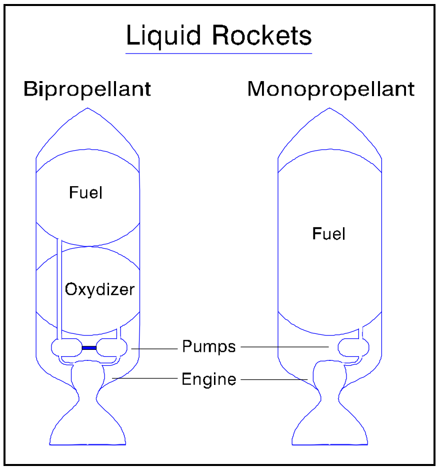


Fig. 5-7: Liquid Propellants

Monopropellant rockets are simple, since they only need one propellant tank and the associated equipment. The most common monopropellant systems use hydrazine. Bipropellant units carry fuel and oxidizer in separate tanks and bring them together in the combustion chamber. At present, most liquid rockets use bipropellants. In addition to a fuel and oxidizer, a liquid bipropellant may include a catalyst to increase the speed of reaction, or other additives to improve the physical, handling or storage properties.

A tripropellant has three compounds. The third compound improves the specific impulse of the basic propellant.

Liquid propellants are commonly classified as either cryogenic or storable propellants. A cryogenic propellant is one that has a very low boiling point and must be kept very cold. For example, liquid oxygen boils at -297° F, liquid fluorine at -306° F and liquid hydrogen at -423° F. Personnel at the launch site load these propellants into a rocket as near launch time as possible to reduce losses from vaporization and to minimize problems caused by their low temperatures.

A storable propellant is one that is liquid at normal temperatures and pressures and may be left in a rocket for days, months, or even years. For example, nitrogen tetroxide boils at 70° F, unsymmetrical dimethyldrazine (UDMH) at 146° F and hydrazine at 236° F. However, the term storage refers to storing propellants on Earth. It does not consider the problem of storage in space.

As described earlier, in order to store the liquid propellants within the rocket vehicle until such time as they are introduced into the combustion chamber of the rocket engine, large tanks are required. Once combustion starts and pressure is built up inside the combustion chamber, the propellants will not flow into the combustion chamber of their own accord. A method of forcing the propellants into the combustion chamber against the combustion pressure is required. Two methods presently used to accomplish this are shown in **Figure 5-8**. The simplest of these provides a gas pressure, usually helium, in the propellant tanks sufficient to force the propellants out of the tanks through the delivery piping and into the combustion chamber.

The pressurization method requires propellant tanks that are strong enough to withstand the pressure and this, in turn, means thick tank walls and increased tankage weight. This decreases the mass ratio. Therefore, there is a definite limit

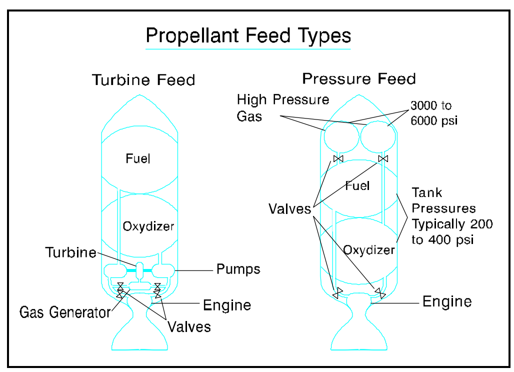


Fig. 5-8. Propellant Feed Types

to the size of the rocket vehicle that can use the pressurization method.

The second method, as previously described, utilizes pumps to drain the propellants from the tanks and force them into the combustion chamber. This requires a pump for each propellant as well as some method of driving the pumps. These pumps are usually the centrifugal type. They are generally driven by a turbine mounted on the same drive shaft. The turbine, in turn, is powered by a small gas generator that may use the decomposition of high-strength (highly concentrated) hydrogen peroxide to produce steam. Other sources of turbine power may be the two rocket propellants, burned in a small auxiliary combustion chamber, or a small solid-propellant grain burned to produce driving gas. A novel method involves bleeding some of the combustion gas from the rocket engine back to the turbine. This is a system which essentially "bootstraps" itself into operation. Pump delivery systems allow the use of extremely thin-walled propellant tanks, which increases the possible mass ratio.

