U.S. MILITARY SPACE REFERENCE TEXT

2006

Base Document Prepared in 2004 by:

Mr. Jefferson H. Barker, ARINC Engineering Services, LLC

Under Contract DASG62-02-D-0002, Task Order 04-601

March 2006 Update Project Leader:

Major Darren J. Brown, USAF

Chief, Space Professional School

National Security Space Institute

Special thanks to the following people for their editorial comments during this year's update process:

LTC Michael McFarland, Maj Chris Eagan, Maj Troy Endicott, Maj Donald Frew, Maj Luis Garcia,

Maj Jeffrey Gray, Maj Joseph Prue, Maj Robert Sheehan

March 2006

U. S. Military Space Reference Text

2006

Developed by the

National Security Space Institute

In Conjunction with

U.S. Army Command and General Staff College

Submit all recommended changes to:

National Security Space Institute

Attn: Space Professional School

7150 Campus Drive

Colorado Springs, CO 80920

Phone: Comm: (719) 593-8794

E-Mail: darren.brown@afspc.af.mil

Base Document Prepared in 2004 by:

Mr. Jefferson H. Barker, ARINC Engineering Services, LLC

Under Contract DASG62-02-D-0002, Task Order 04-601

March 2006 Update Project Leader:

Major Darren J. Brown, USAF

Chief, Space Professional School

National Security Space Institute

Special thanks to the instructors at the NSSI for their review of this document, and to the members of the U.S. Army Command and General Staff College for providing the initial input information for this text

U.S. Air Force Space 200 Reference Text

Table of Contents

Chapter 1
Purpose

PURPOSE

The purpose of this reference text is to provide information about space systems and their use as they relate to U.S. Army and joint military operations. The intended primary users are U.S. Army Command and General Staff College students, although military commanders, staff officers, Noncommissioned Officers, and instructors may also find it useful. Military space operations are truly joint in their nature. Therefore, there are extensive references to policies, programs, operations and applications from many U.S. Government organizations, the military services, and commercial entities.

The format and contents are intended to provide the reader with a central reference as to the environment of space, the capabilities and limitations of U.S. satellite systems, space applications that support the military strategic, operational and tactical levels, and space support planning considerations. In addition, the text provides a cursory background in space history, space policy, orbital mechanics, and threats to U.S. dominance of space.

SCOPE

The scope of this book is intended to provide the reader with a fundamental level of knowledge of space and space systems. It is also intended to be a single reference source. Primary information is on space systems used by the U.S. military. Because of the proliferation of space systems, information about other nations' systems is included on a limited basis. Classified information has been excluded to allow wider dissemination and access.

OVERVIEW

Space capabilities permeate virtually every mission area. Space is no longer the frontier battleground of some future time frame. It is a medium vital to successful operations around the globe, and is recognized as the fourth dimension of warfare (i.e., land, sea, air, and space) through and from which operations may be affected globally now and into the future. Space is a distinct operating environment that is different from land, air, and sea domains. Space-based assets transcend geographical borders unimpeded. Since there are no recognized political boundaries in space, satellites enjoy "open skies" global coverage.

As the military continues to evolve as a 21st Century warfighting force, soldiers must be trained to understand the potential benefits of combat multipliers derived from space assets and how to use them effectively. The medium of space and space products are increasingly a critical consideration for leaders and planners at all levels. Space-based systems and capabilities provide near to real time relevant information directly to the warfighter and quickly "link" the seven battlefield operating systems into a command and control, sensor, and weapon systems network, which will integrate and orchestrate effects within the joint battlespace. Only space capabilities can integrate the effects of widely dispersed weapons platforms and forces, provide dominant awareness of the battlefield, and allow for precision engagement and dominant maneuver. Access to and the availability of space capabilities, as well as awareness of their limitations, is critical to the achievement of enhanced performance across the full spectrum of operations.

Space is the high ground today and will be in the future. Depending upon redundancies and mix of payloads, satellites can provide capabilities day/night and in all weather. The space environment envelops all other mediums thereby creating the ultimate high ground for military operations. Operation DESERT STORM in 1991 proved the space systems were vital assets to enhance land warfare operations. This was the first occasion when the full range of modern military space assets was applied to terrestrial conflict at a tactical and operational level. Space systems provided the communications infrastructure to command and control mobile armor formations and to synchronize precision strikes. The Global Positioning System (GPS) allowed precision navigation and precision strikes across the featureless Arabian Peninsula, and the Defense Support Program (DSP) satellites warned Army forward deployed forces of imminent ballistic missile attacks from Iraqi SCUD missiles. Space-based assets are evolving as integral operating capabilities by providing relevant and time-sensitive information directly to the warfighter.

The expansion of new players in the military space arena may prove to be one of the most distinguishing features of the coming decade. Almost every country has access to communication satellites. Multispectral and Synthetic Aperture Radar imagery is commercially available. Current weather pictures from satellites are available worldwide. At least sixteen nations today have some degree of indigenous capability to employ militarily useful satellites. That number is expected to double in the near future.

Military and non-military activities in space are increasingly interdependent and terrestrial military forces are becoming ever more dependent on an ever-growing number of operational military spacecraft. The division between military and non-military space activities has never been clear, and is becoming increasingly blurred. Some have made the analogy that space is to the Information Age as oil was to the Industrial Age. The control and protection of national, civil and commercial space systems will become paramount to national and international security in the 21st Century. Growing military and non-military growing dependence upon space capabilities is recognized by our adversaries and could eventually increase the risk to those systems.

Chapter 2
Space Law, Policy, Doctrine and Organizations

OVERVIEW

Space policy, law and doctrine define the goals and principles of the U.S. space program. International and domestic laws and regulations, national interests and security objectives shape the U.S. space program. Furthermore, fiscal considerations both shape and constrain space policy. Space policy formulation is a critical element of the U.S. national planning process, as it provides the framework for future system requirements. This chapter examines the international and domestic legal parameters within which the U.S. must conduct its space programs. It also outlines the basic tenets of U.S. policy and doctrine.

Space policy continues to evolve based on revised goals and objectives of the nation, budget constraints, previous space policies, current programs, national and international law, and treaty obligations. DoD Space Policy support the National Space Policy.

The current National Space Policy and several other U.S. Government space related policies can be found at www.globalsecurity.org/space/library/policy/national.

NATIONAL SPACE POLICY

The national space policy contains guidelines and actions to implement in the conduct of space programs and related activities. The present United States space policy is very important in understanding how future space strategies may evolve.

The evolution of national space policy was slow in getting underway. The launch of Sputnik I in October 1957 had a dramatic impact on the formulation of U.S. space policy. Public and political reaction was rapid and strong. The civilian effort to launch a U.S. satellite in December 1957 was an embarrassing failure. The Vanguard rocket lost power after rising a few feet and fell back on to the launch pad where it exploded. In March 1958, President Eisenhower's science advisory committee issued a statement that the development of space technology was potentially vital to the national security.

The first official space policy of the Eisenhower Administration led to the passage of the National Aeronautics and Space Act of 1958, which states that space activities are to be conducted for peaceful purposes benefiting all mankind. Today, the national space policy states the primary goal of space activity is to ensure the security of the U.S. and that the U.S. will conduct those activities in space that are necessary for national defense. This policy recognizes that space is important in achieving national security, scientific, technical, economic, and foreign policy goals.

The current National Space Policy is dated September 1996. It addresses objectives and commitments for the civilian space program, the space-related portion of national defense, and federal policies with respect to the commercial space sector. The greatest departure from previous policy comes in the area related to national defense. In addition to urging closer coordination between the defense and intelligence communities on space policy, the document, for the first time, makes known previously classified information about U.S. photoreconnaissance activities. Key provisions include:

- Within the civil space program, the policy reaffirms a U.S. commitment to the International Space Station and to the next-generation of launch vehicle programs; it calls for an aggressive space science program including the sustained robotic exploration of Mars, sample return missions from celestial bodies within the solar system and a long-term program to identify and characterize planets around other stars; and maintains our current commitment to a long-term program of environmental monitoring from space.

- In the commercial sector, the policy seeks to stimulate private-sector investment by committing the U.S. government to purchase commercially available goods and services, and by offering stable and predictable access to federal space-related hardware, facilities, and data. The policy also lays the groundwork for moving away from international launch quotas toward an international commercial environment characterized by free and fair trade in commercial launch services.

- For national security, the policy directs closer coordination between Department of Defense and intelligence improve the nation's ability to support military operations worldwide, to monitor and respond to strategic military threats, and to monitor arms control and nonproliferation agreements and activities.

The National Space Policy states the National Security Space Guidelines a portion of which is below. A Fact Sheet on the National Space Policy can be found on the Internet at http://www.hq.nasa.gov/office/codez/new/policy/nsc_49.htm.

The United States will conduct those space activities necessary for national security. The Secretary of Defense (SECDEF) and the Director of National Intelligence (DNI) will oversee these activities.

(1) Improving our ability to support military operations worldwide, monitor and respond to strategic military threats, and monitor arms control and non-proliferation agreements and activities are key priorities for national security space activities. The Secretary of Defense and DNI 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.

(2) National security space activities shall contribute to U.S. national security by:

(a) providing support for the United States' inherent right of self-defense and our defense commitments to allies and friends;

(b) deterring, warning, and if necessary, defending against enemy attack;

(c) assuring that hostile forces cannot prevent our own use of space;

(d) countering, if necessary, space systems and services used for hostile purposes;

(e) enhancing operations of U.S. and allied forces;

(f) ensuring our ability to conduct military and intelligence space-related activities;

(g) satisfying military and intelligence requirements during peace and crisis as well as through all levels of conflict;

(h) supporting the activities of national policy makers, the intelligence community, the President of the United States (POTUS) and SECDEF, combatant commanders and the military services, other federal officials, and continuity of government operations.

(3) Critical capabilities necessary for executing space missions must be assured. This requirement will be considered and implemented at all stages of architecture and system planning, development, acquisition, operation, and support.

(4) Defense Space Sector Guidelines:

(a) DoD shall maintain the capability to execute the mission areas of space support, force enhancement, space control, and force application.

(b) In accordance with Executive Orders and applicable directives, DoD shall protect critical space-related technologies and mission aspects.

(c) 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. DoD will be the lead agency for improvement and evolution of the current expendable launch vehicle fleet, including appropriate technology development.

(d) DoD will pursue integrated satellite control and continue to enhance the robustness of its satellite control capability. DoD will coordinate with other departments and agencies, as appropriate, to foster the integration and interoperability of satellite control for all governmental space activities.

(e) The Secretary of Defense will establish DoD's specific requirements for military and national-level intelligence information.

(f) The Secretary of Defense, in concert with the DNI, and for the purpose of supporting operational military forces, may propose modifications or augmentations to intelligence space systems as necessary. The DoD may develop and operate space systems to support military operations in the event that intelligence space systems cannot provide the necessary intelligence support to the DoD.

(g) Consistent with treaty obligations, the United States 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. These capabilities may also be enhanced by diplomatic, legal or military measures to preclude an adversary's hostile use of space systems and services. The U.S. will maintain and modernize space surveillance and associated battle management command, control, communications, computers, and intelligence to effectively detect, track, categorize, monitor, and characterize threats to U.S. and friendly space systems and contribute to the protection of U.S. military activities.

(h) The United States 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 United States; and an advanced technology program to provide options for improvements to planned and deployed defenses.

(7) Intelligence Space Sector Guidelines:

(a) The DNI shall ensure that the intelligence space sector provides timely information and data to support foreign, defense and economic policies; military operations; diplomatic activities; indications and warning; crisis management; and treaty verification, and that the sector performs research and development related to these functions.

(b) The DNI shall continue to develop and apply advanced technologies that respond to changes in the threat environment and support national intelligence priorities.

(c) The DNI shall work closely with the Secretary of Defense to improve the intelligence space sector's ability to support military operations worldwide.

(d) The nature, the attributable collected information and the operational details of intelligence space activities will be classified. The DNI shall establish and implement policies to provide appropriate protection for such data, including provisions for the declassification and release of such information when the DNI deems that protection is no longer required.

(e) Collected information that cannot be attributed to space systems will be classified according to its content.

(f) These guidelines do not apply to imagery product, the protection of which is governed by Executive Order 12951.

(g) Strict security procedures will be maintained to ensure that public discussion of satellite reconnaissance by Executive Branch personnel and contractors are consistent with DNI guidance. Executive Branch personnel and contractors should refrain from acknowledging or releasing information regarding satellite reconnaissance until a security review has been made.

(h) The following facts are UNCLASSIFIED:

(i) That the United States conducts satellite photoreconnaissance for peaceful purposes, including intelligence collection and monitoring arms control agreements.

(ii) That satellite photoreconnaissance includes a near real-time capability and is used to provide defense-related information for indications and warning, and the planning and conduct of military operations.

(iii) That satellite photoreconnaissance is used in the collection of mapping, charting and geodetic data and such data is provided to authorized federal agencies.

(iv) That satellite photoreconnaissance is used to collect mapping, charting and geodetic data to develop global geodetic and cartographic materials to support defense and other mapping-related activities.

(v) That satellite photoreconnaissance can be used to collect scientific and environmental data and data on natural or man-made disasters and such data can be disseminated to authorized federal agencies.

(vi) That photoreconnaissance assets can be used to image the United States and its territories and possessions.

(vii) That the U.S. conducts overhead signals intelligence collection.

(viii) That the U.S. conducts overhead measurement and signature intelligence collection.

(ix) The existence of the National Reconnaissance Office (NRO) and the identification and official titles of its senior officials.

All other details, facts and products of intelligence space activities are subject to appropriate classification and security controls as determined by the DNI.

DOD SPACE POLICY

Consistent with the National Space Policy, Department of Defense space forces will continue to support military operations worldwide, monitor and respond to strategic military threats, and monitor arms control and nonproliferation agreements and activities. DoD will exploit and, if required, control space to assist in the successful execution of the National Security Strategy and National Military Strategy.

DoD Space Policy focuses on operational capabilities that enable the military services to fulfill national security objectives. The policy supports and amplifies U.S. national space policy. Space is recognized as being a medium within which the conduct of military operations in support of our national security can take place, just as on land, at sea, and in the atmosphere, and similarly from which military space functions of space support, force enhancement, space control and force application can be performed. The DoD Space Policy can be found at http://www.au.af.mil/au/awc/awcgate/dod-spc/dodspcpolicy99.pdf.

Key features of the policy are:

(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.

(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.

(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. Contributing goals include sustaining a robust U.S. space industry and a strong, forward-looking technology base. (This section goes on to further describe how pace activities shall contribute to the achievement of U.S. national security objectives.)

(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 POTUS and SECDEF, Combatant Commanders, Military Services, and intelligence users across the conflict spectrum.

(5) Assured Mission Support. The availability of critical space capabilities necessary for executing national security missions shall be assured. Access to space, robust satellite control, effective surveillance of space, timely constellation replenishment and 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 POTUS AND SECDEF, Combatant Commanders, Military Services, and the intelligence users across the conflict spectrum.

(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.

The DoD Space Policy defines space missions as Space Support, Force Enhancement, Space Control, and Force Application.

Space Support

Space support functions are those required to deploy and maintain military equipment and personnel in space. They include activities such as launching and deploying satellites, maintaining and sustaining space vehicles while in orbit (Telemetry, tracking, and commanding), and recovering space vehicles, if required. It includes providing logistics support for the space, ground control and launch elements. It provides for surge launch capabilities to replace loss of space assets and the acquisition of replacement satellites.

Force Enhancement

Force enhancements are defined as any operation conducted from space with the objective of enhancing, enabling, or supporting terrestrial operations in peacetime, conflict and war. Force enhancement includes such capabilities as communications, position and navigation, weather and remote sensing, reconnaissance, intelligence, surveillance, missile launch detection and warning support at the tactical, operational, and strategic levels of war. Also, civil/commercial/allied capabilities may augment DoD systems to support military space force enhancement requirements, particularly if primary DoD capabilities were to be lost. The efficiencies resulting from the use of these space capabilities can have a dramatic effect on operations: reducing uncertainty, facilitating battle command, and moderating the effects of friction and fog of war.

Space Control

Space Control consists of operations that ensure freedom of action in space for friendly forces while limiting or denying enemy freedom of action. It includes the conduct of offensive and defensive space operations to prevent an enemy's space forces from gaining and maintaining space superiority and to ensure survivability and protection of friendly space systems. These missions include naval, air, land, and space operations that disrupt, deny and destroy an adversary's capability to use space systems. It also includes satellite negation and as well as space and ground segment protection. The military's role in this function will be from the terrestrial perspective, such as jamming up/downlink frequencies and attacking satellite control nodes and facilities from the ground.

Force Application

Force application is conducted primarily from or through space with the intent to destroy surface and subsurface targets for the purpose of ballistic missile defense (BMD) or power projection. While force application capabilities from space are limited, the role of space in force application is evolving. It consists of the offensive and defensive use of space and space-related capabilities to project combat power and defend U.S. military forces and their allies from attack. In the broadest sense, any space system capable of providing and disseminating information contributes to force application. Consistent with treaty obligations and national policy, this capability could include the use of space- and ground-based systems to provide protection from ballistic missiles, in programs such as national missile defense (NMD) and theater missile defense (TMD), and to extend the military's force projection range against surface targets.

Joint Pub 3-14

Joint Pub 3-14, *Joint Doctrine for Space Operations*, was published in August 2002. The publication sets forth doctrine, and selected tactics, techniques, and procedures to govern the joint activities and performance of the Armed Forces of the United State in joint operations as well as the doctrinal basis for U.S. military involvement in multinational and interagency operations. It provides guidelines for planning and conducting operations using space forces. It will define the military operational principles associated with supporting from space and operating in space as well as the command relationships and responsibilities.

Key concepts in Joint Pub 3-14 are:

- Joint Forces have come to rely heavily on space capabilities to provide them unprecedented "battlespace awareness". Space, air, land and sea commanders must be aware of the characteristics operational considerations, and constraints inherent to the space region in order to maximize capabilities and forces to support joint operations.
- Commander, USSPACECOM can be either a supported or supporting commander.
- Commander, USSPACECOM has planning and operational responsibility for the region of space, and exploits this fourth operating medium to bring unique capabilities to the joint battlespace. CDR, USSTRATCOM maintains COCOM of DoD space forces. Space assets and space capabilities can be made OPCON and/or TACON to another Unified Command/JCF/JTF Commander.

USSPACECOM executes military space operations in the areas of Space Combat Operations (Space control and Force Application Operations), Space Support Operations and Combat Support Operations (Force Enhancement Operations).

NOTE: USSPACECOM was absorbed by the United States Strategic Command (USSTRATCOM) in October 2002. USSTRATCOM took over all of the responsibilities of USSPACECOM.

Space Combat Operations

The Force Application mission area falls within Space Combat Operations. Space combat operations will provide freedom of action in space for friendly forces, and, when directed, deny the same freedom to the enemy. Space combat operations also include the protection, prevention, and negation functions of space control.

Combat Support Operations

Combat support operations, or force enhancement operations, multiply joint force effectiveness by enhancing battlespace awareness and providing needed warfighter support. The functions include reconnaissance and surveillance; environmental monitoring; communications; imagery/global geospatial information and services; and positioning, navigation and timing.

Space Support Operations

Space support operations consist of operations that deploy, augment, sustain and replenish space forces, including the configuration of command and control structures for space operations. Examples of space support operations are spacelift; satellite operations (TT&C), space satellite activation, and space surveillance.

USSTRATCOM Operational Concepts

USSTRATCOM's four operational areas support this effort:

- **Control of space** assures freedom of operations within the space medium, and, if required, denies others the use of space; includes protection of friendly force assets and prevention and negation of an adversary's use of space, when directed.
- **Global engagement** operations combine world-wide situational awareness and precise application of force from space; includes preparation to hold a limited number of land, sea, and air targets at risk with space-based fires; currently constrained by national policy.
- **Full force integration** aims at integrating space capabilities into air, land, and sea capabilities; includes operations that multiply the effectiveness of the joint force by enhancing battlespace awareness and providing warfighter support in the areas of reconnaissance and surveillance, environmental monitoring, communications, imagery/global geospatial information and services; and positioning, navigation, and timing.
- **Global partnerships** support the leveraging of civil, commercial, intelligence, national, and international space systems for military operations. The main effort focuses on domestic partnerships, but international opportunities are also pursued.

Additional Relevant Space Doctrine

While this text will not specifically discuss all of this doctrine, it is worth noting the USAF body of knowledge to date in the realm of space doctrine. Two documents conceptualize how the USAF envisions space operations impacting and integrating as part of our military operations. Air Force Doctrine Document (AFDD) 2-2, *Space Operations*, is dated 27 Nov 2001 and is available on line at www.dtic.mil/doctrine/jel/service_pubs/afdd2_2.pdf. AFDD 2-2.1, *Counterspace Operations*, is dated 2 Aug 2004 and is available on line at www.dtic.mil/doctrine/jel/service_pubs/afdd2_2_1.pdf. Both documents complement related discussion found in Joint Pub 3-14 and in FM 3-14.

Chapter 3
The Space Environment

OVERVIEW

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 vulnerability to loss of critical satellite functions or entire systems.

Space is often incorrectly thought of as a vast, empty vacuum that begins at the outer reaches of the Earth's atmosphere and extends throughout the universe. In reality, space is a dynamic place that is filled with energetic particles, radiation, and trillions of objects both very large and very small. Compared to what we experience on Earth, it is a place of extremes. Distances are vast. Velocities can range from zero to the speed of light. Temperatures on the sunny side of an object can be very high, yet extremely low on the dark side, just a short distance away. Charged particles continually bombard exposed surfaces. Some have so much energy that they pass completely through an object in space. Magnetic fields can be intense. The environment in space is constantly changing, and is a hostile environment for satellites.

Where Space Begins

There is no formal definition of where space begins. International law, based on a review of current treaties, conventions, agreements and tradition, describes the lower boundary of space as the lowest perigee attainable by an orbiting space vehicle. A specific altitude is not mentioned. By international law standards aircraft, missiles and rockets flying over a country are considered to be in its national airspace, regardless of altitude. Orbiting spacecraft are considered to be in space, regardless of altitude. The U.S. government defines space in the same terms as international law.

The Earth's atmosphere does not suddenly end at a particular altitude and space begins. In fact, the Earth's atmosphere continues out for more than 1,000 miles into space. In practical terms, the lowest altitude for a satellite in a circular orbit is about 93 miles (150 km) but, without propulsion, the satellite would quickly lose speed and fall back to Earth.

Space Weather

Our space weather originates at the sun. The area between the Sun and the planets has been termed the interplanetary medium. Fifty years ago, most scientists believed that Earth was surrounded by an empty, unchanging vacuum. The launches of the first satellites beginning in 1957 (the former U.S.S.R.'s Sputnik was the first) changed all that. We now know that space is filled with debris from disintegrated comets, an ever-changing high-speed solar wind, radiation belts and polar fountains. Bad weather in space can mean poor radio communications or disrupted power grids here on Earth, and potential hazards to astronauts or spacecraft can be even more serious.

Space is actually a turbulent area dominated by the solar wind, which flows at velocities of approximately 250-1000 km/s (about 600,000 to 2,000,000 miles per hour). It is filled with low energy charged particles, photons, electric and magnetic fields, dust, and cosmic rays. The densities of these things are low, particularly for the particulate matter, compared to, for example, the atmospheric density at the surface of the Earth but they are high enough to affect spacecraft, humans in space and even occasionally human activities on Earth. Moreover, other characteristics of the solar wind (density, composition, and magnetic field strength, among others) vary with changing conditions on the Sun that can cause violent and dramatic changes in our atmosphere. These may be visibly manifested in dramatic aurora displays. This is called ***space weather***. Table 3-1 shows how space weather is analogous to common Earth weather measurements and features:

Earth Weather	**Comparable Space Weather**
Wind speed	Solar wind speed
Wind direction	Particle direction
Isobars	Magnetic flux lines
Weather systems	Magnetic field areas (ex: van Allen belts)

Table 3-1: Comparison of Earth Weather to Space Weather

The solar wind flows around obstacles such as planets, but the magnetic fields of those planets respond in specific ways. Earth's magnetic field is very similar to the pattern formed when iron filings align around a bar magnet. Under the influence of the solar wind, these magnetic field lines are compressed in the sunward direction and stretched out in the leeward direction. This creates the magnetosphere (**Figure 3-1a**), a complex, teardrop-shaped cavity around Earth.

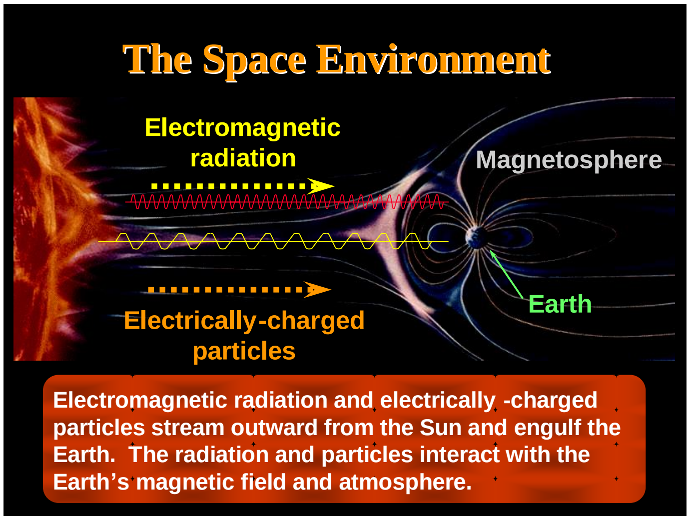

Figure 3-1a: The Space Environment

The Van Allen radiation belts are within this cavity, as is the ionosphere, a layer of Earth's upper atmosphere where photo ionization by solar x-rays and extreme ultraviolet rays creates free electrons. Earth's magnetic field senses the solar wind its speed, density, and magnetic field. Because the solar wind varies over time scales as short as seconds, the interface that separates interplanetary space from the magnetosphere is very dynamic. Normally this interface called the magnetopause lies at a distance equivalent to about 10 Earth radii in the direction of the Sun. However, during episodes of elevated solar wind density or velocity, the magnetopause can be pushed inward to within 6.6 Earth radii (the altitude of geosynchronous satellites). As the magnetosphere extracts energy from the solar wind, internal processes produce geomagnetic storms.

To understand the effects of space weather, one must understand the properties of the various layers of the earth's atmosphere, the properties of the sun and solar energy and the properties of the earth's electromagnetic field. We will begin by discussing the layers of the earth's atmosphere and the properties of those layers as they relate to satellite orbits.

Earth's Atmosphere

The atmosphere limits the lowest altitude at which a satellite can be placed into orbit. The atmosphere absorbs, diffuses, deflects, or delays certain frequencies of signals sent to and from a satellite. Satellites launched from the Earth's surface must pass through the atmosphere to attain orbit. Manned spacecraft and some unmanned payloads must reenter the atmosphere to safely return to the surface. The Earth's atmosphere is divided into numerous regions which have different characteristics (**Figure 3-1b**). The boundaries between the regions are not distinct. Some regions overlap and others are made up of a number of sub-regions. Definitions are complicated by the fact that different scientific fields define these regions in different ways using various criteria, such as pressure or temperature. Altitude alone does not define where one region ends and another begins because the regions are constantly fluctuating in size depending on the time of day, the season of the year, the degree of activity of the sun and many other factors.

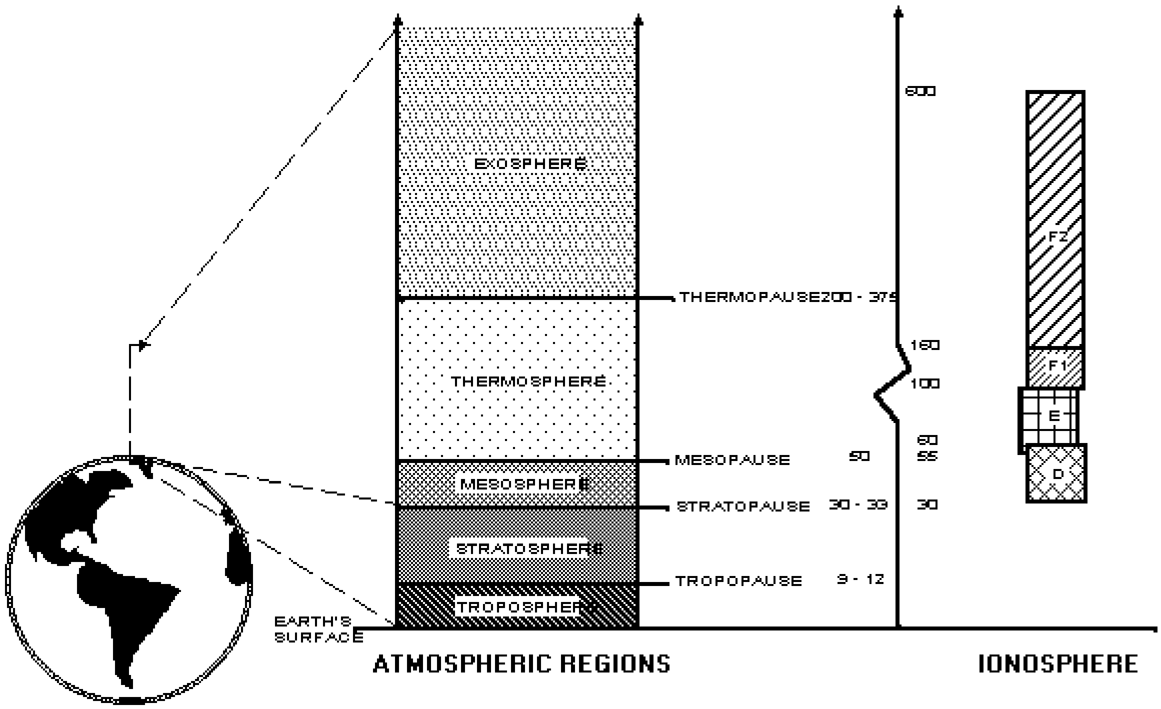

Figure 3-1b: Earth's Atmosphere

Troposphere

The troposphere is the lowest region of the atmosphere. It starts at the Earth's surface and extends to the tropopause, the upper boundary of the troposphere. The altitude of the tropopause varies from 9 to 12 miles (15 to 20 km) at the equator to about 6 miles (10 km) in polar areas. Almost all clouds and weather occur in the troposphere. It contains about 99% of the atmosphere's water vapor and 90% of the air. Above an altitude of 2 miles (3.2 km), a person who has not become adapted requires supplemental oxygen or a pressurized environment to survive. Approximately half of the Earth's atmosphere is below an altitude of 3 miles (5 km).

