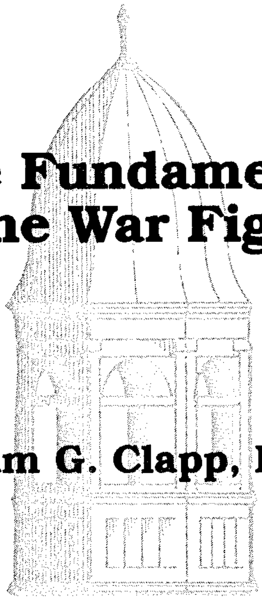
An Occasional Paper of
The Center for Naval
Warfare Studies



Space Fundamentals for the War Fighter

William G. Clapp, Ed.D.

Strategic Research Department
Research Report 3-94

U.S. Naval War College

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE 31 MAY 1994	3. REPORT TYPE AND DATES COVERED FINAL - From 1994 to 1994

4. TITLE AND SUBTITLE SPACE FUNDAMENTALS FOR THE WAR FIGHTER	5. FUNDING NUMBERS
6. AUTHOR(S) WILLIAM G. CLAPP, Ed.D.	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US NAVAL WAR COLLEGE STRATEGIC RESEARCH DEPARTMENT (CODE 30) CENTER FOR NAVAL WARFARE STUDIES 686 CUSHING ROAD NEWPORT, RI 02840-1207	8. PERFORMING ORGANIZATION REPORT NUMBER RESEARCH REPORT 3-94
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US NAVAL WAR COLLEGE 686 CUSHING ROAD NEWPORT, RI 02840-1207	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
12a. DISTRIBUTION/AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This report lays out, in simple and understandable terms, the basic technology and principles upon which space warfare doctrine is based.

14. SUBJECT TERMS SPACE WARFARE; SATELLITES; SPACE COMMUNICATIONS	15. NUMBER OF PAGES 40 16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT NONE

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANS. Std 239-18
298-102

19941128 028

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE NAVY
NAVAL WAR COLLEGE
686 CUSHING ROAD
NEWPORT RI 02841-1207

31 May 1994

Space Fundamentals for the War Fighter

This excellent paper was first produced by Dr. Clapp in partial satisfaction of the requirements of the Operations Department at the Naval War College. Because of the timeliness of the topic and the belief that it deserved wider circulation, the paper has been updated for publication as a Strategic Research Department Occasional Paper.

There is almost universal consensus that we are involved in a revolution in military affairs identified as the 'age of information.' Space plays an increasingly important role in this new age. Indeed, it may well prove to be the 'high ground' in future battles. Whereas the United States, as an island nation, in the past sought to maintain maritime superiority, according to today's National Security Strategy it seeks maritime and *aerospace* superiority.

This easily read and understood primer will help the war fighter understand the environment in which the battle for aerospace superiority must be fought and won.

Donald C. F. Daniel

Donald C.F. Daniel, Ph.D.
Director, Strategic Research
Department
Center for Naval Warfare Studies

NAVAL WAR COLLEGE
Newport, R.I

SPACE FUNDAMENTALS FOR THE WAR FIGHTER

by

William G. Clapp, Ed.D.

Major, Utah Air National Guard

A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Department of Operations.

TABLE OF CONTENTS

INTRODUCTION

Commercial and military space assets are all around us and we use them without thought or concern, unless they fail to meet our expectations. Technology leads us to believe that anything is possible and that we are all privileged users. This is only true if unlimited resources are available to design, build, and purchase these products. Technology is very expensive and not all of us are able to be privileged users.

An understanding of some of the limitations of our space assets should moderate our expectations. The purpose of this paper is to provide a short and concise overview of the space environment and a fundamental understanding of space assets in order to understand their capabilities. Many space assets are often used without the user's knowledge. Space assets are vital elements that influence both peacetime and wartime missions at all three levels of military activity: (1) strategic, (2) operational, and (3) tactical.

The paper has been limited to the basic concepts of the atmosphere, rocket propulsion, launch vehicles, communications spectrum, and satellite assets. Thirty minutes of your time, reading this paper, hopefully will provide you insights concerning a few of the limitations and capabilities of U.S. space assets.

EARTH'S ATMOSPHERE

The Earth's atmosphere is what limits satellites from orbiting close to the surface. The atmosphere allows aircraft to fly, but creates considerable drag that makes the orbiting of objects within it impossible. If it were possible to sustain 18,000 mph at low altitudes, an object could stay in orbit, but atmospheric drag eliminates any possibility of this occurring. An object can orbit the moon at near-surface altitudes because of the lack of an atmosphere.

The Earth's atmosphere is divided into a number of regions that are classified according to their temperature changes. The five major regions are: (1) Troposphere, (2) Stratosphere, (3) Mesosphere, (4) Thermosphere, and (5) Exosphere. (**Figure 1**). The borders of these regions are constantly changing because of temperature changes from day and night cycles. Two other spheres are discussed because of their importance to space systems: (1) Ionosphere and (2) Magnetosphere.

Troposphere. The troposphere is the lowest region of the Earth's atmosphere and extends from sea level to 9-12 miles (i.e., 15-20 km or 48,000-63,000 feet). The troposphere is unstable and accounts for most of the Earth's weather. One half of the Earth's atmosphere is below an altitude of three miles (i.e., 5 km or 16,000 feet). With the radius of the Earth being less than 4000 miles (6600 km), it is remarkable that only a three-mile high layer provides the ingredients to support life.

Ninety percent of the Earth's air can be found in the troposphere. At 10,000 feet, oxygen begins to lose its ability to sustain active body functions. Aircraft systems supplement oxygen to crew and passengers above 10,000 feet by providing it via a mask or by pressurizing the cabin. At the upper part of the troposphere, 9 miles (48,000 feet), the lungs no longer function because the combined pressure of carbon dioxide and oxygen in the lungs equals the outside atmospheric pressure. Pressurized suits become a necessity at these altitudes.

Temperature drops as altitude increases in the troposphere at a rate of about 17 degrees per mile (10°C/km). The temperature drop reverses and begins to rise near the upper limit of the troposphere. At higher altitudes, temperature

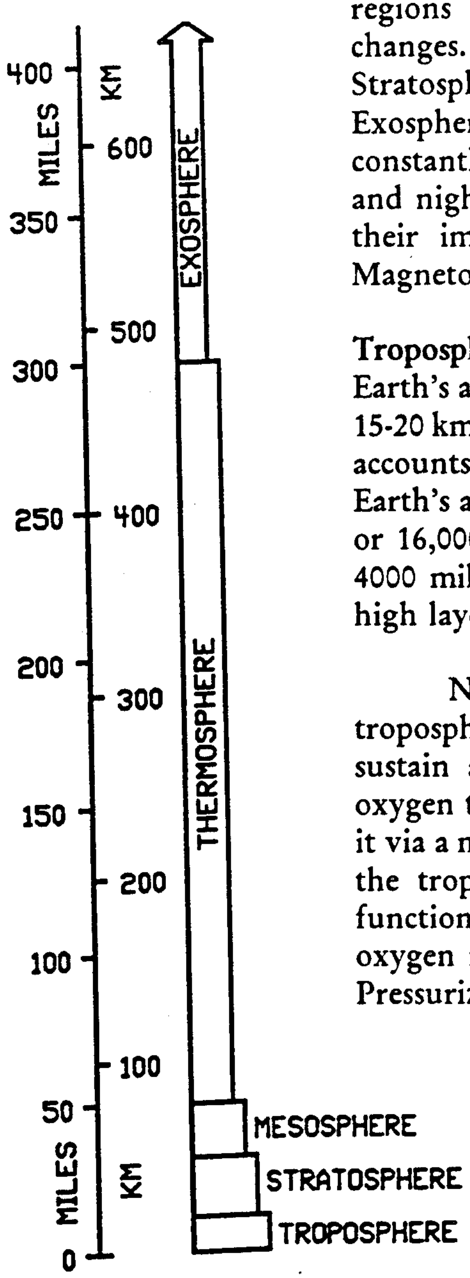


FIG. 1
ATMOSPHERIC REGIONS

swings between night and day become greater than at sea level.

Gasoline propulsion systems perform well near sea level but experience air starvation at altitudes above 25,000 feet. Gasoline engines require great quantities of air for proper air/fuel mixture ratios. Turbojet engines perform well within the troposphere because the turbines within the turbojet compresses the air for proper combustion.

Moving objects within the atmosphere experience friction when in motion. At the Earth's surface, the concentration of particles exceeds 1,000,000,000,000,000,000 (10^{18}) particles per cubic centimeter (Figure 2). As mentioned earlier, these particles allow aircraft to fly, but cause considerable drag that makes orbiting objects at these altitudes impossible.

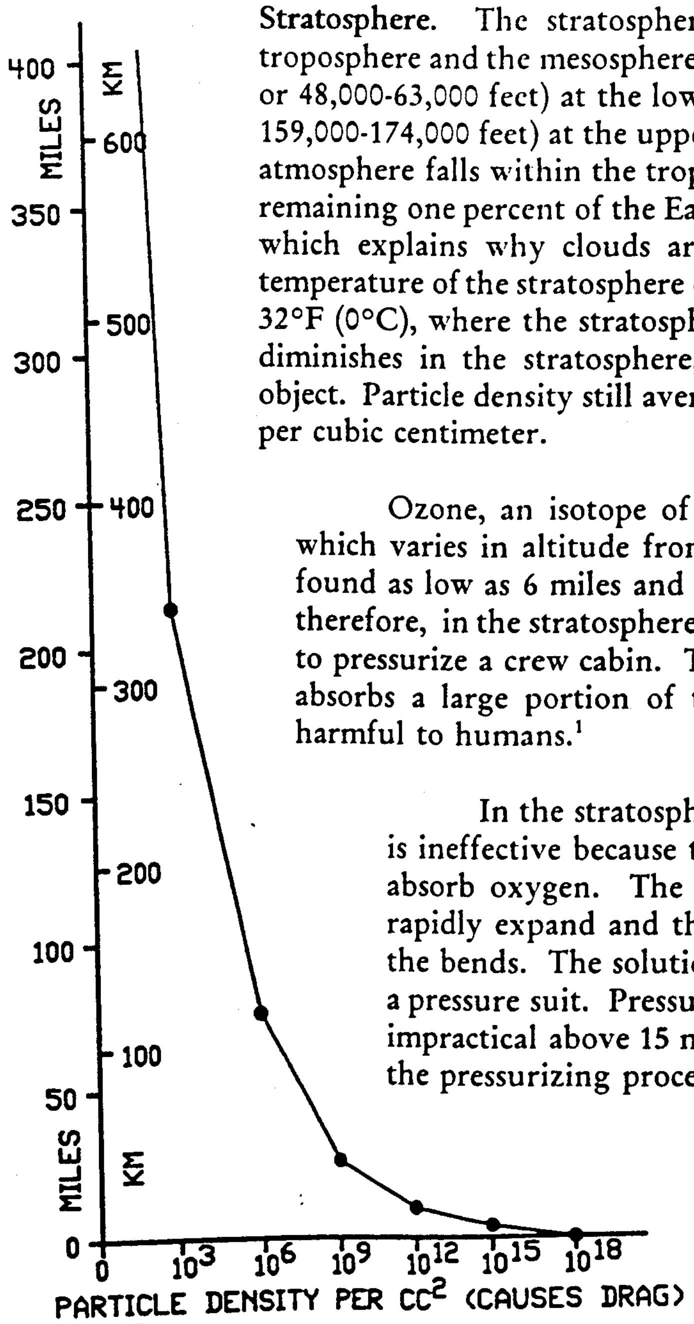


FIG. 2

Stratosphere. The stratosphere, which is sandwiched between the troposphere and the mesosphere, extends from 9-12 miles (i.e., 15-20 km or 48,000-63,000 feet) at the lower end to 30-33 miles (i.e., 48-53 km or 159,000-174,000 feet) at the upper end. About 99 percent of the Earth's atmosphere falls within the troposphere and stratosphere. Most of the remaining one percent of the Earth's water vapor resides in this region, which explains why clouds are practically non-existent in it. The temperature of the stratosphere continually climbs until it reaches about 32°F (0°C), where the stratosphere officially ends. Atmospheric drag diminishes in the stratosphere, but still cannot sustain an orbiting object. Particle density still averages 100,000,000,000,000 (10^{14}) particles per cubic centimeter.

Ozone, an isotope of oxygen, is present in the ozone layer which varies in altitude from 12 to 21 miles. Traces of ozone are found as low as 6 miles and as high 35 miles. Ozone is poisonous, therefore, in the stratosphere the outside atmosphere cannot be used to pressurize a crew cabin. The ozone layer is important because it absorbs a large portion of the sun's ultraviolet radiation that is harmful to humans.[1]

In the stratosphere, breathing oxygen through a mask is ineffective because the lungs no longer have the ability to absorb oxygen. The blood begins to boil as small bubbles rapidly expand and the resulting painful condition is called the bends. The solution is to pressurize the cabin or to wear a pressure suit. Pressurizing a cabin with outside air becomes impractical above 15 miles (i.e., 24 km or 79,000 feet) because the pressurizing process generates too much heat.

At 15 miles, air density is 1/27

that found at sea level. Everything required to sustain life must now be carried aboard.

Turbojet engines fail to function at higher stratosphere altitudes, 20 miles (i.e., 32 km or 106,000 feet). Even ramjet engines run out of air at 28 miles (i.e,. 45 km or 148,000 feet). Propulsion systems above this altitude must provide both fuel and oxidizer; thus, space begins at 28 miles for the propulsion engineer.

Mesosphere. The mesosphere is the third major atmospheric region, sitting just above the stratosphere and below the thermosphere. The mesosphere extends from 30-33 miles (48-53 km) to 50 miles (80 km). The temperature in the mesosphere decreases with increased altitude until it drops to -130° F (-90°C) where by definition it ends.

Thermosphere. The thermosphere is the fourth major atmospheric region and is located above the mesosphere and below the exosphere. The thermosphere extends from 50 miles (80 km) to 200-375 miles (320-600 km). Only one-millionth of the Earth's atmosphere resides in the thermosphere. The sky is totally dark at 100 miles. The temperature of the thermosphere increases with increased altitude. The temperature of the lower end of the thermosphere is -130°F (-90°C) to a maximum of 2,960°F (1,475°C). Day to night temperature swings are extreme in the thermosphere varying from a maximum of 2,960°F to a minimum of 440°F (225°C) (**Figure** 3).

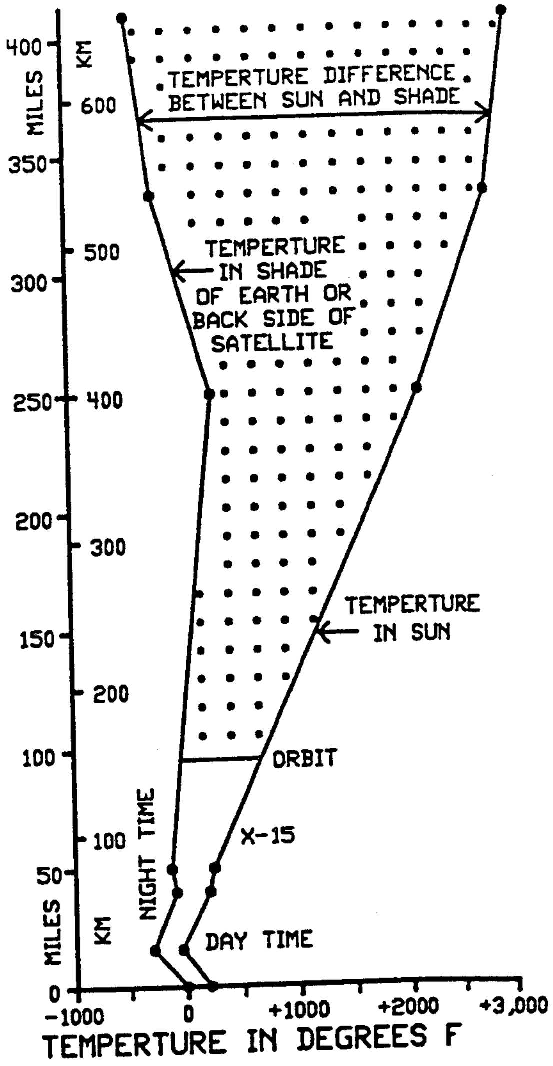


FIG. 3

Above 60 miles wings can no longer be used as control surfaces on spacecraft since the air is too thin to be used for aerodynamic maneuver. The thermosphere can support orbiting objects because air density is low enough that existing propulsion systems can overcome drag. Particle density averages only 1,000,000 (10^6) particles per cubic centimeter.

The altitude of the lowest possible orbit varies by the weight to size ratio and speed of the orbiting object and hence, has not been defined by treaty or international agreement. However, an altitude of 93 miles (150 km) is the lowest altitude that can sustain a circular orbit for one revolution without propulsion. This altitude is the most commonly accepted definition of where space begins.

Exosphere. The exosphere is the highest and last major region of the Earth's atmosphere. The exosphere extends from the thermosphere, 200-375 miles, to outer space. Particle density drops off from a maximum of about 1,000 particles per cubic centimeter at 200 miles to less than one particle per centimeter in deep space. This density varies with local conditions. The sun's solar flare activity is constantly changing the drag of Earth's orbiting satellites. Satellites above 350 miles experience a negligible amount of drag.

The temperature at the lower end of the exosphere is about 2,960°F during the day and 440°F during the night. Space really has no temperature of its own because it takes atmosphere to actually take on a temperature. The temperature of space is measured by the temperature of an object in space. An object takes in heat on the sun side and gives off heat on the dark side.