With liquid propellants, the combustion process starts when the propellants are injected into the rocket engine. The propellants are driven into the combustion chamber through an "injector," which often looks like an overgrown shower head. The injector serves to break up the propellants into atomized spray, thus promoting mixing and complete combustion. Injectors are extremely difficult to design, as there are no definitive mathematical equations that analyze their operation. Modern injectors are built as a single unit that forms the forward end of the combustion chamber. They are perforated with hundreds of tiny holes, the number, size, and angle of which are critical.

Propellants may be chosen so that they react spontaneously upon contact with each other. Such propellants are known as *hypergolic* and do not require a means of ignition in order to get combustion started. Ignition for non-hypergolic propellants requires an igniter. Igniters are usually pyrotechnic in nature, although some engines have used spark plugs.

Typical non-hypergolic combinations are alcohol/LOX, gasoline/LOX, liquid hydrogen/LOX, alcohol and nitric acid, and kerosene (RP-1)/LOX. Typical hypergolic combinations are aniline and nitric acid, fluorine/hydrazine, fluorine and hydrogen, hydrazine/hydrogen peroxide, and aniline and nitrogen tetroxide.

Monopropellants are chemicals which decompose in the presence of a suitable catalyst or at a suitable temperature releasing energy in the process. Hydrogen peroxide (75 percent pure or better) is a common monopropellant used in many vehicles for small adjustment or vernier rockets. Such strong peroxide mixtures, however, must be handled with great care because they decompose with explosive suddenness in the presence of impurities. Other monopropellants are nitro-methane (CH_3NO_2), ethylene oxide (C_2H_4O) and hydrazine (N_2H_4). Many of these propellants are highly unstable, many are highly toxic and some are both.

Liquid propellant engines are extremely versatile, can be throttled, and can be used again by simply reprovisioning the propellant tanks. They provide high specific impulses, but are more complex and therefore, less reliable than a solid motor.

While it is possible to argue endlessly over the merits of both types, it is safe to say that both solid-propellant motors and liquid-propellant engines will continue to be used in the future for specific applications where their respective advantages outweigh their disadvantages.

Solid Propellants

The solid-propellant motor (**Fig. 5-9**) is the oldest of all types and is by far the simplest in construction. Since the propellants are in solid form, usually mixed together, and since a solid-propellant charge undergoes combustion only on its surface, there is no need to inject it continuously into the combustion chamber from storage tanks. Solid propellants are therefore, placed right in the combustion chamber itself. A solid propellant rocket motor combines both the combustion chamber and the propellant storage facilities in one unit. A solid-propellant charge, or "grain," is ignited and burns until it is exhausted, changing the effective size and shape during its operation.

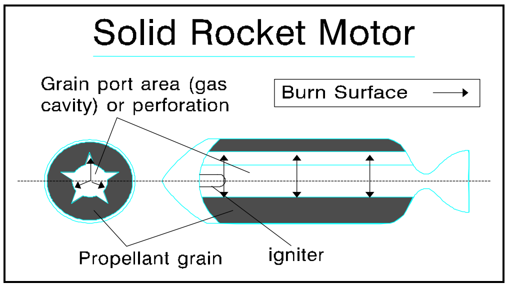


Fig. 5-9. Solid Propellant Motor

Since a solid-propellant grain burns only on its surface, the shape of the grain may be designed to regulate the amount of grain area undergoing combustion.

Since the thrust is dependent upon the mass flow rate, which is in turn dependent upon the amount of propellant being consumed per second, the thrust output of a solid-propellant rocket motor can be determined in advance, or "programmed." A grain that burns with constant area during the thrust period yields constant thrust and is known as a *restricted* or *neutral-burning* grain (It might, for example, burn from the aft end to the forward end in the manner of a cigarette) (**Fig. 5-10**).

In addition, a grain may be designed to burn with increasing area and thrust (*progressive*) or with decreasing area and thrust (*regressive*). Choice of grain style depends on the motor's use.