Stratosphere

The layer above the troposphere is the stratosphere. It extends from the tropopause to the stratopause, the upper boundary at about 30 to 33 miles (48 to 53 km) altitude. In general, the temperature of the stratosphere increases slightly with altitude which results in vertical stability. Approximately 99 percent of the atmosphere is in the stratosphere and troposphere. This region is characterized by the near absence of water vapor and clouds. At altitudes above 9 miles (14.5 km) breathing supplemental oxygen through a mask is no longer effective. Pressurization by means of a pressure cabin or a pressure suit and helmet is required. Above an altitude of 15 miles (24 km) compressing outside air into the cabin or pressure suit usually generates too much heat. Everything required to sustain life must be carried on board. Ozone is in the ozone layer which varies in altitude from 12 to 21 miles above the Earth. 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 which is harmful to humans and most other life forms. In Figure 3-1, the small band around the picture of the Earth represents the combined thickness of the troposphere and stratosphere relative to the size of the Earth.

Mesosphere

The mesosphere extends from the stratopause at the lower boundary to the mesopause, the upper boundary at about 50 miles (80 km) altitude. The temperature of the atmosphere in the mesosphere decreases as the altitude increases. The temperature at the mesopause is about -130° F (-90° C). Above about 30 miles (48 km) altitude there is not enough atmosphere for even a high altitude ramjet to operate. Above this altitude both fuel and oxidizer must be carried for a rocket engine to provide thrust.

Thermosphere

The thermosphere extends from an altitude of 50 miles (80 km) to between 200 miles (320 km) and 375 miles (600 km). The temperature increases with altitude from about -130° F (-90° C) to the thermopause where the maximum temperature is about 2,960° F (1,475° C) during the day and about 440° F (225° C). U.S. astronaut wings or device are awarded to anyone who travels to an altitude of about 50 miles or higher, regardless of whether they completed an orbit of the Earth. An altitude of 93 miles (150 km) is the lowest altitude at which a satellite in a circular orbit can orbit the Earth for at least one revolution without propulsion. At this altitude it takes 87.5 minutes to complete one revolution of Earth. This altitude is the most commonly accepted definition of where space begins but it is not explicitly stated in any treaty or international agreement. An altitude of 80 miles (129 km) is about the lowest altitude (perigee) at which a satellite in an elliptical orbit can pass through the Earth's atmosphere and still remain in orbit. This is discussed further in Chapter 4.

Exosphere

The exosphere begins where the thermosphere ends and extends out into space. In this region the density of atoms and molecules of the atmospheric gases is very low. Typically, individual atoms travel about 1600 miles in 20 minutes before colliding with another atom. After the collision, some atoms have enough velocity to escape the Earth's gravity and enter interplanetary space. The density is so low that all of the atmospheric particles that surround the Earth at an altitude of 1,000 miles could be contained in 1 cm^3 at sea level. Satellites orbiting in the exosphere at an altitude of about 620 miles (1000 km) are, however, slowed by atmospheric drag caused by friction from collisions with individual molecules.

Ionosphere

The ionosphere is a region that is defined by its high density of ionized molecules, rather than by temperature changes. It begins within the mesosphere, between 31 and 50 miles in altitude and extends to about 240 miles (400 km). The atoms and molecules in this layer are bombarded by solar x-rays and ultraviolet radiation from the sun and become electrically charged, or ionized, in a process known as photoionization. This process produces an excess of free electrons and ionized atoms. X-rays and extreme ultraviolet (EUV) radiation from the sun and ultra-high-frequency galactic cosmic rays from the stars of outer space are the prime mechanisms in the formation of the ionosphere. The amount of radiation available to ionize atmospheric molecules varies between day and night, high and low latitude, and with the activity level of the sun. Sunspots, solar flares and other disturbances on the surface of the Sun produce fluctuations in the output of the Sun's energetic rays and particles. These fluctuations cause Sudden Ionospheric Disturbances (SIDs). Simply put, when particles interact with magnetic fields they give off energy which is seen as lights. Interaction between the ionosphere and the concentrated magnetic field of the Earth at the North and South Poles causes the undulating brilliant colors of the aurora borealis (north lights) and the aurora australis (southern lights).

The ionosphere can absorb, delay or reflect certain frequencies of radio signals; therefore, the characteristics of the ionosphere have significant impact on the design and operation of communications systems between satellites and ground stations. The ionosphere is also important for ground-to-ground radio communications systems because they rely on the ability of the ionosphere to reflect or refract radio waves to achieve long range.

Magnetosphere

The magnetosphere is that area of space, around the Earth, that is controlled by the Earth's magnetic field. The solar wind compresses the Earth’s magnetic field on the side closest to the Sun. Therefore, this area changes in relation to changes in the Sun’s activity. The magnetosphere impedes the direct entry of the solar wind plasma into the earth’s atmosphere. This area and the resulting effects on satellites will be discussed in further detail.

THE SUN

The origin of space environmental impacts on radar, communications and space systems lies primarily with the sun. The sun continuously emits electromagnetic energy and charged particles in the form of light and radio frequency noise. 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. The constant stream of these forms of radiation is called the solar wind. In addition, at seemingly irregular intervals, there are solar flares, the explosive ejection of particles (mostly protons and electrons) accompanied by sporadic emissions of electromagnetic radiation.

The Solar Wind

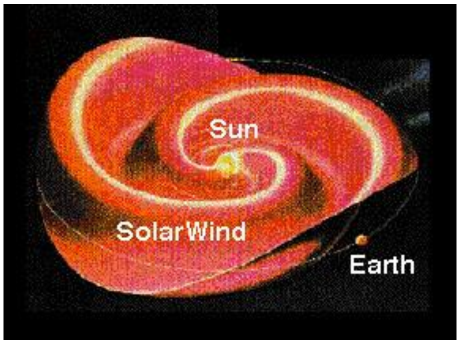

Figure 3-2a: Solar Wind

The sun flings 1 million tons of matter out into space every second. Because of the high temperature of the Sun's corona, solar protons and electrons acquire velocities in excess of the escape velocity from the sun. The result is that there is a continuous outward flow of charged particles in all directions from the sun. This flow of particles is called the solar wind. And this happens every day, day after day, year after year.

The solar wind is a fully ionized gas that literally explodes continuously from the solar corona, the outer region of the sun's dense atmosphere carrying with it magnetic fields still attached to the sun. The solar wind is driven away from the sun by thermal pressure from the two million-degree corona at supersonic velocities, about 500 km/s. By the time the solar wind reaches Earth's orbit, it is traveling at 185 - 435 mi/sec (well over 1,000,000 miles per hour).

The density is 1 - 10 particles per cubic centimeter. When it gets as far away as the orbit of the earth, 150 million km, it is still accelerating and it keeps on going as far as we have been able to probe with our most distant spacecraft.

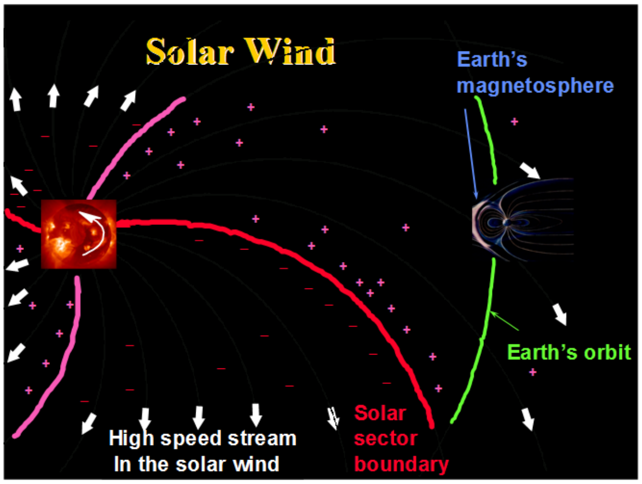

Figure 3-2b: Solar Wind

The Interplanetary Magnetic Field (IMF) emanating from the sun normally has 4 to 6 sectors of alternating positive and negative polarity, and a spiral structure near the plane of the Earth's orbit due to the sun's 27-day rotation period. The IMF guides charged solar wind particles, and those in one IMF sector can't penetrate into another sector. Since particles tend to move faster in a sector's forward rather than tailing portion, particle density tends to build up at "Solar Sector Boundaries (SSBs)." Also dense "High Speed Streams (HSSs)" of particles can exist within a sector. There are regions in the sun's atmosphere where magnetic field lines are open to space and actually facilitate the outward flow of particles. Both SSB and HSS enhancements and discontinuities can disrupt the Earth's magnetosphere as the sun's rotation causes them to sweep by the Earth.

These solar wind enhancements and discontinuities occur throughout the solar cycle, even during Solar Minimum. Fortunately, the size of the disruptions they cause in the Earth's magnetosphere tends to be less than with the disruptions caused by solar flares. Also, since these solar wind enhancements and discontinuities are tied to solar features that persist for longer than the sun's 27-day rotation period, they tend to be recurrent, and thus the geomagnetic storms they produce are somewhat easier to forecast than the sporadic geomagnetic storms produced by spontaneous flares that can occur at any time.

The velocity and density of the solar wind vary with sunspot activity. Gusts and disturbances form in the solar wind associated with violent events on the sun. The gusting and blowing of the solar wind against the Earth's protective magnetic shield in space is responsible for space weather storms. Some of these disturbances are described in the following sections.

Sun Spots

The Sun has a rotation period of 28 days, which exposes Earth to the surface features of the Sun, such as sunspots. One way we track solar activity is by observing sunspots. Sunspots are relatively cool areas that appear as dark blemishes on the face of the sun. They are formed when magnetic field lines just below the sun's surface are twisted and poke though the solar photosphere. The twisted magnetic fields above sunspots are sites where solar flares are observed to occur, and we are now beginning to understand the connection between solar flares and sunspots. Sunspots are normally associated in a complex, but not completely understood, way with solar flares, i.e., the more the sunspots, the more the solar flares

Every 11 years the sun undergoes a period of activity called the "solar maximum", followed by a period of quiet called the "solar minimum." During the solar maximum there are many sunspots, solar flares, and coronal mass ejections, all of which can affect communications and weather here on Earth. During solar minimum there are few events. The last two solar maximums occurred around 1989 and then again at the beginning of the year 2001.

Solar Flares

A solar flare is an explosion of incredible power and violence that releases energy equivalent to about 100 hurricanes in a matter of tens of minutes. (To equal the power of a hurricane one would have to set off about a thousand nuclear devices per second for as long as the hurricane rages on.) It involves

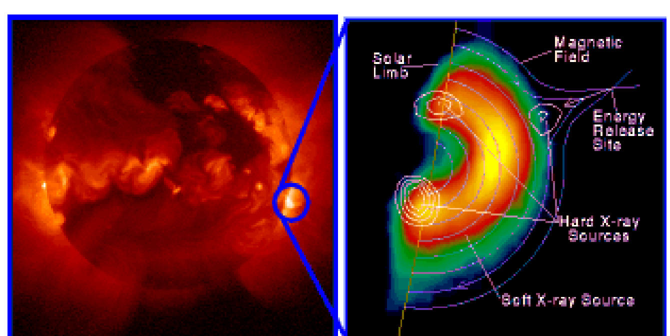

Figure 3-3: Parts of a Solar Flare

sudden bursts of particle acceleration, plasma heating, and bulk mass motion. The strong and twisted magnetic fields in the vicinity of active sunspot groups are thought to provide the power that is released in the solar flares. It is not known as yet exactly how this occurs.

In the largest flares, 10^{32} ergs or more can be released in a few minutes to a few tens of minutes. Such large flares only occur a few times within a year or two of the maximum in solar activity that occurs every 11 years or so. Many smaller flares occur down to the limits of detectability of modern instruments at about 10^{27} ergs. These smaller events generally last for shorter times down to a few seconds; their occurrence rate also follows the 11-year cycle, peaking at several tens of flares per day.

In general, a solar flare produces copious radiation across the full electromagnetic spectrum from the longest wavelength radio waves to the highest energy gamma rays. Flares release energy in many forms - electro-magnetic (Gamma rays and X-rays), energetic particles (protons and electrons), and mass flows. The contrast over the background (quiet-Sun) emission is much higher at the shorter X-ray and gamma ray wavelengths. The X-rays result from the interactions of the high energy electrons energized during the flare, and the gamma rays result primarily from nuclear interactions of the high energy protons and other heavier ions. The X-rays travel at the speed of light and arrive at Earth in just 8 minutes time. The hot particles, which travel at slower speeds, follow several hours later.

There are many events that may occur on Earth following a solar flare. By the time we first observe a flare, it is already causing immediate environmental effects and satellite 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. In addition to the increase in visible light, minutes later there is a Sudden Ionosphere Disturbance (SID) in Earth's ionosphere. This, in turn, causes short wave fade-out, resulting in the loss of long-range over-the-horizon communications for 15 minutes to 1 hour. During the first few minutes of a flare, there may be a radio noise storm. The first few minutes of this storm causes noise over a wide range of frequencies that can be heard as static in radio transmissions. These effects will be discussed in more detail. The National Oceanic and Atmospheric Administration (NOAA) monitors the X-Ray flux from the Sun with detectors on some of its satellites. Observations for the last few days are available at NOAA's website for Today's Space Weather.

Coronal Mass Ejection

Perhaps the most important solar event for the people on Earth is a coronal mass ejection (CME) because it can produce spectacular space weather events at Earth. Periodically, the sun violently expels a huge bubble of gas (called a coronal mass ejection) from its outer atmosphere into space. During the course of such an event on average, several billion tons of gases are blown toward Earth. This is equivalent to the mass contained in a small lake but vaporized and traveling at millions of

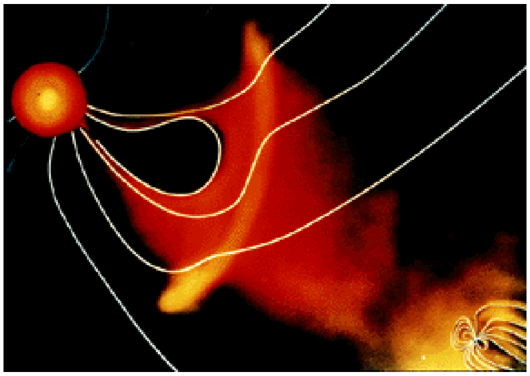

Figure 3-4: Coronal Mass Ejection with Shock Waves

miles an hour (thousands of kilometers per second). The total energy contained in these high-speed charged gases during a large event is roughly the same as a large solar flare (approximately equivalent to the total energy of 100 hurricanes) but expelled over a longer time period than a solar flare (many hours as compared to tens of minutes).

CMEs disrupt the flow of the solar wind and produce disturbances that strike the Earth with sometimes catastrophic results. If a CME collides with the Earth, it can excite a geomagnetic storm. Large geomagnetic storms have, among other things, caused electrical power outages and damaged communications satellites. In space CMEs typically drive shock waves that produce energetic particles that can be damaging to both electronic equipment and astronauts that venture outside the protection of the Earth's magnetic field. Solar flares, on the other hand, directly affect the ionosphere and radio communications at the Earth, and also release energetic particles into space. Therefore, to understand and predict "space weather" and the effect of solar activity on the Earth, an understanding of both CMEs and flares is required.

This high speed gas bubble expands rapidly into space rivaling the sun in size in just a matter of hours. CMEs normally drive shocks ahead of them as they plow into the slower-moving solar wind streams (**Figure 3-4**). Vast quantities of high speed particles are born in these shock structures and speed ahead of the coronal mass ejection to impact the Earth before the CME itself makes an appearance. It is now believed that a large fraction of the solar energetic particles arriving at Earth were produced in these shocks rather than at flare sites on the Sun.

CMEs are difficult to detect and, in fact, were not observed until coronagraphs were build and flow in space. The frequency of CMEs varies with the sunspot cycle. At solar minimum we observe about one CME a week. Near solar maximum we observe an average of 2 to 3 CMEs per day. Many of the CMEs that are blown toward the Earth never actually directly hit us. They pass us by.

Recently an international group of scientist discovered a new way of predicting coronal mass ejections. Using the Japanese Yohkoh satellite, it was discovered that an S-shaped structure often appears on the Sun in advance of the violent eruptions. Early warning of approaching solar storms is very useful to power companies, the communications industry and any space operations.

Other Solar Activities

One type of corpuscular radiation is the cosmic ray. Cosmic rays originate from two sources: the Sun (solar cosmic rays), and other stars throughout the universe (galactic cosmic rays). This radiation is primarily high velocity protons and electrons. The solar cosmic rays are not a serious threat to humans, except during periods of solar flare activity, when the radiation can increase a thousand fold over short periods. Cosmic ray particles can also cause direct damage to internal components through collision. Shielding is not feasible due to the high energy of the particles and the weight of the shielding required. Cosmic rays have the most impact on polar and geosynchronous orbits. This is due to the fact that they are outside or near the edge of the protective shielding provided by Earth's magnetic field.

Thermal energy emitted by the Sun is intense. Satellites in orbit around the Earth do not have the benefit of the shielding provided by the atmosphere. Parts of satellites exposed to sunlight can heat to very high temperatures if they absorb the radiant energy. Sunlight reflected by the Earth is also a significant source of radiant energy for satellites in low Earth orbit. On the shadow side, heat can radiate from the satellite into cold space with the result that surface temperatures can be hundreds of degrees below zero. Thermal energy is also generated by internal components of a satellite such as batteries, transmitters, computers and other devices. This thermal energy must be dissipated so that it does not damage the components.

A Hypothetical Timeline of a Solar Event

Within 8 Minutes….

X-ray and ultraviolet light given off by solar flares arrives at the Earth. These types of light are responsible for the formation of the ionosphere under normal circumstances. But now the intensities of these types of light have increased dramatically. All over the dayside hemisphere, the ionosphere is increased in density, particularly at low altitudes in the D and E regions (**see Figure 3-1b**). This is called a sudden ionospheric disturbance (SID) and lasts usually for between 10 and 60 minutes. Short wave radio signals experience increased absorption when ionization is produced at these low altitudes. Loss of signal at this time is called a short wave fadeout. Enhanced levels of solar radiation can also cause heating and expansion of the neutral atmosphere and increase the amount of atmospheric drag that a satellite experiences in an unpredictable manner.

Minutes to Hours Later...

Solar protons are accelerated to very high velocities in the explosive release of energy associated with a solar flare. These particles first make their way out of the corona. Then they cannot take a straight line path to the Earth but must travel along the Sun's extended magnetic field lines (called the interplanetary magnetic field or IMF). These field lines have a structure resembling the spiral traced out by a spinning lawn sprinkler, which is referred to as a Parker spiral.

Hours to Days Later...

Disturbances in the solar wind arrive at the Earth within hours to days after a violent event on the Sun. The largest space weather disturbances at Earth are produced by coronal mass ejections and fast solar wind streams emanating from coronal holes. Coronal holes are the main source of recurrent solar activity.

ELECTROMAGNETIC FORCES

Earth's Magnetic Field

The Earth has a magnetic field which emanates from its south magnetic pole, extends out into space and comes back to its north magnetic pole. The north and south magnetic poles are near the north and south celestial poles about which the Earth rotates. The magnetic field around the Earth is similar to one that would be formed if a bar magnet extended through the center of the Earth with the tips at the north and south magnetic poles.

According to accepted theory, Earth's magnetic field arises from electrical currents flowing in the molten metallic core of the planet. The Earth's magnetic field is thought to be produced by electric currents circulating in the molten core. However, the exact mechanism is not yet understood. This magnetic field extends outward from the Earth's core into interplanetary space where it encounters the magnetic field and moving charged plasma of the solar wind. The solar wind flows around the Earth's magnetic field but distorts the field as it does so. The solar wind compresses the Earth's magnetic field on the dayside and stretches it out into a long anti-sunward tail on the night side.

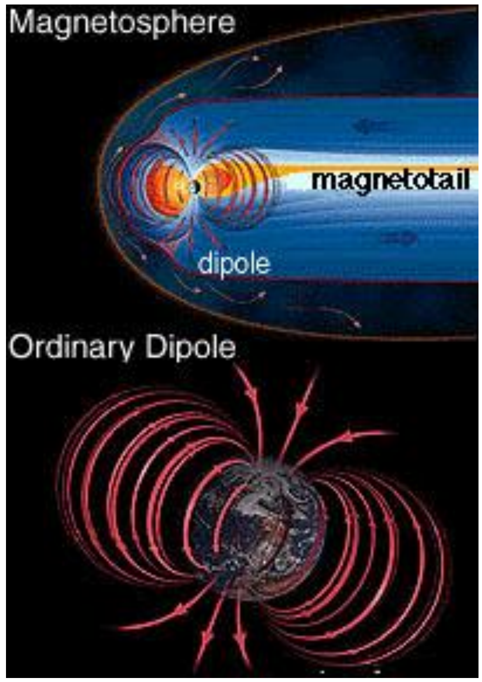

Figure 3-5: Dipole vs. Magnetosphere Magnetic Fields

Magnetosphere

The solar wind hits the earth's magnetic field. Because the solar wind is mostly charged particles, electrons and protons, it cannot easily penetrate the earth's field. It meets an immovable obstacle and it forms a shock front and tries to flow around the sides in a manner very much analogous to a supersonic aircraft moving through the atmosphere. In so doing, it compresses and confines the magnetic field on the side toward the sun and stretches it out into a long tail on the night side. The magnetic cavity formed by this process is called the "magnetosphere" and is shown in **Figure 3-5**. In the process, energy and charged particles are transferred from the solar wind to the magnetosphere.

The space around our atmosphere is alive and dynamic because the Earth's magnetic field reacts to changes in the solar wind. The interaction between the solar wind and the plasma of the magnetosphere acts like an electric generator, creating electric fields deep inside the magnetosphere. These fields in turn give rise to a general circulation of the plasma within the magnetosphere and accelerate some electrons and ions to higher energies. During periods of highest solar wind, powerful magnetic storms in space near the Earth cause vivid auroras, radio and television static, power blackouts, navigation problems for ships and airplanes with magnetic compasses, and damage to satellites and spacecraft. Events on the Sun and in the magnetosphere can also trigger changes in the electrical and chemical properties of the atmosphere, the ozone layer, and high-altitude temperatures and wind patterns.

On the sunward side of Earth, the solar wind compresses the magnetic field in toward the Earth, increasing the magnetic field strength in the compressed areas. On the opposite side of Earth, the solar wind acts to stretch out the magnetic field thus giving it a teardrop shape. The boundary of the magnetosphere is the magnetopause. It is where the pressure of the solar wind is balanced by Earth's magnetic field pressure. The magnetopause is most defined on the sunward side where it is located approximately 10 Earth radii (10 times 3962 mi) from the Earth. This boundary fluctuates between 7 to 14 Earth radii during magnetic disturbances resulting from large variations in the solar wind.

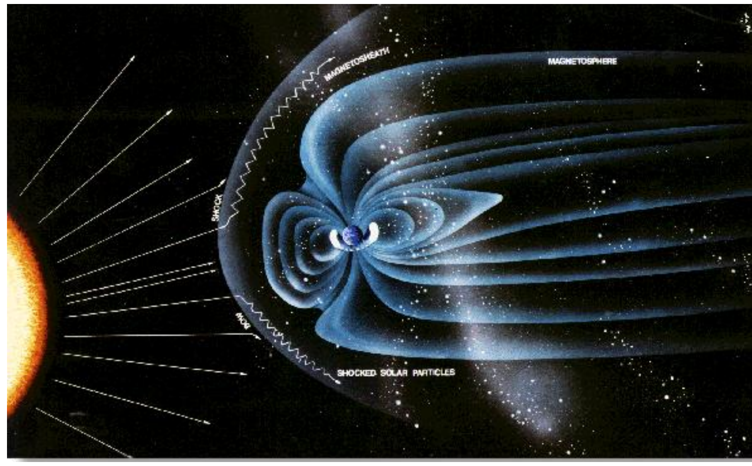

Figure 3-6: Magnetosphere and the Sun

On the side of Earth opposite from the Sun, the solar wind draws the magnetic field out into a long tail, called the magnetotail. This tail extends out to 1,000 earth radii or more. Located within the magnetotail is a region of high density, high energy plasma, known as the plasma sheet. It may extend out past 300 earth radii. Within the plasma sheet is the neutral sheet. This is where the magnetic field lines reverse direction from a component towards Earth (northern lobe) to a component away from Earth (southern lobe).

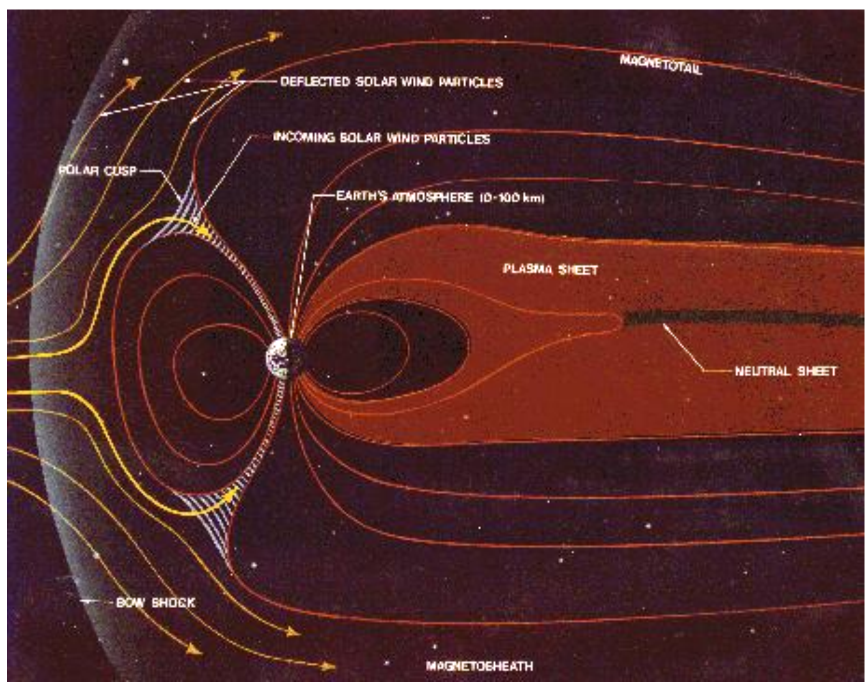

Figure 3-7: Earth's Magnetosphere

Since the beginning of the space age in 1957, and even before, scientists have been probing and defining regions of the magneto-sphere and trying to understand how they arise. We now have a fairly good understanding of the morphology of the magnetosphere. The magnetic field lines from the dayside of the magnetosphere are drawn over the poles and into the night side to form this long stretched tail. In the process, they form the northern and southern lobes which are separated from each other by a very interesting region called the plasma sheet. In the plasma sheet, by some process not yet fully understood, the magnetic energy of the lobes is converted to plasma kinetic energy. A plasma is a gas that is fully ionized, i.e. the atoms, mostly hydrogen, have had all of their electrons removed. Although almost unknown to us on earth, taking the universe as a whole, plasma is the most common form of matter, being found mostly in stars. Plasma is generally considered to be electrically neutral, but the fact that the atoms are ionized means that the weak magnetic and electric fields that pervade the region strongly influence the charged particle motion. In fact, the definition of the magnetosphere is that region where the earth's magnetic field controls the particle behavior. The story of the dynamics of the magnetosphere is one of motion of particles from the solar wind and the earth's ionosphere being shoved around and energized by electric and magnetic fields.