Satellites must be carefully designed to maintain a feasible temperature. Materials used in satellite designs must have the right combination of heat absorption and dissipation factors. For example, solar panels have a tendency to overheat on the sun side in space unless considerable care is taken to dissipate the heat out the back of the panel using special materials. Satellite electrical systems must be kept cool enough to ensure long life, but not so cool as to prevent electro-mechanical systems from functioning.

Ionosphere. The ionosphere is another region within the Earth's atmosphere (30-240 miles), but is not determined by temperature. The ionosphere is an area of the atmosphere that becomes electrically charged, or ionized, by solar x-rays and ultraviolet radiation. The amount of ionization is dependent on the time of day and the level of solar activity. Sunspots and solar flares on the surface of the sun produce fluctuations in the ionosphere (**Figure 4**).

The ionosphere absorbs, delays, or reflects radio signals of certain frequencies that can both help or hinder radio communications at different times of the day. Radio frequencies up to high frequency (HF) are greatly affected by the ionosphere, whereas, higher frequencies are generally unaffected.

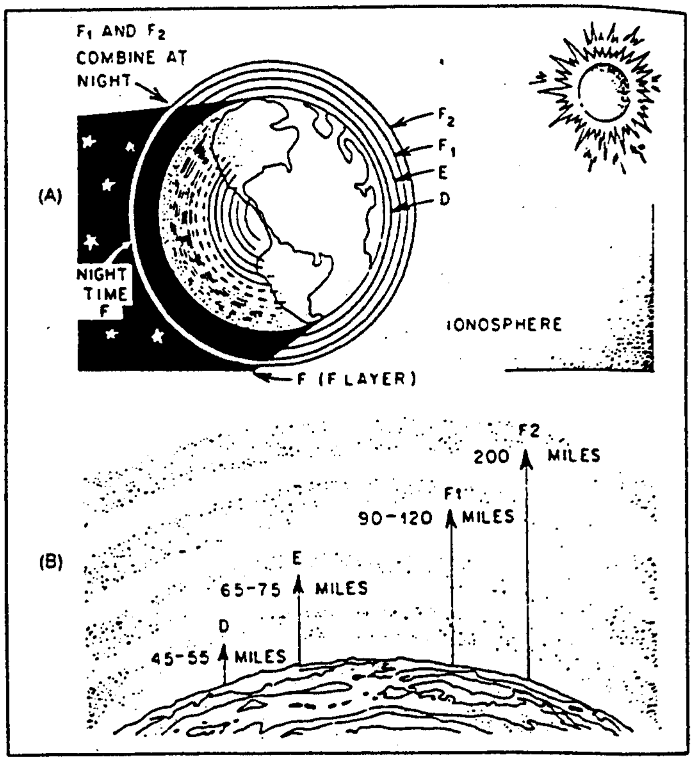


FIGURE 4
IONOSPHERIC LAYERS[2]

Magnetosphere. The magnetosphere refers to the magnetic field that surrounds the Earth. The Earth takes on the characteristics of a large magnet with its north seeking pole near the North Pole and the south seeking pole near the South Pole. The magnetic lines of force extend out from the poles and form continuous loops (**Figure 5**). Compasses use the Earth's magnetic properties as crude navigation aids. Satellites use magnetometers to determine its location in reference to the Earth's magnetic field. Magnetometers only work effectively at low Earth orbits (LEO) because the Earth's magnetic lines of force are too weak at higher altitudes to effectively measure. Magnetometers are generally suspended away from the main body of a satellite in order to reduce the effects of onboard electro-mechanical interference. Satellites can also use the Earth's magnetic field to perform attitude maneuvers in space. Large coils, called torquing coils, can be used as electro-magnets to twist or turn a satellite in relationship to the Earth's magnetic field. Torquing coils are only effective at low Earth orbit.

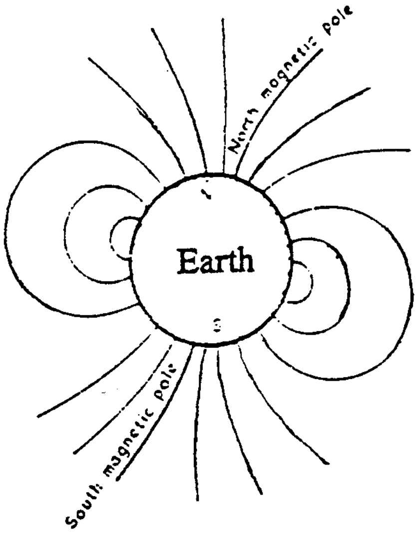


FIGURE 5. EARTH'S MAGNETIC LINES OF FORCE

Van Allen Radiation Belt. The Van Allen radiation fields are regions around the Earth of trapped high energy protons and electrons. These regions have been carefully plotted and spacecraft trajectories are designed to avoid or limit exposure to these areas. The charged particles have been known to damage electronic systems and care must be taken to shield circuits that must pass through them. Satellites in The Van Allen Belt is constantly shifting due to changes in solar activity (**Figure 6**).

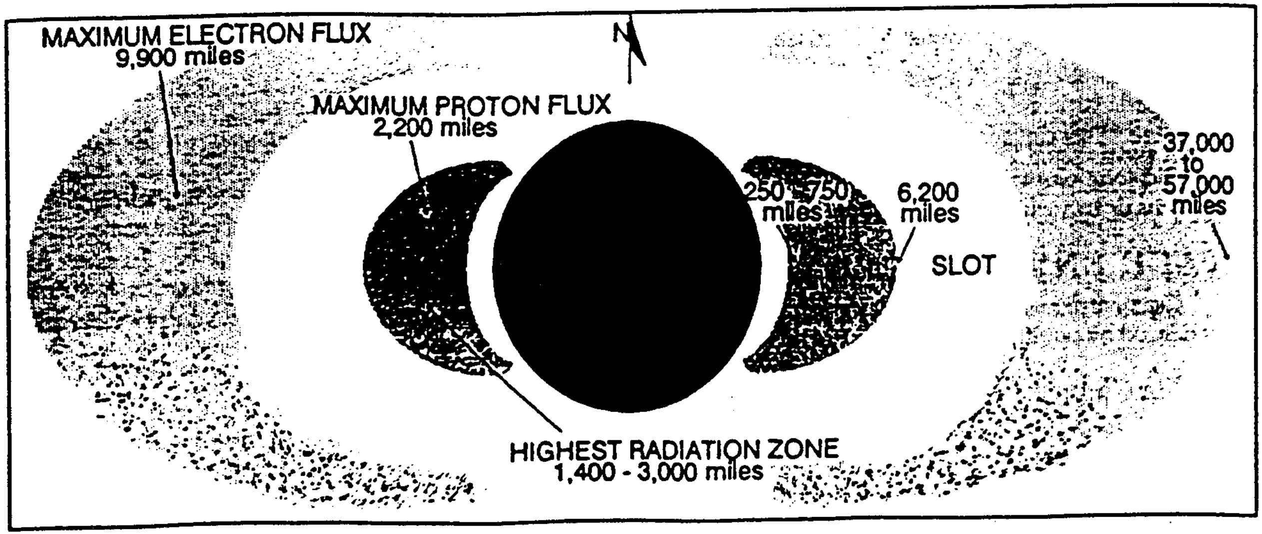


FIGURE 6. CROSS SECTION VIEW OF VAN ALLEN RADIATION BELT

SATELLITE ORBITS

A number of conditions must be met to put a satellite into orbit. The two most critical elements are velocity and altitude. A satellite must be accelerated to a velocity parallel to the Earth's surface that matches the downward pull. On the Earth's surface, an object will drop about 16 feet the first second due to gravity. The Earth's curvature drops off at about 16 feet per every 5 miles. It can be concluded that an object must travel five miles in one second to match the drop equal to the curvature of the Earth. 5 miles per second x 60 seconds per minute x 60 minutes per hour = a speed of 18,000 mph. **(Figure 7)**.

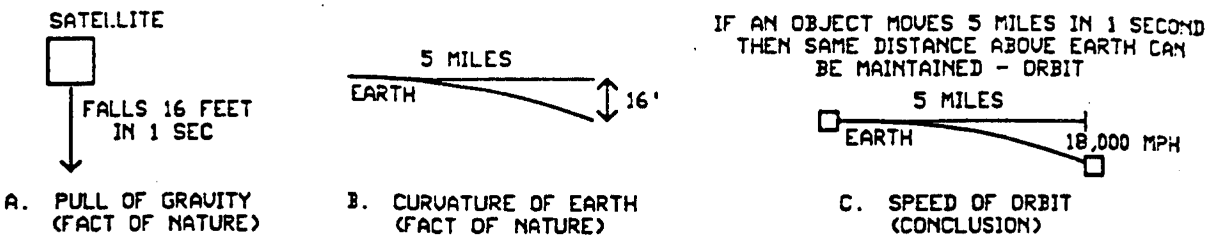


FIGURE 7
THE SPEED REQUIRED TO ORBIT AN OBJECT NEAR EARTH'S SURFACE

At the Earth's surface, an object traveling at 18,000 mph would experience considerable heat from drag and would quickly burn up before traveling very far. Near surface orbit around the Earth is therefore impossible, but is possible on planets that do not have an atmosphere. As altitudes increase, the speed required to maintain orbit decreases. For example, the gravitational pull of an object at an altitude of 100 miles is 95% of that experienced at the surface; therefore, a satellite must travel slower at 100 miles because the Earth's gravitational pull is less. At an altitude of 100 miles, an object will drop about 15 feet the first second. The Earth's curvature drops off slightly more than 16 feet per every 5 miles. We can conclude that an object must travel about 4.7 miles in one second to match the drop equal to the curvature of the Earth. 4.7 miles per second x 60 seconds per minute x 60 minutes per hour = a speed of about 17,000 mph. **(Figure 8)**.

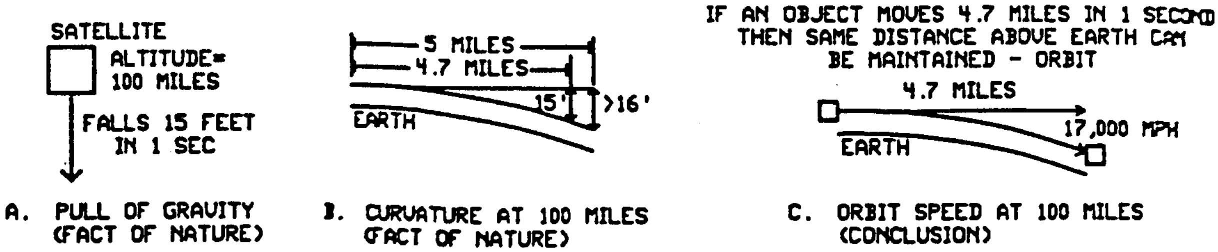


FIGURE 8
THE SPEED REQUIRED TO ORBIT AN OBJECT AT 100 MILES ALTITUDE

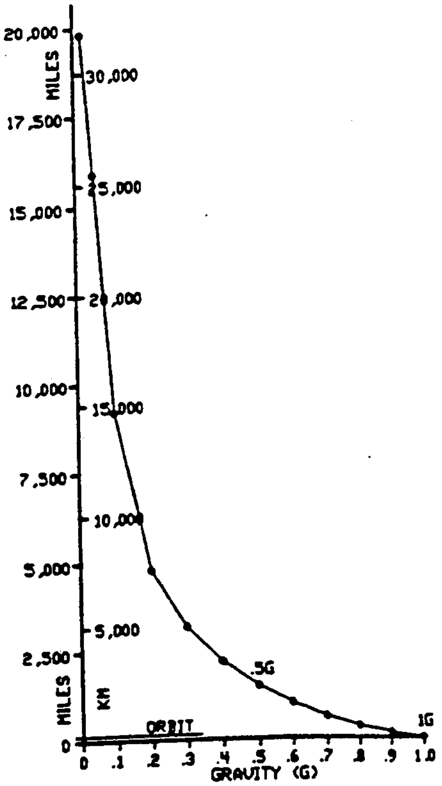


FIG. 9
DIMINISHING GRAVITY WITH ALTITUDE

Atmospheric particle density is low enough to sustain orbit near a 100 mile altitude if the object is traveling fast enough to overcome the downward pull from gravity. The Earth's gravity drops off the farther an object is from the surface (**Figure 9**). The shuttle generally orbits between 140-160 miles and experiences sufficient drag and gravitational pull to force re-entry on its own after only a few weeks. Weight to size ratios play a considerable role in determining orbit life. A small dense satellite ejected from a shuttle will stay in orbit many months after the shuttle would have been dragged into an early re-entry.

A number of types of orbits have become very popular because of their unique characteristics. The five most popular orbits are: **(1) Low Earth, (2) Sun-Synchronous, (3) Semi-Synchronous, (4) Elliptical,** and **(5) Geostationary (Figure 10).**

Low Earth Orbit (LEO). A low Earth orbit is generally agreed to be an orbit between 100 (160 km) and 530 miles (850 km) above sea level. Orbit altitudes less than 200 miles are considered inferior because orbital life is typically less than one year. However, the NUSAT (Northern Utah Satellite), which was launched from the Challenger Shuttle in 1985, stayed in orbit eighteen months. The explanation was that solar activity was at its lowest and that NUSAT was very dense, the diameter of a basketball and weighed 100 pounds.

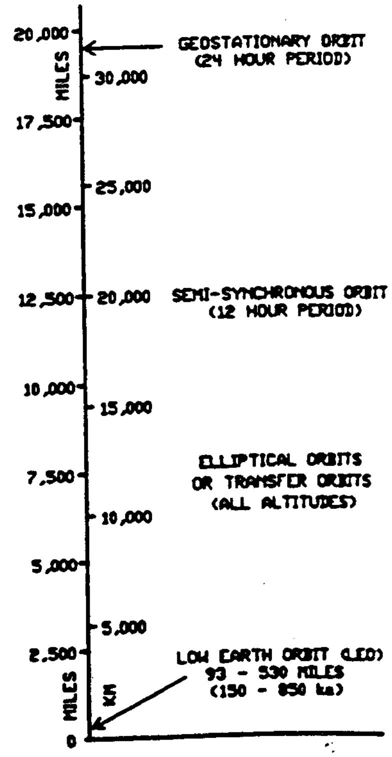


FIG. 10
POPULAR ORBITS

Low Earth Orbits are commonly used for imaging, infrared, radar, and communications payloads. Altitudes of 400 miles (640 km) to 500 miles (800 km) are commonly selected because the reduced drag will easily allow the satellite to stay in orbit 10 years. One significant disadvantage of a LEO is that the satellite's ground path covers the Earth in about 100 minutes. Because of the Earth's rotation, the orbital path moves west each orbit and consistently flies over the same point only a few times each day. LEO satellites come within radio contact of the same ground station a couple of times each day for 2-10 minutes. User ground stations must have antennas capable of chasing satellites across the sky in less than ten minutes.

The inclination of the launch determines the north and south latitude ground track that a satellite will follow. The ground path of a satellite will follow the inclination angle as it completes its orbit. The location and angle a rocket is launched, determines the final orbit inclination angle. A rocket fired at a 45 degree angle from the equator will end up in a 45 degree inclination orbit. Launches from Kennedy Space Center require special consideration to obtain a particular orbit inclination. For example, a due east launch from Kennedy will put a satellite into a 28.5 degree orbit inclination because the latitude at Kennedy is 28.5 degrees. To put a satellite into a 57 degree orbit inclination, the rocket must be fired at 35 degrees (**Figure 11**).

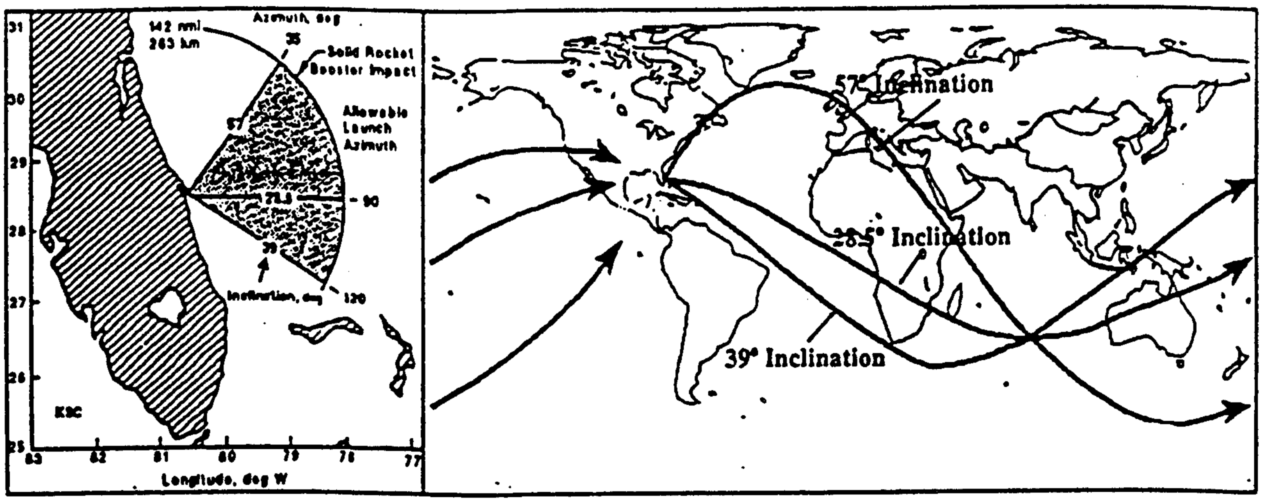


FIGURE 11. ORBITAL INCLINATIONS FROM KENNEDY SPACE CENTER

The Earth rotates on its axis once every 24 hours, which means that it rotates 15 degrees per hour (360 degrees/24 hours = 15 degrees). Therefore, the Earth will rotate 30 degrees while a satellite with a 2 hour period completes one revolution. The ground path will cover a new area 30 degrees to the west with each successive orbit. (**Figure 12**).