There are many chemical combinations that make good solid propellants. Aside from gunpowder and metal-powder mixtures (such as zinc and sulfur) which have erratic burning rates and poor physical properties, there are two classes of solid propellants which were originally developed for rockets during and after World War II and are in wide use today: *double-base* (homogeneous) and *composite* (heterogeneous) propellants. Double-based propellants consist chiefly of a blend of nitrocellulose and nitroglycerin with small quantities of salts, wax, coloring and organic compounds to control burning rates and physical properties. The double-based propellants may be regarded as complex colloids with unstable molecular structure. Homogeneous propellants have oxidizer and fuel in a single molecule. The blast from a small chemical igniter easily starts the rapid recombination of this structure in the process of burning. Aging allows a slower rearrangement of the molecules, and thus often significantly changes the burning properties of the propellant. Double-based propellants can be formed efficiently in many shapes by either casting or extrusion through dies.

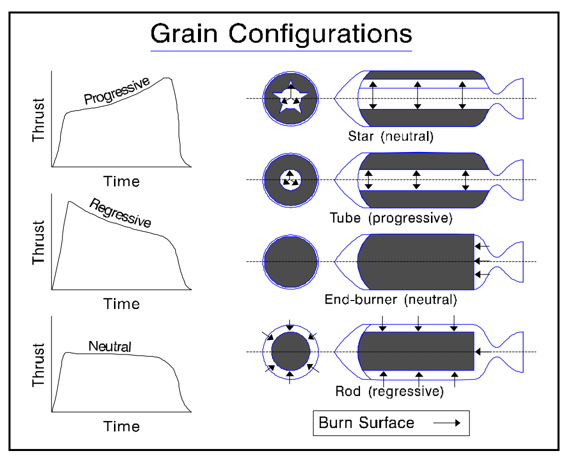


Fig. 5-10. Grain Configurations

Composite propellants, as the name implies, are mixtures of an oxidizer, usually an inorganic salt such as ammonium perchlorate, in a hydrocarbon fuel matrix, such as an asphalt like material. The fuel contains small particles of oxidizer dispersed throughout. The fuel is called a binder because the oxidizer has no mechanical strength. Usually in crystalline form, finely ground oxidizer is approximately 70 to 80 percent of the total propellant weight. Composites are usually cast to shape. Current work with composites and double-based propellants incorporates light metals (such as boron, aluminum, and lithium), which yield very high energies.

Although less energetic than good liquid propellants (lower specific impulse), solids have the advantages of fast ignition (0.025 seconds is common) and good storability in the rocket. Making them, however, is costly, complex and dangerous.

An ideal solid propellant would possess these characteristics:

- High release of chemical energy
- Low molecular weight of combustion products
- High density before combustion
- Readily manufactured from easily obtainable substances by simple processes
- Insensitive to shock and temperature changes and no chemical or physical deterioration while in storage
- Safe and easy to handle.
- Ability to ignite and burn uniformly over a wide range of operating temperatures
- Nonhygroscopic (nonabsorbent of moisture)
- Smokeless and flashless

It is improbable that any propellant will have all of these characteristics. Propellants used today possess some of these features at the expense of others, depending upon the application and the desired performance.

Propellant Tanks

The function of the propellant tanks is simply the storage of one or two propellants until needed in the combustion chamber. Depending upon the kind of propellants used, the tank may be nothing more than a low pressure envelope or it may be a pressure vessel for containing high pressure propellants. In the case of cryogenic propellants (described later), the tank has to be an exceptionally well insulated structure to keep propellants from boiling away.

As with all rocket parts, weight of the propellant tanks is an important factor in their design. Many liquid propellant tanks are made out of very thin metal or are thin metal sheaths wrapped with high-strength fibers. These tanks are stabilized by the internal pressure of their contents, much the same way balloon walls gain strength from the gas inside. Very large tanks and tanks that contain cryogenic propellants require additional strengthening or layers. Structural rings and ribs are used to strengthen tank walls, giving the tanks the appearance of an aircraft frame. With cryogenic propellants, extensive insulation is needed to keep the propellants in their liquefied form. Even with the best insulation, cryogenic propellants are difficult to keep for long periods of time and will boil away. For this reason, cryogenic propellants are usually not used with military rockets/ missiles.

The propellant tanks of the shuttle can be used as an example of the complexities involved in propellant tank design. The external tank (ET) consists of two smaller tanks and an intertank. The ET is the structural back bone of the shuttle and during launch it must bear the entire thrust produced by the solid rocket boosters and the Orbiter main engine.