Van Allen Radiation Belts

Within the magnetosphere are found the Van Allen radiation belts, named after Dr. James Van Allen, who was responsible for the interpretation of the data from the Explorer I satellite, launched by the U.S. Army. Their existence was not discovered until early 1958, when Explorer I data was used to map particles trapped by Earth's magnetic field. Data from this satellite and other satellites revealed the strange shape of the magnetosphere and toroidal shaped pockets of trapped charged particles. Other scientific satellites have added even more detail. The Van Allen radiation belts consist of concentric doughnut shaped regions of energetically charged particles (**Figure 3-8**). The Van Allen belts have an inner and outer portion filled with high energy protons and electrons. The protons are most intense at about 2,200 miles. The electron flux breaks at about 10,000 miles. The area of low particle density separating the two belts is often called the "Slot." Although the cross sectional view shown in **Figure 3-8** shows two distinct belts, they are not really that distinct. The density of electrons in the slot is just somewhat lower than in the two Van Allen radiation belts.

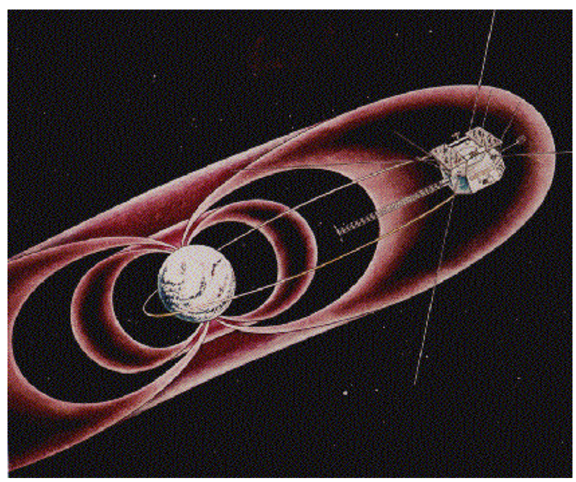

Figure 3-8: Van Allen Radiation Belts

The inner Van Allen radiation belt starts at an altitude between 250 miles to 750 miles, depending upon the latitude. It extends to about 6,200 miles. This is where the "slot" begins. The inner belt extends from about 40° north latitude to about 40° south latitude.

The outer Van Allen belt begins at about 6,200 miles (depending on latitude) and extends to between 37,000 and 57,000 miles. The upper boundary is dependent upon the activity of the sun. When electrons, protons, and perhaps some other charged particles encounter Earth's magnetic field, many of them are trapped by the field. They bounce back and forth between the magnetic north and south poles, following the magnetic field lines.

Experience has shown that spacecraft (manned or unmanned) in low circular orbits (120-340 mi) receive an insignificant amount of radiation from the Van Allen zones. A satellite in a geosynchronous orbit, however, would be close enough to the center of the outer zone (22,500 mi) to accumulate a hazardous dose. For manned space systems, the spacecraft must be shielded and an orbit that minimizes radiation exposure must be selected. Other satellites in other-than-geosynchronous orbits may transition in and out of the Van Allen zones repeatedly, receiving varying amounts of radiation.

Electromagnetic Forces

As a satellite orbits the Earth, it travels through the magnetic fields that cause the satellite to act like a magnet. The electrical or electronic components within or outside the satellite set up magnetic fields, which react with the Earth's magnetic field. Another reason a satellite may act as a magnet is due to a negative electrical charge that is generated by the satellite passing through the partly ionized medium which produces a negative charge on the satellite's skin. The negative charge is higher on the dayside of the orbit than on the night side. The motion of a charged satellite made of conductive materials through Earth's magnetic field also results in the satellite acquiring an electrical potential gradient which is proportional to the intensity of the magnetic field and the velocity of the satellite as it passes through the field. These cause a magnetic drag to act upon the satellite. The drag can cause torquing of the satellite.

Auroras

The aurora borealis (northern lights) and the aurora australis (southern lights) are multicolored bands of visible light effects seen in the nighttime sky. Auroras occur in the upper atmosphere of both the north and south poles where the Earth's magnetic field bends towards the Earth's surface. The bottom of the aurora curtain is about 62 miles (100 km) in altitude, extending up to about 190 miles (300 km). Seen from above by research satellites, the aurora curtain appears along oval belts around the Earth's geomagnetic poles. The average radius is about 1,400 miles from the poles (about 70° north or 70° south latitude) and extends thousands of miles to the east and west. Typically, the aurora band is only about one mile or less thick.

Figure 3-9: Auroras

The light of the auroras is caused by electrical discharges powered by the interaction of the Earth's magnetic field and the solar wind. The solar wind supplies the necessary charged particles which perturb the magnetosphere so that the particles are "dumped" into the atmosphere near Earth's magnetic poles. As these particles collide with gas molecules in the upper atmosphere, light energy is released, causing aurora displays. Increased activity in the auroras indicates major solar activity that can affect military communications.

Geographic Anomalies

The center of Earth's magnetic field is offset from the center of Earth by 270 miles towards the Western Pacific Ocean. This leads to two areas on Earth where the magnetic field strength will be either stronger or weaker than expected. These areas are geomagnetic anomalies. The South Atlantic anomaly is a region of unusually low magnetic field strength. At this location where the low strength field lines dip to a low altitude, many particles enter the atmosphere and collide with the higher density atmospheric particles. As a result of these collisions, we have ionospheric effects similar to those produced in the aurora regions. This will disrupt high frequency (HF) transmissions. The Southeast Asian anomaly is an area of unusually high magnetic field strengths. As a result of this strong field, the trapped particles will have a higher density at any given altitude. This leads to an enhanced F_2 region in the ionosphere. This can adversely affect communication transmissions that pass through this region. The solutions to the problems caused by these anomalies are to use a frequency not affected by the disturbed conditions or to avoid transmissions within either region.

EFFECTS ON SPACE AND GROUND SYSTEMS

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 satellite system impacts 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.

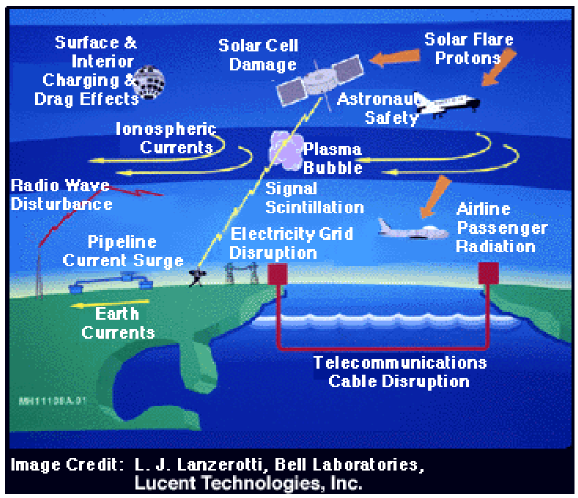

Figure 3-10: Effects of Space Weather on Ground Systems

Ground systems are also affected by solar-geophysical activity (**Figure 3-10**). Some of these ground system impacts can indirectly affect military operations. For example, system impacts from a geomagnetic storm can include: (1) induced electrical currents in power lines and in long pipelines (such as the Alaskan oil pipeline), which can cause transformer failures and power outages and (2), magnetic field variations, which

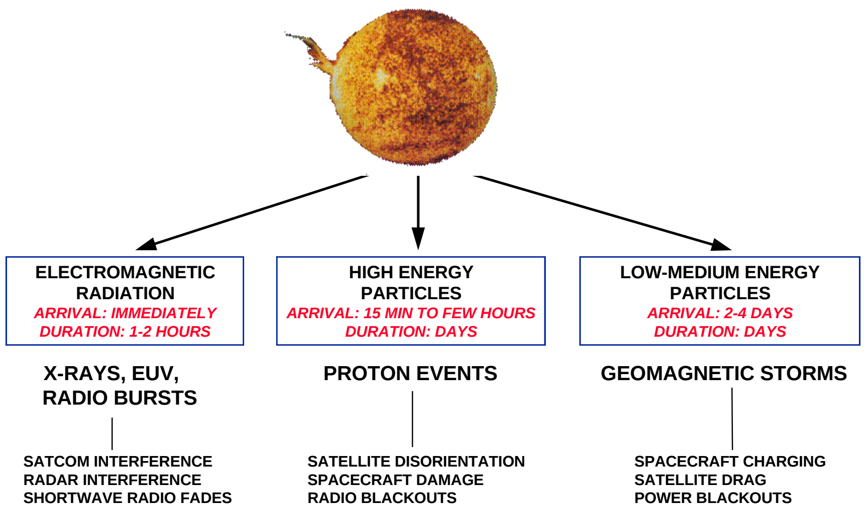

Figure 3-11: Three Categories of Solar Radiation

can lead to compass errors and interfere with geological surveys. Each of the three general categories of solar radiation (**Figure 3-11**) has its own characteristics and types of system impacts.

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 simply miss hitting the Earth. For those events that do affect the near-Earth environment, effects can be both immediate and delayed.

Electromagnetic Radiation

Electromagnetic radiation 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

Figure 3-11: Three Categorie

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,

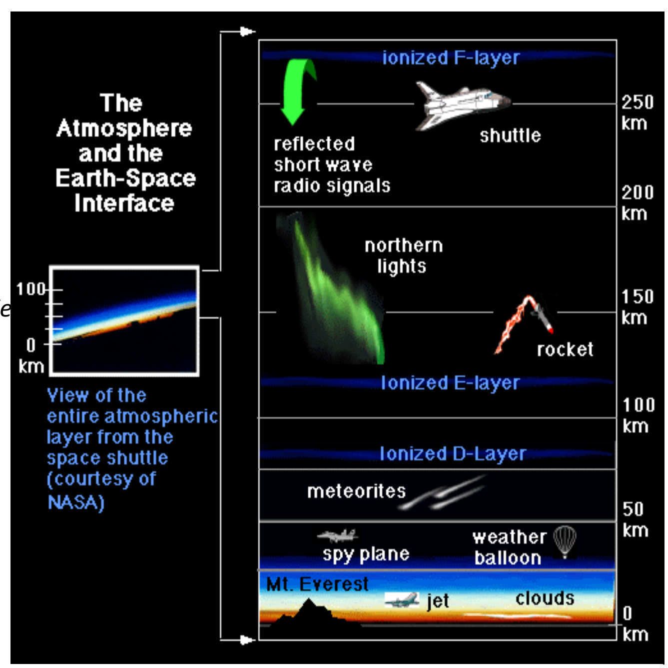

Figure 3-12: Ionospheric Regions

enhanced background noise), LORAN navigation errors and absorption of HF (3-30 MHz) radio communications.

The first of the specific 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.

Short Wave Fade (SWF) Events

The High Frequency (HF, 3-30 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 waves are refracted by the ionosphere's F-layer. 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 (**Figure 3-12**). However, each passage through the ionosphere's D-layer causes signal absorption, which is additive.

The portion of the ionosphere with the greatest degree of ionization is the F-layer. 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 to Extremely High Frequencies (VHF/EHF 30 MHz to 300 GHz). The lowest layer of the ionosphere is the D-layer (normally between 50 and 90 km altitude). The D-layer acts to absorb passing radio wave signals. The lower the frequency, the greater the degree of signal absorption.

X-ray radiation emitted during a solar flare can significantly enhance D-layer ionization and absorption 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). 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 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.

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

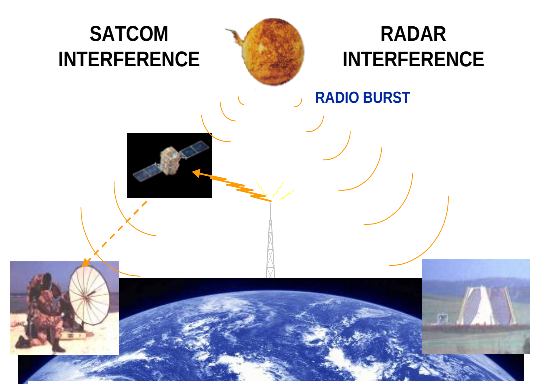

Figure 3-13: Radio Burst Effects

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. (**Figure 3-13**). 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.

Most radio signals within the 300 MHz to 300 GHz band will pass through the atmosphere, allowing communications between the ground and satellite. In the F2-region, however, radio signals can still experience some interference in the form of refraction. Refraction is the bending of the signal path just as light is refracted through a prism due to the difference in the density of the air outside the prism and the glass inside. In such a situation, the signal travels farther than just the straight-line distance between the transmitter and the receiver. This delays reception of the signal that has an impact on systems that rely on precise time, such as the Global Positioning System.

Solar radio busts are another “immediate” effect, experienced simultaneously with observation of the causative solar flare. 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 7 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.

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.

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

High energy 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. The event can last from hours to days. 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. Low to medium energy 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 that 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.

The sources of the charged particles (mostly protons and electrons) include solar flares, 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.

Key characteristics of particle effects are they can last for hours to days and be mostly felt in the nighttime sector (as the particles that cause them usually come from the magnetosphere's tail), although they are not limited to that time/geographic sector. Another 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.

Ionospheric Scintillation

The intense ionospheric irregularities found in the aurora zones are also one cause 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. 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 drop-outs on satellite command uplinks, data down-links or on communications signals.

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.

Scintillation is also frequency dependent; the higher the radio frequency (all other factors held constant), the lesser the impact of scintillation. 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 higher geomagnetic latitudes (the aurora 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.

There is no fielded network of ionospheric sensors capable of detecting real-time scintillation occurrence or distribution. Presently space environmental forecasters are heavily dependent on its known association with other environmental phenomena (such as aurora) and scintillation climatology.

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. Scintillation occurrence is positively correlated with solar activity and 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.

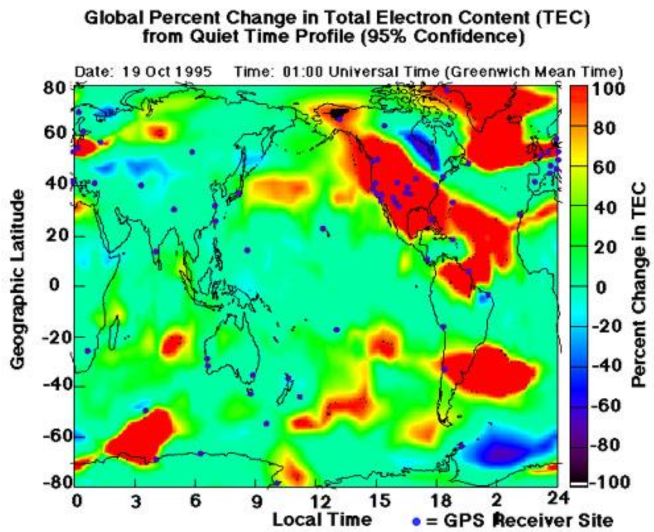

Figure 3-14: GPS and Ionospheric Disruptions

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. Unfortunately, this approach will not work for single-frequency receivers. Thankfully, modeling inside the GPS signal can offset much of this problem. Additionally, this effect is in a limited region of the GPS receiver's field of view, so other satellites may still be able to get their signal to the receiver unaffected.

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 aurora oval. Visually, this phenomenon 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 phenomenon known as “radar aurora.”

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.

Surveillance Radar

The presence of free electrons in the ionosphere causes radio waves 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. 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.

Although radar operators routinely attempt to compensate for these bearing and range errors by applying correction factors, individual solar and geophysical events will cause unanticipated, short-term variations from the predicted 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 variations are occurring help radar operators minimize the impacts of their radar’s degraded accuracy.

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.

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). Satellites in orbit around the Earth experience atmospheric drag. Atmospheric drag is the resistive force of the molecules of the atmosphere. The amount of drag is dependent on the density of the atmosphere, the shape and size of the object, the material it is made of, and other factors. 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. The expansion of the atmosphere will also result in more atmospheric drag at higher orbital altitudes thus effecting satellites that would not normally experience atmospheric drag.

This drag decreases an object’s altitude and increases its orbital speed. Atmospheric drag causes a satellite to slow down, thus the satellite "falls" to a lower altitude to gain velocity. 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. Conversely, exceptionally calm solar and/or geomagnetic conditions will cause *less* atmospheric drag than predicted and an object would be higher and behind where it was expected to be found.

The approximate value of atmospheric drag can be calculated and considered in updating a satellite's position and deciding on orbital maneuvers to maintain a satellite in orbit. Long term predictions are difficult because of the inability to predict what the Sun will do. 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.

Space Environment Effects on Satellites

The environment in space has significant effect on the satellites themselves. Atmospheric drag was discussed above. The discussion below highlights the other principal effects experienced by satellites orbiting the Earth.

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.

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.

“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 of the Van Allen Radiation 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.

Electrical Charging

One of the most common anomalies caused by the radiation hazards discussed above is spacecraft or satellite electrical charging. Charging can be produced by: (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

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. 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.

The two primary mechanisms responsible for charging are plasma bombardment and photoelectric effects. Plasma bombardment occurs due to varying plasma density, resulting in the surface of the satellite becoming electrostatically charged. Charging from plasma bombardment usually results in a negative charge on the surface of the satellite. The photoelectric effect results from solar radiation which liberates electrons on a satellite's surface, resulting in a positive charge on the satellite's sunlit side. A satellite will usually have a negative potential on shaded areas (due to plasma charging) and a positive potential on sunlit areas (due to the photoelectric effect). If the surface of the satellite is conductive, a current will develop to cancel these potentials. For a non-conducting surface, the charge separation will be maintained until voltage exceeds the resistive threshold of the material. This leads to a sudden electrostatic discharge.

The satellites most vulnerable to charging/discharging are those located at geosynchronous altitude. Discharges as high as 20,000 volts (V) have been experienced. Satellites in geosynchronous orbits typically move both in and out of the upper regions of the Van Allen Radiation Belts and the Earth's magnetotail. A *single* proton or cosmic ray can (by itself) deposit enough charge to cause an electrical upset. Sudden electrostatic discharge (high current or arc) can cause hardware damage, such as: (1) blown fuses or exploded transistors, capacitors and other electronic components, (2) vaporized metal parts and structural damage, and (3) breakdown of thermal coatings. They can cause electrical or electronic problems, such as: (1) false commands, (2) spurious circuit switching, (3) memory changes, (4) solar cell degradation, and (4) false sensor readings. 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.

Outgassing

Although the environment in space is not benign, the density of particles above 100 miles altitude is extremely low. There is almost no atmospheric pressure, similar to a complete vacuum. As a result, satellites and the materials they are made of experience phenomena which are not encountered on Earth. In a vacuum, some materials experience outgassing. Outgassing is a phenomenon where molecules of material evaporate into space. Although many materials experience outgassing, composite materials and those made with volatile solvents are particularly susceptible. These include electronic microchips, plastics, glues and adhesives. Outgassing can result in changes to the physical properties of a material. In addition, the evaporating molecules can form a thin film over other components of the satellite, thereby affecting their performance. Outgassing can be minimized through careful selection of component materials but eventually some components will exhibit different characteristics and properties.

OTHER SPACE PROBLEMS

Space Debris

Space debris is defined as any non-operational man-made object of any size in space. The size of space debris varies from complete inoperative satellites and expended rocket bodies to small chips of paint. Of the almost 10,000 man-made items in space currently tracked and catalogued, only about 5% are operational space systems. The rest is space debris. Space debris smaller than approximately 2 cm (0.78 inches) cannot be detected and tracked reliably, therefore it is reasonable to assume that there is significantly more space debris than we know about. It has been estimated that as many as 100 satellites have broken up while in orbit, sometimes due to explosions of propulsion systems, and at other times due to impact with other space debris. The result is an estimated 40,000 to 80,000 pieces of debris in orbit around the Earth. There is even a wrench that became space debris when it drifted away from an astronaut during a space walk. Most debris is small but it can be traveling at relatively high speeds.

Debris in low Earth orbit tends to have much higher velocities relative to other objects in orbit than those at geostationary orbit altitude (22,300 miles). In a collision between two objects, the relative velocity and the masses of the objects determine the force of impact. A dense object like the wrench could do catastrophic damage if it were to hit a satellite at even a low relative velocity. At

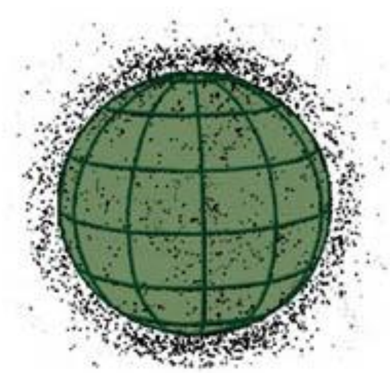

Figure 3-15: Space Debris Cartoon

high impact velocities of 30,000 mph, even small objects are capable of inflicting significant damage. A small paint chip damaged a window on the space shuttle when it impacted at about 8,000 miles per hour. Shielding, energy absorbing panels and other design considerations can make a satellite more resistant to damage from impacts with small space debris. At altitudes below 200 miles, atmospheric drag tends to cause much debris to reenter the Earth's atmosphere where it is usually vaporized. This self-cleaning space debris located at the altitude of geostationary orbits tends to have lower relative velocities (200 - 1,000 mph) and the density is much less. Atmospheric drag at this altitude is almost zero, therefore the debris is present for a much longer time.

Meteoroids

It is estimated that approximately 20,000 tons of natural material is added to the Earth each year from impacts of meteoroids and asteroid fragments with the Earth's atmosphere. Most of these particles are the size of dust particles, however, some are much larger. When meteoroids enter the Earth's atmosphere they usually burn up due to the friction with the air molecules. Larger meteoroids generate enough light to be seen as meteors streaking across the night sky. Occasionally, larger objects don't completely vaporize. When a piece strikes the surface of the Earth it is called a meteorite. These particles represent a constant natural danger to satellites in orbit around the Earth. The Long Duration Exposure Facility (LDEF) was a U.S. research satellite that remained in orbit for six years before it was recovered by the Shuttle and returned to the Earth. Examination of the exposed surfaces indicates thousands of impacts by micro-meteoroids. Microscopic examination has revealed extensive damage to metal surfaces. Most meteoroids are too small and traveling too fast to be detectable in time for satellite controllers to direct a satellite to change it's orbit to avoid collision. Shielding and other design considerations are the most effective means to protect satellites from catastrophic damage.

The last meteoroid storm that caused great concern was the Leonids from the comet Temple-Tuttle in November 1998. Meteoroids normally travel at about 12 miles per second; but because of the relationship of the Earth's orbit to Temple-Tuttle's orbit, Leonids meteoroids rocketed past at the speed of a 22-caliber bullet. If an impact occurs; if the resulting impact causes a discharge; if the discharge gets inside the satellite vs. escaping into the space environment; if the path of that discharge hits an electrical component, then the result could be a fried satellite. To minimize the storm's damage, a Tiger Team determined a comprehensive series of mitigation strategies to protect space assets and allow the Air Force to continue its vital missions. These strategies included normal precautions such as powering down unnecessary onboard electronics and reducing a satellite's cross-section.

Space Environment References

Websites:

http://www.windows.umich.edu/spaceweather - Excellent starting point if new to space weather.

Excellent site for earth-sun relationship and effects of space weather.

http://wwwssl.msfc.nasa.gov/ssl/pad/sppb/edu - This is an excellent resource to help get started and understand basic space weather concepts and relationships.

http://umtof.umd.edu/pm/ - This site provides a real time printout of the last 48 hours of solar wind activity.

http://www.ngdc.noaa.gov/stp/GLOSSARY/glossary.html -Index of solar and terrestrial weather terms.

http://hesperia.gsfc.nasa.gov/hessi/brochure.htm - HESSI, High Energy Solar Spectroscopic Imager, at NASA Goddard Space Flight Center

http://lheawww.gsfc.nasa.gov/docs and http://universe.gsfc.nasa.gov/ - NASA Educational sites for Space Weather basic information among other things.

http://hesperia.gsfc.nasa.gov/hessi/flares.htm - A solar flare is an enormous explosion in the solar atmosphere, involving sudden bursts of particle acceleration, plasma heating, and bulk mass motion. It is believed to result from the sudden release of energy stored in the magnetic fields that thread the solar corona in active regions around sunspots

http://solar.uleth.ca/ - This site provides information on the state of the sun and its affects on earth.

http://www.sunspotcycle.com/ - Up-to-date monitoring of sunspots and the solar cycle, with tutorials, material for educators, and interactive activities.

http://hesperia.gsfc.nasa.gov/sftheory/ - These pages are about solar flares, the biggest explosions in the solar system. Their purpose is to provide some general information about solar flares.

http://www.spacescience.org/ExploringSpace/SpaceWeather/1.html – Good tutorial of how the sun actually impacts us here on Earth. Our solar system has the cosmic equivalent of wind, clouds, storms, and hurricanes called space weather. It's one of the consequences of living with a star.

http://www.ucar.edu/research/sun/ - Good information about the sun and space weather.

Chapter 4
Satellite Orbits

OVERVIEW

Satellites move predictably according to the laws of physics. Satellites do not escape Earth's gravity. In fact, it is Earth's gravity that holds them in orbit. Without gravity there would not be any satellites because nothing would stay in orbit. Many different types of orbits can be achieved by changing a satellite's orbital parameters. For example, it is possible to position a satellite over the equator at an altitude where the time for it to revolve around the Earth is exactly one day. The result is the satellite will appear to be stationary to an observer on the surface of the rotating Earth below. It is also possible to create an orbit so that a satellite will pass within view of every point on the Earth at the same time every day and night. Some orbits are not possible. For example, it is not possible to position a satellite in low Earth orbit so that it will loiter or hover over a particular spot. The orbit chosen for a satellite is determined by the mission it is designed to perform.

The intent of this section is to present information in non-mathematical terms that allow the reader to develop an understanding of the motion of Earth satellites. This provides a basis for understanding the capabilities and limitations of various orbits, particularly with respect to the service that the satellite provides to the user.

BASICS PHYSICS OF ORBITS

Kepler's Laws of Planetary Motion

In the early 1600's, Johannes Kepler formulated three Laws of Planetary Motion. Although his laws were intended to explain the motion of the planets around the Sun, they also apply to any satellite orbiting around another object.

Kepler's First Law: Law of Ellipses

"The orbit of each planet is an ellipse with the sun at one focus."

As it applies to satellites in orbit around the Earth, Kepler's first law can be restated as,

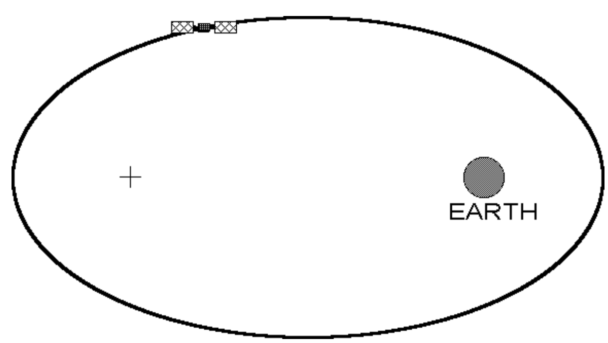

Figure 4-1: Kepler's First Law

*"The orbit of each satellite is an ellipse with the center of the Earth at one focus." (*Figure 4-1*)*

Neglecting such influences such as atmospheric drag, mass asymmetry and third body effects, the law applies accurately to all orbiting bodies. 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 Second Law: Law of Areas

"Every planet revolves so that the line joining it to the sun sweeps over equal areas in equal times anywhere in the orbit."

For earth orbiting satellites this can be restated as,

"A satellite orbits so that the line joining it with the center of Earth sweeps over equal areas in equal times anywhere in the orbit."

In a circular orbit a satellite travels at the same speed at all points. In an elliptical orbit the speed of the satellite varies. As the satellite approaches closer to the Earth its speed increases. The maximum speed is attained at the point of closest approach called the perigee. As the satellite moves away from the Earth it slows down. The slowest velocity occurs at the point farthest from the Earth, the apogee.

Kepler discovered his third law ten years after he published the first two in Astronomia Nova (*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 dogged persistence, he fell upon his famous relationship: Kepler's Third Law: Law of Harmonics

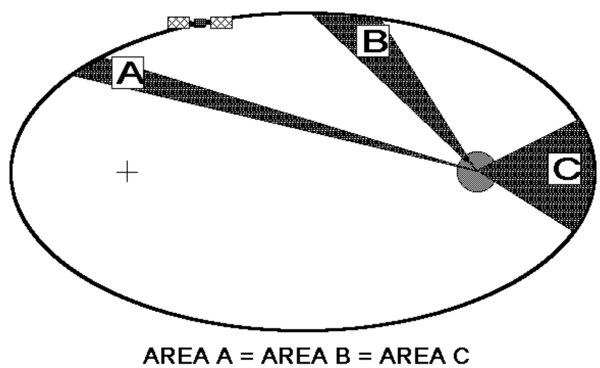

Figure 4- 2: Kepler's Second Law

"The square of the sidereal periods (the time it takes to complete one orbit of the Sun) of any two planets are to each other (proportional) as the cube of their mean distances from the center of the Sun."

For a satellite in orbit around the Earth this can be restated as,

"The squares of the orbital periods (time it takes a satellite to complete one orbit) of any two satellites are proportional to each other as the cubes of their mean distances from the center of the Earth."