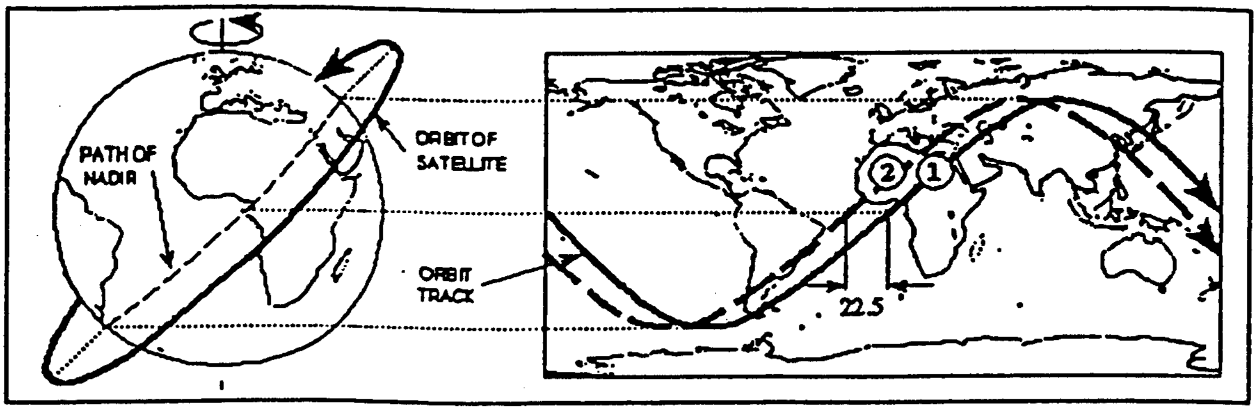


FIGURE 12. SATELLITE GROUND TRACK FOR TWO ORBITS

Orbits higher than 530 miles are considered unfavorable because the extra energy required to get there does not provide any significant advantage. Higher altitude satellites take longer to orbit the Earth which means that the Earth rotates more between each period. Thus, ground paths become further apart as the altitude increases. Orbits above 530 miles may occasionally not even pass over some ground stations, which could cause havoc with a mission. A typical imaging or communications satellite has a useful ground view radius of only about 500 miles as the satellite passes overhead. A low Earth orbit satellite has an excellent chance of flying near a key point on the ground at least once each day. Each type of orbit has its own unique characteristics and the mission must be well understood to determine the best type of orbit.

Sun-Synchronous Orbit. A sun-synchronous orbit is a type of low Earth orbit which passes over the poles and has the unique characteristic of repeating the same ground tracks twice each day, noon and midnight. A significant advantage of a sun-synchronous orbit is that noon images can be repeated, day after day, to scrutinize a target. Because the shadows of ground objects are consistently the same size, new construction or moved objects can easily be identified. Sun-synchronous satellites must be inserted into orbit by boosters capable of launching toward the poles. Vandenberg AFB, California, is the only U.S. launch facility that can place a satellite into a sun-synchronous orbit. Rockets launched from Vandenberg can be launched to the south, which is required for sun-synchronous orbit insertion. Kennedy Space Center, Florida, is limited to low inclination orbit insertion launches out over the Atlantic to avoid risky overland launches.

Semi-Synchronous Orbit. A semi-synchronous orbit is a medium altitude orbit that completes two revolutions per day over the same ground track. This type of orbit is generally a poor orbit because the ground track covers only a small portion of the Earth's surface. The only significant users of this orbit are U.S. and Russian navigation satellites. A constellation of 24 U.S. NAVSTAR GPS satellites resides in semi-synchronous orbits (**Figure 13**).

GPS satellites were put into medium altitude semi-synchronous orbits to optimize stability, longevity, and coverage. GPS satellite orbits must be free of fluctuations from the Earth's magnetic field and solar particle density to ensure predictable and extremely accurate orbits. Even as stable as this orbit is, ground station operators must make minor orbit adjustments to each of the 21 GPS satellites (plus 3 backup spares) as often as every four hours.

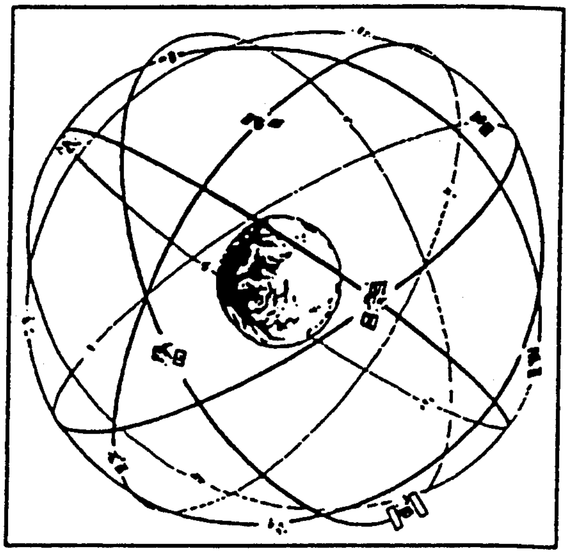


Fig. 13. GPS Constellation

Elliptical Orbit. All orbits start out as elliptical orbits until their final orbit is reached. Most elliptical orbits are used as transfer orbits to put a satellite in its final circular orbit. To circularize an elliptical orbit, rocket motors are fired at the highest point of the orbit, called the apogee. A Molniya orbit is a specific elliptical orbit that spends considerably more time, at apogee, over a specific target area than it does at its close-to-the-Earth perigee (**Figure 14**). The Molniya orbit works well for communications satellites intended to provide coverage near the poles where geostationary satellites are out of range.

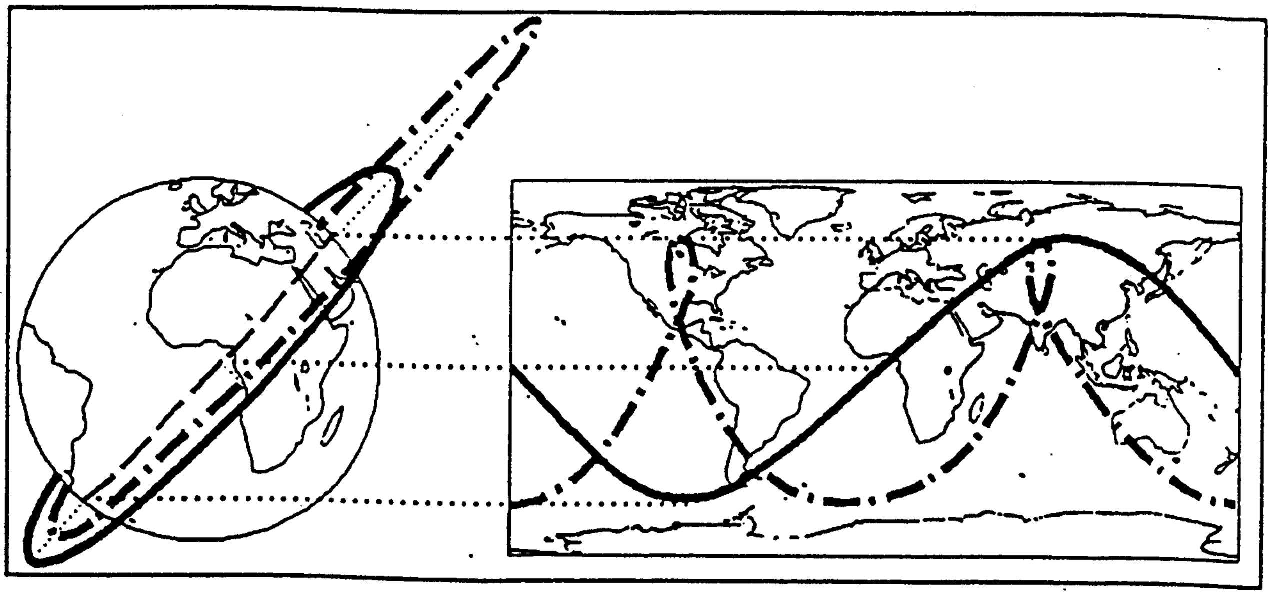


FIGURE 14. ELLIPTICAL ORBIT GROUND TRACKS

Satellites in elliptical orbits slow down as they travel away from the Earth and reach their slowest speed at apogee because of the Earth's gravitational pull. On the other hand they speed up as they return to Earth, also because of the Earth's gravitational pull. This slowing down and speeding up cycle would continue indefinitely if it were not for the particle density near the Earth's surface. Elliptical orbits, at the minimum altitude (perigee) can come as low as 90 miles (145 km) and still make it back out to space. This cycle will not last long, however, because the increased drag experienced at this extremely low altitude slows the satellite to the point it never fully recovers. Early spy satellites took advantage of this low altitude to obtain great photographs, but this method was very costly because of the short life of the satellite.

Geostationary Orbit. A geostationary orbit occurs when a satellite orbits the Earth once per day following a path around the equator. A geostationary satellite gives the illusion that is not moving, but in fact, it is moving very fast to keep up with the Earth's rotation. A geostationary orbit is a high orbit that averages 19,300 miles (31,000 km) above sea level and travels about 6,900 miles (11,000 km) per hour to keep up with the Earth's rotation. The Earth's gravitational pull at this altitude is considerably less than at lower altitudes, which means that satellites must travel much slower to maintain a constant altitude. The difference between a geosynchronous and a geostationary orbit is that a geostationary orbit is always circling around the equator whereas a geosynchronous orbit will be moving north and south of the equator. Both types of orbits circle the Earth once per day and keep up with the Earth's rotation.

The most significant advantage of a geostationary orbit is that ground receivers can be permanently aimed at the satellite, which makes communications an ideal mission. Fixed satellite receivers solve the tracking problems that plague low Earth orbit satellites, but they have another problem because the satellite is considerably further away, 19,300 miles (31,000 km) versus 400 miles (650 km). Large high-gain antennas, 6-8 foot reflecting dishes, are required to receive the weak signals. These signals are even weaker at northern latitudes and impossible to receive beyond 70 degrees latitude. The problem can be better understood when one notices the low angle a dish must be aimed to receive geostationary signals, especially at northern latitudes of the United States (see **Figure 15**). Geostationary satellites can be moved anywhere around the globe to serve the community below them. The only restriction to moving the satellite is the amount of fuel consumed during the move. Most geostationary satellites carry aboard enough fuel for 6-8 years of station keeping maneuvers.

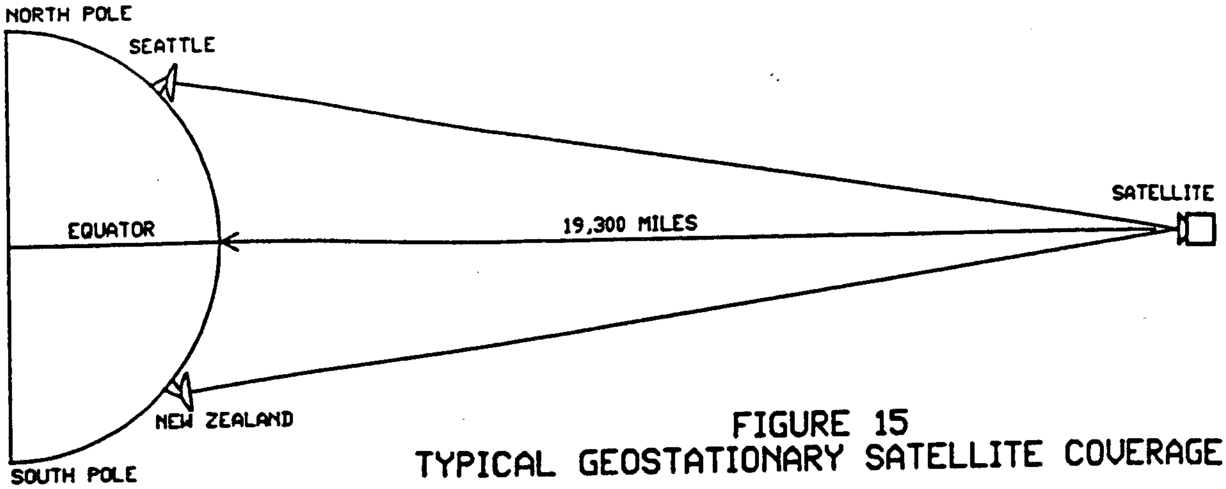
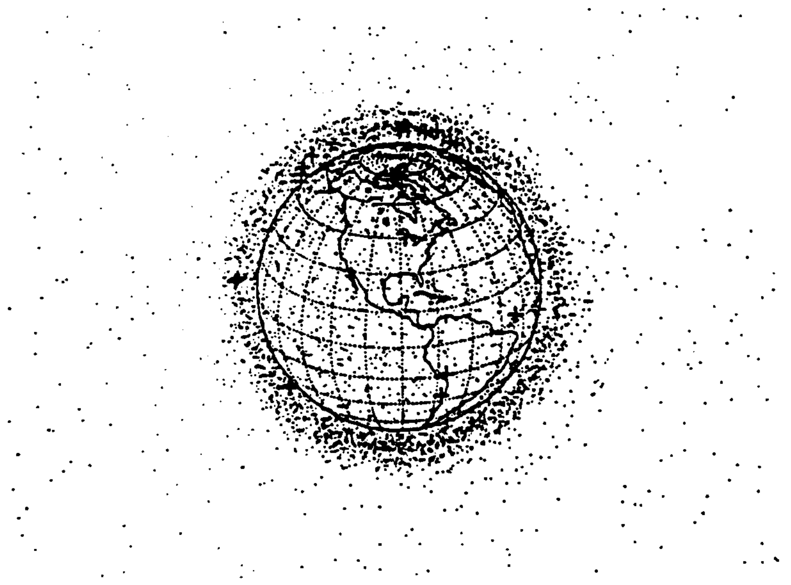


FIGURE 15
TYPICAL GEOSTATIONARY SATELLITE COVERAGE

Space Debris. The U.S. is currently tracking over 7,000 objects of which 500 are active spacecraft and the remaining are classified as debris. Objects the size of toasters are easily tracked by special ground-based radar. Smaller objects, depending on their radar reflection properties are often tracked. If objects down to 1 centimeter, a small marble, could be tracked, then the number of objects would grow to 25,000. Naval scientists have shown that they can simultaneously compare positions of 7,000 objects and detect close encounters between all of them. An NRL experiment detected a close encounter of two weather satellites that came within 2 km of each other and was photographed by Air Force Space Command's optical telescope in Hawaii.[3]

Satellites in high orbits will remain aloft long after they stop functioning. Three hundred objects are now clustered within the narrow band at geostationary orbit. These objects will never find their way into the atmosphere and must be monitored. On the other hand, constant cleansing occurs at low Earth orbit. Fifty-five hundred of the seven thousand objects are below 1,000 miles and will find their way into the atmosphere. Small objects cannot yet be tracked and these objects can cause considerable damage to life and property if collision occurs. Many satellites have mysteriously stopped functioning, but evidence is lacking as to whether a collision occurred. There has been evidence that a few launch vehicles have collided with their payloads during ejection. Still collisions in space are rare. A recent Navy experiment simulated the explosion of 10 low Earth orbit satellites into 400 fragments traveling up to 100 meters per second. A six-hour simulation revealed that even though 300 satellites would come within 5 km of a fragment there were no collisions with any of the 500 active satellites. The closest a fragment came was 500 meters (Figure 16).[4]



Locations of satellites in the Naval Space Command catalog on Sept. 25, 1993, are shown in the graphic at right. The dots indicate positions of objects, while the crosses indicate the positions of objects that are within 10 kilometers of another.

FIGURE 16. COMPUTER REPRESENTATION OF OBJECTS IN ORBIT

Moon. The Moon gracefully circles the Earth every 27 days and gives the illusion that it rapidly travels overhead, but it is really lumbering along to equal the Earth's gravitational pull. The mass of the Moon equals 1/83 that of Earth and its effects can be felt on Earth as it circles overhead. When the Moon is overhead, the Earth's tides are at their highest. The gravitational pull of the Moon gathers the water from the sides of the Earth and this high water follows the Moons path over the surface of the Earth. The large amount of water that is displaced to one side would create a tremendous imbalance of weight if centrifugal forces did not compensate by creating equally high tides on the opposite side.

ROCKET PROPULSION

A rocket is the propulsion system used to carry objects out of the Earth's atmosphere. For rockets to function out of the Earth's atmosphere, they must carry their own fuel and oxidizer. Velocities greater than 18,000 mph are required to exceed the Earth's gravitational pull. The thrust generated from the first stage rocket motor must exceed the total weight of the vehicle. Additional stages are required because the weight of the empty first stage becomes a burdensome payload and must be dropped. In describing rocket propulsion, this section will be divided into four areas: (1) Thrust, (2) Liquid Propellants, (3) Solid Propellants, and (4) Hybrid Propellants.

Thrust. Thrust is a measurement of the force provided by an engine. A rocket differs from other engines because the fuel and oxidizer are carried aboard. The thrust and duration of the thrust are called total impulse, rated in pounds or kilograms per second. A shoulder fired rocket such as the LAW has an average thrust of 600 lbs. and a firing duration of 0.2 seconds for a impulse of 120 lb/sec. The Saturn V rocket, the largest rocket ever made by the U.S., generated an impulse of 1.15 billion lb/sec.