The forward or nose tank contains LOX. Antislosh and antivortex baffles are installed inside the LOX tank as well as inside the other tank to prevent gas bubbles inside the tank from being pumped to the engines along with the propellants. Many rings and ribs strengthen this tank.

The second tank contains LH. This tank is two and a half times the size of the LOX tank. However, the LH tank weighs only one third as much as the LOX tank because LOX is 16 times denser than LH.

Between the two tanks is an intertank structure. The intertank is not actually a tank but a mechanical connection between the LOX and LH tanks. Its primary function is to join the two tanks together and distribute thrust loads from the solid rocket boosters. The intertank also houses a variety of instruments.

Turbopumps

Turbopumps provide the required flow of propellants from the low-pressure propellant tanks to the high-pressure rocket chamber. Power for the pumps is produced by combusting a fraction of the propellants in a preburner. Expanding gases from the burning propellants drive one or more turbines which, in turn, drive the turbopumps. After passing through the turbines, exhaust gases are either directed out of the rocket through a nozzle or are injected, along with liquid oxygen into the chamber for more complete burning.

Combustion Chamber and Nozzle

The combustion chamber of a liquid propellant rocket is a bottle-shaped container with openings at opposite ends. The openings at the top inject the propellants into the chamber. Each opening consists of a small nozzle that injects either fuel or oxidizer. The main purpose of the injectors is to mix the propellants to ensure smooth and complete combustion with no detonations. Combustion chamber injectors come in many designs.

The purpose of the nozzle is to provide for gas expansion to achieve the maximum transfer of thermal energy into directed kinetic energy.

HYBRID ROCKETS

Another rocket engine should be mentioned. Composite (hybrid) engines are combinations of solid and liquid propellant engines. In a composite engine, the fuel may be in solid form inside the combustion chamber with the oxidizer in a liquid form that is injected into the chamber.

Though not in widespread use, they do offer some advantages in rocket propulsion. **Figure 5-11** depicts a simplified structure of the hybrid system.

Theoretical work on hybrid propulsion

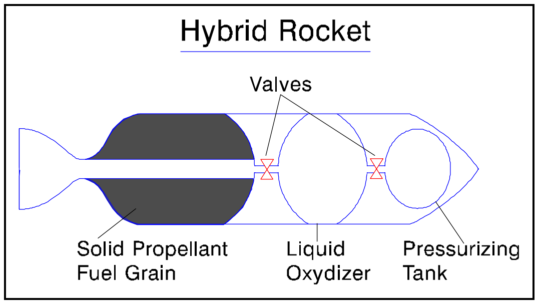


Fig. 5-11. Hybrid Rocket System

dates back to the 1930s in both the U.S. and Germany. In the 1940s, a hybrid motor was built that burned Douglas Fir wood loaded with carbon black and wax in 10% liquid oxygen. Germany's wartime experiments tried powdered and re-formed coal fuel cores, but even clean coal contained too many impurities to be a good rocket fuel. Work continued into the 1960s with both the Navy and Air Force funding research.

The hybrid fuel burns only on contact with the oxidizer, and cracks in the fuel grain do not admit enough oxidizer to support catastrophic failures common to solids. Also, unlike conventional solids, the flow of oxidizer makes the hybrid throttleable and restartable. Even though hybrids cannot match the density-impulse of solid rocket motors loaded with aluminum, motors with thrusts ranging from 60,000 to 75,000 pounds have been tested. Future tests expect thrusts reaching 225,000 pounds.

Safety is an inherent advantage, claim makers of hybrid systems. As noted above, cracks in the fuel, because they are not exposed to the oxidizer, do not cause an explosion. Hybrid propulsion makes launch vehicles safer in flight. Engine thrust can be verified on the pad before releasing the vehicle for flight. And, unlike solids, hybrids can be shut down on the pad if something goes wrong.

Environmental concerns are lessened using hybrid systems specially designed to minimize pollution effects. The hydrogen chloride in solid fuel exhaust has already become an environmental concern for the acid it dumps on the surface of the Earth, and the damage it does to the protective ozone. Aluminum oxide, an exhaust component of traditional solid rockets, is also environmentally suspect. A hybrid launch vehicle using polybutadiene fuel and liquid oxygen produces an exhaust of carbon dioxide, carbon monoxide and water vapor similar to that of kerosene/liquid oxygen engines.