The square of the period divided by the cube of the mean distance from the center of the Earth is a constant for all objects. The constant number is not dependent upon the mass of the satellite.

Kepler's third law of planetary motion has many implications. First, satellites of different masses with exactly equal orbits have equal speeds. The mass of a satellite does not determine its period or orbital speed. Second, satellites with orbits of equal semi-major axis length have equal periods, whether or not their eccentricities are the same. Finally, comparing two satellites with orbits of equal eccentricity, the orbit with the longer semi-major axis has a larger circumference, and the satellite in the larger circumference orbit has a lower speed. Thus, satellites farther away from the Earth have more distance o travel and move more slowly than satellites closer to the Earth.

Newton's Laws

Sir Isaac Newton was a British scientist who, in the late 1600's, formulated his laws of motion and a law of universal gravitation. Kepler's laws provided mathematical formulas for the orbits of satellites but did not explain what forces cause satellites to move in space the way that they do. 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:

Newton's First Law: Law of Inertia

"Every body continues in a state of rest or of uniform motion in a straight line unless it is compelled to change that state by a force impressed on it."

An object at rest will remain at rest and an object in motion will remain in motion in a straight line, unless it is acted upon by an outside force. 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 describes the relationship between the impressed forces, the masses of objects and the resulting motion:

Newton's Second Law: Law of Momentum

"When a force is applied to a body, the time rate of change of its momentum is proportional to, and in the direction of, the applied force."

Momentum is a measure of an object's motion. It is the property of a moving body that determines what force is required to bring the body to rest in a given amount of time. Newton continued his discoveries and with his third law, completed his grand view of motion:

Newton's Third Law: Law of Action-Reaction

"For every action there is a reaction, equal in magnitude, but opposite in direction, to the action."

The effect of this law is most easily demonstrated where friction is not present or is extremely low. This is the law that explains how rockets work. The rocket exhaust gases are light but are ejected at high velocity. This results in a force that accelerates the larger mass of the rocket. The maximum velocity of the rocket is the maximum velocity of the rocket gases; however, the propellant is usually expended before that velocity is attained.

Newton's Law of Universal Gravitation

Newton theorized gravity, which he believed to be responsible for the "falling apples" and the planetary motion. He formulated the Law of Universal Gravitation. It states,

"Between any two objects in the universe there exists a force of attraction that is in proportion to the product of the masses of the objects and is in inverse proportion to the square of the distance between them."

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.

$$F=G\ m_1 m_2/d^2$$

Where F 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.

The gravitational attraction between two objects is greater for more massive objects and decreases as the square of the distance between the objects increases. "G" is the Universal Gravitational Constant which is the same everywhere in the universe. Newton based his derivation on large objects rotating mutually about each other, such as the Earth and the Moon. It applies equally to man-made satellites orbiting the Earth except that the mass of the man-made satellite is so small compared to the mass of the Earth that the offset of the center of rotation of the two objects from the center of the Earth's mass is so small it is ignored.

It is the force of gravity that allows satellites to orbit. Gravity is the force that continually acts on the satellite to continually change its direction in order to circle Earth. Without gravity, the satellite would fly off into space in a straight line, maintaining constant velocity.

The Law of Universal Gravitation states that all objects with mass in the universe exert a gravitational attraction on all other objects. The number of objects in the universe is almost infinite but the gravitational forces from objects farther away than the immediate solar system are very insignificant. The force of the Earth's gravity at sea level results in an acceleration of about 32 ft/sec^2. This is called a "1 g force". For a satellite in orbit 200 miles above the Earth the effects of gravity from the most significant sources are shown below:

Gravitational Effect of an Earth Satellite with 200 mile Altitude		
Source of Gravitation	Strength of Gravitational Force	
Earth	0.89 g	28.600 ft/sec^2
Earth's Oblateness	0.001 g	0.030 ft/sec^2
Sun	0.0006 g	0.019 ft/sec^2

Moon	0.00000033 g	0.001 ft/sec^2

Table 4-1: Gravitational Effects

Satellites do not escape Earth's gravity but are held in orbit by it. Without the constant force of Earth's gravitational attraction on the satellite it would go off into deep space in a straight line. As the distance from the Earth increases the Earth's gravitational force decreases, thus the gravitational effects of other bodies in the solar systems become relatively more significant.

A misconception is that centrifugal force somehow affects the orbit of a satellite. It does not. Centrifugal force only exists when there is a physical link between two objects and one is moving around the other. A ball tied to the end of a string and swung around in a circle is an example. If the string breaks, the ball moves in a straight line except that the Earth's gravity pulls it toward the center of the Earth. The ball follows an arching path until it hits the ground. Obviously, there is no string, rope or equivalent attached to each satellite. The principle force that holds satellites in orbit is gravity.

Newton's Derivation of Kepler's Laws

Kepler's laws of planetary motion are empirical (found by comparing vast amounts of data in order to find the algebraic relationship between them); they 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:

<u>Newton's Derivation of Kepler's First Law:</u> 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.

<u>Newton's Derivation of Kepler's Second Law</u>: 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

<u>Newton's Derivation of Kepler's Third Law</u>: 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. 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.

To put a man-made object into orbit around the Earth requires that a number of conditions be met. The most critical are velocity and altitude. 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. 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. How far the ball travels along the ground in that one second depends on its horizontal velocity. At sea level an object falls 16 feet in the first second of travel due to gravity. The curvature of the Earth is about 16 feet every five miles. The faster the horizontal velocity of the ball, the greater the horizontal distance that it travels. Eventually one would come to the point where the Earth's surface drops away as fast as the ball drops toward it, assuming no air resistance to continually slow the ball down

To put a satellite into orbit around the Earth the satellite must be accelerated to a velocity parallel to the surface of so that the curvature of the Earth compensates for the distance the satellite falls toward the center of the Earth. Near the surface of the Earth an object would have to travel about five miles per second (about 18,000 miles per hours). Of course, friction from the atmosphere near the Earth's surface is substantial. At 18,000 miles per hour air friction would quickly heat the object to a high temperature and it would burn up before traveling very far. To avoid air friction, the object must be boosted to an altitude high enough to avoid most of the atmosphere. These factors determine the basic altitude and velocity necessary to put an object into orbit around the Earth. The minimum speed for an object to be placed into orbit around the Earth is about 17,500 miles per hour and the minimum altitude of a circular orbit is about

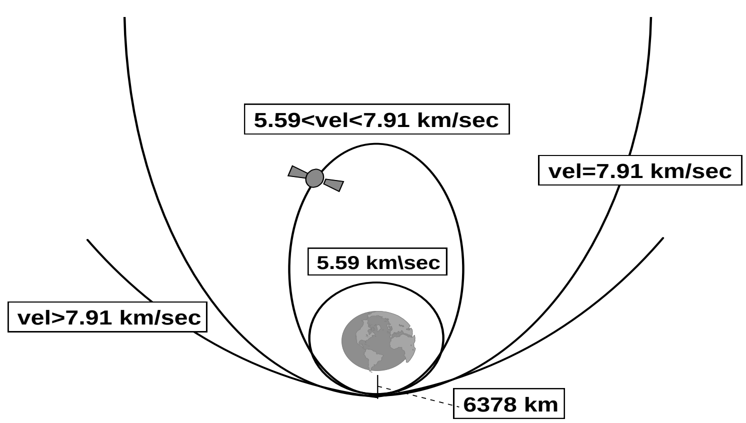

Figure 4-3: Velocity vs. Trajectory

90 miles. At this altitude the atmospheric density is still enough to cause the satellite to slow down so that it would fall out of orbit after only a couple of revolutions. It would either burn up during the high-speed reentry through the atmosphere or it would impact on the surface.

Figure 4-3 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 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.

Newton's three laws and his Law of Universal Gravitation describe the satellite's motion. 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.

Location Reference Systems

Reference systems are used everyday. To give or follow directions both the giver and acceptor have to agree on a common reference system or the directions are worthless; left, right, north, south, the origin and so on, must be agreed upon. Once a common reference has been determined, spatial information can be traded. The same must be done when considering orbits and satellite positions. Before positions can be defined, a common reference must be agreed upon and understood. The reference system utilized depends on the situation, or the nature of the knowledge to be retrieved. Of the many reference systems available, the Geographic Coordinate Reference Systems (often referred to as the Earth-Fixed Greenwich Reference Systems) and the Geocentric (or Earth Centered) Inertial Coordinate System stand out because of their use in locating points on the surface of the Earth or describing the motion of Earth orbiting objects.

Although each location reference system has its own unique terminology, all have a fundamental plane, a point of origin or a reference point located on the fundamental plane, and a principle direction on the fundamental plane. Once the fundamental plane, origin, and principle direction have been established, it is possible to make distance and angular measurements from them. These measurements are sometimes called displacements.

Geographic Coordinate Reference Systems

These systems are used to describe locations on most maps of the Earth's surface (**Figure 4-4**). The fundamental plane is the equatorial plane of the Earth. The point of origin is the center of the Earth. The principal direction is a line from the center of the Earth through the point where the prime meridian intersects the fundamental plane. The prime meridian is 0° longitude, an imaginary line on the surface of the Earth from the North Pole to the South Pole that passes through Greenwich, England. Altitude is usually stated as distance above sea level. Sea level is approximately one Earth radius from the center of the Earth (point of origin). The Military Grid Reference System (MGRS), the Universal Transverse Mercator (UTM) coordinate system and latitude/longitude are examples of Geographic Coordinate Reference Systems. The Earth is constantly spinning about its axis, therefore the principle direction also rotates. This makes these location reference systems unsuitable for describing the location and motion of objects orbiting the Earth.

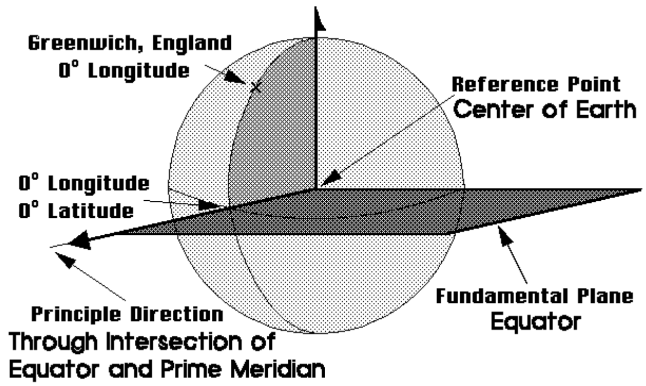

Figure 4- 4: Geographic Coordinate Reference System

Geocentric Inertial Coordinate System

The Geocentric (Earth-Centered) Inertial Coordinate System **(Figure 4-5)** is used to determine the orientation of an object orbiting the Earth in space. The origin is the Earth's center, the fundamental plane is the equatorial plane and the principal direction is a line to the First Point of Aries which is the direction from the center of the Earth to the center of the Sun when the Earth is at the vernal equinox (**Figure 4-6**). This can also be

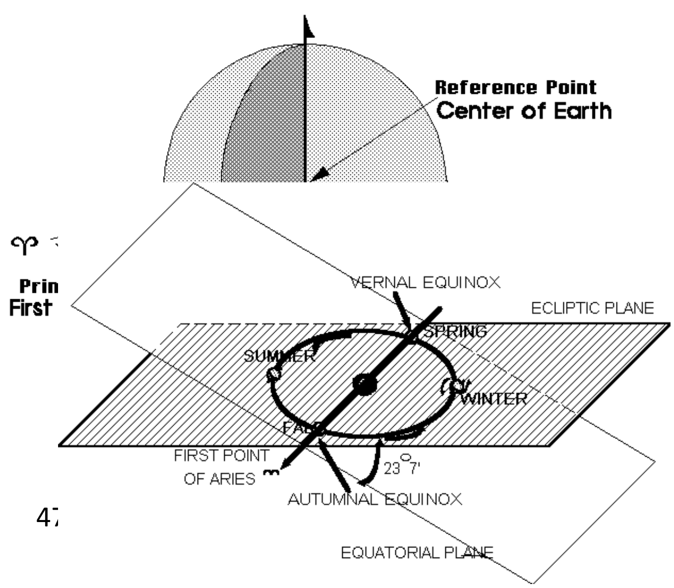

Figure 4-6: Determination of First Point of Aries

drawn as a line from the vernal (spring) equinox to the autumnal (fall) equinox. The Earth rotates daily about its axis at an angle (23° 7') to the orbital (ecliptic) plane of the Earth as it rotates yearly about the Sun, thus the Earth's equatorial plane is at an angle to the ecliptic plane. Twice a year the Earth's orbit crosses the point where the ecliptic plane and the Earth's equatorial plane intersect. These points are called equinoxes because the length of daylight and night are the same. The Autumnal (Fall) Equinox occurs on 21 September, the first day of Fall. The Vernal (Spring) Equinox occurs on the first day of spring, 23 March. Using the direction to the First Point of Aries as the principle direction provides a way to describe the location of a satellite in orbit around the Earth without regard to the Earth's rotation about its axis.

Orbital Element Set

How does one know where satellites are, were or will be? Intermeshing coordinate reference systems have been intricately constructed from which measurements are defined to result in the parameters required to differentiate and describe orbits. A set of these parameters is a satellite's *orbital element set*. As stated previously, 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.

A set of orbital parameters or elements is used to describe the size and shape of a satellite's orbit, the orientation of the orbital plane, the orientation of the orbit within the orbital plane, and to locate the satellite within the orbit at any specified time. Element sets or "elsets" are used to calculate where a satellite is at a specified time and to predict where it will be in the future. Predictions are only approximations because many of the minor forces which influence a satellite's orbit are not included in the calculations. If the values in the element set are current, the predictions can be quite accurate. The values in the orbital element set must be updated more frequently for satellites in low Earth orbit than for those in geostationary orbit.

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. We are interested in using the Keplerian, or classical, element set. The orbital elements tell us four things we want to know about orbits, namely:

- Orbit size (semi-major axis)
- Orbit shape (eccentricity)
- Orientation (inclination)
    - orbit plane in space
    - orbit within plane

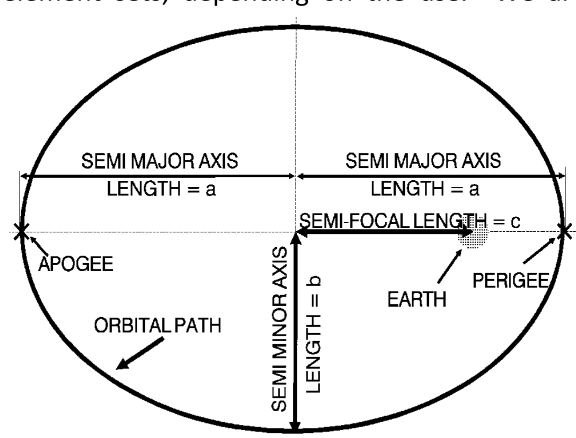

Figure 4-7: Components of and Ellipse

- Location of the satellite

Semi-Major Axis (a)

The first parameter describes an orbit's size. The maximum distance from the center of an ellipse to a point on the ellipse is called the semi-major axis, ***a***; the minimum distance from the center to a point on the ellipse is called the semi-minor axis, ***b***. The semi-major axis is a significant measurement since it also equals the average radius and thus, is a measure of the mechanical energy of the orbiting object. (**Figure 4-7**.)

Eccentricity (e)

Eccentricity, ***e,*** measures the shape of an orbit. The shape determines the positional relationship to the central body, because the central body must occupy one of the foci of the ellipse (or other conic section). Eccentricity describes the amount an ellipse deviates from a circular shape. Eccentricity is the ratio of the distance from a focus to the center of the ellipse divided by the length of the semi-major axis.

$$e=c/a$$

The center of a circle is the same point as the focus, therefore the eccentricity of a circle equals 0. All elliptical orbits have an eccentricity equal to or greater than 0 but less than 1. An eccentricity equal to 1 describes a parabolic path. An eccentricity greater than 1 describes a hyperbolic path which does not represent an orbit. (**Figure 4-8**.)

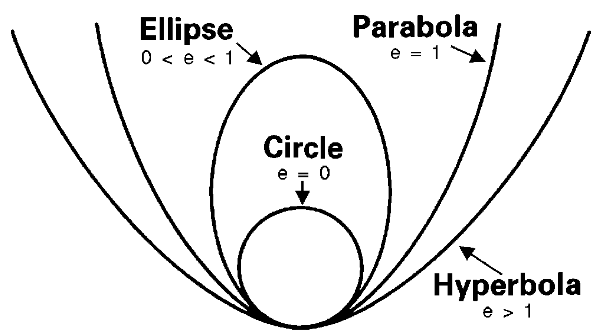

Figure 4-8: Values of Eccentricity (e)

Inclination *(i)*

The first angle used to orient the orbital plane is *inclination,* (***i***): a measurement of the orbital plane's tilt. Because it defines the tilt of the orbital plane, it defines the maximum latitude, both North and South, which will be directly beneath the satellite. This is an angular measurement from the equatorial plane to the orbital plane ($0° \leq i \leq 180°$), measured counter-clockwise at the ascending node while looking toward Earth. The ascending node is the point in the orbit where the satellite crosses from the Southern Hemisphere to the Northern Hemisphere. The value of the inclination of an orbit is also the value of the northernmost and southernmost latitudes of the satellite ground track. The inclination of an orbit helps to describe its orientation in space. Orbits are sometimes described by their inclination. (**Figure 4-9**.)

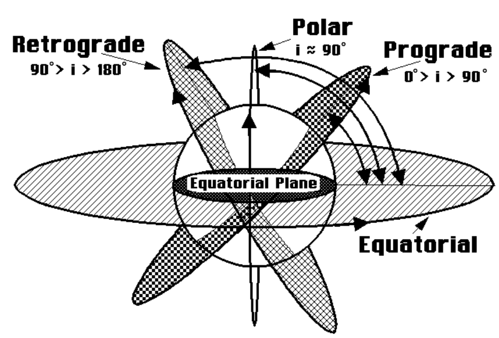

Figure 4-9: Inclination of Orbits

- Prograde (or posigrade): Inclination greater than or equal to 0° but less than 90°; the satellite orbits Earth in the same direction as Earth's rotation.
- Retrograde: Inclination greater than 90° but less than or equal to 180°; the satellite orbits Earth opposite to Earth's rotation. Sun synchronous orbits, common for weather and remote sensing satellites, are retrograde orbits.
- Polar: Inclination equal to 90°; the satellite orbits from the north pole to the south pole and back to the north pole. Orbits with an inclination very close to 90° (88° - 92°) are often referred to as being polar.
- Equatorial: Inclination equal to 0° or 180°; the satellite's orbital plane and the equatorial plane of the Earth are the same therefore, the satellite is in orbit directly above the equator of Earth.

Right Ascension of the Ascending Node (Ω)

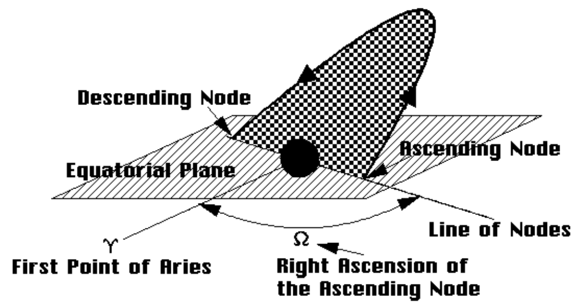

Figure4-10: Right Ascension of the Ascending Node

The Right Ascension of the Ascending Node 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 ($0° \leq \Omega \leq 360°$) (**Figure 4-10**). The First Point of Aries is simply a fixed point in space. The ascending node is the point where the satellite's orbit intersects the Earth's equatorial plane when the satellite is crossing from south to north. The line of nodes is an imaginary line between the ascending node and the descending node. Since an orbital plane always intersects the center of the Earth, the line of nodes will always pass through the center of the Earth. The right ascension of the ascending node helps to describe the orientation of a satellite's orbit in space.

Argument of Perigee (ω)

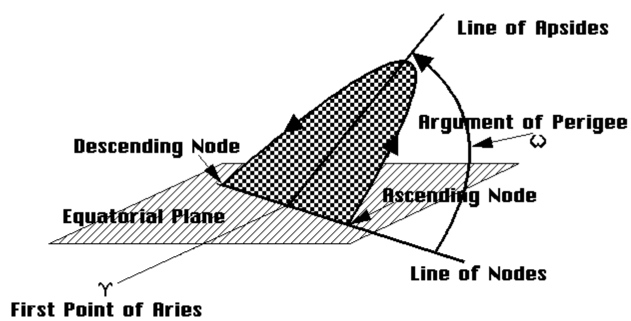

Figure 4-11: Argument of Perigee

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, 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 ($0° \leq \omega \leq 360°$) (**Figure 4-11**). The apogee is directly opposite the perigee, a difference of 180°. The line of apsides is an imaginary line between the apogee and the perigee of an orbit. It will also pass through the center of the Earth. The argument of perigee helps to describe the orientation of a satellite's orbit in its orbital plane.

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 is the angular measurement (0° to 360°) from the center of the Earth in the direction of a satellite's motion from the point of perigee along the orbital path to the location of the satellite at a specific or Epoch time. Epoch time is an arbitrary time used as a reference point at which other orbital parameters are measured. The Air Force Space Command states the epoch time when the satellite is at the ascending node. In traditional Keplerian element sets, epoch time is usually stated when the satellite is at its perigee. An orbit number or revolution number associated with the epoch time is usually included in the orbital element set.

Mean Anomaly

The mean anomaly is the angle measured from the center of an ellipse from the perigee to the satellite's position through which it would move in a specified period of time if it moved at its mean angular rate of motion. The mean angular rate of motion is the period of the orbit divided by 360° (one complete revolution). The mean anomaly is the same as the true anomaly for a satellite in a perfectly circular orbit.

Period

The element set describes the average orbit for a satellite. Due to perturbations, the satellite's actual orbit will deviate somewhat from a perfect ellipse. The period defines the ground track's *westward regression*. The period of a satellite is not an orbital element, but it is extremely useful. There are four different ways to describe the period of a satellite:

- Nodal Period: The time it takes a satellite to travel once from ascending node to ascending node. In most space discussions, "period" is used when referring to the nodal period.
- Keplerian Period: The period defined by Kepler's third law. This period does not take perturbations into account and is only an average.
- Anomalistic Period: The time it takes a satellite to travel once from perigee to perigee.
- Sidereal Period: The time it takes a satellite to cross the equatorial plane at 0° right ascension from the last time it crossed at 0° right ascension.

Table 4-2. 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: $0 \leq e < 1$ open orbits: $1 \leq e$
i	inclination	Orbital plane's tilt	angle between the orbital plane and the equatorial plane, measured counter clockwise at the ascending node	equatorial: $i = 0°$, $180°$ prograde: $0° \leq i < 90°$ polar: $i = 90°$ retrograde: $90° < I \leq 180°$
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	$0° \leq \Omega < 360°$ undefined when $i = 0°$, $180°$ (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	$0° \leq \omega < 360°$ undefined when $i = 0°$, $180°$, or $e = 0$ (circular orbit)
ν	true anomaly	Satellite's location in its orbit	angle, measured in the direction of satellite motion, perigee to satellite's location	$0° \leq \nu < 360°$ undefined when $e = 0$ (circular orbit)

Satellite Ground Tracks

The physics of two body motion dictates the motion of the two will lie within a plane (two-dimensional motion). The orbital plane intersects the Earth's surface forming a *great circle*. A satellite's ground track is the intersection of the line between the Earth's

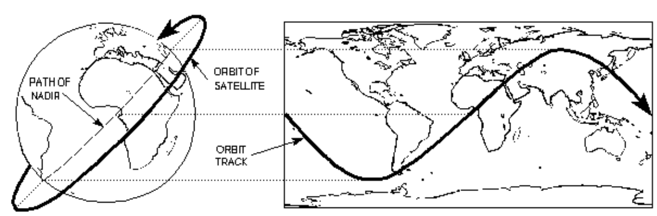

Figure 4-12: Satellite Ground Track for Single, Moderately Inclined, Circular Orbit

center and the satellite and the Earth's surface; this point is also called the *satellite subpoint or nadir.*

The ground track (also called ground trace) of an orbiting satellite is the trace of its subpoint path across the surface of the Earth over time. A satellite ground track drawn on a map shows what areas the satellite will pass directly over. The example in **Figure 4-12** shows a moderately inclined, circular orbit and the resulting ground trace for a single orbit.

Effect of Earth's Rotation

If the Earth did not rotate, a satellite's ground track would simply repeat itself until some force changed the orbit. Of course, the Earth does rotate about its axis once (360°) each day. This equates to an angular rotation speed of about 15° per hour. The result is that each successive orbit track will be offset 15° to the west for each hour of the satellite's period. **Figure 4-13** shows the effect of the Earth's rotation for a satellite in a circular orbit with a period of 90 minutes.

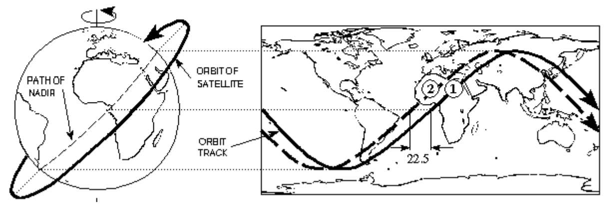

Figure 4-13: Satellite Ground Track for a Moderately Inclined, Circular Orbit (two revolutions)

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.

Effect of Inclination

The inclination of an orbit determines the highest north and south latitude of the ground track. Since all satellite orbital planes must pass through the center of the Earth, a satellite's ground track must be over or pass through the Equator. For a prograde orbit, the inclination of the orbit equals the highest north or south latitude of the ground track. A polar orbit has an inclination at or near 90°. For a retrograde orbit (90° to 180° inclination), the highest inclination of the orbit equals 180° minus the highest latitude of the nadir. **Figure 4-14** shows the effect on the ground track of a satellite's orbit when only the inclination is changed.

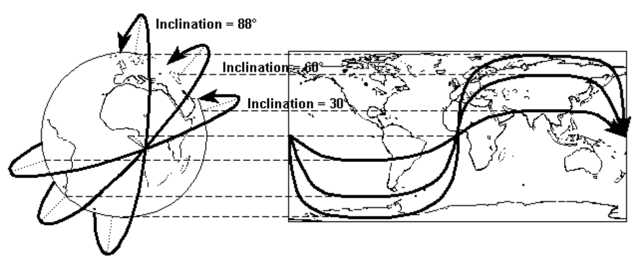

Figure 4-14: Effect of Inclination on a Satellite Orbit

Effect of Altitude

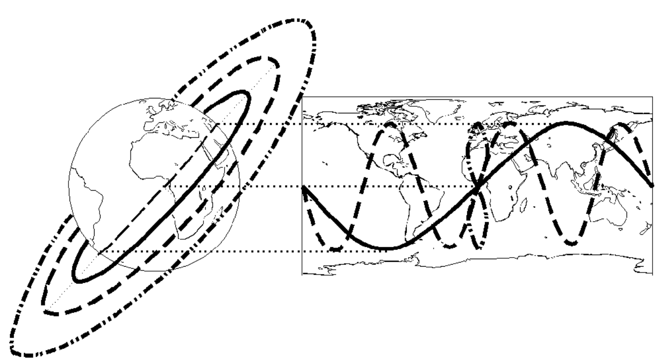

Figure 4-15: Effect of Altitude on a Satellite Orbit

As the altitude of an orbit increases, the period becomes longer and the satellite's speed is lower. The result is that it takes more complete orbits to make a complete track around the globe. Figure **4-15** shows the effect on the ground track when only the altitude is changed.

Effect of Eccentricity

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. The ground track of a satellite in a circular orbit (eccentricity = 0) is similar to a continuous sine wave. The portion above the equator is identical to the portion below. As the eccentricity of an orbit increases from zero to 1, the perigee remains close to the Earth while the apogee increases in distance. For highly eccentric orbits, the ground track of the portion near the perigee is wider than near the apogee. This is because the maximum speed of the satellite occurs at perigee and, therefore, the satellite ground track covers a greater portion of the Earth's surface. It also means at perigee a satellite is in view of a ground observer for less time. An advantage of a highly eccentric orbit is that as the satellite approaches the apogee of the orbit, it slows down and seems to linger over a geographic area. **Figure 4-16** shows the effect on a satellite's ground track caused by a change in the eccentricity of the orbit.

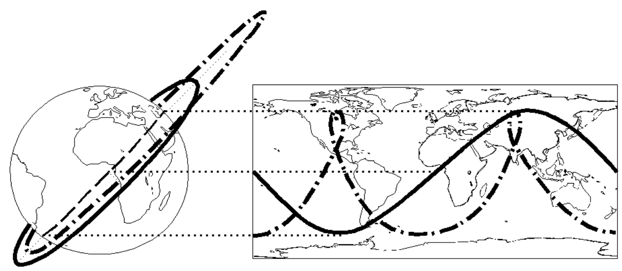

Figure 4-16: Effect of Eccentricity on a Satellite Orbit

Effect of Launch Site Location

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, as energy is limited, the most cost efficient methods must be utilized (which usually equates to the most energy efficient). 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. Thus, the lowest inclination that can be achieved by directly launching is the latitude of the launch site. For launches due east (90° azimuth) or due west (270° azimuth) from a launch site, the resulting orbital inclination will equal the latitude of the launch site. To attain an inclination that is lower than the latitude of the launch site requires additional orbital maneuvers, usually after the satellite has achieved orbit.