Specific impulse is another very important factor which rates the efficiency of an engine. Specific impulse is the amount of fuel burned per second to generate a certain thrust (**Figure** 17). A specific impulse of 300 is good and means that one pound of propellant can generate one pound of thrust for 300 seconds. For example, the solid propellant Castor 4A rocket motor used to improve the performance of the Delta launch vehicle has a thrust of 107,000 lb. and carries 22,000 lb of propellant which burns for 53 seconds. Specific impulse (Isp) is determined by the thrust (in lb.) divided by the amount of fuel burned in one second. The Castor motor burns 22,000 lb./53 seconds = 415 lbs of fuel every second. 107,000 lb thrust/415 lb. = 258 Isp. Isp becomes a relative efficiency rating useful for comparison of rocket motors.

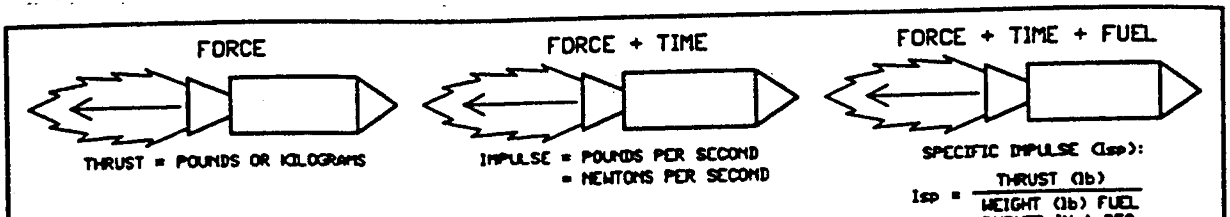


FIGURE 17
ROCKET MOTOR THRUST AND SPECIFIC IMPULSE

The mass ratio of a rocket is the weight ratio of a fully loaded rocket at lift off to the same rocket after all of the fuel is expended. A high Isp rocket motor does little good if the weight of the vehicle is not controlled. Acceleration occurs because the weight of the rocket is less than the thrust provided. When the fuel is expended the extra weight of the empty stage is jettisoned. The next stage has a smaller engine and much lighter in weight, but it also accelerates because the thrust of the smaller engine exceeds the weight of the remaining rocket stages. Specific impulse, or engine efficiency, still falls short of being able to take a single-stage space plane to orbit.

Liquid Propellants. Liquid propellant rocket engines burn two liquids that are stored in separate tanks until needed. Common liquids used are hydrogen and oxygen. Both of these liquids are gasses at room temperature and must be cooled below -300°F to convert them into a liquid form. Hydrogen and oxygen, as gases, cannot be compressed enough into the onboard storage tanks to provide the necessary specific impulse. The conversion into a liquid is required to bring the density up to the required efficiency.

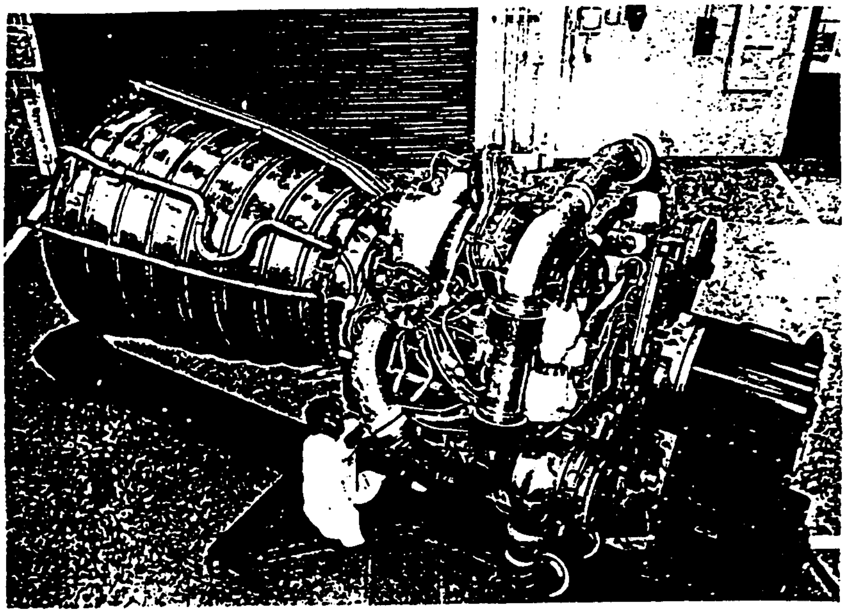
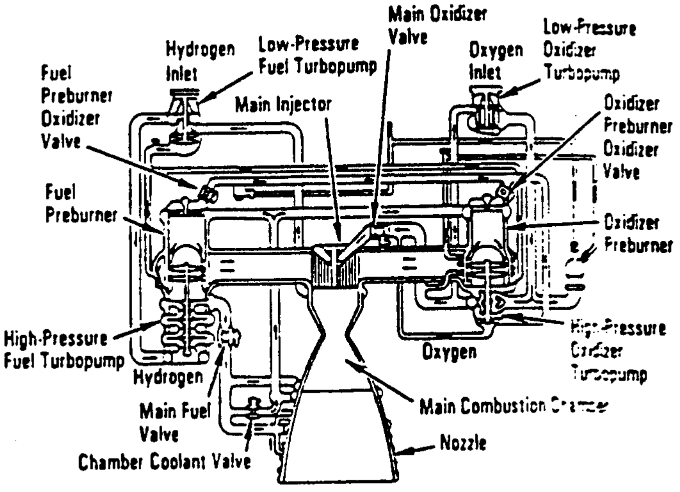


FIGURE 18. SPACE SHUTTLE MAIN ENGINE[5]

Liquid propellant rocket engines are very efficient and specific impulse ratings are generally high. A significant advantage is that the thrust can be adjusted during launch and can even be cycled on and off. If the fuel used is oxygen and hydrogen, the cost is low and quantities are plentiful.

There are a few significant disadvantages that must be considered when considering using liquid propellant rocket engines.

One significant disadvantage of liquid propellant rocket engines is that they require complex fuel metering and control plumbing to sustain the proper combustion (**Figure 18** and **Figure 19**). Rapid launch systems are not feasible for cooled liquid hydrogen and oxygen because they cannot be maintained in the launch vehicle for more than a few hours before launch. Hydrogen and oxygen



Main Engine Flow

FIGURE 19. MAIN SHUTTLE ENGINE FLOW[6]

fuels are often replaced with toxic fuels, like aniline and nitric acid, but they are very dangerous. These toxic fuels are commonly used in upper stage rocket motors.

Solid Propellants. Solid propellent rocket engines were developed to overcome the weaknesses of the liquid propellant engines. Solid propellant rockets burn a mixture of fuel and oxidizer that are mixed as a slurry and hardened into the rocket motor case. The preformed exposed surface area determines the speed in which the solid burns. The largest solid rocket booster (SRB) used by the U.S. is the 100 foot long Thiokol booster used on the Space Shuttle (**Figure 20**). All small missiles: Patriot, Hawk, Sidewinder, Sparrow, TOW, and Hellfire, use solid propellant rocket engines for propulsion. The only significant disadvantage of a solid rocket motor is that its thrust is not controllable after the ignition process has begun, hence, the use has to be carefully planned in advance.

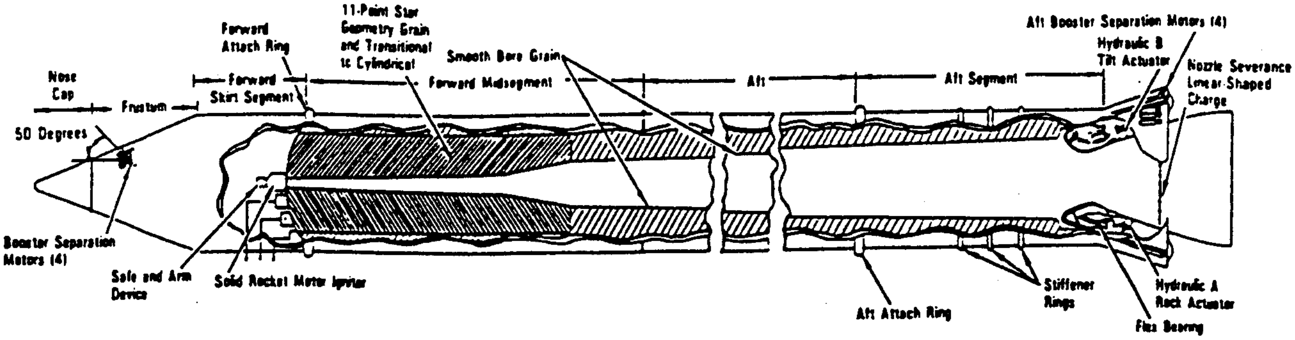


FIGURE 20. THIOKOL'S SHUTTLE ROCKET MOTOR[7]

LAUNCH VEHICLES

The military Services and NASA use a mixed fleet concept for placing payloads into orbit. The Atlas, Delta, Pegasus, Scout, Shuttle, and Titan are current U.S. space launch vehicles. Contracts have been awarded to develop two new launch vehicles called the Taurus and the LLV. The Shuttle was intended to be the ultimate answer and replace the Expendable Launch Vehicles (ELV's) by the end of the 1980s. The Challenger disaster in 1986, however, grounded the Shuttle for two years and contractors scrambled to find alternate launch vehicles to put their satellites into orbit. The Challenger disaster radically changed the direction of the U.S. space program, which now uses a mixed fleet concept. Missions are now matched with available launch systems.

Atlas. The Atlas is a medium lift launch vehicle that was originally developed in the late 1950s. Later versions were used to put the first U.S. manned orbital flights. The Atlas has been updated many times and the current vehicle is the extended Atlas 2. The Atlas launch vehicle can put 5900 lb. (2700 kg) satellite into a geo transfer orbit (GTO). The Atlas has been used to launch GPS, Military Fleet Satellite Communications (FLTSATCOM), Defense Satellite Communications Systems (DSCS) and Defense Meteorological (DMSP) satellites (**Figure 21**). General Dynamics, Space Systems Division, currently produces the Atlas which had an 85.5% success rate before 1991 and an 85% rate on the last 20 vehicles.[8] Of the two failures in the last 10 years, one was due to lightning.

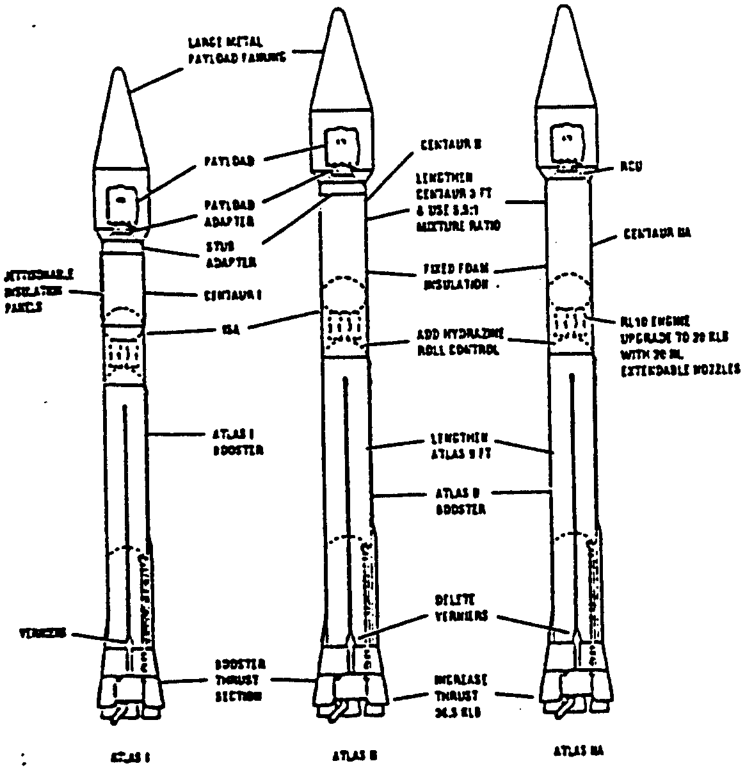


FIGURE 21. PARTIAL ATLAS FAMILY OF LAUNCH VEHICLES

Delta. The Delta is a medium lift launch vehicle originally developed as an intermediate range ballistic missile in the late 1950s. The Delta vehicle family has been consistently updated and the current Delta II version was first launched in 1989. The Delta has been considered the workhorse of the U.S. space program and has placed over 180 satellites into LEO and geostationary orbits (**Figure** 22). The 128 foot Delta II can place a 1000 lb satellite into an elliptical 19,000 mile high geo transfer orbit (GTO). The Delta II has been the primary launch vehicle for GPS and many DOD satellites.

McDonnell Douglas Space Systems Company currently produces the Delta which has had a career life success of 94.2% and a 100% rate for the last 25 launches.[9] The Delta can be launched from either Vandenberg AFB in California or Cape Canaveral Air Force Station in Florida.

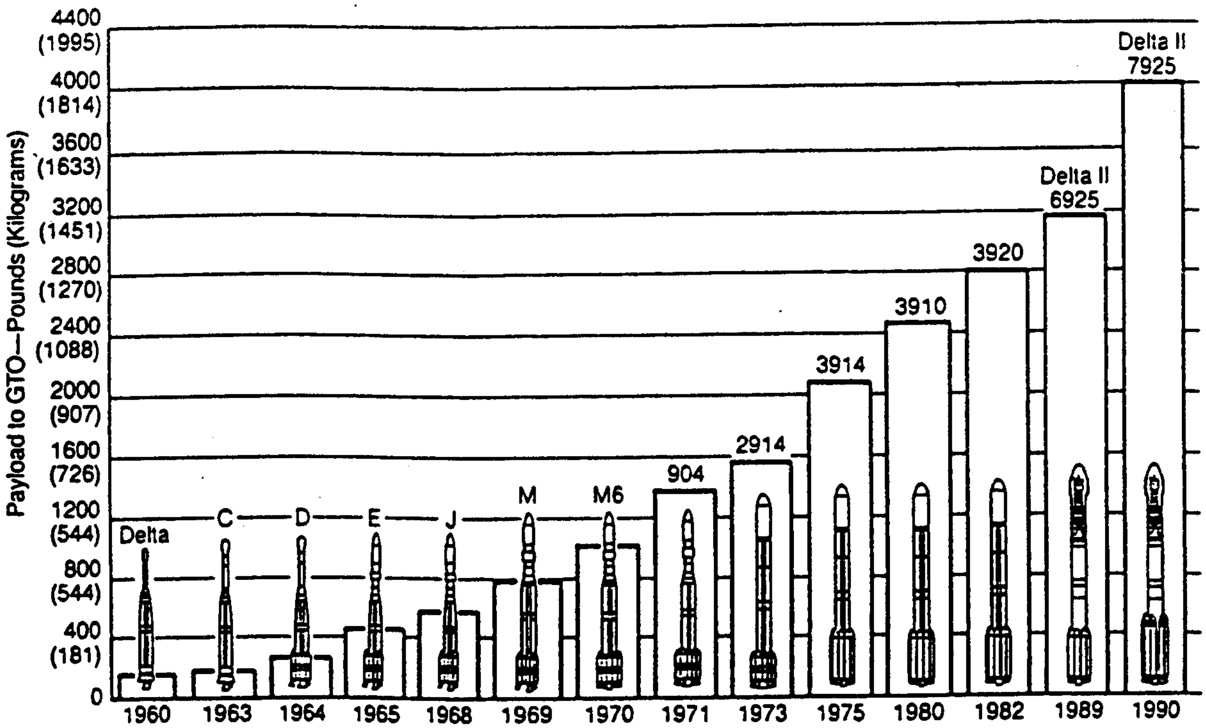


FIGURE 22. DELTA FAMILY OF LAUNCH VEHICLES[10]

Scout. The Scout is the smallest solid propellant launch vehicle in the U.S. inventory. It was pieced together from older rocket systems designed in the 1960s with continual updates occurring since 1976. The Scout has placed over 100 satellites into low Earth orbits. This small 75 foot rocket can place 480 lb (220 kg) payloads into a 300 mile (480 km) circular orbit.

LTV Aerospace and Defense Missiles Division currently produce the Scout which has had a 96% success rate.[11] The Scout can be launched from facilities at Vandenberg AFB in California, Wallops Island in Virginia, and an Italian facility in Kenya, Africa. There are only a few Scout missiles left and they will be replaced by the Taurus or

Pegasus launch vehicles. A new, larger capacity, Scout is under development, but has not been awarded any U.S. contracts.

Pegasus. The Pegasus is a winged launch vehicle designed to be launched from under the wing of a high flying aircraft (Figure 23). The Pegasus is a small satellite delivery system which can place 900 lb (410 kg) satellites into equatorial low Earth orbits and 600 lb (270 kg) satellites into polar orbits (Figure 24). The purpose of the Pegasus design was to reduce the launch costs of placing small payloads into low Earth orbits without the usual delays of building the rocket on the launch pad. Pegasus payloads could be launched with short notice to accommodate rapid employment of special payloads for emergency contingencies. The first launch took place off the coast of California, in 1990. Orbital Sciences corporation and Hercules manufacture the Pegasus. The Pegasus can be launched anywhere and is not limited to existing launch facilities.