COOLING TECHNIQUES

The very high temperatures generated in the combustion chamber transfer a great deal of heat energy to the combustion chamber and nozzle walls. This heat, if not dissipated, will cause most materials to lose strength. Without cooling the chamber and nozzle walls, the combustion chamber pressures will cause structural failure. There are many methods of cooling, all with the objective of removing heat from the highly stressed combustion chamber and nozzle.

Radiation Cooling

This is probably the simplest method of cooling a rocket engine or motor. The method is usually used for monopropellant thrusters, gas generators, and lower nozzle sections. The interior of the combustion chamber is covered with a refractory material (graphite, pyrographite, tungsten, tantalum or molybdenum) or is simply made thick enough to absorb a lot of heat. Cooling occurs by heat loss through radiation into the exhaust plume. Radiation cooling can set an upper limit on the temperature attained by the walls of the thrust chamber. The rate of heat loss varies with the fourth power of the absolute temperature and becomes more significant as the temperature rises.

Ceramic Linings

In relatively small (low temperature) rockets, the interior walls of the combustion chamber and nozzle may be lined with a heat-resistant (refractory) ceramic material. The ceramic gets hot, but because it is a poor conductor of heat, it prevents the metal walls of the motor/engine from becoming overheated during the short operating period. This method is not adequate for large rockets in which the more intense heat must be transferred rapidly from the walls of the thrust chamber. Ceramic linings are also too heavy for use in large rockets.

Ablation Cooling

As mentioned earlier, in the ablation cooling method, the interior of the thrust chamber is lined with an ablative material, usually some form of fabric reinforced plastic. This material chars, melts and vaporizes in the intense heat of the nozzle. In this type of “heat sink cooling,” the heat absorbed in the melting and burning (the energy alters the chemical form instead of raising its temperature) of the ablative material prevents the temperature from becoming excessively high. The charred material also serves as an insulator and protects the rocket case from overheating. The gas produced by burning the ablative material provides an area of “cooler” gas next to the nozzle walls. The synthetic organic plastic binder material is reinforced with glass fiber or a synthetic substance. Solid rocket motors use ablative cooling almost exclusively, as there are no other fluids to use to cool the nozzle throat.

Film Cooling

With this method of cooling, liquid propellant is forced through small holes at the periphery of the injector forming a film of liquid on the interior surface of the combustion chamber. The film has a low thermal (or heat) conductivity since it readily vaporizes and protects the wall material from the hot combustion gases. Cooling results from the vaporization of the liquid which absorbs considerable heat. Film cooling is especially useful in regions where the walls become exceptionally hot, e.g., the nozzle throat area.

Transpirational Cooling

This technique is very similar to film cooling. The combustion chamber has a double-walled construction in which the inside wall is made of a porous material. Propellant is circulated through the space between the walls and seeps continuously through inner wall pores into the combustion chamber. There it forms a film which rapidly vaporizes. The cooling action is much the same as film cooling, but has the additional advantage of allowing considerable heat to be absorbed by the propellant within the walls of the chamber. This method is also referred to as evaporative or sweat cooling. Major drawbacks to transpirational cooling are that it is difficult to manufacture this type of chamber, and also difficult to maintain a steady liquid flow through the pores.

Regenerative Cooling

This is the most common method of cooling for cryogenic propellant rockets. It involves circulating one of the super-cooled propellants through a cooling jacket around the combustion chamber and nozzle before it enters the injector. The propellant removes heat from the walls, keeping temperatures at acceptable levels. At the same time, the temperature of the propellant rises, causing it to vaporize faster upon injection. This cooling method is often used with gas generator systems as a way to drive turbopumps (**Fig. 5-12**).