A satellite launched on an azimuth between 0° and 180° will have an inclination of between 0° and 90°, hence a prograde orbit. Satellites launched on azimuths between 180° and 360° will have an inclination between 90° and 180°, hence a retrograde orbit. Launching due north or due south (0° and 180° azimuth, respectively) will result in a polar orbit. It doesn't matter where the launch site is, the orbit will be polar.

The Earth spins to the east at 1,037 miles-per-hour (mph) at the equator and 0 mph at the poles. A substantial savings in rocket propellant is possible by locating the launch site on or near the equator and launching to the east. This gives the launcher up to 1,037 mph more velocity without burning fuel if launched due east. To launch a satellite into a retrograde orbit it is desired to launch from as high a latitude as possible so that the launcher has to overcome as little of the Earth's rotational speed as

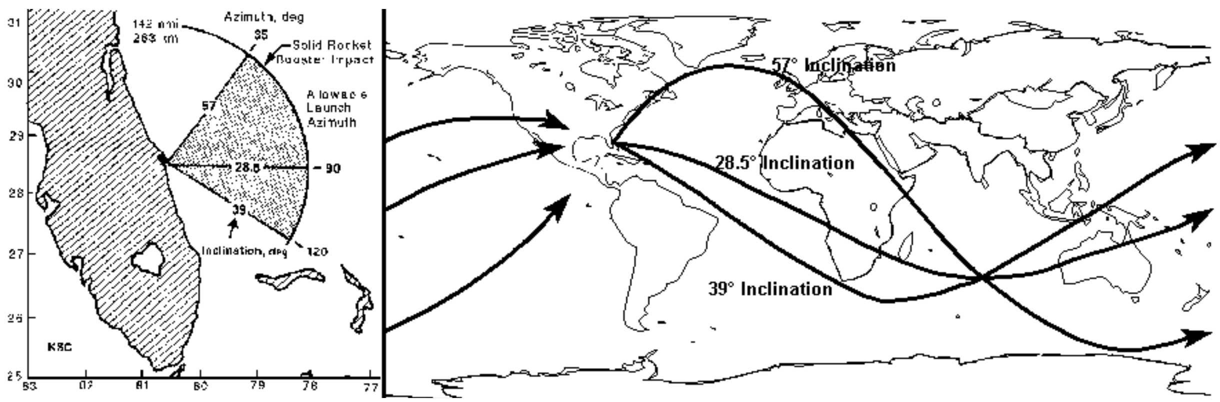

Figure 4-17: Launch Azimuth Limits and Orbital Inclinations from Kennedy Space Center, FL

possible.

Figure 4-17 shows the allowable launch azimuths and resulting initial orbital inclinations for Cape Canaveral AFS and Kennedy Space Center in Florida.

Figure 4-18 shows the range of allowable launch azimuths and resulting initial orbital inclination for

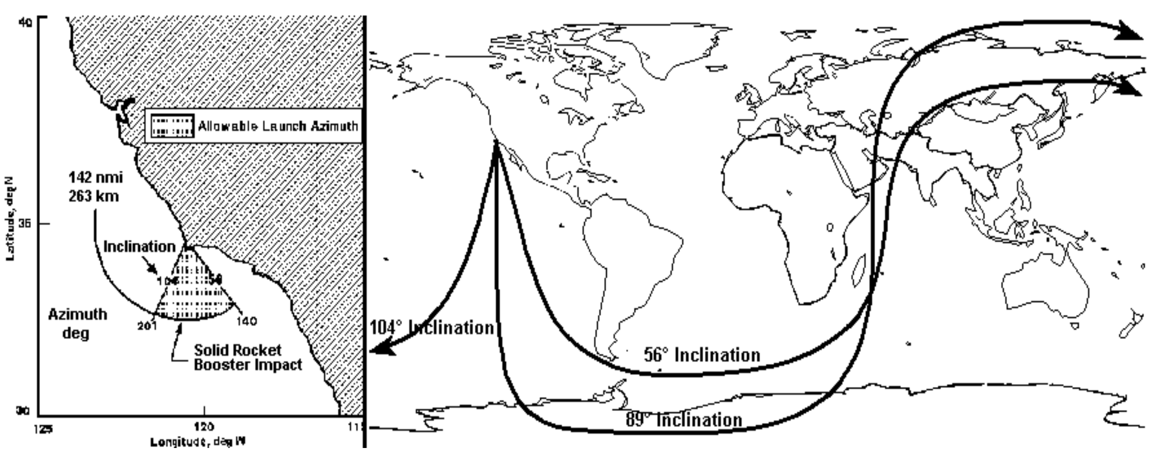

Figure 4-18: Launch Azimuth Limits and Orbital Inclinations from Vandenberg AFB, CA

launches from Vandenberg AFB, CA.

Orbital Perturbations

Kepler's laws of planetary motion and Newton's laws of motion and law of universal gravitation describe how two objects move in a uniform environment. The universe, however, is not uniform. The Earth does not have a uniform density and it is not a perfect sphere. The Earth has an atmosphere and a magnetic field which extend out into space. The Sun emits vast amounts of matter and energy that vary significantly. The solar system is made up of many massive objects. The result is that there are variations in the movement and path of objects in orbit around the Earth. These variations are called perturbations. Perturbations are the effect of a variety of outside forces that act on a satellite to change its orbit.

Oblateness of the Earth

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 effect of Earth’s oblateness is gravitational perturbations, and, as such, has a greater influence the closer a satellite is to the Earth. The oblateness of Earth also causes satellites in an inclined orbit to precess. Satellites in a prograde orbit precess to the west. Satellites in a retrograde orbit precess to the east. The amount of precession is more pronounced in low altitude satellites. This precession can be an advantage to help maintain a satellite in a sun synchronous orbit without expending any fuel for course changes.

Homogeneousness of the Earth

The Earth is not homogeneous. It does not have uniform density, therefore the force of gravity from the Earth's mass is not quite the same in all directions. There is a region over the Andes Mountains in South America where gravity is somewhat weaker. This is often referred to as a "gravity hill." A satellite in geostationary orbit over this region requires more station keeping because the satellite tends to drift away to other areas with stronger gravity potential. There is an area over the Indian Ocean where gravity is somewhat stronger. This is often referred to as a "gravity well". Satellites in geostationary orbit over this region tend to remain there with very little station keeping. The area over the Indian Ocean is useful for holding inactive satellites in a temporary storage location.

Atmospheric Drag

The Earth’s atmosphere does not suddenly cease, rather it trails off into space. However, after about 1,000 km (620 miles), we can disregard its minuscule effects. Generally speaking, atmospheric drag can be modeled in predictions of satellite position. The highest drag occurs when the satellite is closest to the Earth (at perigee).

Third Body Effects

According to Newton’s law of Universal Gravitation, every object in the universe attracts every other object in the universe. This force affects our satellites’ orbits. The farther a satellite is from the Earth, the greater the third body forces are in proportion to Earth's gravitational force, and therefore, they have a greater effect on the high and deep space satellites. The greatest third body effects come from those bodies that are very massive and/or close such as the Sun, Jupiter and the Moon.

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 the electronics, the satellites produce their own localized magnetic fields that interact with the Earth's causing unwanted torque. In some instances, this torques is advantageous for stabilization. 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 use a long tether in space for, among other reasons, using Earth's magnetic field to generate electrical power.

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 due to this energy transference. The magnetic field is strongest and satellites travel faster closer to the Earth, resulting in the largest effect 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. Unfortunately, satellites are not a perpetual invention, and when no longer useful, they must be removed from their present orbit. Sometimes natural perturbations 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 *deorbiting*. This is usually done to recover something of value: men, 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 *decay*.

In some situations, the satellites are in such stable orbits that natural perturbations will not do the disposal job for us. 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 to come.

TYPES OF ORBITS

Low Earth Orbits

There is no formal definition of what constitutes a Low Earth Orbit (LEO) but it is generally considered to have an apogee (maximum altitude) of no more than approximately 530 miles. Inclination of the orbital plane can be any value. Most low Earth orbits are nearly circular, therefore the eccentricity is very close to zero. At low altitudes, atmospheric drag significantly limits the lifetime of satellites unless they are periodically boosted into a higher orbit. Orbital lifetime, without any propulsion, is about one year at an altitude of 200 miles. Orbital lifetime at 500 miles altitude is more than 10 years. A considerable amount of space debris has collected in the higher altitudes, thus increasing the chances of having a collision with a piece of space debris or a meteoroid large enough to do significant damage to an orbiting satellite.

Low Earth orbits are commonly used for observation, environmental monitoring, small communications satellites, and science instrument payloads. Manned orbiting satellites, such as the U.S. Space Shuttle and the Russian Mir, generally remain below an altitude of 300 miles so that heavy shielding to protect the crew from radiation from the Van Allen radiation belts is not needed.

Satellites in LEO have the advantage that they pass relatively close to areas on the Earth. This makes them significant to those who image the earth from space. Also, this orbit is good if wish to keep antenna size and power down. The closer the satellite is to the earth the smaller the antenna can be to receive the signal and the less power required to transmit to and from the satellite. Navigation and cellular phone services use this type of orbit.

There are disadvantages to this type of orbit which must be considered. The satellite is in view of the ground user for only a short period of time as it passes quickly overhead and the footprint of the satellite can be quite small. A satellite in LEO cannot provide continuous coverage to a specific geographic point or area. The orbit *period* at these altitudes varies between ninety minutes and two hours. The radius of the *footprint* of a communications satellite in LEO varies from 3000 to 4000 km. The maximum time during which a satellite in LEO orbit is above the local horizon for an observer on the earth is about 20 minutes. In many orbits, the satellite may orbit the Earth many times before it passes within view again. A global communications system using this type of orbit requires a large number of satellites, in a number of different, inclined, orbits. When a satellite serving a particular user moves below the local horizon, it needs to be able to hand over the service to a succeeding one in the same or adjacent orbit. Lastly, maintaining constant communications with a low Earth orbiting satellite requires a large number of ground stations located around the world or a few relay satellites in high, geostationary orbit. The shuttle and Landsat satellites communicate through relay satellites.

“Big LEO” systems are normally those providing mainly mobile telephony services. Many of the new proposed 'global mobile phone' services will be provided by this type of satellite. They are located between 700km-1,500km from the Earth. Examples of Big LEO" systems are Globalstar (48+8 satellites in 8 orbital planes at 1400 km), and Iridium (66+6 satellites in 6 orbital planes at 780 km). There are many "Little LEO" systems. “Little LEO” systems normally provide mobile data services such as Orbcomm and Teledesic. One particular example of such a system is PoSat, built by SSTL in1993 and launched into an 822 x 800 km orbit, inclined at 98.6 degrees.

Semi-Synchronous Orbit

A semi-synchronous orbit has a period equal to half of a day. The satellite only makes two revolutions around the Earth every day. The altitude is about 10,900 miles for a circular orbit. It is possible to have an inclined, nearly circular semi-synchronous orbit which repeats an identical ground trace twice each day. There is no precession due to the Earth’s rotation because the 12 hour period allows the earth to turn half way around in one orbit and the rest of the way around in the second daily orbit, synching up with the same four equatorial crossing points every 24 hours. This consistent ground trace makes it easy to configure at satellite constellation to keep a certain number of satellites in view from any point on the earth.

A satellite with this period is considered to be in a medium altitude orbit. Satellites in this orbit are, however, subject to high doses of radiation in the Van Allen radiation belts. Satellites in this orbit must, therefore, be designed to withstand the increased radiation levels encountered while passing through the belts. The characteristics of this orbit make it an excellent choice for navigation systems like the U.S. GPS satellites and the Russian GLONASS satellites.

Polar Orbit

Polar-orbiting satellites provide a more global view of Earth, circling at near-polar inclination (the angle between the equatorial plane and the satellite orbital plane -- a true polar orbit has an inclination of 90 degrees). The orbit is fixed in space, and the Earth rotates underneath. Therefore, a single satellite in a polar orbit provides in principle coverage to the entire globe, although there are long *period*s during which the satellite is out of view of a particular ground station. Most desired orbits are between 700 and 800 km altitude with orbit periods between 98 and 102 minutes.

These satellites operate in a sun-synchronous orbit, providing continuous Sun-lighting of the Earth-scan view. The satellite passes the equator and each latitude at the same time each day meaning the satellite passes overhead at essentially the same solar time throughout all seasons of the year. This feature enables regular data collection at consistent times as well as long-term comparisons. This orbit provides global daily coverage of the Earth with higher resolution than geostationary orbit. Even though satellites do not pass directly over the poles they come close enough that their instruments can scan over the polar region, providing truly global coverage.

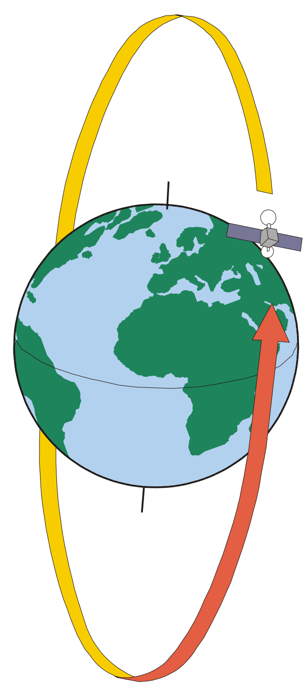

Figure 4-19: Polar Orbit

Advantages of this type of orbit are: the satellite samples each region at the same time each day (regular schedule); high resolution due to low orbit Polar coverage (except right at the pole); one can observe the whole earth from one satellite; it is relatively inexpensive to launch into orbit (low orbit); the shadows from clouds can be used to estimate cloud heights. Some disadvantages are the poor time resolution (12 hours) and it requires a sophisticated ground system.

Once again, the mission of the satellite must be considered when determining the orbit type to be used. In the case of remote sensing and weather missions, the emphasis is placed high resolution and better multi-spectral coverage more than constant global coverage. Examples of satellites in polar orbits are NOAA/POES and DMSP (weather satellites) and Landsat and SPOT (remote-sensing satellites). Another particular example of a system that uses this type of orbit is the COSPAS-SARSAT Maritime Search and Rescue system. This system uses 8 satellites in 8 near polar orbits: Four SARSAT satellites move in 860 km orbits, inclined at 99 degrees, which makes them sun-synchronous. Four COSPAS satellites move in 1000 km orbits, inclined at 82 degrees.

Sun-Synchronous Orbit

There are situations where we want a satellite to pass over points on the Earth at the same time every day so that sunlight conditions are the same. In a Sun-synchronous or Helio-synchronous orbit, the angle between the orbital plane and Sun remains constant, which results in consistent light conditions of the satellite. This can be achieved by a careful selection of orbital height, eccentricity and inclination which produces a precession of the orbit (node rotation) of approximately one degree eastward each day, equal to the apparent motion of the sun. This condition can only be achieved for a satellite in a retrograde orbit. Most commonly the inclination is about 98°.

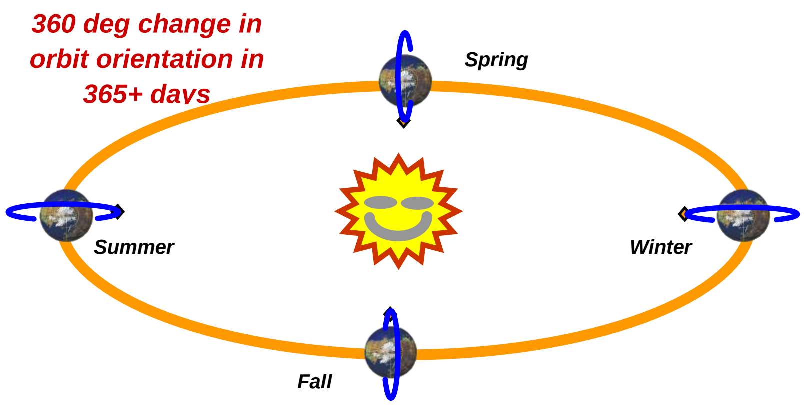

Figure 4-20: Sun Synchronous Orbit

A satellite in sun-synchronous orbit crosses the equator and each latitude at the same time each day and it will always maintain the same relative orientation to the position of the sun. This type of orbit is therefore advantageous for an Earth Observation satellite, as it provides constant lighting conditions. For example, the shadows cast by objects on the surface of Earth at any given latitude are always the same length when the satellite passes overhead. Thus, any change, such as new construction, is easily observed. Some weather and remote sensing environmental satellites use this type of orbit.

The sun-synchronous orbit takes advantage of a perturbation caused by the oblateness of the earth. Since the Earth is not a perfect sphere, the gravitational pull on the satellite in a polar orbit is not uniform. The result is that the orbit twists a little bit. This small twist compensates for the daily shift in position of the sun as the Earth rotates around the Sun each year. The greater gravitational force at the

Equator causes the orbit to precess to the East. This precession is slightly less than one degree. This makes sense when note that the Earth rotates 360 degrees around the Sun in about 365 days.

The same sun angle every day allows photo interpreters and data analysts to rule out shadows if something in a picture has changed from one satellite pass to another. Landsat and SPOT imaging Earth resource imaging satellites are in sun-synchronous orbits for this reason. Low Earth orbiting weather satellites such as DMSP and NOAA polar orbiters are in sun-synchronous orbits so that weather images and data from on-board sensors are gathered at the same time every day.

Medium Earth Orbits

Medium Earth Orbits (MEO) are also called Intermediate Circular Orbits (ICO). MEOs are circular orbits at an altitude of around 10,000 km. Their orbit *period* measures about 6 hours. The maximum time during which a satellite in MEO orbit is above the local horizon for an observer on the earth is in the order of a few hours. A global communications system using this type of orbit requires a modest number of satellites in 2 to 3 orbital planes to achieve global coverage. MEO satellites are operated in a similar way to LEO systems. However, compared to a LEO system, hand-over is less frequent, and *propagation delay* and *free space loss* are greater. Examples of Companies employing MEO orbits are ICO (10 +2 satellites in 2 inclined planes at 10355 km), and Odyssey (12 + 3 satellites in 3 inclined planes, also at 10355 km). Typically they are used to provide mobile telephone services.

Geosynchronous Orbits

(from ***geo*** = Earth + ***synchronous*** = moving at the same rate).

Figure 4-21: Geosynchronus Orbit

A geosynchronous orbit has a period equal to that of Earth's rotation (1day). A satellite with this period is considered to be in a high altitude orbit; its mean orbital radius is about 22,300 miles. A geosynchronous orbit can have any inclination. Varying the inclination of the orbit produces ground traces that fluctuate about a point on the equator in the pattern of a figure eight. The larger the inclination, the larger the figure eight, until, when at polar inclination, a figure eight ground trace with its top near the north pole and bottom near the south pole is produced.

The world's major existing telecommunications and broadcasting satellites use some type of geosynchronous orbit. Weather and surveillance/warning satellites also use geosynchronous orbits.

Geostationary Orbit

A satellite that appears to remain in the same position above the Earth is called a "geostationary satellite." A geostationary orbit is a special kind of geosynchronous orbit. This is an orbit having a period equal to that of the earth and an inclination equal to 0 degrees. The orbit is as circular as possible, therefore eccentricity is almost zero. The orbital period of the satellite is the same as the period of the Earth's rotation around its axis (1 day). To an observer on the ground the satellite appears to be stationary in the sky. The satellites can be positioned so that they are over any east/west longitude along the equator. The most significant advantage is that the satellite provides continuous coverage of specific areas of the Earth and antennas do not need to track the satellite.

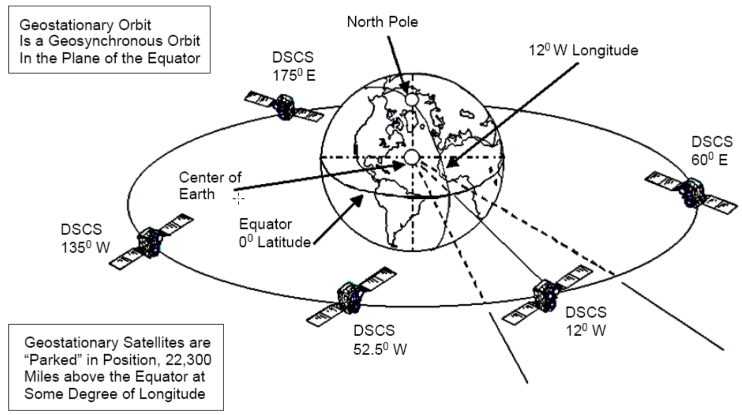

Figure 4-22: Geostationary Orbit

The footprint, or service area of a geostationary satellite covers almost 1/3 of the Earth's surface (from about 75 degrees South to about 75 degrees North latitude), so that a minimum of three satellites in orbit can provide global information but cannot see to the polar regions. The signal has to travel through much more atmosphere and the amount of interference from ground clutter makes the use of geostationary satellites impractical at latitudes greater than 70°. In the Southern Hemisphere, only Antarctica is affected. In the Northern Hemisphere, the northernmost part of Alaska along the Arctic Ocean, extreme northern Canada, Greenland, extreme northern Scandinavia and northern Siberia have restricted access to geostationary satellites nor can sensors on geostationary satellites observe these areas effectively.

Geostationary orbits are used extensively for communications, weather and some detection satellites. Communications satellites like DSCS III, FLTSAT, Milstar, TV relays and commercial communications satellites are in geostationary orbit. DSP satellites are in geostationary orbit so they can continually monitor an area of the Earth and provide warning if a missile is launched. Weather satellites such as GOES are in geostationary positions to provide coverage of global weather patterns. Any satellite system with a mission to provide continuous coverage or service to the same area of the world is ideally suited to be placed in a geostationary orbit.

Geostationary orbits are perfect for communications satellites because they are always in view of the ground station and customers in the coverage area, providing continuous TV and telecommunications services to customers. Antennas on the Earth can be simple, directional antennas since they do not need to track the satellite. A disadvantage of a geostationary satellite in a voice communication system is the *round -trip delay* of approximately 250 milliseconds.

These orbits provide a "big picture" view for coverage of weather events. This is especially useful for monitoring severe local storms and tropical cyclones. However, because a geostationary orbit must be in the equatorial plane, it provides distorted images of the polar regions with poor spatial resolution. The resolution measurements also suffer from the great height at which observations must be made.

Highly Elliptical Orbits

There is no universal definition for a highly elliptical orbit, however, those with an eccentricity greater than 0.5 are generally considered to be highly elliptical. A satellite in a highly elliptical orbit spends most of the time on the side with the apogee. There is no specific inclination, altitude nor period associated with highly elliptical orbits.

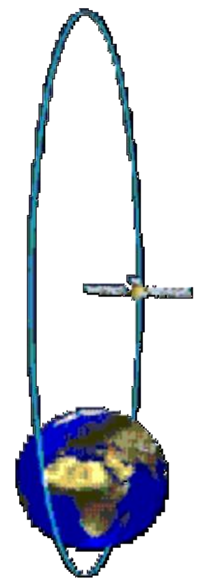

Figure 4-23: Highly Elliptical Orbit

Highly Elliptical Orbits (HEOs) typically have a perigee at about 500 km above the surface of the earth and an *apogee* as high as 50,000 km. The orbits are inclined at 63.4 degrees in order to provide communications services to locations at high northern latitudes. The particular *inclination* value is selected in order to avoid *rotation of the apses*, i.e. the intersection of a line from earth centre to *apogee* and the earth surface will always occur at a latitude of 63.4 degrees North. Orbit *period* varies from eight to 24 hours. Owing to the high *eccentricity* of the orbit, a satellite will spend about two thirds of the orbital *period* near *apogee*, and during that time it appears to be almost stationary for an observer on the earth (this is referred to as *apogee* dwell). After this *period* a switchover needs to occur to another satellite in the same orbit in order to avoid loss of communications. *Free space loss* and *propagation delay* for this type of orbit is comparable to that of geostationary satellites. The major disadvantage of the HEO orbit is that steerable antennas are needed at Earth terminals in order to maintain high data rate connections. Examples of HEO systems are:

- The Russian Molniya system, which employs 3 satellites in three 12 hour orbits separated by 120 degrees around the earth, with *apogee* distance at 39,354 km and perigee at 1000 km;
- The Russian Tundra system, which employs 2 satellites in two 24 hour orbits separated by 180 degrees around the earth, with *apogee* distance at 53,622 km and perigee at 17,951 km;
- The proposed Loopus system, which employs 3 satellites in three 8 hour orbits separated by 120 degrees around the earth, with *apogee* distance at 39,117 km and perigee at 1,238 km;
- The European Space Agency's (ESA's) proposed Archimedes system. Archimedes employs a so-called "M-HEO" 8 hour orbit. This produces three *apogee*s spaced at 120 degrees.

Each *apogee* corresponds to a service area, which could cover a major population centre, for example the full European continent, the Far East and North America.

Molniya Orbit

The most common highly elliptical orbit is the Molniya orbit, originally conceived and used by the Soviet Union. This was a benefit for two reasons. First, the satellite's orbit provides better coverage of the Russian land mass for communications than a geosynchronous satellite. Communications satellites in a geostationary orbit can only provide reliable communications from about 70 degrees north latitude to 70 degrees south latitude. Much of Siberia and northern Russia is above 70 degrees north latitude. Second, the ability to launch directly into this orbit (saving on launch costs) was available simply by constructing a launch site at Plesetsk (63.4 degrees).

It has a 63.4° inclination, 0.7 eccentricity, and perigee over the southern hemisphere. A satellite in a Molniya orbit spends 11.7 hours of its 12 hour period in the northern hemisphere. A satellite moves slower at its apogee than and fastest at its perigee. A satellite in a Molniya orbit is north of the Equator almost all the time and seems to linger near its apogee. This makes the Molniya orbit well suited for communications satellites intended to provide coverage in the extreme north where access to geostationary satellite is generally not feasible.

Orbital Maneuvers

A satellite is rarely launched directly into its final orbit. After being launched into an initial parking orbit, at least one orbital maneuver is needed to get the satellite into the correct orbit to begin its mission. Orbital maneuvers are necessary to maintain a satellite in its proper orbit or to change the orbital parameters based on revised mission requirements. Changing the orbital parameters of a satellite requires careful planning and precise execution. Satellites carry a limited amount of fuel to power maneuvering engines. Once the fuel has been expended there is no way to change a satellites orbit or even to correct for small changes resulting from perturbations. There are two basic categories of orbital maneuvers: in-plane maneuvers and out-of-plane maneuvers.

In-Plane Maneuvers

In-plane maneuvers can change the size and shape of the orbital plane but do not change its orientation. In-plane maneuvers include changing the altitude of the apogee or perigee, the eccentricity of the orbit, the length of the semi-major axis, and the argument of perigee.

Hohmann Transfer Maneuver

The most energy efficient in-plane maneuver is known as the Hohmann Transfer. It is a two impulse maneuver between two coplanar orbits. The first burn is made at the perigee of the initial orbit to increase the speed of the satellite and change the eccentricity of the orbit. The magnitude and direction of the change, called the "delta-v", must be precisely controlled. If the new, more elliptical orbit is the desired final orbit, then no other burn is needed. If the final desired orbit is a circular orbit with a higher altitude than the original orbit, another burn must be made at the apogee of the transfer orbit. The second burn places the satellite in a higher, more circular orbit. The Hohmann Transfer is efficient but can take up to half of one period to execute. This technique is often used to boost communications satellites from an initial low Earth orbit into a geostationary orbit.

Fast Transfer Maneuver

Another method of changing orbits is the Fast Transfer method, used when time is a factor. This method also uses two impulses. The difference between this method and the Hohmann Transfer is that the satellite approaches its new orbit at a higher angle and velocity. Thus, the second burn must be stronger to brake the satellite into the new orbit. Fast transfer is used by various surveillance satellites when new targeting requirements are critical.

Out-Of-Plane Maneuvers

Out-of-plane maneuvers change the orientation of a satellite's orbital plane. As with a spinning gyroscope, making a change to the orbital plane of a satellite can require large amounts of energy. Two common out-of-plane maneuvers are changes to the inclination and to the right ascension of the ascending node. To change only the inclination of a satellite's orbit, one burn is made at either the ascending node or the descending node. To change only the right ascension of the ascending node requires one burn anywhere in the original orbit except at the ascending or descending nodes.