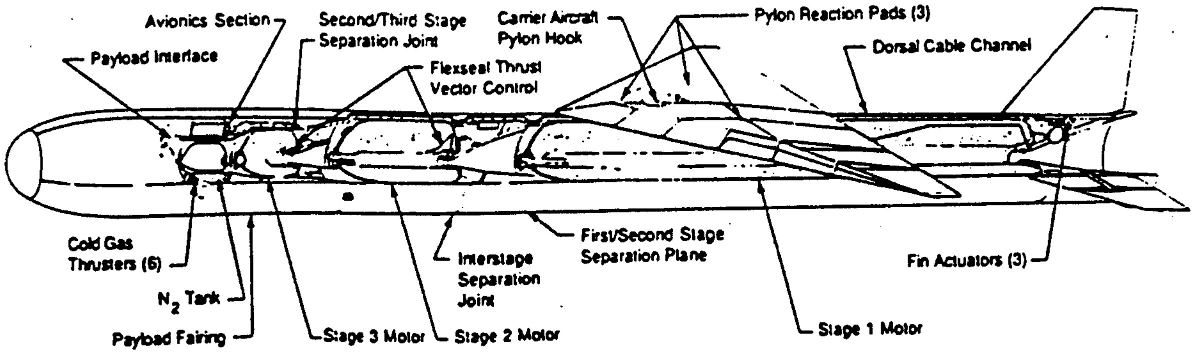


FIGURE 23. PEGASUS AIRCRAFT LAUNCHED SPACE VEHICLE[12]

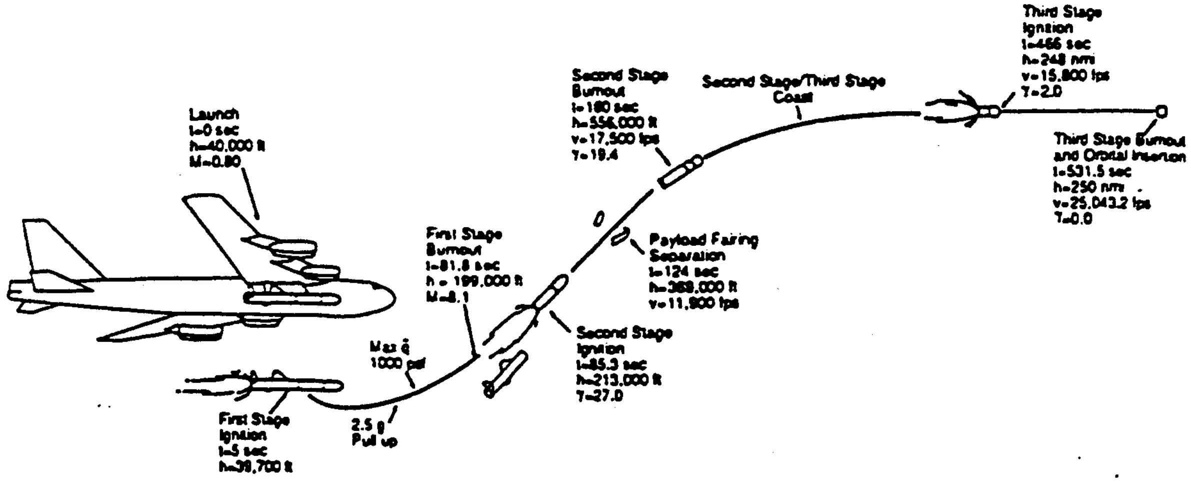


FIGURE 24. PEGASUS LAUNCH SEQUENCE[13]

Shuttle. The Shuttle launch vehicle was originally designed to replace all other expendable launch vehicles for NASA and DOD satellites. The Challenger Shuttle disaster in 1986 caused a dramatic policy change which reduced the reliance on one type of launch vehicle. A mixed fleet concept was quickly reintroduced and payloads were transferred to expendable launch vehicles (ELV's). The Shuttle was designed in the late 1970s and made its first flight in 1981. The payload capacity of 65,000 lbs (29,500 kg) into a LEO makes the Shuttle the heaviest lifter in the U.S. space inventory. The Shuttle is limited to a low Earth orbit, which means that it must carry the boosters, in the cargo bay, to carry satellites to higher orbits (**Figure 25**).

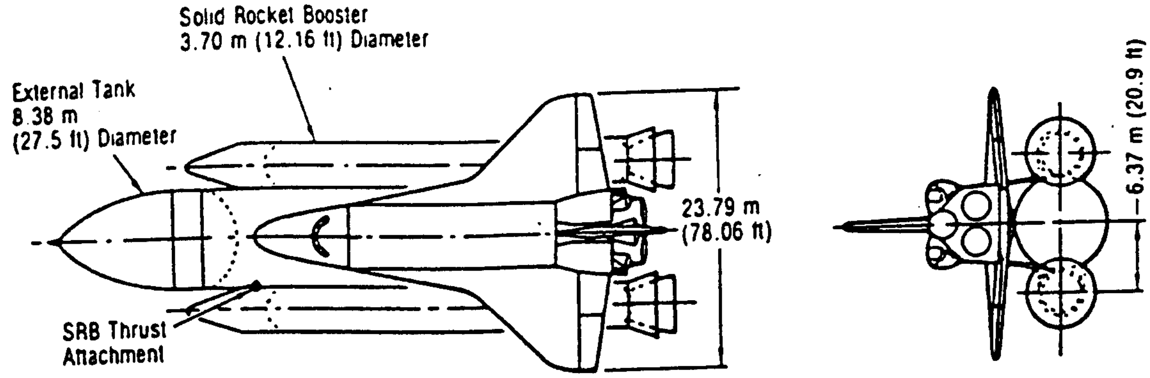


FIGURE 25. SPACE TRANSPORTATION SYSTEM SHUTTLE[14]

The Shuttle is the launch vehicle for the Space Transportation System (STS), which is totally owned and operated by NASA. Kennedy Space Center in Florida, is the only launch facility completed. The west coast launch facility at Vandenberg AFB in California, was never completed because of budget cuts and policy changes. The Shuttle is limited to placing satellites into geostationary and low inclination orbits.

Titan. Titan series launch vehicles also have a long history of upgrades and changes that now make it the only polar orbit heavy lifter in the U.S. inventory. Earlier versions were used for the two-man Gemini program and intercontinental ballistic missiles (ICBM's).

Martin Marietta Space Launch Systems currently manufactures the Titan III and IV series launch vehicles which can be launched from either Vandenberg AFB in California or from Cape Canaveral Air Force Station in Florida. Because a Shuttle launch facility was never completed at Vandenberg AFB in California, the Titan has been the primary launch vehicle for polar orbit missions.

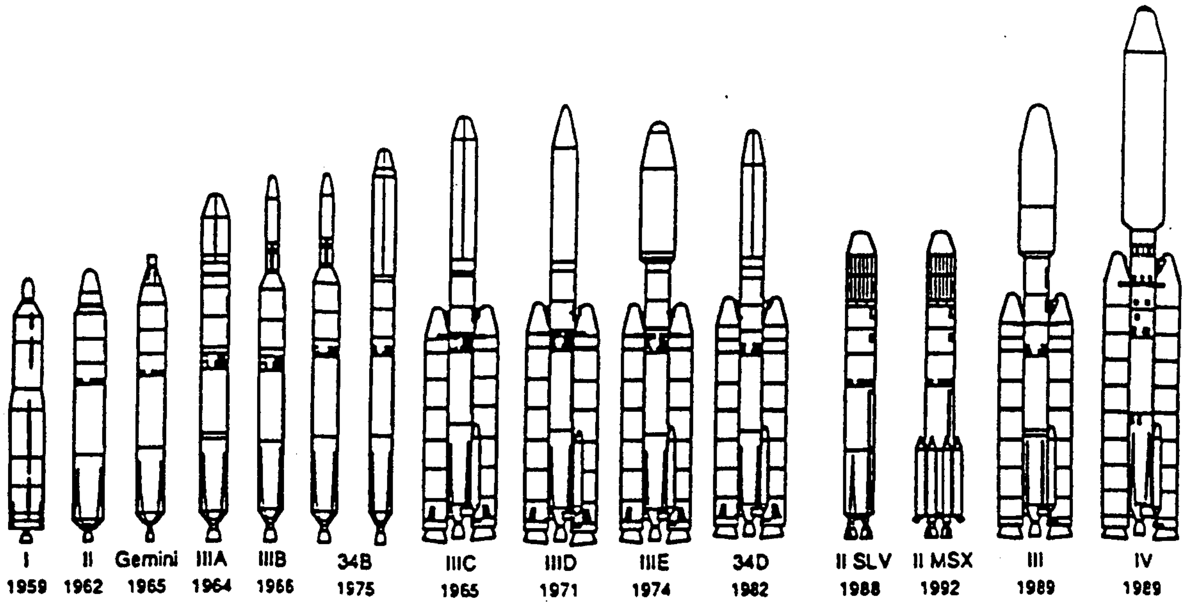
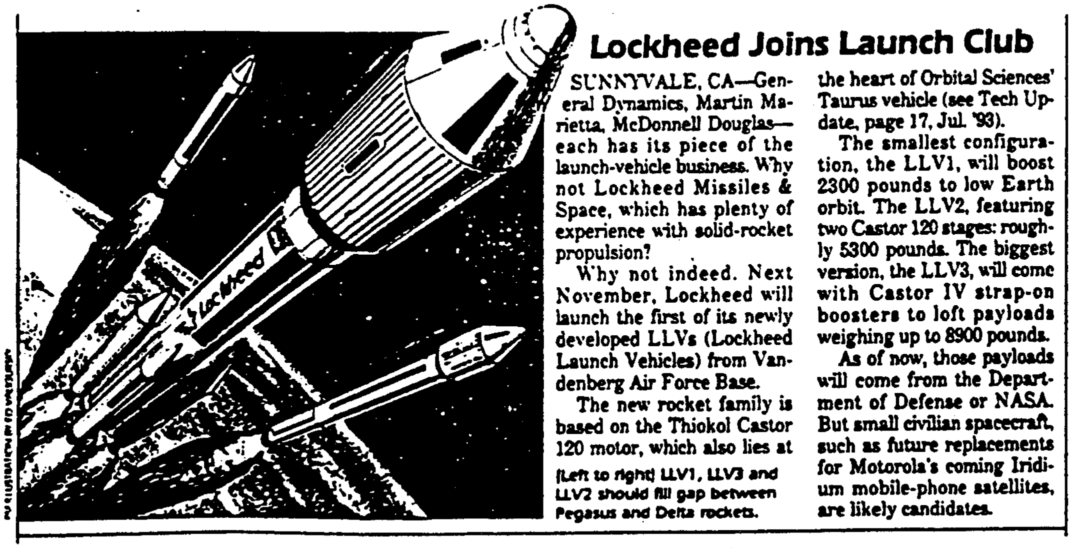


FIGURE 26. TITAN FAMILY CONFIGURATION HISTORY[15]

Taurus. The Taurus is basically a Pegasus with a rocket motor replacing the aircraft launch vehicle. The purpose of the Taurus is to accommodate short notice launches within 72 hours from dispersed locations. Payloads of 3000 lb (1360 kg) to low Earth orbits or 700 lb (330 kg) to geo transfer orbit are possible. The first stage is a Thiokol MX/Peacekeeper motor. The Taurus launch system is made by Orbital Sciences.

LLV. A new, yet untested, entry into the rocket launch vehicle family, the Lockheed Launch Vehicle (LLV) is contracted to fly by the end of this year with DOD or NASA payloads. The LLV is capable of lifting 8900 lbs (4000 kg) into low Earth orbit. The new rocket family also uses a Thiokol MX/Peacekeeper stage 1 motor (**Figure 27**).

LLV. A new, yet untested, entry into the rocket launch vehicle family, the Lockheed Launch Vehicle (LLV) is contracted to fly by the end of this year with DOD or NASA payloads. The LLV is capable of lifting 8900 lbs (4000 kg) into low Earth orbit. The new rocket family also uses a Thiokol MX/Peacekeeper stage 1 motor (**Figure 27**).



Lockheed Joins Launch Club

SUNNYVALE, CA—General Dynamics, Martin Marietta, McDonnell Douglas—each has its piece of the launch-vehicle business. Why not Lockheed Missiles & Space, which has plenty of experience with solid-rocket propulsion?

Why not indeed. Next November, Lockheed will launch the first of its newly developed LLVs (Lockheed Launch Vehicles) from Vandenberg Air Force Base.

The new rocket family is based on the Thiokol Castor 120 motor, which also lies at the heart of Orbital Sciences' Taurus vehicle (see Tech Update, page 17, Jul. '93).

The smallest configuration, the LLV1, will boost 2300 pounds to low Earth orbit. The LLV2, featuring two Castor 120 stages: roughly 5300 pounds. The biggest version, the LLV3, will come with Castor IV strap-on boosters to loft payloads weighing up to 8900 pounds.

As of now, those payloads will come from the Department of Defense or NASA. But small civilian spacecraft, such as future replacements for Motorola's coming Iridium mobile-phone satellites, are likely candidates.

(Left to right) LLV1, LLV3 and LLV2 should fill gap between Pegasus and Delta rockets.

FIGURE 27. UPCOMING LOCKHEED LAUNCH VEHICLE[16]

SPACE LAUNCH FACILITIES

The United States owns and operates four orbital launch facilities: (1) Eastern Space and Missile Center, (2) Kennedy Space Center, (3) Western Space and Missile Center, and (4) Wallops Flight Facility. Each one of these facilities has unique characteristics and limitations.

Eastern Space and Missile Center. The Eastern Space and Missile Center (ESMC) is located at Cape Canaveral Air Force Station and is managed by the Air Force Space Command (**Figure 28**). ESMC is located on the eastern coast of Florida, west of Orlando. Over 40 different launch stands have been constructed and all the current launch vehicles can be launched with the exception of the Shuttle. The test range extends from Cape Canaveral, across the Atlantic and Africa, to the Indian Ocean. The most efficient launch inclination is due east, which places satellites in 28.5 degree inclination orbits because Cape Canaveral is located on the north 28.5 degree latitude. Other orbit inclinations can be obtained with fuel being the significant limiting factor. Launches are generally made over water to allow for a margin of safety if something were to go wrong. Cape Canaveral launches are limited to a minimum angle launch of 35 degrees to a maximum angle launch of 120 degrees.

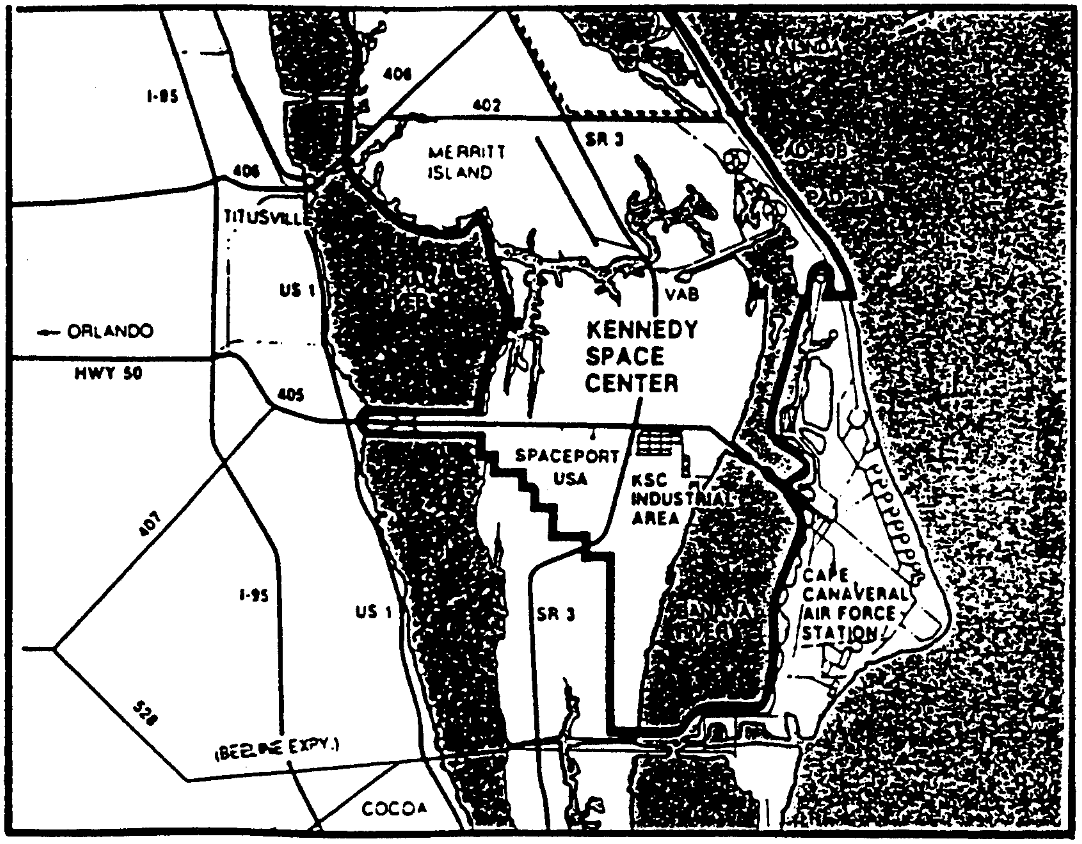


FIGURE 28. CAPE CANAVERAL AND KENNEDY SPACE CENTER

Kennedy Space Center. The Kennedy Space Center, located just north of Cape Canaveral, is owned and operated by the National Aeronautics and Space Administration (NASA). Like ESMC, Kennedy is limited to launches to the east (**Figure 29**). The facility was designed to launch only Space Shuttles and is heavily supported by the Air Force Space Command's Eastern Missile and Space Center.