Solid Rocket Motor Cooling

In solid propellant motors, the nozzle

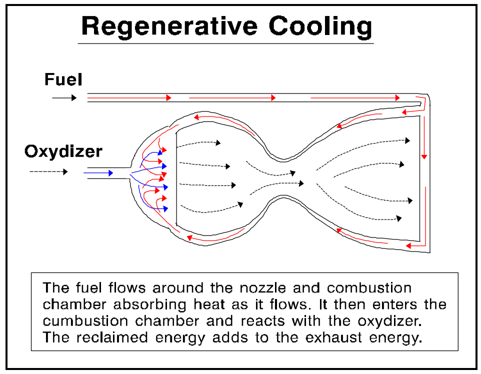


Fig. 5-12. Regenerative Cooling

serves the same purpose as in the liquid engine. Because there is no super-cooled propellant available to provide cooling, we use other methods for thermal protection. If not properly constructed, the walls of the combustion chamber will become excessively hot. This could cause case failure under the high operating pressures existing in the interior. To prevent this, the inner wall of the motor case is coated with a liner or inhibitor. This liner provides a bond between the propellant grain and the case preventing combustion from spreading along the walls, and acts as a thermal insulator, protecting the case from heat in areas where there is no propellant. The unburned propellant provides additional thermal protection as it must be vaporized before it will burn.

In solid-propellant rockets, the nozzle's form is often achieved with a shaped insert which keeps the nozzle throat cool to prevent significant damage during the operation of the motor. Common insert materials include both refractory substances, like pyrographite and tungsten or ablative substances. The ablative materials are fabric reinforced high temperature plastics as previously discussed. There is usually no significant change in motor performance due to deterioration of nozzle throat ablatives.

Another method of keeping the nozzle throat cool is the use of a cooler burning propellant located near the throat area which will burn and form a thin layer of cooler gas next to the nozzle walls. This thin film of gas protects the nozzle from the high temperature gas created by the main propellant.

THRUST VECTOR CONTROL

In a rocket, the rocket engine or motor not only provides the propulsive force but also the means of controlling its flight path by redirecting the thrust vector to provide directional control for the vehicle's flight path. This is known as thrust vector control (TVC). TVC can be divided into those systems for use with liquid engines and those for solid motors.

When choosing a TVC method, we need to consider the characteristics of the engine/motor and its flight application and duration. Also, the maximum angular accelerations required or acceptable, the environment, the number of engines/motors on the rocket, available actuating power, and the weight and space limitations are all weighed against each other to produce a cost effective, yet appropriate, system of control. The effective loss of engine performance due to the use of a particular TVC method and the maximum thrust vector deflection required are major design considerations

Liquid Rocket TVC Methods

Gimbaled Engines

Some liquid propellant rockets use an engine swivel or gimbal arrangement to point the entire engine assembly. This arrangement requires flexible propellant lines, but produces negligible thrust losses for small deflection angles. This method is relatively common (**Fig. 5-13**).

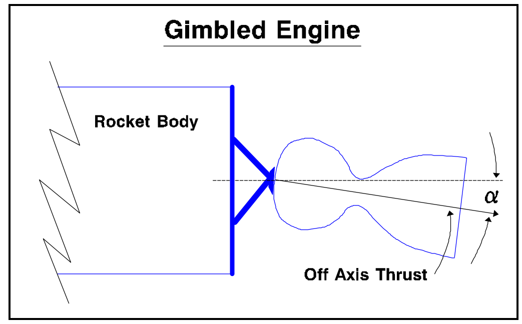


Fig. 5-13. Gimbaled Engine

Vernier Rockets

Vernier rockets are small auxiliary rocket engines. These engines can provide all attitude control, or just roll control for single engine stages during the main engine burn, and a means of controlling the rocket after the main engine has shut off (**Fig. 5-14**).

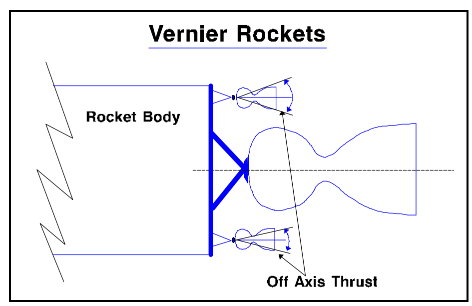


Fig. 5-14. Vernier Rocket

Jet Vanes

Jet vanes are small airfoils located in the exhaust flow behind the nozzle exit plane. They act like ailerons or elevators on an aircraft and cause the vehicle to change direction by redirecting the rocket. Jet vanes are made of heat-resistant materials like carbon-carbon and other refractory substances. Unfortunately, this control system causes a two to three percent loss of thrust, and erosion of the vanes is also a major problem (**Fig. 5-15**).