SATELLITE ORBIT REFERENCES

Websites:

http://www.phy.hw.ac.uk/resources/demos/orbit_simulator/orbit_sim.html - Animated simula-tions of Kepler's Laws

http://www.thetech.org/exhibits_events/online/satellite - Satellite orbits with animation. A satellite's orbit depends on its task, speed, and distance from Earth.

http://marine.rutgers.edu/mrs/education/class/paul/orbits2.html - Good site describing several orbits and providing graphical descriptions of those orbits.

http://science.nasa.gov/Realtime/JTrack/3D/JTrack3D.html - Cool site with actual data plugged into a java tracking program. Click on a dot to see what satellite you've got and what it's orbit around the Earth looks like.

http://lectureonline.cl.msu.edu/~mmp/kap7/orbiter/orbit.htm - With this applet you can put your own satellite into orbit around Earth. Keep the mouse down and drag to adjust the velocity vector. With a little practice, you can keep your own Sputnik on an orbit without it crashing into Earth or escaping.
http://www.sat-net.com/winorbit/ - Predict satellite orbits using this downloadable free software.

Chapter 5
Satellite Communications

OVERVIEW

Space force enhancement functions are similar to combat support operations in that they improve the effectiveness of forces across the full spectrum of operations by providing operational assistance to combat elements. Command and support elements also integrate space force enhancement functions into their operations. The functions include:

- Communications
- Position/Navigation or Position, Velocity and Timing
- Intelligence, Surveillance and Reconnaissance
- Environmental Monitoring
- Early warning.

Civil, commercial, and allied capabilities may augment DoD systems to support military space force enhancement requirements. The efficiencies resulting from the use of these space capabilities can have a dramatic effect on military operations.

COMMUNICATIONS

Communicating with military units and individuals dispersed across the battlefield or deployed a great distance from their home stations has always been a major challenge. Our military continues to adapt to the political and military situations of the future. The requirement for immediately deployable forces has increased significantly. Forces require Beyond Line Of Sight (BLOS), long range communications while enroute, immediately upon arrival and continuously throughout and following deployment. Radio communications using Ultra High Frequency (UHF), Very High Frequency (VHF) and Extremely High Frequency (EHF) are limited to line-of-sight (LOS). High Frequency (HF) transceivers bounce signals off the ionosphere; however, the ionosphere is always changing, thus HF signals tend to fade in and out. An alternative is to connect into existing communications systems in the operational area. In many places, however, an adequate communications infrastructure does not already exist in the area of operations or it will take significant resources and time to connect into it.

Communications was the first practical application of space technology for both the military and business. Today there are more communications satellites in use than of any other type. Satellite communications provides the warfighting commander a reliable means to control his forces and conduct operations at various operational tempos. The flexibility of SATCOM allows different options to be considered based on the mission at hand. Satellite systems provide the backbone of national and DoD worldwide communications

MILSATCOM provides single channel and multi-channel communications throughout the military. Multi-channel terminals provide range extension for Mobile Subscriber Equipment and joint service interoperability. Single channel terminals support battlefield voice and data communications as a part of Combat Net Radio and special communications for force management, Emergency Action Message (EAM) dissemination and Special Operations Forces (SOF) communications.

Satellite communications systems can significantly enhance our joint communications capabilities, but they are not a panacea. Satellite communications do not necessarily replace but rather complement ground based communications systems. A thorough understanding of the operations, types, capabilities and limitations of military and commercial satellite communications systems is necessary for the military leader to use SATCOM to enhance operations.

This chapter will discuss various U.S. military satellites, review some of the commercial satellites, and list many of the foreign satellites. The chapter will review the orbits used for communication satellites, give a quick introduction to the SATCOM frequency spectrum and provide a starting point for planning considerations. It will not discuss terminal equipment in great detail. For more information about SATCOM support to the Army see The Army Satellite Communications Architecture Book published by Fort Gordon.

Orbits of Communications Satellites

Although the majority of communications satellites operate in geostationary orbits, there are other orbits that are used to provide coverage to other areas or to provide a capability not suitable for geostationary satellites. **Figure 5-1** shows three representative orbits typically used by communications satellites (annotated here as Type 1, 2 and 3). The resultant ground traces of each type are shown on the right.

GEO

Geosynchronous Earth orbits (GEO) (Type 1) are typically used to provide continuous communications to a specific area because the satellite's motion is synchronized with an area of the earth below it along the equator. A geosynchronous orbit can have any inclination. A minimum of three satellites in geosynchronous orbit is needed to provide global coverage. There are some communications satellites in GEO, although most are in a special orbit called geostationary.

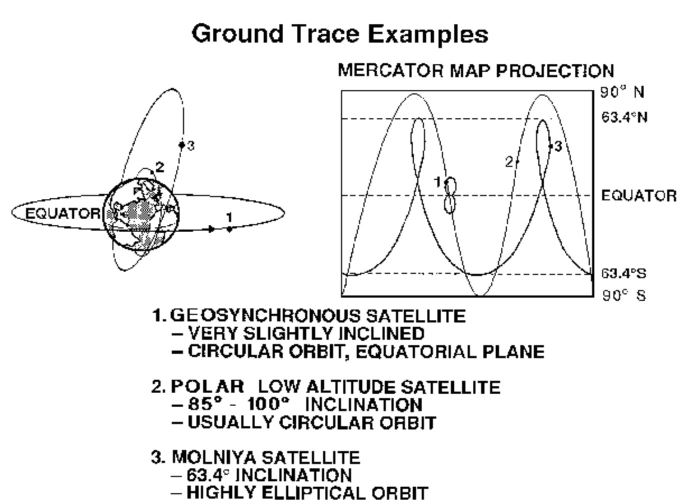

Figure 5-1: Types of Orbits and Ground Traces

A geostationary orbit is a type of geosynchronous orbit which seems to be positioned at one location over the equator at an altitude of approximately 25,645 statute miles

(22,300 nautical miles) at 0 degrees inclination. In practice, the coverage of geostationary satellites is limited to areas between approximately 70° north latitude and 70° south latitude. For our ground forces this has limited impact since only the very northernmost part of Alaska, northern Greenland, the northern tip of Norway, northern Siberia and Antarctica are in the area not covered by geostationary satellites. However, it does impact naval forces and some strategic Air Force missions. Geostationary orbits have the communication advantage of a large, stable footprint. Fixed antennas can be used without tracking the satellite. This orbit is currently the world's standard for most GEO communications satellites. There are already many satellites positioned in the GEO belt. It will become increasingly difficult in the future to de-conflict GEO belt locations for new satellites because of overcrowding demand.

LEO

A communications satellite in low Earth orbit (LEO), polar, (Type 2) passes within view of every point on the Earth at some time. A LEO in any other inclination will not cross the poles. LEO satellites offer many advantages for communications. LEOs are normally used for short burst, narrowband communications using radio frequencies below one gigahertz. Time delay is decreased for communications traffic using LEO satellites. Smaller and simpler antennas can be used. These low altitude communication satellites require less power to transmit signals because of the shorter signal path.

The biggest disadvantage of LEO as a communications orbit is each satellite is not in view of the ground receiver at all times. Their footprint is small and quickly passes out of view of the ground terminal. Because of this, communication satellite constellations in LEO normally consist of more than one satellite to provide 24-hour coverage.

Molniya

The Molniya orbit (Type 3) is designed to provide extended coverage to a specific extreme northern area. This is a highly elliptical orbit (HEO) inclined to 63.4°. A satellite in a Molniya orbit is within view of its ground stations about 80% of the time. As a satellite in a Molniya orbit approaches its apogee it slows down while the Earth continues to rotate at a constant speed. The resultant ground trace makes a loop, indicating that this particular orbit will provide maximum coverage time over the northern latitudes. The size of the area of coverage is also determined by the width of the antenna beam and signal frequency from the satellite. Since the satellite is usually at a high altitude, the area of regard can be large.

This orbit is ideal for communications satellites used to provide coverage in the extreme northern latitudes where access to geostationary satellites can be difficult. Molniya orbits have poor coverage of the southern hemisphere. There can also be a problem in transmission delays and signal loss when the satellite is farthest from the earth. The orbit requires multiple satellites for 24-hour coverage. Normally three satellites in Molniya orbit are used for coverage.

MILITARY COMMUNICATION APPLICATIONS

SATCOM resources are essential for military force projection. The seamless connectivity provided by SATCOM ensures that planning and coordination occurs when and where needed.

The Army uses single channel SATCOM to support tactical battlefield voice and data range-extension requirements. The ground terminals are user owned and operated and can be man portable, man-packable, or vehicular mounted. Single channel SATCOM is used extensively in a variety of warfighter missions because of the flexibility and mobility provided. Military single channel SATCOM is used to provide communications for SOF operations, mobile warfighter C2 nets, and intelligence dissemination.

The primary purpose of multi-channel SATCOM is to extend the range of the area common user system (ACUS). Strategic ground terminals provide the international satellite trunking for the Defense Information Systems Network (DISN). Tactical terminals are deployed to provide range extenuation links for critical nodes. Multi-channel SATCOM is used for EAC through Brigade MSE range extension and strategic reachback.

Global Broadcast Service (GBS) is a tool for the warfighter that provides a high speed, one-way flow of information tailored to a commander’s mission requirements. GBS provides battlefield awareness video and data broadcasts down to brigade level (i.e. UAV video) plus any other theater intelligence broadcasts necessary to support operations.

The use of commercial SATCOM is evident throughout the military. Commercial SATCOM is an alternative means of satisfying those communications requirements that cannot be satisfied using military SATCOM (MILSATCOM). INMARSAT and INTELSAT are a couple of examples of commercial SATCOM systems that the military has relied upon for communications. Mobile Satellite Service systems such as Iridium are rapidly assuming a place in the Army SATCOM architecture. Currently, commercial SATCOM (vice MILSATCOM) is used primarily for Admin and Log C2, as a surge supplement for MILSATCOM, to provide Mobile Satellite Service with cellular-like voice and fax capability, and for peace keeping, disaster relief and humanitarian operations.

Each phase of an operation brings with it a unique communications plan. Early in the deployment scenario, there is a heavy reliance on single channel SATCOM. As the operation progresses and more units are established in country, more emphasis is placed on multi-channel SATCOM. Peacetime operations require a different mix of communications and SATCOM requirements than wartime operations. The need for C2 links that are reliable, fast and flexible dictate the use of SATCOM. SATCOM must become a seamless part of the overall communications network that will successfully function and interoperate in a complex and sensitive single-nation or multinational mission.

Satellite communications provided invaluable support during Operation DESERT STORM. About 75% of the more than 1,500 satellite communications terminals deployed to the theater were single channel, man portable military and commercial sets. They provided critical inter and intra-theater communications links to widely dispersed and fast moving units.

Task Force Hawk used SATCOM during operations in Kosovo to achieve proper C2 for the AH-64s. The Task Fore Commander determined early on that the mountainous, rugged terrain would require a robust C2 plan. SINCGARS and HAVEQUICK II were not effective in this environment because of limited line of sight. A UH-60 with SATCOM was used to relay messages to Hawk Base. The recommendation after the operation was the AH-64 should be equipped with SATCOM.

In operations in Somalia and Afghanistan, SATCOM was essential to deployed forces due to a combination of their relatively small size, wide disbursement, and the lack of a local communications infrastructure.

In Operation Iraqi Freedom, SATCOM was used to provide fast moving ground forces with communications. The organic Army ground communications systems were unable to deploy and set up fast enough to be able to support the fast moving advance.

Other changes in operational capability have been implemented through the use of SATCOM. For example, Unmanned Aerial Vehicles (UAV) are able to fly over enemy held areas and send video and sensor data over SATCOM. The advent of GPS guided munitions increase the accuracy of air strikes. There are numerous examples of ground soldiers and Forward Air Controllers using SATCOM to communicate directly with in-bound aircraft to reprogram the target coordinates before the aircraft were within line-of-sight communications range. The effect was that long range bombers were able to be quickly redirected to hit targets of opportunity and provide close air support to ground forces because of the use of SATCOM.

SATCOM CONSIDERATIONS

Frequency Ranges

ELF/SLF/ULF/VLF

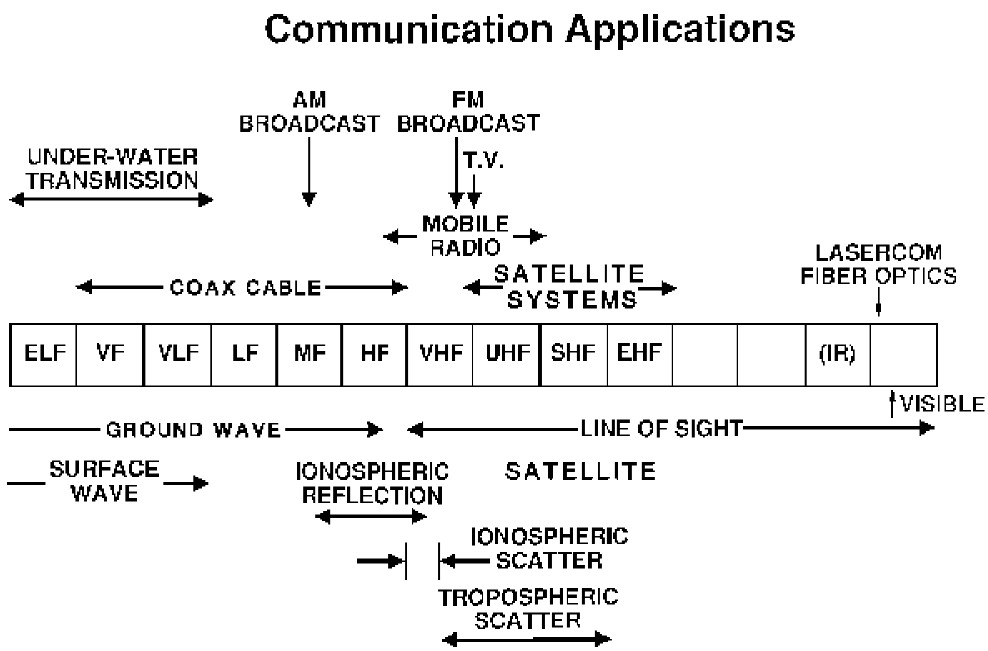

Figure 5-2a: Frequency Bands and Communication Applications

The frequency of any communications signal is the number of cycles per second at which the radio wave vibrates or cycles. Electro-magnetic waves cycle at phenomenal rates: one thousand cycles per second is called a kilohertz (kHz), one million cycles per second a megahertz (MHz), and one billion cycles per second a gigahertz (GHz). Today we refer to the continuum of frequencies used to propagate communications signals, 100 kHz to 100 GHz and beyond, as the electro-magnetic spectrum. SATCOM resides primarily in the UHF to EHF range.

Figure 5-2a shows the communications applications portion of the frequency spectrum. The top portion highlights various transmission mediums. The lower portion shows the wave propagation effects. Radio waves that propagate along a line of sight are best suited for satellite communications. Ground wave, surface wave and ionospheric reflection are not appropriate for satellite communications

Typically, both military and civil SATCOM frequencies fall across Ultra High Frequency (UHF) (0.3 – 3 GHz), Super High Frequency (SHF) (3 – 30 GHz) and Extremely High Frequency (EHF) (30 – 300 GHz) bands of the frequency spectrum. **Figure 5-2b** points out that the designations of frequency bands can be confusing. The U.S. military defines the frequencies of the UHF, SHF and EHF bands differently than the International Telecommunication Union (ITU). The Institute of Electrical and Electronics Engineers (IEEE) uses letters to designate frequency bands. The military UHF SATCOM band actually covers frequencies from 225 MHz to 400 MHz. Technically the frequencies below 300 MHz are in the VHF band according to ITU standards, but for military purposes we still refer to it as UHF. The military SHF SATCOM band is often referred to as the military X-band which covers 7.25 GHz to 8.4 GHz. The lower portion of the military X-band within the SHF band is actually in the upper portion of the C-band as defined by the ITU. The military EHF SATCOM band covers frequencies 22 GHz to 40 GHz. The lower portion of the military EHF band is in the upper portion of SHF band as defined by the ITU.

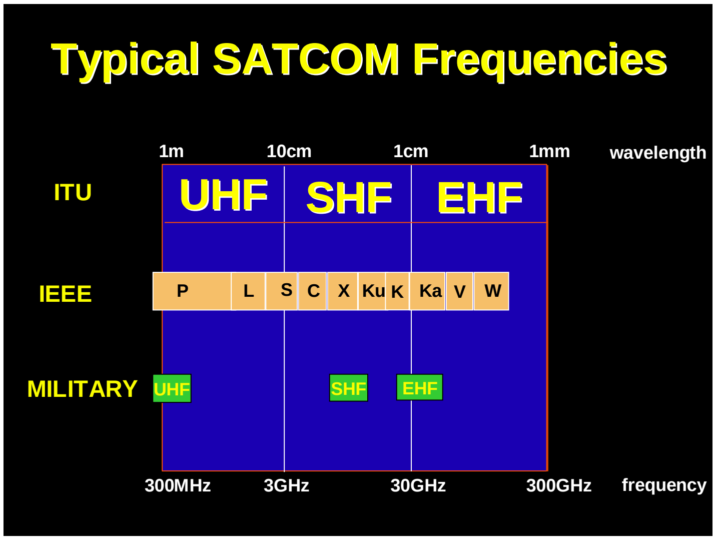

Figure 5-2b: Typical SATCOM Frequencies

Ultra High Frequency (UHF)

A UHF communications satellite uses the lowest frequency of all the MILSATCOM systems. Military UHF fall in the band of frequencies from 225 MHz to 400 MHz. It has a narrow bandwidth and a wide beam width. It provides only a relatively low data rate and single channel voice communications to small, portable transceivers. The wide beam width of the signals means that antenna pointing is not as critical as with higher frequency systems.

It has only limited resistance to jamming because the frequency range and bandwidth is narrow, therefore, there is less that can be done to counter jamming or interference and still maintain communications. UHF is adequate for voice circuits or low data rate transmissions. UHF user terminals are relatively inexpensive, simple to operate and do not require large antennas. All the U.S. military services use UHF, especially the Navy and the Army.

Super High Frequency (SHF)

SHF communication satellites are the most common type. They form the backbone of the space portion of the Defense Communications System. The higher frequencies result in a narrower beam width which allows the transmitted power to be concentrated into a smaller area. The military commonly uses the term “X-band” to mean the specific band of frequencies from 7.25 – 8.4 GHz that are strictly for military use. Future SHF SATCOM systems will use even higher frequencies in the Ku-band. The higher the frequency, the greater the bandwidth is thus allowing for more data to be transmitted. Additionally, more anti-jamming techniques can be used. Sophisticated modulation techniques can be used to increase the number of simultaneous users. There is, however, more atmospheric attenuation than at lower frequencies. The Army has a significant number of SHF satellite terminals.

Extremely High Frequency (EHF)

EHF communications satellites are the newest type. Typically the military uses the Ka and V-band. The high frequency allows a wide bandwidth and a very small beam width. The beam width can be small enough so that the transmitted signal is focused into a spot beam. Very high gain antennas are used to receive these EHF signals. Considerable anti-jamming can be implemented to assure communications in even the most demanding jamming conditions. Atmospheric attenuation, especially from clouds and rain, can be significant.

There is one major drawback to satellites down linking signals at frequencies greater than 10 gigahertz: the length of these microwaves is so short that rain, snow or even rain-filled clouds passing overhead can reduce the intensity of the incoming signals. At these higher frequencies, the length of the falling rain droplets are close to a resonant sub-multiple of the signal's wave length; the droplets therefore are able to absorb and de-polarize the microwaves passing through the Earth's atmosphere. In places such as Southeast Asia or the Caribbean, torrential downpours can lower the level of the incoming Ku-band satellite signal by 20 dB or more; this may severely degrade the quality of the signals or even interrupt reception entirely. Predictability of rain outages in certain parts of the world can at least be planned for as a consideration.

Bandwidth

Frequency, first and foremost, along with power and gain, dictate actual usable bandwidth capacity. Satellite design and use is directly tied to how much channel capacity, or information throughput, a satellite transponder can accommodate. Throughout the satellite communications industry the term “wide bandwidth” is commonly used to mean “high throughput capacity” and “high channel capacity”, although (strictly speaking) these terms are not necessarily equivalent. The greater a transponder’s bandwidth, the greater will be its potential channel capacity (in bits per second) to convey information at higher throughput rates. However, wider bandwidth means an increase in noise. Unless the conditions in all parts of the transmission signal path can be made just right to minimize the noise or to make the signal more powerful than the noise, the wider bandwidth will not allow for increased capacity. Transmitted signal power, the gain of the antennas and the efficiency of the receiver all have an impact on throughput capacity.

Antenna Size

Ground antennas come in different sizes and shapes and are designed for a specific purpose. If the dish is large then it will pick up more signals from space and be able to transmit with less power. If the dish is small it will pick up fewer signals from the satellite and require more power. The size of an antenna is determined by the frequency (wavelength) of the transmitted signal, the bandwidth (rate of transmission) and the desired gain or signal strength. Other factors remaining constant, larger antennas are needed at lower frequencies which have longer wavelengths. Higher bandwidth at a particular frequency requires a larger antenna. Digital messages transmitted at a slow rate do not require high gain to provide reliable communications. Voice circuits generally don't need high gain. High speed data circuits must have superior reliability so that the transmitted data is not altered.

Susceptibility to Jamming

Any receiver can be jammed. Satellite systems are no exception. In two way satellite communications systems there are receivers and transmitters on the ground and on the satellites. Susceptibility to jamming is determined by the frequency, bandwidth, signal modulation and other factors. Lower frequencies have narrower bandwidth and are more susceptible to jamming. Beam width of an antenna is inversely proportional to the frequency, thus lower frequencies have a wider beam width. Higher frequency transmitters can limit the beam width of the transmitted signal to a more specific area. More effective signal modulation techniques can be used at higher frequencies.

Most user receivers use directional antennas to communicate with the satellites. This limits the strength of jamming signals being received unless the jammer is in the path of the signal from the satellite to the receiver. Since the antennas of ground receivers are pointed into the sky, they are not significantly susceptible to ground jammers unless they are extremely powerful or very close.

Commercial satellites have virtually no protection against jamming. Military communications satellites have some ability to resist jamming through the use of various signal modulation and some frequency hopping techniques. Although jamming can be countered, a common result is a decrease in the amount of traffic that can be transmitted through the system when anti-jamming techniques are implemented. It is a conscious decision by the military to exchange data rate for security.

Solar activity such as large solar flares can disrupt all long distance radio transmissions.

COMMUNICATION SATELLITE SYSTEMS

DoD Satellite Systems

U.S. Military Satellite Communications (MILSATCOM) systems operate in three specific frequency ranges primarily in geosynchronous orbits.

- The UHF spectrum in comprised primarily of UHF Follow-on (UFO) satellites, the replacement for Fleet Satellite Communications System (FLTSATCOM).

- The Defense Satellite Communications System Phase III (DSCS III) operates in the Super-high Frequency (SHF) spectrum.
- Milstar operates in the Extremely-high Frequency (EHF) spectrum.

Each of the three systems above provides 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.

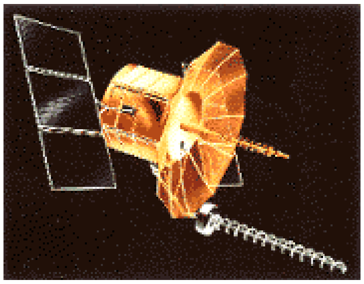

Figure 5-3: Fleet Satellite Communications Satellite

Fleet Satellite Communications (FLTSATCOM)

The Fleet Satellite Communications System (FLTSATCOM) was a UHF/EHF military satellite communications system. The FLTSATCOM system provided worldwide operational communications for naval aircraft, ships, submarines and ground stations. It also provided communications between the POTUS and SECDEF and the strategic nuclear forces as well as between other high-priority users. High priority users included the White House Communications Agency, reconnaissance aircraft, Air Intelligence Agency and ground forces (e.g., Special Operations Forces). However, its main purpose was for naval afloat communications. These satellites are no longer the operational mainstay. FLTSATCOM is worth noting here because of its outstanding service supporting the U.S. for over two decades.

UHF Follow-On

(http://www.globalsecurity.org/space/library/report/1999/uhf_follow-on_fact_sheet.pdf)

The UHF Follow-On (UFO) satellites replaced the Fleet Satellite Communications (FLTSATCOM) and the Hughes-built Leasat spacecraft currently supporting the Navy's global communications network, serving ships at sea and a variety of other U.S. military fixed and mobile terminals. They are compatible with ground- and sea-based terminals already in service. The UFO satellite system is deployed as a multi-satellite constellation.

The first UHF F/O was launched March 25, 1993. The Atlas II rocket booster malfunctioned, placing the spacecraft in a dangerously low orbit. After efforts by the 3rd Space Operations Squadron, Schriever AFB, Colo., the satellite was prevented from crashing back to Earth and was finally placed in a safe, though unusable, orbit. The second UHF F/O satellite (F-2) was launched September 3, 1993, and was successfully placed in its proper orbit, becoming the first fully operational spacecraft in a planned nine-satellite constellation. The launch of the final satellite (F-11) took place in December 2003. The satellites are arranged in pairs in four different locations above the Earth for global coverage.

Figure 5-4: UHF Follow-On Satellite

Using a building-block approach, Hughes and the Navy enhanced the constellation capabilities in stages. Satellites F-1 through 3 carry UHF and SHF (super-high frequency) payloads. Starting with F-4 there was an additional payload for EHF (extremely high frequency) communications. F-7 introduced an enhancement to the EHF package that essentially doubled capacity. The SHF payload is replaced by the GBS package on F-8 through 11.

The UHF F/O satellites offer increased communications channel capacity over the same frequency spectrum used by previous systems. UHF F/O supports global communications to Naval forces, provides channels to replace the 5 kHz narrow-band channels previously provided by FLTSATCOM and replaces the 500 kHz DoD wide-band channel with an appropriate number of 5 and 25 kHz channels. Each spacecraft has 11 solid-state UHF amplifiers and 39 UHF channels with a total 555 kHz bandwidth. The UHF payload comprises 21 narrowband channels at 5 kHz each and 17 relay channels at 25 kHz. In comparison, FLTSATCOM offers 22 channels. Since the design is for two satellites at each orbital position, 78 UHF channels should be available over the Atlantic, Pacific and Indian Ocean regions as well as CONUS.

The F-1 through F-7 spacecraft include an SHF subsystem, which provides command and ranging capabilities when the satellite is on station as well as the secure uplink for Fleet Broadcast service, which is downlinked at UHF.

Beginning with F-4 the Navy added an extremely high frequency communications package. This addition included 11 EHF channels distributed between an earth coverage beam and a steerable 5-degree spot beam compatible with Milstar ground terminals. The EHF subsystem provides enhanced anti-jam telemetry, command, broadcast, and fleet interconnectivity communications, using advanced signal processing techniques. The EHF Fleet Broadcast capability supersedes the need for the SHF fleet uplink. Beginning with UHF F/O F-7, the EHF package has been enhanced to provide 20 channels through the use of advanced digital integrated circuit technology.

Each satellite has a projected orbital operational life of 14 years. The satellite is designed to operate for 30 days without ground contact if necessary.

The Naval Space Command at Point Magu, CA took control the UFO constellation from the Air Force in July 1999. The responsibilities were transferred to the Naval Network and Space Operations Command in July 2002. Although UFO satellites are owned by the Navy, who is also responsible for satellite communications configuration, the system will provide satellite communications to all services. Channel allocation is accomplished in the same manner as for FLTSATCOM. The JCS has mandated that 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. (see more below)

Global Broadcast System (GBS)

In order to meet the demands of a rapidly deployed, highly mobile force structure, today's in-the-field warfighter demands a high data rate information infrastructure. The Global Broadcast Service capitalizes on the popular commercial direct broadcast satellite technology to provide critical information to the nation's warfighters. The GBS system is a space based, high data rate communications link for the asymmetric flow of information from the United States or rear echelon locations to deployed forces. It is designed to provide information in a dynamically reconfigurable format rapidly adaptable to peace and wartime circumstances, and deliver it to theaters of operation worldwide.

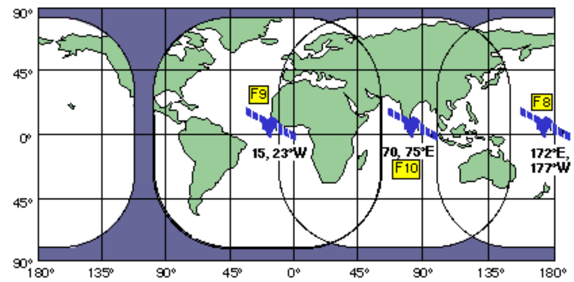

Figure 5-5: Location of GBS Satellites

GBS is an extension of the Defense Information Systems Network (DISN) and a part of the overall DoD MILSATCOM Architecture. As such, it is designed to employ an open architecture which can accept a variety of input formats. It exploits commercial off-the-shelf (COTS) technology. It must interface with, and augment other major DoD information systems, such as the Global Command and Control System (GCCS), as well as other theater information management systems. Eventually, GBS may supplant some theater information management systems.

The first GBS payload was put into service in 1998 on UFO F-8. UFO F-9 was launched in October 1998. Full three-satellite operational capability was gained with the launch of F-10 (see **Figure 5-5**).