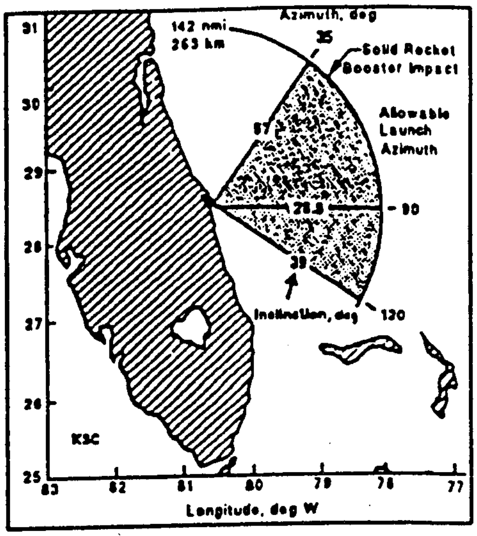


FIGURE 29. ESMC AND KSC

Western Space and Missile Center. The Western Space and Missile Center (WSMC) is located at Vandenberg AFB in California and is managed by the Air Force Space Command. The range extends out over the Pacific to meet the Eastern Test Range over the Indian Ocean. The Vandenberg facility was needed to place satellites into polar orbits, which the Eastern Range could not do for safety reasons. The launch angle safety limit for this facility is between 140 and 201 degrees, which means that satellites can be safely flown south into polar orbits (**Figure 30**). Surveillance, weather, and imaging satellites are commonly launched from this facility. The launch facilities can handle Atlas, Delta, Scout, and Titan launch vehicles. At one time, the Space Shuttle was intended to be flown from Vandenberg and a partially completed Shuttle launch facility is being retrofitted to handle Titan IV heavy expendable launch vehicles.

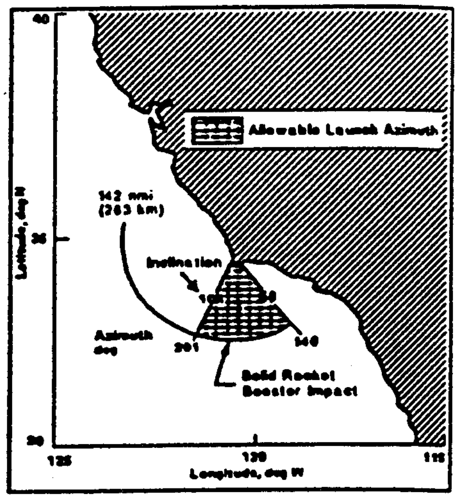


FIGURE 30. WSMC

Wallops Flight Facility. The Wallops Flight Facility is located off the coast of Virginia and is owned and operated by NASA. The facility was designed to launch only very small rockets, which includes the Scout launch vehicle. Twenty-one Scout missiles have been launched into orbit from Wallops Flight Facility.

COMMUNICATIONS SPECTRUM

The natural phenomenon of resonant frequency allows us to communicate with each other. Resonant frequency is the ability to maintain a specific frequency oscillation long enough to convey information from one source to another. By changing tones or modulating the resonant frequency with coded information, intelligence can be broadcast, and hopefully a receiver can and will interpret the message. Resonant frequency communications covers a wide spectrum from audio through visible light, which includes very low frequency (VLF), low frequency (LF), medium frequency (MF), high frequency (HF), very high frequency (VHF), ultra high frequency (UHF), super high frequency (SHF), extremely high frequency (EHF), and infrared (IR) frequency spectrum (see **Figures 31A, 31B** and **31C**). A basic understanding of some characteristics and relationships of these frequencies will be helpful in better comprehending satellite communications systems.

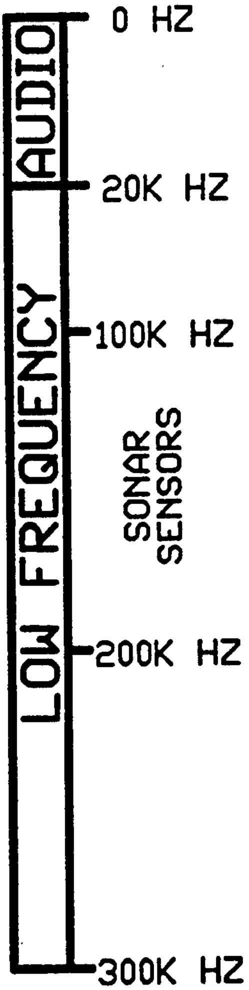


FIGURE 31A

Audio (20 - 20,000 Hz). Human vocal chords can sustain varying intensity and frequency long enough to project intelligible sounds to others. These frequency inflections fall between 100 and 3,000 (3K, where K = 1,000) cycles per second (called Hertz, Hz) with harmonics reaching much higher. Human ears can hear sounds far above (15K Hz) what the typical human voice can generate. Have you ever had difficulty understanding voices coming over radio communications systems? One reason is that audio frequencies in radio receivers are usually limited to 3,000 Hertz, which means that you are not receiving the complete audio signal.

Every mechanical design has its own resonant frequency characteristic. During launch, spacecraft designs generally have resonant frequencies in the audio range. The Shuttle has a resonant frequency of 45 Hertz during launch, which means that onboard satellites must have a different resonant frequency to avoid destructive oscillations. The famous and ill-fated Tacoma Bridge had a very low resonant frequency that allowed the prevailing winds to start it oscillating until it twisted apart.

Low Frequency (LF) (20K - 300K Hz). Resonant frequencies can be created with large electrical coils and capacitors or mechanical crystals. Low frequency, electrically-tuned circuits are very large and corresponding antennas are hundreds of feet in length. Low frequency transmitting devices are not found on satellites because of the immense size of the tuned circuits and antennas. Crystals are commonly used to transmit ultrasonic sounds into water as sonar devices. Low frequency signals are the only radio waves that readily pass in water with little attenuation. Sonar and ultrasound systems take advantage of this phenomenon.

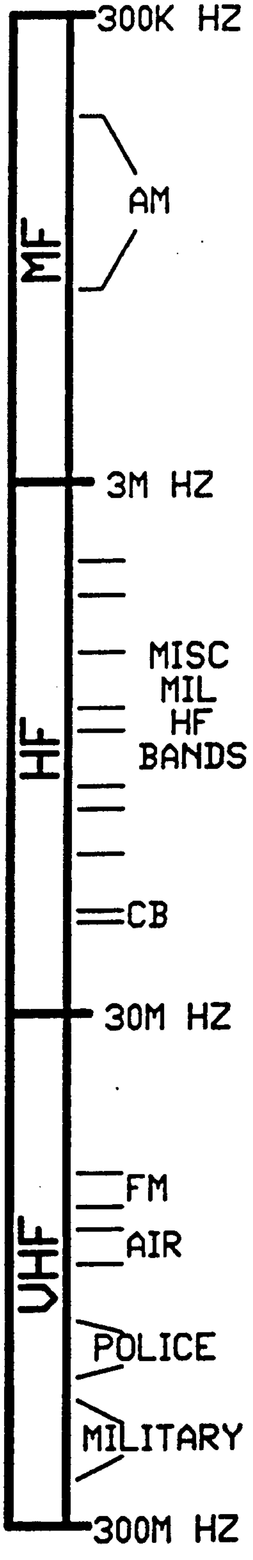


FIGURE 31B

Medium Frequency (MF) (300K - 3000K Hz). The AM radio band is the major user of this region. The AM band is divided into 107 channels, each only 10K Hz wide. This limited bandwidth explains why AM radio signals do not have the same quality as FM signals. AM signals are limited to frequencies below 10K Hz, which leaves out a significant portion of the sounds produced by musical instruments. Medium frequency transmissions are greatly affected by static noise and lightning. The ionosphere absorbs the signals during the day and reflects them around the globe during the night. Communications between the ground and a satellite in the medium frequency band would be poor at best because the ionosphere would absorb much of the signal. Medium frequency radio towers are hundreds of feet tall, which makes these systems unfeasible for satellites.

High Frequency (HF) (3M - 30M Hz). HF radio frequencies start just above the AM radio band, are measured in millions of Hertz (M = 1,000, 000) and end after the Citizens Band (CB). Shortwave radio listening is accomplished on HF frequencies. Tuned circuits and antennas are much smaller, but still too large to carry aboard satellites. Antennas are still about 20 feet in length. The ionosphere also creates problems with these frequencies by either reflecting the signals during the night or absorbing them during the day. This explains why HF radio communications performance can quickly change during the course of just a few hours.

Very High Frequency (VHF) (30M Hz - 300M Hz). VHF tuned circuits and antennas are small enough and free of ionospheric disturbance to make them acceptable for satellite systems. VHF frequencies are the first of the truly line-of-site communications because the ionosphere is no longer reflecting or absorbing the signals. TV channels 1-12, FM radio, police, and commercial aircraft share the band. Commercial aircraft and police bands are restricted to a narrow 3K Hz bandwidth, whereas, the TV and FM bands have considerably more bandwidth to send their signals. TV channels consume 6M Hz bandwidth to transmit one TV program, that uses the same bandwidth as 600 aircraft or police channels. Satellite transceivers are typically restricted to narrow band channels because the other bands have been consumed by earlier agreements between world nations involving amateur, commercial, and military users. Tremendous amounts of data can still be relayed over narrow bands using digital modulation techniques. 20,000 bits per second is common for narrow band digital transmissions.

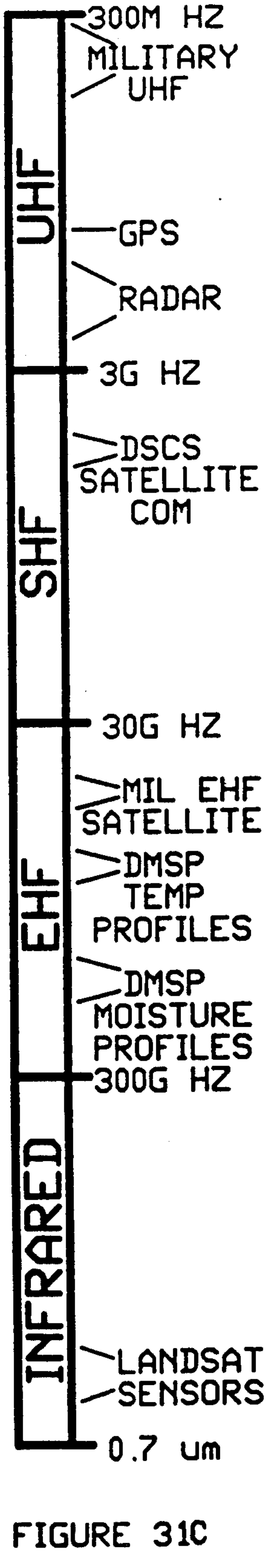


FIGURE 31C

Ultra High Frequency (UHF) (300 - 3000M Hz). UHF radios and antennas are a fraction of the size of VHF systems. Typical users of the UHF band are UHF TV, military aircraft, cellular telephone, microwave, satellite, and radar systems. This is a very popular band of frequencies and an international struggle continues to obtain and keep valuable frequency bands. The higher UHF signals now use reflective dishes to collect and focus the weak signals.

Super High Frequencies (SHF) (3 - 30G Hz). Super high frequency transceivers are relatively new because of the advanced technology required to make devices that will resonate at these frequencies (measured in gigahertz where G = 1,000,000,000). A critical shortage of bandwidth spurred development of effective systems commonly used in satellites. Channel assignments are considerably wider, which means millions of bits per second can be transmitted between a ground station and a satellite. Sending high-resolution photographs to ground stations is possible at these frequencies, but still require a few minutes to send each picture.

Extremely High Frequency (EHF) (30 - 300G Hz). Gigahertz frequencies are receiving most of the communications development dollars in order to take advantage of available frequencies and their allocated wide bandwidths. Real time high-resolution image transmission is now possible, but very costly.

Infrared Frequency (IR) (1000 - 0.7 um). Infrared frequencies are usually referred to in terms of wavelength. Wavelength is the distance it takes to complete one cycle and that distance gets smaller as the frequency goes up. Infrared spectrum ranges from 1000 um (0.001m) down to 0.7 um (0.0000007m). Night vision goggles and weather satellites use infrared sensors to collect the energy in this narrow band, amplify it, and present the view to the user. Infrared sensors in satellites can provide data on the temperature of water, land, and clouds. The Defense Meteorological Satellite Program (DMSP) satellites commonly use visible light sensors during the day and infrared sensors during the night. IR night sensors are capable of providing equally high resolution pictures at night as the visible light sensors during the day. The pictures provide a new and totally different perspective because IR night sensors differentiate between heat levels and not variations in visible light. Temperatures and some gas compositions in the atmosphere are now measurable using visible and IR combinations.

Visible Light (0.7 - 0.4 um). The human eye can detect resonant frequency waves that have wavelengths between 0.7 um (0.0000007m) and 0.4 um (0.0000004m) (**Figure 32**). Weather satellites carry sensors that can detect these wavelengths and a much wider band of infrared to enhance the resolution. Visible and infrared data is processed through computers to obtain comparable weather imagery using day and night photographs. Laser systems typically use the visible light spectrum because at this wavelength the atmosphere causes little attenuation. Laser beams become very effective communications mediums because of their tremendous bandwidth. Thousands of wideband signals can be placed or modulated onto laser beams. These beams are often sent through fiber cables and are referred to as fiber optics. Laser weapons have been developed and the beam has the unique characteristic of arriving at the target without a lead time to intercept because it is traveling at 186,000 miles per second.

Ultraviolet (0.4 - 0.005 um). Ultraviolet emissions start just above the visible light and extend to the X-ray spectrum.

X-Ray (0.005 - 0.00001 um). X-ray emissions have been effectively used for generations in the well known X-ray imaging system because bone matter has the unique characteristic of absorbing X-rays. Many surveillance satellites use X-ray sensors to detect and locate nuclear explosions. X-ray sensors are located on the U.S. military Block II GPS, DSP, and DMSP satellites.

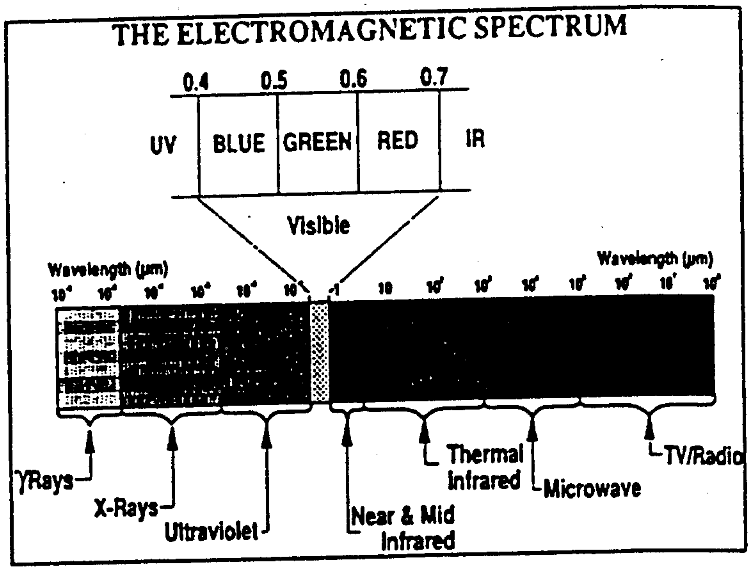


FIGURE 32. WAVELENGTH SPECTRUM

Gamma Ray (0.00001 - 0.000001 um). Gamma rays sensors are part of the DMSP satellite sensor package.

SATELLITE SYSTEMS

Satellite systems are very costly to build, launch, and use. Military satellites typically cost a billion dollars by the time all the bills are paid, which includes a sufficient number of user ground stations to accomplish the mission. DOD policy has been to design and operate satellites apart from civilian satellites in order to insure security of links, protection against jamming, and the ability to move satellites to where they are most needed. Military satellite missions have been limited to three major types: (1) **Communications, (2) Navigation,** and **(3) Surveillance.**

1. **Communications Satellites.** Communications satellites are divided into three categories based primarily on the frequencies used (**UHF, SHF,** and **EHF**). The first category, UHF bands, are used by FLTSATCOM, AFSATCOM, LEASAT, and UHF FOLLOW-ON satellites and are used to communicate with the troops in the field who have small portable radios. The secondary category, SHF bands, are used by the Defense Satellite Communications System (DSCS) and are used for worldwide long haul communications between the National Command Authority and Department of Defense Agencies. The third category, EHF bands, is intended to be used in the coming years by the MILSTAR satellite communications system. Each category has its own strengths and weaknesses that become important factors for the success of future engagements. The differences between cost, capacity, antijam, and mobility are very important characteristics that should be understood by the operational commander (**Figure 33**).