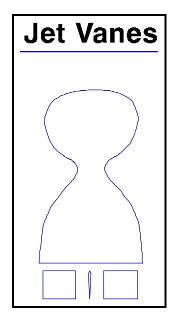


Fig. 5-15. Jet Vanes

Solid Rocket TVC Methods

Rotating Nozzle

The rotating nozzle has no throat movement. These nozzles work in pairs and are slant-cut to create an area of under expansion of exhaust gases on one side of the nozzle. This creates an unbalanced side load and the inner wall of the longer side of the nozzle. Rotation of the nozzles moves this side load to any point desired and provides roll, yaw and pitch control. This system is simple but produces slow changes in the velocity vector. Rotating nozzles are usually supplemented with some other form of TVC.

Swiveled Nozzle

The swiveled nozzle changes the direction of the throat and nozzle. It is similar to gambaling in liquid propellant engines. The main drawback in using this method is the difficulty in fabricating the seal joint of the swivel since this joint is exposed to extremely high pressures and temperatures (**Fig. 5-16**).

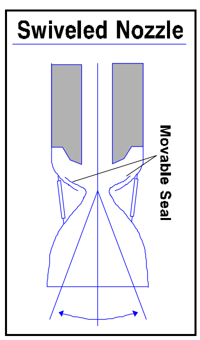


Fig. 5-16. Swiveled Nozzle

Movable Control Surfaces

Movable Control Surfaces physically deflect the exhaust or create voids in the exhaust plume to divert the thrust vector. This method includes jet vanes, jet tabs, and mechanical probes. These TVC approaches are all based on proven technology with low actuator power required. They suffer from erosion and cause thrust loss with any deflection.

A similar system is the jetavator, a slip-ring or collar at the nozzle exit which creates an under expansion region (as discussed in conjunction with rotating nozzles). The jetavator is a movable surface which allows the under expanded region to be moved 360 degrees around the rocket nozzle to produce pitch and yaw control. This system was developed for the Polaris SLBM.

Secondary Fluid Injection

A secondary fluid is injected into the exhaust stream to deflect it, thereby changing the thrust vector (**Fig. 5-17**). Fluid injection creates unbalanced shock waves in the exhaust nozzle which deflects the exhaust stream. There are two types of fluid injection systems.

The Liquid Injection TVC uses both inert (water) and reactive fluids (rocket propellants) for the TVC. Reactive fluid combustion in the exhaust plume creates the greater effect. Hydrazine, water, nitrogen tetroxide, bromine, hydrogen peroxide, and Freon have all been used.

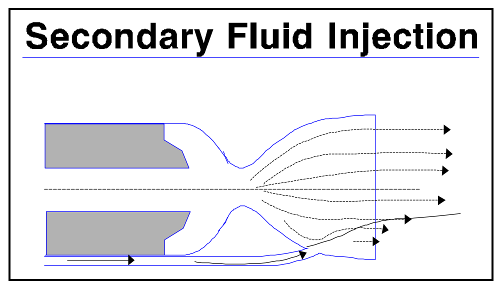


Fig. 5-17. Thrust Vectoring

The Hot Gas Injection TVC uses gas either vented from the main combustion chamber, or from an auxiliary gas generator. These gases are "dumped" into the nozzle to cause the unbalanced shock wave.

SUMMARY

Table 5-1 summarizes the capabilities of the different types of rocket engines and propellants. Each has its own advantages and disadvantages. Specific use of a particular type depends upon the mission.

Type	Thrust (1000 lbs)	I_{sp}	Missions
Chemical Liquid Solid	 1500 2000-3000	 260-455 200-300	Manned missions near Earth and Moon. Instrumented probes to Venus and Mars.
Nuclear	250	600-1000	Heavy payload manned missions to Moon, Venus and Mars.
Arc-Jet	.01	400-2500	Very heavy payloads from Earth orbit.
Plasma	.005	2000-10,000	To other planets and stationkeeping
Ion	.001	7500- 30,000	For deep space missions

Table 5-1. Rocket Engines and Propellants

TOC

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