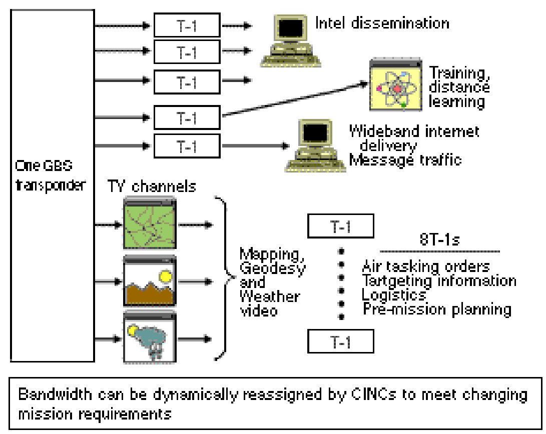

Figure 5-6: Types of GBS Services

The GBS payload replaces the SHF X-band payload with four 130-watt, 24 mega-bits-per-second (Mbps) military Ka-band (30/20 GHz) transponders. There are three steerable downlink spot beam antennas (two at 500 nm and one at 2000 nm) as well as one steerable and one fixed uplink antenna. This modification results in a 96 Mbps capability per satellite. The system will transmit to small, mobile, tactical terminals. **Figure 5-6** shows the types of services that can be provided by one 24 Mbps spacecraft transponder, a vast increase over today's warfighter capability.

High-power satellite transponders, which provide high-speed, wideband, simplex broadcast signals, characterize the Phase II Global Broadcast Service (GBS). This information is disseminated to small, 22-

inch-diameter, mobile, and affordable tactical terminals. Broadcast management centers provide the information management to package, schedule, and deliver the broadcast product. They also respond to user information requests from the field. Typical information products include video, mapping, charting and geodesy, imagery, weather, and digital data.

Data is received by the satellite via a fixed receive antenna from a broadcast management center (primary injection point) and a steerable receive antenna from theater injection point(s). Each of the four transponders can be accessed through either of the receive paths, configured by ground command. Data is transmitted on three steerable spot beam antennas per spacecraft into 22-inch ground receive antennas. Each of two spot beams covers an area of 500 nautical miles in diameter at the sub-satellite point and supports data rates of up to 24 Mbps per transponder, with two transponders assigned to each of the spot beams. The third downlink spot beam covers an area of 2,000 nm in diameter at the sub-satellite point, supporting a data rate down to 1.5 Mbps. One of the transponders is switchable by ground command from the 500 to the 2000 nm spot beam.

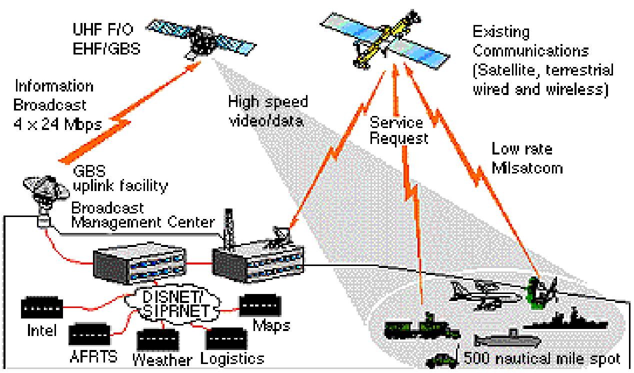

Figure 5-7: How GBS Works

Demand Assigned Multiple Access (DAMA)

The evolution of UHF SATCOM has seen enormous changes in mission philosophy, technical capabilities, and user population. The current theater commander wants high speed encrypted voice and data supporting thousands of terminals. UHF SATCOM is a highly flexible and low cost means for beyond-line-of-site command and control. As tactical satellite communications requirements have increased, UHF satellite capacity has been quickly saturated. The available frequencies are limited and only the efficient use of those frequencies can satisfy the increasing demands of the warfighter.

Demand Assigned Multiple Access (DAMA) is automated channel sharing. Instead of having dedicated channels and transponders, users share the capacity. The unused transponder space can be dynamically reallocated in near real-time on the basis of precedence. This increases the loading efficiency by providing roughly four to twenty times the information through out of the current systems.

The DAMA Control Station divides a channel into segments of time called “time slots.” A user terminal interacts with the control station, which dynamically allocates time slots for that user’s communications. Channel resources are allocated on the basis of current needs and network rankings. Any unused DAMA channel resources are available to be shared by everyone.

The Chairman Joint Chiefs of Staff Instruction, CJCSI 6251.01, "Ultrahigh Frequency Satellite Communications Demand Assigned Multiple Access Requirements," 31 July 1996, mandates that:

"All users of non-processed UHF MILSATCOM are required to have DAMA terminals that are interoperable in accordance with MIL-STD-188-181, MIL-STD-188-182, and MIL-STD-188-183, no later

than 30 September 1996... All users who are unable to comply with this policy are required to submit a waiver."

More information about DAMA can be found in the Army Satellite Communications Architecture Book. To get information about terminals that have been DAMA certified go to: http://jitc.fhu.disa.mil/it/uhfdama.htm.

Mobile User Objective System (MUOS)

UHF is the only part of the spectrum the permits sufficient triple canopy foliage signal penetration to small hand-held terminals. Also, there is a great deal currently invested in UHF terminals and any follow-on system will have to take into consideration the need for backward compatibility.

Several studies have clearly shown that many existing and emerging narrowband requirements could be satisfied by commercial SATCOM systems.

The Mobile User Objective System (MUOS) is the next generation narrowband system for the mobile warfighter and is the follow-on to UFO. Initial operational capability will occur in 2007 using existing satellites. The first of two new satellites (with possibly three additional satellites to follow those) for the MUOS space segment will be launched in 2010. MUOS segments will include the new satellites, ground control systems, ground terminals, and gateways/teleports.

Ground terminals will migrate from the AN/PSC-5, Spitfire to the SCAMP and then eventually to the Joint Tactical Radio System (JTRS). The JTRS will be a software programmable and modular communications system that will be interoperable with legacy waveforms. When JTRS is fully fielded, true interoperability will then finally be achieved between Services.

Defense Satellite Communications System Phase III (DSCS III)

(http://www.af.mil/factsheets/factsheet.asp?fsID=95)

DSCS III is designed to provide SHF wideband communications for worldwide long haul communications to fixed and mobile national, strategic, tactical and other designated governmental users. This includes Presidential communications, the Worldwide Military Command and Control System (WWMCCS), from early warning sites to operations centers, and unified and specified commands and tactical forces. The system consists of DSCS III satellites in geosynchronous orbit, ground control stations and user terminals. Residual satellites with some limited operational capability are available for increased traffic capacity and flexibility in providing coverage to specific areas around the world. The final DSCS III satellite was launched in 2004.

Under normal operating conditions DSCS III provides substantial worldwide capacity of high quality voice circuits and wideband data circuits. During and after nuclear attack or when being jammed, the system concentrates its capabilities by reducing the number of channels to meet minimum essential communications requirements of high priority users. The U.S. Army Space and Missile Defense

Command (SMDC) performs DSCS III communications payload control while Air Force Space Command (AFSPC) provides command and control of the satellite vehicles in the constellation via the 50th Space Wing's 3rd Space Operations Squadron.

The first DSCS III satellite was launched in October 1982. There are currently ten DSCS III satellites in geostationary orbit, five of which are primary and five are in reserve. Each of the five operational satellites and spare satellites has a primary and alternate network control station located at major nodes such as Ft. Detrick, Maryland. The design life for each satellite is 10 years. The satellites are at an altitude of approximately 22,300 miles in a geostationary orbit around the equator. All ten satellites are in continuous 24-hour operations with the reserves/spares primarily used for GMF training missions.

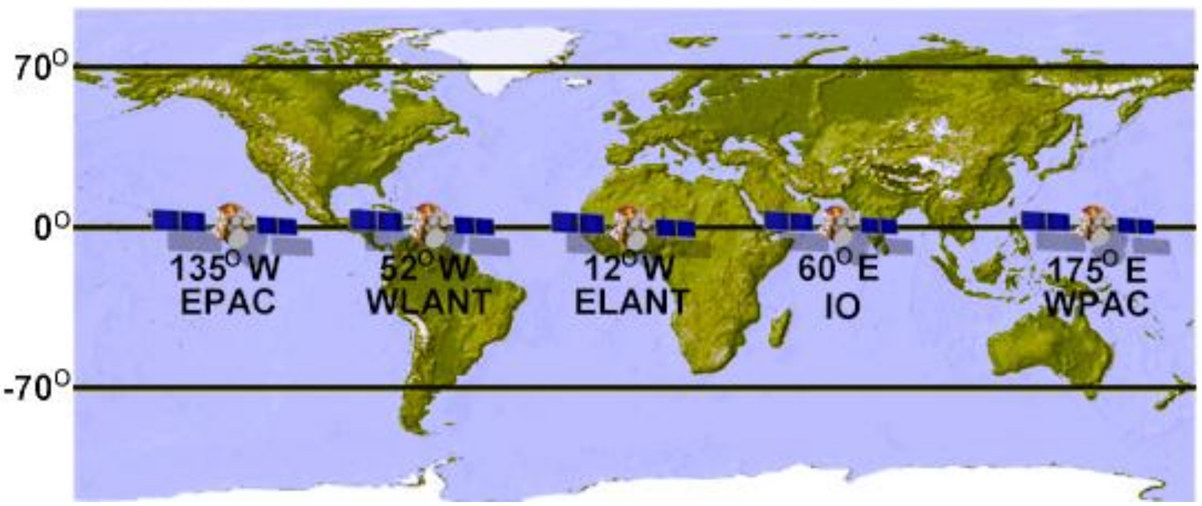

Figure 5-8: Primary DSCS Locations

The 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 above 70° latitude to 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 ten satellite constellation of DSCS III allows most earth terminal locations to access at least two satellites.

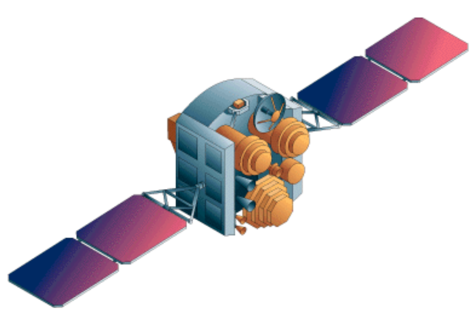

Figure 5-9: DSCS III

The DSCS III 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.

There are two communications subsystems on the DSCS III. The primary system has eight antennas which can be connected in various ways to six independent transponders. Each transponder has its own limiter, mixer and transmitter so that it can be configured to serve specific types of user requirements. There are two earth coverage horns and one multi-beam receiving antenna. The multi-beam antenna can form any beam of arbitrary size and shape, and can be oriented toward specific locations within the footprint by means of a beam-forming network that controls the relative amplitudes and phases of each of 61 individual beams. This antenna can also form "nulls" in selected directions to counter jammers on the ground. Two transmitters on the satellite are always connected to earth coverage antennas. One antenna is a Gimbaled Dish Antenna which provides a 3-degree spot beam. The other earth coverage antennas are two 19-beam transmit multi-beam antennas. These antennas do not have the "nulling" capability.

The secondary communications subsystem on DSCS III is AFSATCOM. This package has its own UHF transmitting and receiving antennas, but can be connected to the earth coverage or multi-beam receiving antennas.

DSCS III provides range extension for the following types of networks:

- Global Command and Control System (GCCS)
- Defense Switched Network (DSN)
- Jam Resistant Secure Communications Networks
- Tactical Warning/Attack Assessment Networks (TW/AA)
- Mobile Subscriber Equipment (MSE)
- White House Communications Agency
- Navy Flagship Command and Control Network
- Ground Mobile Forces and AFLOAT communications

Ground terminal characteristics such as transmit power, antenna size, and antenna elevation angle with respect to the satellite determine a terminal's ability to communicate within a footprint from its particular location.

Satellite Control

The Chairman, Joint Chiefs of Staff has primary responsibility for DSCS III with the Defense Information Systems Agency (DISA) having management responsibility for its control segment. 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.

USARSTRAT/SMDC's, (1st Space Brigade) 1st Satellite Control Battalion, has a critical role in the worldwide operation of DSCS III. Its mission is to provide communications network control for the DSCS III. The 1st SATCON Battalion operates and maintains the five DSCS III Operations Centers (DSCSOCs) worldwide. The DSCSOCs provide real-time monitoring and control for the DSCS III and GMF networks. They provide payload control of the satellites, which involves commanding changes to transponder and antenna configuration.

The DSCS III 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. The control segment optimizes the network configuration, responds to jammers and generates command sets to configure the satellite and processes telemetry from the satellites.

To accomplish these responsibilities, the U.S. Army Space and Missile Defense Command operates the DSCS III Operations Centers (DSCSOC's), Regional Space Support Centers (RSSC), the AN/MSQ-114 SATCOM Control Terminals, and provides personnel in the DSCS III Control Facility which is part of the Consolidated Space Operations Center (CSOC) at Schriever Air Force Base.

DSCS III Operations Centers (DSCSOC)

The DSCS III Operations Centers perform payload control on DSCS III satellites and control the user network. Each DSCSOC is a control center for a designated DSCS III satellite. There are currently DSCSOC's in operation at Fort Meade, Maryland; Fort Detrick, Maryland; Camp Roberts, California; Landstuhl, Germany and Fort Buckner, Japan.

Regional Space Support Centers

Regional Space Support Centers (RSSC) are another component of the U.S. Army Space and Missile Defense Command. There are three RSSCs. (Washington, D.C.; Wheeler Air Force Base, Hawaii; and Vaihingen, Germany.) The RSSCs are focal points for Combatant Commander tactical MILSATCOM requirements. At present the focus of the RSSCs is on DSCS III; however, there are concepts to expand the RSSCs role to handle requirements for other MILSATCOM systems, DMSP, GOES, NOAA satellites, GPS, and surveillance and warning systems.

DSCS III Access

Access to the DSCS III satellites is accomplished differently for the DSCS III network and the GMF network. For DSCS III network access, the following is a summary of the process:

- Users identify their requirements.
- Users submit their requirements to their supporting Combatant Commander.
- The joint command J6 will coordinate with DISA (GCC or RCC) for the required resources.
- DISA will engineer the link parameters to support the requirements. The information is passed to the DSCS III Ops Centers where the Network Controllers add/subtract/ monitor the entire net.

- The user is informed of the circuit design (power/bandwidth/times of usage).
- 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 (Co-located with DISA-GCC or RCC) 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 the 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.

Wideband Gapfiller Satellite (WGS) System

In 2000, the Space and Missile Systems Center (SMC) led a multi-service program to acquire a new series of communications satellites known as the Wideband Gapfiller Satellite (WGS) system to augment DSCS III after about 2004 and finally replace it. Ultimately, WGS would create an Advanced Wideband Satellite system beginning in about 2008. However, the capabilities of the WGS system would be vastly enhanced in comparison to DSCS III. WGS would be able to support 96 channels of communication. SMC awarded a contract for design and advance procurement of WGS to Boeing Satellite Systems on 7 January 2001. On 31 January 2002, SMC authorized Boeing to begin production of the first two satellites, and it authorized production of the third satellite on 21 November 2002.

The WGS space segment will consist of at least three Gapfiller satellites in geosynchronous orbit. Each satellite will provide coverage and capacity to military forces operating anywhere within a field of view from at least 65 degrees North to at least 65 degrees South latitude.

Through nine X-band antennas and ten Ka-band antennas, each satellite will provide two-way X-band, two-way Ka-band and broadcast Ka-band services. The X-band connectivity will be fully compatible with the existing DSCS III service and the Ka-band broadcast capability will be fully compatible with existing GBS service.

Military two-way Ka-band services and crossbanding (X- to Ka- or Ka- to X-) will be a new capabilities initiated on the WGS.

Each satellite will have the flexibility and capability to provide the coverage and capacity needed to support military forces operating in a Major Theater War and/or Small Scale Contingencies. Each satellite will be able to focus its resources to support high concentrations of users in very small areas, surrounding users operating within the theater, and dispersed users transiting to a theater or performing other military missions. The satellites will also be able to provide support to naval, ground, and air forces performing their day-to-day global missions.

WGS satellite acquisition does not include the procurement of ground terminals. Therefore, it is essential that the satellites be 100-percent compatible with the existing ground terminal equipment.

As the WGS satellites are launched, current X-band terminals will capable of operating on either DSCS III or WGS. Additionally, WGS will allow GBS information to be transmitted X-band, crossbanded to Ka-band, and received on existing GBS receive suites. There are no existing terminals that use the military Ka-band required for the two-way Ka-band service; however, the Army will develop ten Engineering Developmental Models to operate over WGS.

As the specifications for this service further develop, the Army will initiate acquisition more programs to procure terminals that are compatible with the WGS satellites.

Milstar

(http://www.af.mil/factsheets/factsheet.asp?fsID=118)

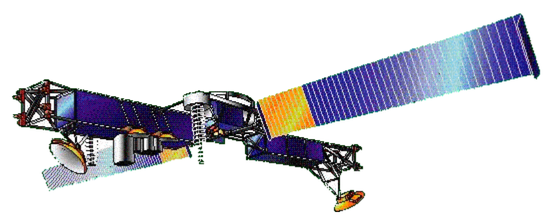

Figure 5-10: Milstar

Milstar (which stands for Military Strategic, Tactical and Relay) satellites operate 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.

Milstar is designed to meet the minimum essential command, control and communications requirements of our POTUS and SECDEF and strategic and tactical multi-service military forces well into the 21st century. The system will allow flexible reconfiguration of the transponders and antennas to optimize the allocation of resources in the satellites. The satellites are in low-inclination geosynchronous orbit at an altitude of approximately 22,300 miles. This orbit gives coverage from 65 degrees north to 65 degrees south. Survivability and durability requirements are satisfied by anti-jam, hardening and system autonomy features.

There are two types of satellites. The Milstar I satellites carry a secure, robust low-data-rate (LDR) communications payload, and a crosslink payload that allows the satellites to communicate globally without using a ground station. The Milstar II satellites extend the communications capabilities to higher data rates by adding a medium-data-rate (MDR) payload. The Milstar I and II satellites are fully interoperable for LDR communications and crosslinks. Using the crosslinks, the constellation supports multiple users simultaneously without reliance upon physically vulnerable nodes. Milstar satellites provide a "communications switch in the sky."

Milstar I satellites carry a low data rate payload that provides worldwide, survivable, highly jam-resistant communications for the POTUS and SECDEF as well as tactical and strategic forces. Advanced processing techniques on board the spacecraft as well as satellite-to-satellite cross linking allow Milstar satellites to be relatively independent of ground relay stations and ground distribution networks. Space Division awarded concept validation contracts for the satellite and mission control segment of Milstar I in March 1982 and a development contract to Lockheed on 25 February 1983. The first Milstar I was successfully launched on 7 February 1994, and the second, on 6 November 1995.

In October 1993, SMC awarded a contract for development of the Milstar II satellite, which carried both low and medium data rate payloads. The addition of the medium data rate payload greatly increased the ability of tactical forces to communicate within and across theater boundaries. Only four Milstar II satellites were produced because DOD had decided in 1993 that they were to be replenished by a new, lighter, cheaper series of Advanced EHF satellites. Unfortunately, the first Milstar II satellite went into an unusable orbit on 30 April 1999. The next two Milstar II satellites were successfully launched on 27 February 2001 and 16 January 2002 to complete an on-orbit constellation of four satellites. The sixth and final Milstar satellite was successfully launched on 8 April 2003.

LDR Payload

The LDR payload offers nearly 200 user channels and relays coded teletype and voice messages at data rates of 75 to 2400 bits per second. The first two satellites are block one birds with only a Low Data Rate (LDR) (75 to 2400 BPS) capability. Milstar flight 1 is positioned at 120° west longitude and flight 2 is positioned at 4° east longitude Milstar LDR supports strategic and tactical requirements for high anti-jam and nuclear scintillation protection. The strategic users are the same as those currently using AFSATCOM. To support this mission, Milstar is designed to be a far more survivable system than AFSATCOM.

MDR Payload

Milstar 1 satellites have been replaced with the constellation of four block two satellites, flights three through six, with increased data rate capabilities. Milstar MDR meets the needs of multiple users by supporting the connectivity of tactical and conventional forces. The MDR payload provides secure, jam-resistant communications services through unique onboard signal and data processing capabilities. It sends real-time voice, video and data to military personnel in the field at rates up to 1.5 Mbps. The payload uses a 32-channel EHF uplink and a SHF downlink. The MDR payload dynamically sorts incoming data and routes them to the proper downlinks to establish networks and provide bandwidth on demand. If necessary it passes the data on to another satellite via crosslink.

The MDR antenna coverage subsystem consists of eight narrow spot beam antennas provided by TRW: two narrow spot beams with nulling capabilities (nuller antennas) and six distributed user coverage antennas, each supporting two-way communications. In contrast to commercial communications satellites, whose beams can cover entire continents, Milstar's beams are very narrow, providing less opportunity for enemy detection and penetration. The nuller antennas resist jamming from within their respective coverage areas by changing their gain patterns when a jamming signal is detected. The distributed user coverage antennas provide high gain/low side lobes for distributed users.

Crosslink Payload

Like a handshake in space, crosslinks provide rapid, secure communications by enabling the satellites to pass signals to one another directly through space while requiring only one ground station on friendly soil. The crosslink payload provides V-band (60 GHz) data communications between Milstar satellites for both the MDR and LDR payloads. This includes modulation and demodulation of the data, upconversion, amplification for transmission and downconversion.

	MDR	**LDR**
Data rate	4.8 kbps - 1544 kbps	75 bps - 2400 bps
No. communications channels	32	192
No. users/channel	1-70	1-4
Coverage	8 high-gain narrow spot beams	2 narrow spot beams 1 wide spot beam 1 earth coverage antenna 1 UHF transmit antenna 1 UHF receive antenna 5 earth coverage uplink agile beams 1 earth coverage downlink agile beam
Anti-jam	Waveform Nuller - active Transmission security	Waveform Transmission security

Table 5-1: Milstar Features

On December 15, 1995, Milstar was the world's first satellite constellation, government or commercial, to employ crosslinks. A message was uplinked from the national Military Command Center at Fort Belvoir, Va., through the Milstar F-1 satellite. It was crosslinked to the Milstar F-2 spacecraft, then downlinked to commanders at Pacific Command at Camp H.M. Smith, Hawaii, and U.S. Atlantic Command at Norfolk, Va.

The Milstar system provides uplink communications at extremely high frequency (EHF), 44 GHz, and ultrahigh frequency (UHF), 300 MHz, and downlink communications at super-high frequency (SHF), 20 GHz, and UHF, 250 MHz. The crosslinks operate in the 60 GHz region.

Communications features of the MDR and LDR payloads are compared in the table above.

Advanced EHF System

The Advanced Extremely High Frequency (AEHF) System is a joint service satellite communications system that will provides near-worldwide, secure, survivable, and jam-resistant communications for high-priority military ground, sea, and air assets. In view of the limited future of the Milstar system, SMC began the acquisition of this follow-on EHF military communications system, known ultimately as AEHF.

The system will consist of three satellites in geosynchronous earth orbit (GEO) providing up to 100 times the capacity of the 1990s-era Milstar satellites, servicing up to 4,000 networks and 6,000 terminals. Assuming a full constellation of three AEHF and one Transformational Satellite (T-Sat), this will provide continuous 24-hour coverage between 65 degrees north and 65 degrees south latitude. Advanced EHF will allow the National Security Council and Unified Combat Commanders to contact their tactical and strategic forces at all levels of conflict through general nuclear war and supports the attainment of information superiority. AEHF will provide connectivity across the spectrum of mission areas, including land, air, and naval warfare; special operations; strategic nuclear operations; strategic defense; theater missile defense; and space operations and intelligence. The AEHF System will provide warfighters with broadcasting, data networking, voice conferencing, and strategic report-back capabilities. It will also provide commanders with the advantages of near-worldwide coverage, multi-user connectivity, protected data, and ease of use. AEHF protections include anti-jam capabilities, Low

Probability of Detection (LPD), a Low Probability of Intercept (LPI), and advanced encryption systems. Finally, the AEHF system is a multinational effort with international partners from the United Kingdom, the Netherlands, and Canada. These international partners will gain access to the AEHF network through their own terminals.

The AEHF system will consist of three segments: space (the satellites), terminals (the users), and mission control and associated communications links. The segments will provide communications in a specified set of data rates from 75 bps to approximately 8 Mbps. The space segment consists of a cross-linked constellation of satellites to provide worldwide coverage. The mission control segment controls satellites on orbit, monitors satellite health, and provides communications system planning and monitoring. This segment is highly survivable, with both fixed and mobile control stations. System uplinks and crosslinks will operate at extremely high frequency (EHF), and downlinks at super high frequency (SHF). The terminal segment includes fixed and mobile ground terminals, ship and submarine terminals, and airborne terminals. User terminals supported by AEHF include Secure Mobile Anti-Jam Reliable Tactical-Terminal (SMART-T), Single Channel Anti-Jam Man Portable (SCAMP), Family of Advanced Beyond Line-of-sight Terminals (FAB-T), and Navy Multiband Terminals (NMT). The AEHF satellites will respond directly to service requests from operational commanders and user terminals providing real-time point-to-point connectivity and network services on a priority basis. On-board signal processing will provide protection and ensure optimum resource utilization and system flexibility among the Military Services and other users who operate terminals on land, sea, and air. The AEHF system will be backward compatible with the low data rate (LDR) and medium data rate (MDR) capabilities of legacy Milstar satellites and terminals, while providing extended data rates (XDR) and other improved functionality at substantially less cost than the previous system. Each satellite will be launched with the Evolved Expendable Launch Vehicle (EELV); the initial launch is planned for 2008-2010. The MILSATCOM Joint Program Office (MJPO) of SMC is responsible for development, acquisition, and sustainment of the AEHF Program.

The system will be compatible with Milstar elements and would incorporate them throughout their useful lifetimes. Like Milstar, but greatly enhanced, the AEHF system will feature on-board signal processing and satellite crosslinks to eliminate reliance on ground stations for routing data. Data uplinks to the satellites and crosslinks between satellites will operate at EHF, and downlinks will operate at SHF.

Transformational Satellite Communications (T-Sat) System

T-Sat will be one of the key enablers for the American vision and doctrine of Network Centric Warfare. The system is intended to provide internet-like capability that extends high-bandwidth satellite capabilities to deployed troops worldwide, and delivers an order of magnitude increase in available military bandwidth. Using laser communications inter-satellite links will create a high data-rate backbone in space, radically improving the system's bandwidth transmission capacity.

A visual image from a UAV that would take 2 minutes to process with the Milstar II satellite system would take less than a second with T-Sat. A radar image from a Global Hawk UAV (12 minutes), or a multi-gigabyte radar image from space-based radar (88 minutes), would also take less than a second with the T-Sat network.

The T-Sat program is actually just one node in a broad spectrum of programs known as the Transformational Communications Architecture (TCA), version 1.0 of which was approved by a Joint Requirements Oversight Council Memorandum (JROCM) on October 23, 2003.

The TCA envisions a Global Information Grid (GIG) that would offer tremendous advances over the current Milstar II systems. They include the Wideband Gapfiller System (WGS), Mobile User Objective System (MUOS) scheduled for launch in 2010, Advanced Extremely High Frequency (AEHF) to be launched between 2008-2010, the Transformational Satellite Communications (T-Sat) System that could be launched from 2012 (as a major improvement over deploying AEHF #s 3, 4 & 5), and an Advanced Polar System for various strategic missions. These programs are all organized around the lifespan of the current Milstar II constellation, which is estimated to remain capable through potentially 2014.

Air Force Satellite Communications System (AFSATCOM)

There are no separate AFSATCOM satellites. Instead, AFSATCOM transponders are packages added to other satellite systems. AFSATCOM provides secure, reliable and survivable two-way global communications between the POTUS and SECDEF and the strategic nuclear forces. The AFSATCOM system is used for Emergency Action Message (EAM) dissemination, JCS/Combatant Commander Internetting, Combatant Commander 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).

Primary satellite systems in geosynchronous orbit carrying AFSATCOM packages include DSCS III and Milstar. The DSCS III payload offers an alternate path for EAM dissemination. 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 that was 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.

There are twelve AFSATCOM 5 kHz channels independent of other communication systems on their host satellites. Seven of the twelve 5 kHz narrow-band channels are regenerative and can only be used for 75 BPS digital communications (not voice). Additionally, the CONUS, Atlantic and Pacific AFSATCOMs have a 500 kHz UHF wideband transponder. This transponder provides connectivity for the JCS/COMBATANT COMMANDER Internets which frequency-hop within the 500KHz bandwidth or it can be divided into 21 accesses of 25KHz allowing customers to share the 500 kHz bandwidth.

Channel capacity is allocated by the JCS. AFSATCOM is “owned” by the Air Force.

OTHER MILITARY SATCOM SYSTEMS

There are far too many satellite systems to discuss in this text. Communications is vital to every country. Satellite communications gives each country the broadcast and range extention capbilities to contect even the most remote areas. Therefore, each country typically places importance on communications satellites as the first satellite priority. The SATCOM can be owned by the country it supports or a leased communications package on another country's satellite. There are several cases where two or more countries form a consortium to build satellites that will support more than one country.