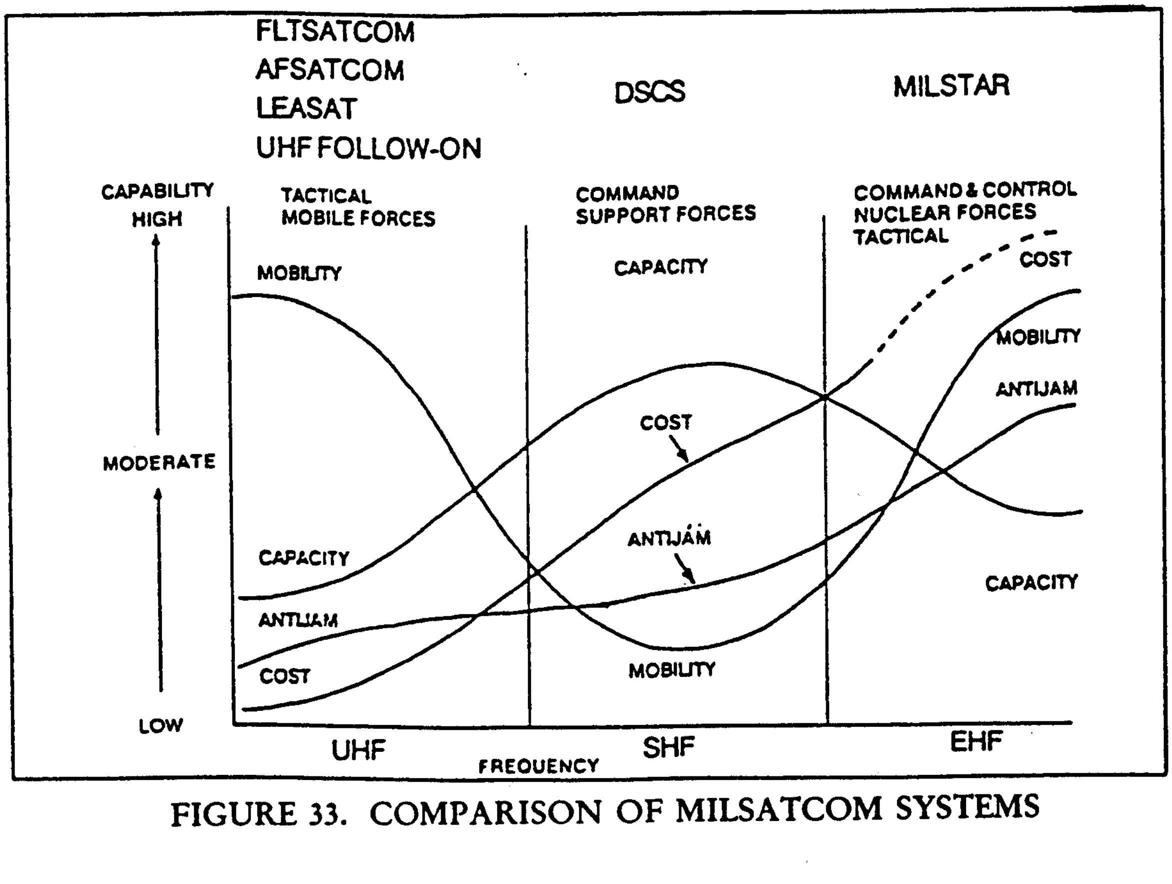


FIGURE 33. COMPARISON OF MILSATCOM SYSTEMS

UHF Satellites. The family of ultrahigh frequency (UHF) satellites consists of FLTSATCOM, AFSATCOM, LEASAT, and UHF FOLLOW-ON satellites and are used to communicate with the troops in the field that have small portable radios. These portable terminals have voice and data capability.

FLTSATCOM. The Fleet Satellite Communications System is managed by the Naval Space Command and consists of five active geostationary FLTSATCOM satellites spread out around the equator to provide worldwide coverage that is limited to 70 degrees north and south (**Figure 34**). Each satellite has 23 UHF channels available that are allocated to specific CINCs by the JCS. The CINCs prioritize their own users according to real world situations. The FLTSATCOM carries additional USAF transponders for control of nuclear forces and AWACS. These transponder channels are in constant demand and typically not available for training purposes.

FIGURE 34. FLTSATCOM[17]

AFSATCOM. The Air Force Satellite Communications (AFSATCOM) system provides JCS/CINC command and control of special forces, Air Force Electronic Security Command, nonstrategic nuclear forces and AWACS. The USAF does not own its own UHF communications satellite, but has transponders on FLTSATCOM, LEASAT, and DSC III satellites.

LEASAT. Additional UHF satellites were needed to meet increasing mission requirements. Congress mandated that more military systems must be commercially leased. Consequently, the Navy leased four LEASATS from Hughes Aircraft Company. (**Figure 35**). LEASAT Satellites are in strategically located geostationary orbits. Each LEASAT satellite has 13 UHF channels available that are primarily used for peacetime command and control between U.S. Navy ships, submarines, and shore stations. Orbit adjustments and satellite maintenance are contracted to Hughes Aircraft Company, working under direction of the Naval Space Command. LEASATS carry additional USAF transponders for control of conventional forces.

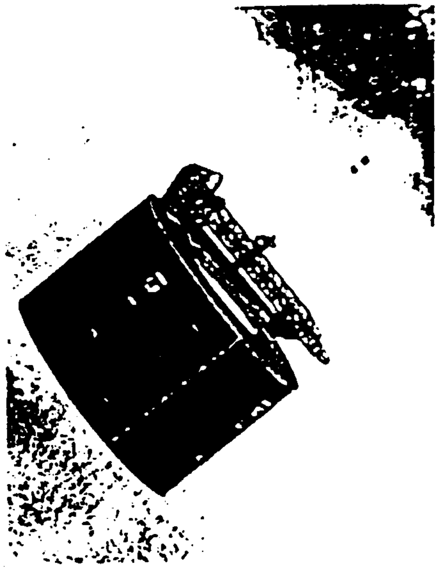


FIGURE 35. LEASAT[18]

UHF Follow-On (UFO). Valuable satellite channels are in constant demand, therefore the Navy has contracted to increase the number of UHF satellites in the fleet from 9 (5 FLTSATCOM and 4 LEASAT) to 18. UHF Follow-On satellites have 42 UHF channels and will also be owned and controlled by the Naval Space Command. These satellites will not have any additional USAF equipment.

Lightsats. A number of small low-cost satellites are under development as UHF communications relay stations. These small satellites have been placed into low Earth orbit, which means that the user has to actively chase the satellite across the sky in order to utilize its 10-minute window. Messages are transmitted up to the satellite and stored in its memory until the intended user requests the message to be sent back down. They are called store and forward satellites and the concept has been well proven by the amateur radio community.

UHF Ground Stations. More than 1000 mobile ground stations have been issued to the military services. Small, light, and portable ground stations make the FLTSATCOM system an excellent solution to the difficult problem of reliable troop communication. The AN/PSC-3A UHF SATCOM transceiver is just one of many models available (**FIGURE 36**).

FIGURE 36. UHF AN/PSC-3A

SHF Satellites. The Defense Satellite Communications Systems (DSCS) was designed to utilize higher wideband communications, Super High Frequency (SHF), to pass large volumes of data worldwide. The most significant SHF user is the Worldwide Military Command and Control System (WWMCCS), which includes early warning operations centers, unified and specified commands, and tactical forces. The highly successful twenty-six Phase I DSCS satellites launched between 1966 and 1968 were followed by Phases II and III. All of the DSCS satellites have been placed into geostationary orbits spread evenly around the globe for worldwide coverage. Their operational design life was five years, but they averaged 6-8 years. Each phase was designed to replace its older predecessor as it neared the end of its expected life.

DSCS II. Six DSCS II satellites were placed into geostationary in the 1980s. The last one, launched in 1989, remains the only one functioning. DSCS II has only two wide band repeaters, but is far more capable and flexible than any previously designed military satellite. The bandwidth for each uplink and downlink channel is an unbelievable

500,000,000 cycles per second (500M Hz). The DSCS II can handle 1,300 voice channels or 100 wideband data channels. The signals can be sent back to Earth using either a narrow or wide beam antenna. The narrow beam antenna has the advantage of increasing the signal level to the user inside the smaller foot print. The DSCS system is a significant link in the Worldwide Military Command and Control System (WWMCCS), AUTOVON, AUTODIN, AUTOSEVOCOM, the Defense Data Network, and the Defense Switched Network (which will replace AUTOVON).[19] The DSCS system is owned by the US Space Command and traffic management is the responsibility of the Defense Communications Agency (DCA). About twelve percent of the channels for the DSCS II and III constellation are allocated to the CINCs, who prioritize and assign them to their commanders.

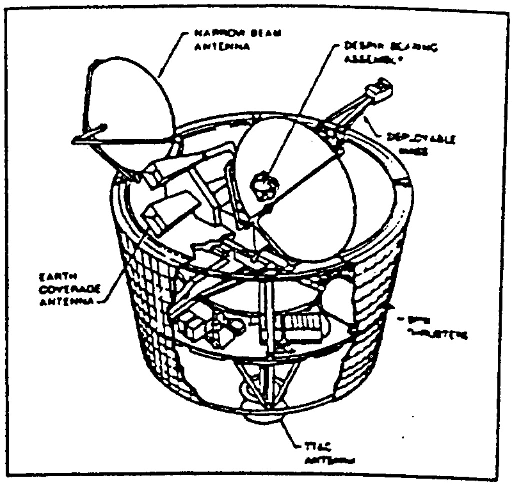


FIGURE 37. DSCS II

DSCS III. DSCS IIIs have replaced all but one DSCS II in geostationary orbits (**Figure 38**). DSCS IIIs's have six 50-85M Hz bandwidth transponders that can be configured to user needs. A total of seven DSCS II and III satellites are in service with four partially functioning spares. DSCS III satellites are nuclear hardened and can run automatically for extended periods.

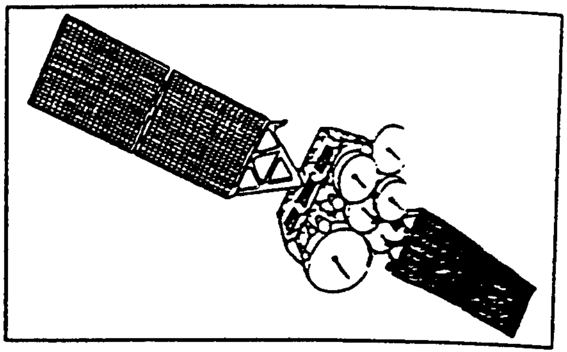


FIGURE 38. DSCS III

SHF Ground Stations. More than 200 mobile ground stations have been issued to the military services. Super high frequency (SHF) ground stations are considerably larger and more expensive than the UHF systems because SHF signals are higher frequency and have much greater bandwidth. One type of ground station terminal is the 24 channel AN/TSC-93A (**Figure 39**). Terminals are typically assigned where multiple-channel or hub communications is required.

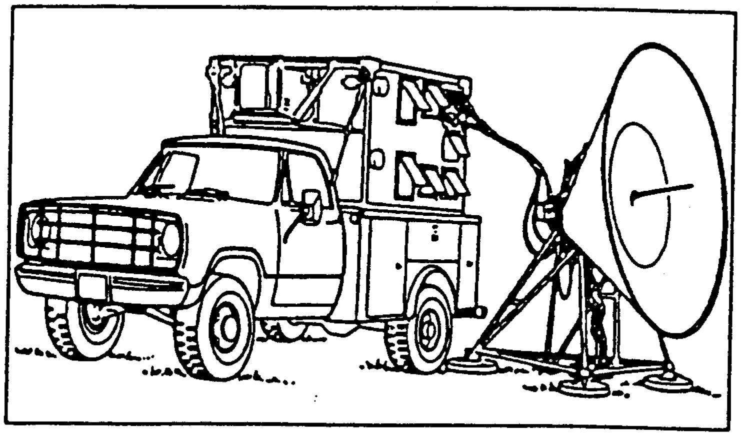


FIGURE 39. AN/TSC-93A SHF TERMINAL

EHF Satellites. The next generation satellites will use an even higher band of frequencies, extremely high frequency (EHF). EHF frequencies fall between 30G Hz (30,000,000,000 Hz) and 300G Hz. EHF are somewhat immune to nuclear blast effects and may be our only source of communications under nuclear attack. On the other hand, EHF frequencies are far from perfect because they can be absorbed by rain in the signal path, if rain drops are the same size as the wavelength of the radiating signal. EHF transponders are part of the UHF Follow-On satellite.

MILSTAR. A constellation of 10 MILSTAR satellites was originally anticipated, but was reduced to two because of the tremendous cost overruns and will be launched in 1994 (**Figure 40**). The 4.5-ton, billion dollar satellites will provide worldwide, jam-resistant, and survivable long-haul communications. The uplink frequency from ground stations will be at EHF of 44G Hz and the downlink will be at SHF frequencies. Anti-jam capability is accomplished by frequency hopping sequencing if jamming is detected. MILSTAR will be under JCS control and channels will be allocated to the CINCs. MILSTAR users will be at any of the three levels (strategic, operational, or tactical), depending on the needs of the CINCs.

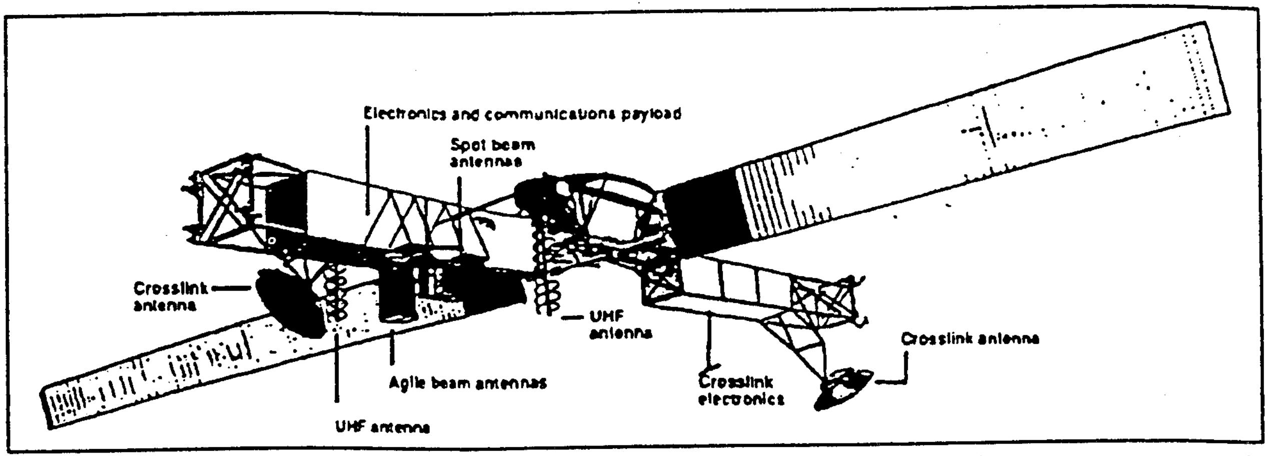


FIGURE 40. MILSTAR EHF SATELLITE

EHF/SHF Ground Stations. The ground stations will include large permanent installations as well as small portable SCAMP terminals. The 15-pound SCAMP terminals will have voice and secure data at 2400 bps (**Figure 41**).

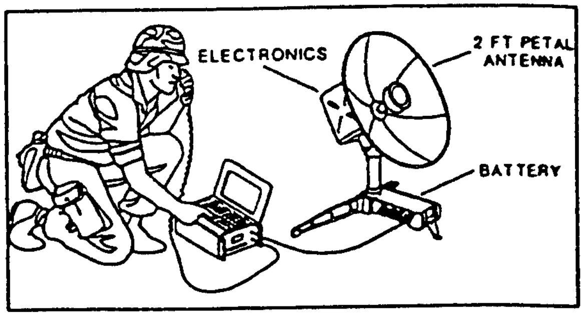


FIGURE 41. MILSTAR EHF SCAMP

2. **Navigation Satellites.** Navigational aids have provided the American war fighter with a technical advantage unsurpassed by others. As simple as it sounds, knowing where you are provides a significant advantage over someone who does not know quite where he is. Using GPS receivers on warheads to guide them to a target provides tremendous over-the-horizon capability.

Transit. The first significant satellite navigation aid, Transit, was developed by the Navy to provide all weather, worldwide, position information to surface ships and submarines to within 100 meters. Transit works on the Doppler frequency shift principle. This frequency shift can accurately be measured and used to calculate a fix. One disadvantage of the Transit system is that a ship must take a 4-6 minute fix to receive the Doppler measurements from a satellite pass. A constellation of Transit satellites, averaging 16, has been maintained at 600 mile (1000 km) altitudes since the early 1970s. Transit is suitable where dead reckoning will suffice for an hour at a time. The Transit system has been replaced by GPS in all but a few Navy assets.

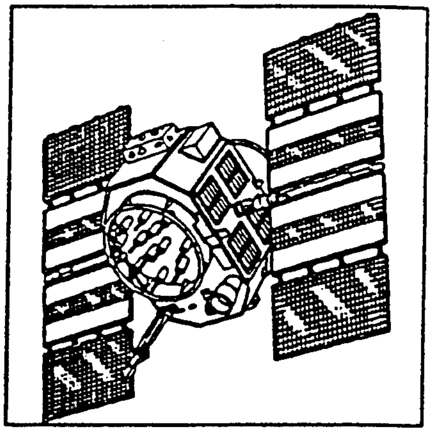


FIGURE 42. GPS SATELLITE

NAVSTAR Global Positioning System (GPS). The GPS constellation of 24 satellites, 21 on station and 3 spares, has been completed since Desert Storm. GPS satellites are all in circular, semi-synchronous (12 hour period) orbits in six different orbit planes 12,500 miles (20,000 km) above the Earth (**Figure 42**). A user will be in receiving range of at least four GPS satellites at any one time. A 2-dimensional position requires the reception of three GPS satellites, whereas, a 3-dimensional position requires the reception of four. The success of GPS is attributed to the precision clocks in each satellite. The time it takes for each satellite signal to reach the ground receiver is recorded and compared to the other received signals. Triangulation software calculates the fix of the ground receiver. GPS satellites require considerable on-orbit adjustments to insure that accurate orbit parameters are maintained. The higher orbit was selected to reduce near-Earth orbit fluctuations.

GPS Receivers. Many types of GPS receivers have been manufactured for the military services. 8,500 AN/PSN-10 receivers have been issued to the Army (**Figure 43**).

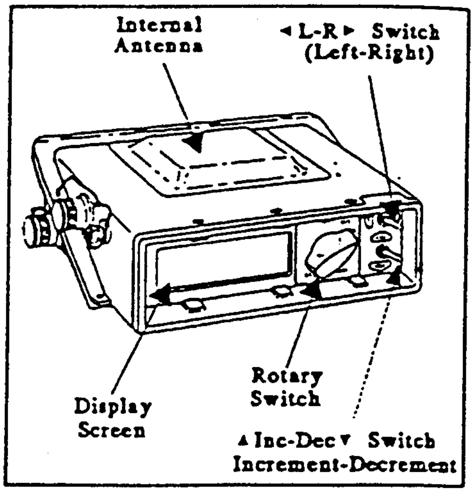


FIGURE 43. GPS AN/PSN-10

3. **Surveillance Satellites.** The surveillance task covers a wide variety of missions, which are essential for the preparation of intelligence to support strategic, operational, and tactical commanders. Satellite tasks have been divided into the following categories: **(A) Early Warning, (2) Geographic Imaging, (3) Meteorology**, and **(4) Nuclear Detection.**

DSP Early Warning Satellites. The Defense Support Program (DSP) uses satellites as the most important element of a large scale system to warn of an attack by incoming ballistic missiles. (**Figure 44**). DSP satellites can see and track a missile launch and immediately transfer the data back to ground Data Reduction Centers for processing. Confirmed warnings are relayed to the appropriate designated commanders. All of the SCUD missiles launched by Iraq in Desert Storm were identified and warnings were relayed to the field, which provided only a few minutes of warning because of the short trajectories.

DSP Generation 3. Nine DSP Generation 3 satellites were ordered with the first launch in 1990. At scheduled 18 month intervals, DSP Generation 3 satellites were to be placed on station in geostationary orbits spaced around the equator. The satellites can be moved to different locations in time of crisis situations. The heart of the system lies with the IR wavelength imaging system used to detect the hot exhaust from missiles. Two different IR wavelength detectors are used to avoid laser jamming. IR sensor systems are very expensive, so a 6000 IR detector row is rotated through the observation window by spinning the satellite. A complete scan takes about 10 seconds and a launch confirmation requires a number of scans, so verification make take a couple of minutes. The next generation DSP will not require a scan time because well over 100,000 IR detectors may be used, but the cost will be considerably higher.

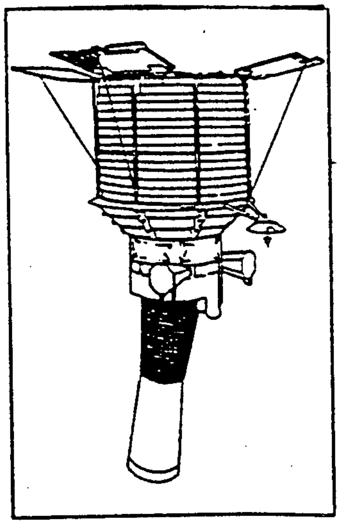


FIGURE 44.
DSP SATELLITE

Geographic Imaging Satellites. Geographic surveillance of the Earth provides a unique view when multispectral imagery (looking at many wavelengths) is used. Geographic imagery can be used to update maps, identify objects and routes, view below the surface of water, and detect contamination. Different wavelength sensors are even able to assess vegetation vigor and soil moisture content. Imaging satellites are usually placed in low-Earth orbits to be as close to the viewing as practical. Earlier U.S. satellites took photographs from very low, short life, 100 mile high orbits. Their resolution was higher because they were much closer, but the cost of replacing them became excessive. The U.S. moved to higher orbit, computer image storing techniques, whereas, the Russians continued to replace low-cost imaging satellites that take photographs at much lower altitudes.

LANDSAT. LANDSAT satellites are mainly used by the DOD for terrain analysis and topographical mapping. The LANDSAT family of satellites was introduced in the early 1970s and LANDSAT 6 is in orbit (as of early 1194, Figure 45). They were all launched into sun-synchronous low-Earth orbits. The LANDSAT satellites repeat their orbital path every 16 days and process the data on the ground. The turn around time for a photograph is typically 30 days unless a crisis occurs.

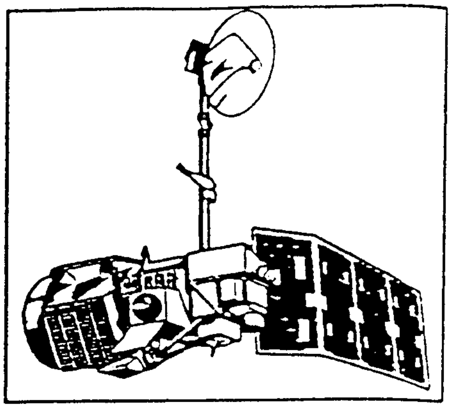


FIGURE 45. LANDSAT 5

Meteorology Satellites. Meteorology satellites are designed primarily for weather observation. The impact of weather on military operations has been demonstrated throughout history. Weather prediction has provided significant advantages to campaign planning. Visual light sensors accurately record cloud, land and water formations and infrared detectors record their temperatures. The combination of light and infrared data is processed with fantastic results. Wind speed and atmospheric pressure can even be calculated from processed meteorological satellite data.

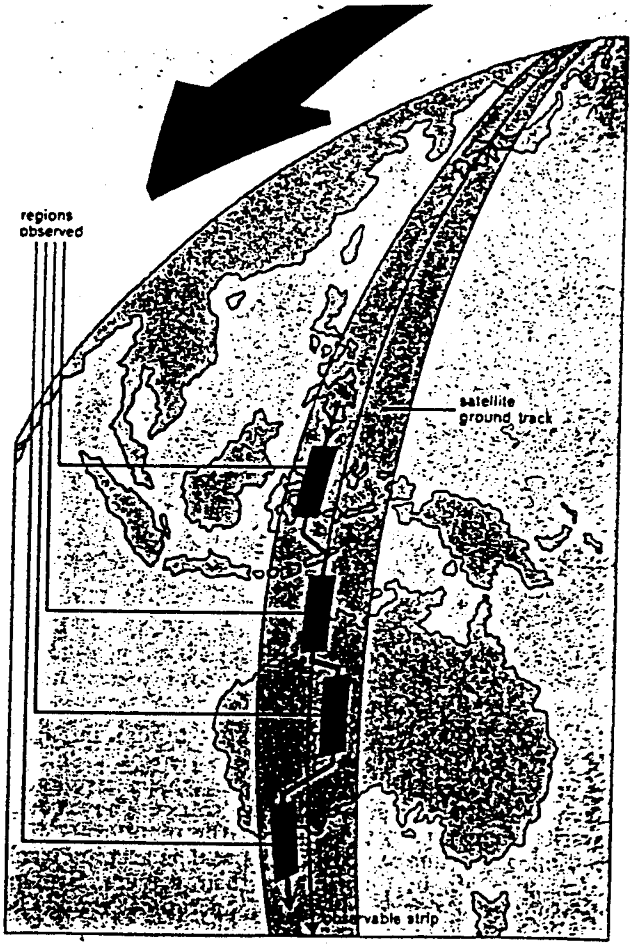


FIGURE 46. TYPICAL IMAGERY PASS[20]

Weather satellites are by far the most popular type of satellite because of their commercial market value. Most weather satellites have been placed into low Earth orbits because high resolution images can easily be obtained, but expensive ground tracking stations are required to receive the signal. An example of a low Earth orbit weather satellite is the Television Infrared Observation Satellites (TIROS) operated by the National Oceanographic and Atmospheric Administration (NOAA). Another group of weather satellites are found at geostationary orbits, which cater to users who have only simpler satellite dish receiver systems. An example of a geostationary weather satellite is the Geostationary Operational Environmental Satellites (GOES) also operated by NOAA.

DMSP. The Defense Meteorology Satellite Program (DMSP) was created to gather weather data for military uses. DMSP satellites have been placed into low Earth sun-synchronous orbits. The two active DMSP satellites are placed so one passes overhead at 6 AM and the other passes at 10:30 AM. Data is stored onboard until it can be downlinked to one of two permanent ground stations at Offutt, Nebraska, or Monterey, California. DMSP satellites carry transportable ground stations allow the information to be directly downlinked to tactical users. DMSP information is provided to NOAA for civilian use.

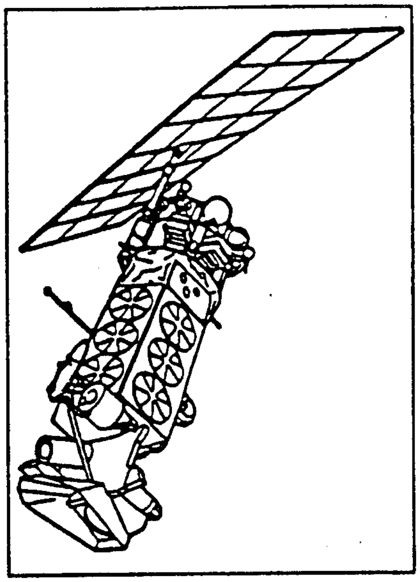


FIGURE 47. DMSP SATELLITE

CONCLUSION

The U.S. has fielded military satellite systems based primarily on a Soviet threat. With the demise of the Soviet threat, much of the justification for these extremely expensive systems also disappeared. Budgets that were going to provide the next generation of bigger and better satellite systems have been reduced significantly. The military must accept the fact that next generation of satellite security systems are now too expensive to field.

The dilemma for CINCs is to sort out the "nice to have" features from the "must have" ones. They must also decide what dedicated military systems must be fielded and which ones can be leased from commercial sources. For the soldier in the field or the sailor upon the sea, the availability of overhead systems will make a significant difference in the transparency of the battlefield. Systems like GPS that were once "nice to have" are now "must have" capabilities. Secure, worldwide communications have also become essential command-and-control tools for National Command Authorities. Yet to assure the availability of these systems, the U.S. must understand that its commitment to space is completely open-ended. A commitment to space also means a commitment to the use of higher frequencies and to pay for the more expensive equipment needed to support them.

A narrow view of space today, by either policymakers or warfighters, can adversely affect tomorrow's battlefield. In searching for ways to maintain the U.S. commitment to space at a reasonable cost, decision-makers will inevitably have to weigh the benefits of international cooperation against the risks of not completely controlling its destiny in space. Even the risks are significant and the costs are high, the benefits of maintaining a vigorous military space program are even greater.

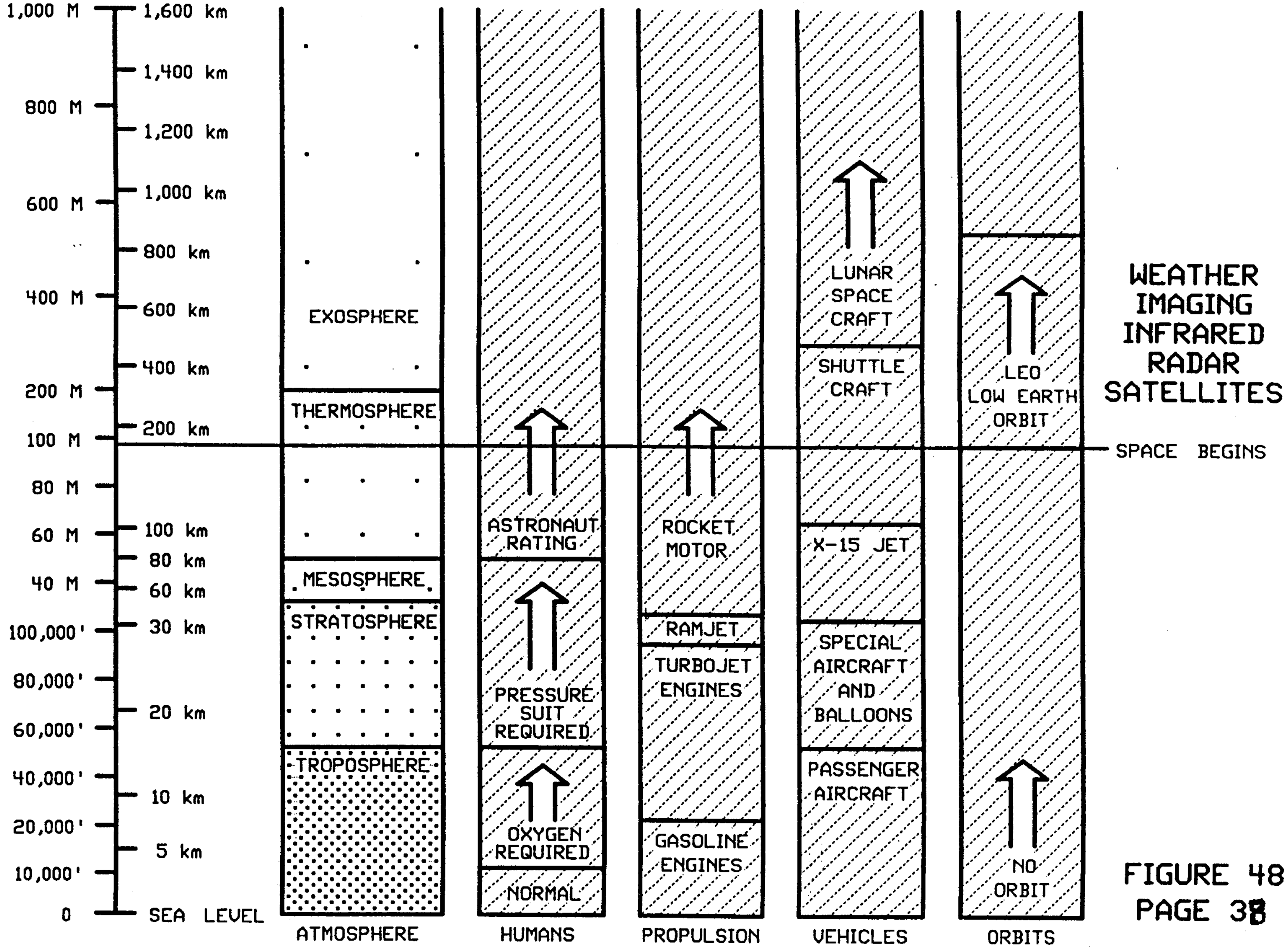


FIGURE 48
PAGE 38

BIBLIOGRAPHY

Canan, James W. "A Watershed in Space." Air Force Magazine. The Air Force Association: Aug 1991. NWC # 3105.

Dougherty, William A. "Storm from Space." Proceedings. U.S. Naval Institute, 1992.

Jane's Spaceflight Directory, 1988-89. Surrey, UK: Jane's Information Group, 1989.

Lyon, David C. and Cipollone, Lawrence V. Space Launch Vehicle Alternatives for Small Satellites and the Current Commercial, Political and Physical Environments. Monterey, CA: Naval Post Graduate School, Sep 1985.

Malutich, Steve and Thieman, Bruce. Space: The Fourth Military Arena. Montgomery, Alabama: Air University, 1990.

Muolo, Michael. Space Handbook, A War Fighter's Guide to Space. Montgomery, Alabama: Air University Press, Dec 93.

Space Directory, 1992-93. Surrey, UK: Jane's Information Group, 1993.

Space Handbook. Montgomery, Alabama: Air University Press, Jan 1985.

U.S. Space Command. Space Systems Handbook for Staff Planners and Operators. Colorado Springs, CO: Center for Aerospace Analysis, no date. NWC #3112.

U.S. Air Force. AF Doctrine Directive 4, Space Operations. Washington DC: HQ U.S. Air Force, Nov 93.

U.S. Army. Space Reference Text. Fort Leavenworth, Kansas: U.S. Army Space Institute, 1993.

U.S. Army. Space Support to Army Operations, FM 100-18. Fort Leavenworth, Kansas: Combined Arms Command, 4 Jun 93.

The ARRL Handbook for Radio Amateurs. Newington, CT: The American Radio Relay League, 1993.

"Watching for Close Encounters." Space Tracks, January-February, 1994. Dahlgren, Virginia: Naval Space Command.

END NOTES

1. U.S. Army, Space Reference Text. (Fort Leavenworth, Kansas: U.S. Army Space Institute, July 93). p. 5-2.

2. The ARRL Handbook for Radio Amateurs. (Newington, CT: The American Radio Relay League, 1993). p. 22-2.

3. "Watching for Close Encounters." Space Tracks, January-February, 1994. (Dahlgren, Virginia: Naval Space Command). p. 7.

4. Ibid. p. 5.

5. Space Directory, 1992-93. (Surrey, UK: Jane's Information Group, 1993). p. 351.

6. Ibid. p. 351.

7. Ibid. p. 353.

8. Ibid. p. 287.

9. Ibid. p. 287.

10. Ibid. p. 323.

11. Ibid. p. 291.

12. Ibid. p. 329.

13. Ibid. p. 329.

14. Jane's Spaceflight Directory, 1988-89. (Surrey, UK: Jane's Information Group, 1989). p. 131.

15. Space Directory, 1992-93. (Surrey, UK: Jane's Information Group, 1993). p. 315.

16. "Technical Update." Popular Mechanics, December 1993. p. 16.

17. Space Directory, 1992-93. (Surrey, UK: Jane's Information Group, 1993). p. 202.

18. Ibid. p. 202.

19. Malutich, Steve and Thieman, Bruce. Space: The Fourth Military Arena. (Montgomery, Alabama: Air University, 1990). p. 86.

20. Jane's Spaceflight Directory, 1988-89. (Surrey, UK: Jane's Information Group, 1989). p. 23.