This text will only discuss the foreign satellites that are used to support international military operations. It will not discuss "red" SATCOM.

SKYNET

(http://www.space-technology.com/projects/skynet/)

SKYNET 4 first entered service in 1988. Three satellites were built by British Aerospace and Marconi (now part of Matra Marconi Space (MMS)) for UK service and two more for NATO (NATO IV). All five of these satellites are controlled on behalf of the three UK armed services and NATO by the Royal Air Force (RAF) from ground stations in the UK. Skynet 4B and Skynet 4C were launched by Arianespace in December 1988. As the existing UK satellites (SKYNET 4A, B and C) reach the end of their operational lives, after nearly a decade's service, they will be replaced by three further satellites (SKYNET 4D, E and F), known collectively as SKYNET 4 Stage 2. SKYNET 4D was launched in January, 1998 to replace 4B. 4E was launched in February, 1999. SKYNET 4A and C, still have some useful life left, and will continue to serve alongside the Stage 2 satellites in the short term. The final satellite of the program, SKYNET 4F, has been launched.

The newest satellites have an enhanced communications package that provides UHF (Ultra High Frequency) and SHF (Super-High Frequency) communications services designed to support the UK armed forces in their enhanced roles, such as the NATO Rapid Reaction Force and support of humanitarian aid anywhere in the satellite's coverage. Multiple beams with nulling capabilities at SHF, together with the EHF payload, can provide improved capacity, performance and services combined with ease of use.

A Memorandum of Understanding was signed with France and Germany to undertake a collaborative Project Definition phase for this program, under the title of TRIMILSATCOM.

NATO III and IV

The North Atlantic Treat Organization (NATO) has a constellation of NATO III and IV satellites providing a "general Purpose" military communications system. These SHF satellites which operate in the military X-band are designed to provide communications and intelligence support to the Combatant

Commanders, NATO and to the national command authority of NATO forces. U.S. forces in their NATO role use the NATO constellation.

The NATO SATCOM system currently consists of the NATO IVA and NATO IVB satellites and a previous generation NATO IIID satellite. The satellites are operated in inclined geosynchronous orbits with the NATO IVA satellite carrying operational traffic at 17.8°W, the NATO IVB as the primary spare at 20.2°W and the NATO IIID at 18°W as the final spare.

The NATO IV satellites are versions of the UK Skynet 4 satellites. An important feature of the NATO IV satellites is the ability to survive EMP and electronic interference. The satellites employ signal processing and anti-jamming techniques. They can support a wide range of satellite ground terminals, from strategic to man-pack. The satellite operational life is designed to be 7 years. The NATO IIID satellite has exceeded that design life already.

These satellites should be replaced around year 2005. The present trend is not to replace them by a dedicated NATO system, but to have recourse to commercial systems.

AIR FORCE SATELLITE CONTROL NETWORK

The Air Force Satellite Control Network (AFSCN) is designed to have the flexibility to support a wide spectrum of orbiting satellites. A large number of satellites with various altitudes and orbit inclinations are supported on a 24-hour per day, 7-day a week schedule. In addition to the primary support provided to the Department of Defense (DOD), the AFSCN also provides services for non-DOD organizations, including NASA, and U.S. sponsored programs of foreign governments.

The AFSCN consists of Mission Control Complexes (MCCs), Remote Tracking Stations (RTSs), Automated Remote Tracking Stations (ARTSs), and test facilities located around the world. These personnel, equipment, and facilities of the AFSCN are used to accomplish satellite maintenance. However, these resources are not responsible for the payload data received from the various programs, and do not directly interface with the program users. The resources are there to maintain the satellite in the optimum orbit for mission accomplishment and to ensure the vehicle and payload are performing as designed. They also are there to assist in the restoration of malfunctioning satellites.

The AFSCN accomplishes its assigned mission by tracking data generation, telemetry monitoring, commanding, and testing.

Tracking Data Generation -- Tracking Data is the range, range rate, azimuth, and elevation angles with a time tag received from the Remote Tracking Stations (RTS). This data is used to determine the position of the satellite in its orbit.

Telemetry Monitoring -- The AFSCN systems all space operations squadron crews to monitor the telemetry data from satellites. From this data, the health of the vehicle's various subsystems/sensors can be determined.

Commanding -- The AFSCN also allows crews to send commands to the satellite to operate/configure it. These commands can either be executed in real-time or can be stored by the vehicle for execution at a specified time.

Testing -- Some communications and navigation satellites require extensive measurement, testing, and calibration while in orbit. This procedure is normally performed soon after launch during early orbit testing; however, it can also be done throughout the life or even at the end of life for data collection/trouble shooting purposes. The information gathered in this method can be used to improve future spacecraft.

The network consists of eight subordinate tracking stations located around the world: 23rd Space Operations Squadron, New Boston Air Force Station, NH; Detachment 1, Vandenberg AFB, CA; Detachment 2, Diego Garcia, Chagos Archipelago; Detachment 3, Thule AB, Greenland; Detachment 4, Kaena Point, Oahu, HI; Detachment 5, Andersen AFB, Guam; Colorado Tracking Station, Schriever AFB, and Oakhanger, England, operated by the United Kingdom. The tracking stations command, track, record, and process on-orbit satellite data in support of DOD, NASA, and NATO programs.

COMMERCIAL AND CIVIL SATCOM SYSTEMS

The warfighter will always require the ability to communicate over DoD satellite systems. However, these systems will never satisfy all of the requirements for SATCOM to support military operations. The U.S. military is actively involved with the civil and commercial SATCOM industry in identifying current and emerging technologies that can be leveraged to support the military's goal of full-spectrum dominance. The rapid product cycle that the commercial industry can generate is something that DoD can rely upon and leverage to upgrade military battlefield systems.

The most critical communications in hostile threat environments will be placed on military SATCOM systems. The administrative and logistics traffic as well as peacetime operations traffic can be satisfied more flexibly and economically quite possibly by commercial means. The Army is already using commercial SATCOM extensively (INMARSAT and Iridium represent two of the better known systems). Commercial leases of C- and Ku-band capacity have long been accepted as part of the MILSATCOM system.

Tactical applications for commercial satellites have been tested successfully during recent military operations around the world. Commercial satellites not only provide interoperability between services but also between allied nations. U.S. peacekeeping forces in Bosnia and Kosovo currently use a commercial telecommunications system provided by Spring, Inc. which provide voice and data access to local, worldwide long-distance, and internet services via SATCOM. Alascom transportable terminals, initially deployed to support training

Figure 5-11: INTELSAT

Alascom transportable terminals, initially deployed to support training exercises in Alaska, we transferred to use in Panama during Operation Just Cause. PanAmSat, another commercial satellite system, has provided satellite links to the Army in support of drug interdiction programs in Bolivia and Peru. In Operations Desert Storm and Desert Shield, INTELSAT and INMARSAT were used extensively.

Commercial satellites have limitations, however, that must be mitigated by careful planning. See the section on Planning Considerations to compare the differences between military and commercial satellite systems.

This section will cover some of the more extensively used systems. This is not intended to be all encompassing.

International Telecommunications Satellite (INTELSAT)

The foremost international commercial provider of fixed-site satellite communications services is INTELSAT. INTELSAT was created in 1964, formed on the basis of an international treaty signed by U.S. President John F. Kennedy the previous year. Since then, INTELSAT has achieved a notable record of "firsts" that have inspired other satellite operators to model themselves after the INTELSAT system. It is a UN sponsored, not-for-profit, commercial consortium comprising 143 member countries and signatories.

The satellites operate in the C- and Ku-bands to provide voice, data, and video communications services. INTELSAT has a fleet of 17 high powered, technically advanced spacecraft in geostationary orbit: one INTELSAT V/V-A series, five INTELSAT VI series, seven INTELSAT VII/VII-A and four INTELSAT VIII/VIII-A series. The INTELSAT V-A has 26 C-band transponders and six Ku-band transponders. The INTELSAT VIIIA has 38 C-band transponders and six Ku-band transponders.

The newest generation of INTELSAT spacecraft, the INTELSAT IX series, is in production. The INTELSAT IX satellites will have the largest satellite capacity in the system with 44 C-band transponders and 16 Ku-band transponders. Information about each of the systems can be found at http://msl.jpl.nasa.gov/Programs/intelsat.html.

Tracking and Data Relay Satellite System (TDRSS)

The Tracking and Data Relay Satellite System (TDRSS) is a communication signal relay system which provides tracking and data acquisition services and serves as the sole means of continuous, high-data-rate communication with the Space Shuttle, with the Space Station upon its completion, and with dozens of satellites in low earth orbit. The system is capable of transmitting to and receiving data from customer spacecrafts over at least 85% of the customer's orbit. LANDSAT is an example of a satellite system in low earth orbit that uses TDRSS to relay information.

The TDRSS space segment consists of six on-orbit satellites located in geosynchronous orbit. Three TDRSs are available for operational support at any given time. The operational spacecraft are located at 41, 174 and 275 degrees west longitude. The other TDRSs in the constellation provide ready backup in the event of a failure to an operational spacecraft and, in some specialized cases, resources for target of opportunity activities.

The steerable, single-access antennas can simultaneously transmit and receive at S-band and either Ku- or Ka-band, supporting dual independent two-way communication. The selection of Ku- or Ka-band communications is done on the ground. Receive data rates are 300 megabits/second at Ku- and Ka-band, and 6 Mbps at S-band. The spacecraft carries additional capability for Ka-band receive rates of up to 800 Mbps. Transmit data rates are 25 Mbps for Ku- and Ka-band, and 300 kilobits/second for S-band. In addition, an S-band phased array antenna can receive signals from five spacecraft at once, while transmitting to one.

More information can be found at http://msl.jpl.nasa.gov/Programs/tdrss.html.

International Maritime Satellite (INMARSAT)

INMARSAT is an internationally owned satellite consortium that provides mobile satellite communications services to the shipping, aviation, offshore, and land mobile industries. INMARSAT, with its headquarters in London, England, has 86 member nations.

INMARSAT was originally created in 1979 to serve a global maritime industry by developing a communications satellite system for distress and safety applications. INMARST has expanded significantly to include services to land mobile and aeronautical user terminals. INMARST can be used for disaster relief and emergency communications, and is also widely employed by the media, health teams, disaster relief workers and others in areas where communications would otherwise be difficult or impossible. Services supported by INMARSAT include direct-dial telephone, telex, fax, e-0mail, and data connection.

The system uses 12 satellites (10 operational and 2 spares) at an altitude of about 10,000km and arranged in two intermediate circular orbital planes with an inclination of 45 degrees. Currently there are four INMARSAT-2 and five INMARSAT-3 satellites. The satellites provide cover the globe except the poles. Each of the INMARSAT-2 spacecraft has a capacity equivalent to 250 INMARSAT-A voice circuits and has a design life of 10 years. The communications payload operates in the L-band and C-band.

INMARSAT-3 features spot-beam capability and are each eight times more powerful than INMARSAT-2. The higher power supplies voice and data communications services to mobile terminals as small as pocket-size messaging units on ships, aircraft and vehicles. Each INMARSAT-3 also carries a navigation transponder designed to enhance the accuracy, availability and integrity of the GPS and GLONASS satellite navigation systems.

The use of INMARSAT in the military has grown since Operation Desert Shield and Desert Storm when it was used extensively. There are now over 640 INMARSAT terminals on hand throughout the Army. However, the INMARSAT organization is very specific about how their system can be used. Army users are restricted from accessing INMARSAT resource except under the limitation prescribed by the INMARSAT international consortium charter which states it be used exclusively "for peaceful purposes."

Basically, INMARSAT may be used by the military in life endangering situations, UN peacemaking/peacekeeping operations and forces not involved in armed conflict. The Army policy adheres to these guidelines.

Army forces that require INMARSAT communications services must first have a commissioned terminal and receive permission for access. Army users requiring INMARSAT terminals must follow the procedures in AR 71-9. Users who have a commissioned terminal and require satellite access must submit a Request for Service (RFS) to the Director, DISA, Defense Communications Office (DCO) and to the U.S. Army Signal Command (USASC) Budget Office.

Additional details can be obtained at http://www.inmarsat.com/home.aspx.

Iridium

(http://www.iridium.com)

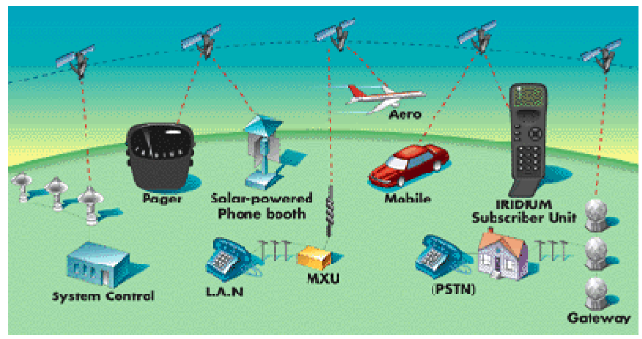

Figure 5-12: How Iridium Works

Iridium is a satellite based personal communications system from Motorola intended to allow service from any point on the globe. Originally consisting of 77 satellites (the atomic number of iridium, hence the name), the system has been redesigned to use only 66 low earth orbiting satellites. Starting on May 5, 1997, the entire constellation was deployed within twelve months on launch vehicles from three continents: the U.S. Delta II, the Russian Proton, and the Chinese Long March.

Iridium is designed to provide commercial voice, data, paging, facsimile, and messaging services. It allows for the use of handheld units much like those used in the cellular industry. Iridium is the first full LEO system in operational orbit to be used by DoD personnel and it is currently under sole source contract to provide DoD Mobile Satellite Service (MSS).

The Iridium constellation is at an altitude of about 420 nautical miles. The satellites are in near-polar circular orbits inclined at 86.4° and distributed into six planes separated by 31.6° around the equator with eleven satellites per plane. There is also one spare satellite in each plane. This low constellation dramatically cuts down the propagation delay of transmissions. It allows for the use of lower powered units. The biggest disadvantage of such a low orbit is the large number of satellites required for global coverage because the satellites pass over the earth quickly. The period of revolution of an Iridium satellite is approximately 100 minutes, so that any given satellite is in view overhead of a user for about 9 minutes at a time.

The system employs L-Band using FDMA/ TDMA to provide voice at 4.8 kbps and data at 2400 bps with 16 dB margin. Each satellite has 48 spot beams for Earth coverage with each beam covering an area the size of the state of Arizona. The satellite has three main beam phased array antennas, each of which serves 16 cells. Each satellite has a capacity of about 1100 channels. However, the actual number of users within a satellite coverage area will vary and the distribution of traffic among cells is not symmetrical. A key feature of Iridium is the use of crosslinks to route traffic directly to other satellites. For the warfighter this means less delay in transmissions and it is also a hedge against jamming and interception of traffic by enemy forces. Iridium uses Ka-Band for crosslinks and ground commanding.

The master control facility for the Iridium constellation is located outside of Washington, DC in northern Virginia. With the aid of three TTAC's (Telemetry, Tracking, and Control centers) located in Canada and Hawaii, this facility will regulate the positioning of the satellites during the initial placement and the ensuing orbit. The system is coordinated by 12 physical gateways distributed around the world, although in principle only a single gateway would be required for complete global coverage. The potential for Iridium's use by the warfighter was considered so great that DoD invested over 14 million dollars to build and have exclusive use of an Iridium gateway in Hawaii.

In late 1999, Iridium ran into financial problems and declared bankruptcy. A consortium of investors purchased the entire Iridium system and made it operational again.

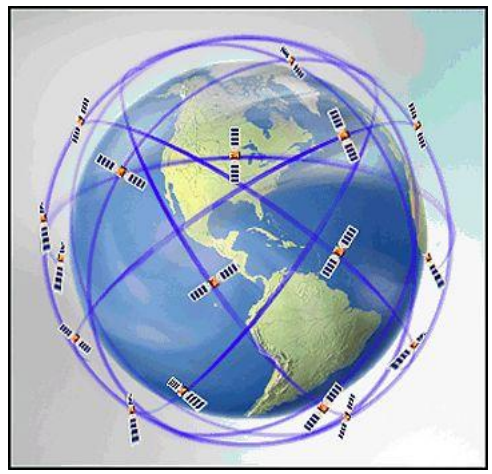

Figure 5-13: Globalstar

DISA, on behalf of DoD, had already invested in the establishment of the military gateway in Hawaii. DISA contracted with Iridium to provide the U.S. military with approximately 5,000 Iridium portable phones and unlimited service. The military Iridium phones are different from civilian Iridium phones in that the military phones have a service that only downlinks from the satellites to the DISA operated Iridium gateway.

Iridium phones are used extensively in Afghanistan and Iraq, and in many other parts of the world.

Globalstar

Globalstar is a consortium of leading international telecommunications companies originally established in 1991. It is a wholesale provider of mobile and fixed satellite-based telecommunications system designed to provide voice, messaging, roaming, and position location services. As Globalstar expands its services it will also offer a range of data services and facsimile services. Globalstar transmits calls from your wireless phone or fixed phone station to a terrestrial gateway, where they are passed on to existing fixed and cellular telephone networks in more than 100 countries on 6 continents.

Globalstar began its progressive roll out of service in September 1999. To ensure quality service to its users, Globalstar service is beginning to be gradually introduced in each location once support systems have been completed and quality service is assured. There are 41 countries scheduled for initial service.

Users can place or receive calls using handheld, vehicle-mounted, or fixed terrestrial terminals. Globalstar's transmission data rate of 9600 bps can support numerous data services. Position location services can determine a user's location within 300 meters.

Globalstar coverage is limited to regions that lie within the same satellite footprint as a gateway station, and Globalstar associates have built far fewer gateway stations than originally planned. Users need to be in the footprint with a gateway station to complete a call. For example, service in Alaska will not be provided further north than Kodiak, as no gateway is near enough - although putting a gateway in Iceland provides service at slightly higher latitudes for North Atlantic shipping.

The first 4 satellites were launched in Feb 1998. The constellation was completed with 48 satellites in 1999. The satellites are in 764 nm circular orbits with 52 degrees of inclination. There are six active and one spare satellite in 8 planes. The satellite design life is 7.5 years. The satellites cover the globe from 70 degrees North latitude to 70 degrees South.

The Globalstar satellite is simple and proven. Each consists of an antenna, a trapezoidal body, two solar arrays and a magnetometer. Each phased array antenna provides 16 user up/down L/S band beams. C-band feeder antenna provides up/down gateway-to-satellite feeder links. The satellites use a "bent-pipe" architecture. On any given call, several satellites transmit a caller's signal to a satellite dish at the appropriate Gateway where the call is then routed locally through the terrestrial telecommunications infrastructure.

Orbital Communications (ORBCOMM)

ORBCOMM is the world's first commercial provider of global low-Earth orbit satellite data and messaging services. The ORBCOMM system enables businesses to track remote and mobile assets such as trailers, railcars and heavy equipment; monitor remote utility meters and oil and gas storage tanks, wells and pipelines; and stay in touch with remote workers anywhere on the globe.

ORBCOMM offers affordable global wireless data and messaging communications services from space. The ORBCOMM system is capable of sending and receiving two-way alphanumeric packets, similar to two-way paging or e-mail. Data rates of 2400 bps subscriber uplink and 4800 bps subscriber downlink are currently available.

The ORBCOMM constellation has 36 satellites in circular orbits 825 km above the earth. There are 16 spacecraft in near polar orbits inclinations of either 70 degrees or 108 degrees. The others are in orbits with 45 degree inclination. Unlike some of the other commercial LEO systems, ORBCOMM provides true worldwide coverage to include the Polar Regions. Pegasus is the launch vehicle used with seven to eight satellites being launched at one time.

FOREIGN SATCOM

There are far too many SATCOM systems to discuss in this text. Below is a list of some of the other SATCOM systems (other than Russia) and the country that owns them. The satellite may support countries other than the owning country.

COUNTRY	SATELLITE SYSTEM	COUNTRY	SATELLITE SYSTEM
Consortium	ARABSAT	Japan	JCSAT
Argentina	NAHUEL	Luxembourg	ASTRA
Australia	AUSSAT	Malaysia	MEASAT
Brazil	BRASILSAT	Mexico	SOLIDARIDAD
Canada	ANIK	Norway	THOR
Egypt	NILESAT	PRC	ASIASAT
Europe	EUTELSAT	Philippines	AGINA
France	TELECOM	Singapore	ST
Germany	DFS	South Korea	KOREASAT
India	INSAT	Sweden	SIRIUS
Indonesia	PALAPA	Thailand	THAISAT
Israel	AMOS	Turkey	TURKSAT
Italy	ITALSAT	UK	SKYNET

Table 5-2: Foreign SATCOM Systems

FUTURE SATCOM SYSTEMS

The DoD's vision for future SATCOM systems foresees advanced telecommunications services using Unmanned Aerial Vehicles, multi-band satellite constellations, superior antenna and ground terminal technologies extending into a worldwide terrestrial fiber-optic network in a clean, seamless manner. The future systems supporting the warfighter must come on line without any degradation or gap in the quantity or quality of required communications. Commercial SATCOM systems will be heavily used when possible to take advantage of the rapid developments in technology.

The nature of future satellite communications systems will depend on the demands of the marketplace (direct home distribution of entertainment, data transfers between businesses, telephone traffic, cellular telephone traffic, etc.); the costs of manufacturing, launching, and operating various satellite configurations; and the costs and capabilities of competing systems - especially fiber optic cables, which can carry a huge number of telephone conversations or television channels. In any case, however, several approaches are now being tested or discussed by satellite system designers.

SATCOM CAPABILITIES

As discussed previously there are many things SATCOM can provide. This section will discuss general capabilities, the capabilities of the various frequency ranges, and the capabilities of the types of SATCOM.

General Capabilities

Satellites provide beyond-line-of-sight communications which are not significantly affected by man-made objects or natural terrain and can provide communications quickly to mobile units. In some situations, neighboring countries may not allow the positioning of ground relays on their territory. For example, during Operation DESERT STORM communications were required between headquarters in Saudi Arabia and Turkey. A ground based line-of-sight system would have required many terrestrial relays to be placed in Jordan and Syria or in Iran. Even if those countries would have allowed U.S. ground relay stations on their soil, security and logistics for such remote sites would have been very difficult.

SATCOM can provide long range communications to remote areas without the need to establish numerous intermediate ground relay links thus communications is available to military forces worldwide, 24 hours a day. Communications satellites are highly reliable and typically operate in space for many years. SATCOM can provide a high volume of signal traffic and high quality circuits. SATCOM terminals are generally smaller and more deployable than the components of comparable non-SATCOM long distance communication systems.

The cost of transmitting information between two users via satellites is essentially the same despite the distance. A signal can be relayed across the country or across the ocean by satellite as cheaply as across the street by satellite. Satellites can be used as broadcast transmitters. Information can be relayed and received over a wide area. Satellites can deliver large amounts of information within a given amount of time

Most satellites can be moved or its antennas aimed to provide better coverage of specific areas. Satellite communication uplinks have a relatively low probability of being intercepted. Directional ground antennas can make transmissions to satellites very hard for an enemy to detect. Many SATCOM satellites are in a geosynchronous orbit and are therefore more survivable against anti-satellite weapons because they are so far away. Lastly, the unique capabilities of satellites are rapidly giving rise to new communications concepts bringing more information more quickly to the warfighter.

Capabilities by Frequency

As indicated in **Figure 5-14**, SATCOM using UHF frequencies are normally more flexible and mobile than the other frequency ranges. SATCOM in the UHF frequency can operate in dense overhead cover and rain. It is the least costly and therefore used quite frequently. SHF is the work horse for the military and commercial user. It offers great capacity at a medium price. Although not as naturally jam resistant as the EHF spectrum, there are ways to make the SHF frequency jam resistant without adding a lot of cost. SHF is typically associated with fixed station and gateway communications.

EHF is very jam resistant and mobile. EHF can operate in a scintillated environment better than UHF or SHF. Although the capacity of Milstar (the Military EHF system) is currently low, EHF, in general, offers the greatest amount of capacity in the future.

Capabilities by Type of SATCOM

Single channel SATCOM supports a variety of missions because of the flexibility and mobility provided. For the warfighter on the ground who is already burdened with large amounts of life support gear, the use of small, portable, single channel SATCOM terminal is very beneficial. Single channel SATCOM is extremely useful in deployment, entry, and short duration operations.

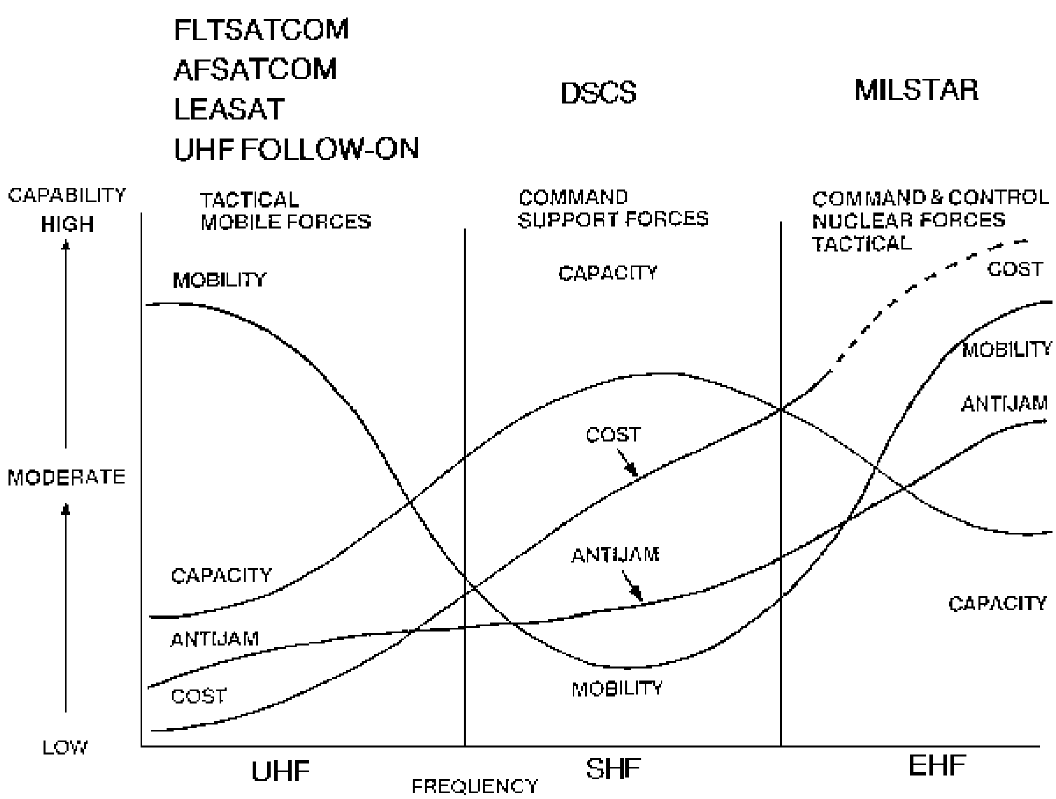

Figure 5-14: Capabilities and Limitations of UHF, SHF, EHF

Access to commercial SATCOM is usually less difficult than military SATCOM access, barring any host nation approval problems. The Army cannot satisfy its myriad communications requirements without commercial SATCOM.

The advantages of multi-channel 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. Satellite communication systems can connect with other military communications systems such as Mobile Subscriber Equipment (MSE), other multi-channel systems, FM radio and radio teletype thus extending the range of users. The inherent flexibility that a satellite communications system provides is essential to the conduct of military operations both nationally and globally.

Commercial SATCOM is readily available and offers better interoperability among multi-national forces.

SATCOM Limitations

There is really no viable alternative to satellite communications for military applications. However, SATCOM has limitations that must be considered.

Limitations in General

From a terrestrial perspective, SATCOM is considered a beyond-line-of-sight system. There must, however, be line-of-sight between the terrestrial terminal and the satellite. Terrain can still effect line-of-sight especially when the angle between the terminal and the satellite it must communicate with is very low. Spot beam downlinks from some communications satellites limit where the signals can be received and downlinks are more susceptible to interception than direct line-of-sight ground systems or cable systems. Broadcast communications can be received by any terminal capable of operating in the frequency band with the correct cryptographic key. Communications on-the-move is possible but still limited.

GEO SATCOM is not easily moved to provide more coverage to the area of operation. Any moves beyond the standard three moves budgeted in the satellites' design life is time consuming and uses fuel that was meant to keep the satellite in orbit thus shortening its life span. GEO SATCOM does not provide communications coverage of the poles. LEO SATCOM doesn't have the polar coverage problem. However, because of the lower orbit, the life span of the satellites is shorter and it is more susceptible to anti-satellite weapons.

Limitations by Frequency

Access to UHF SATCOM channels is tightly controlled. The capacity is relatively low, however, it is adequate to support single channel voice circuits. The long-awaited implementation of Demand Assigned Multiple Access (DAMA) will increase the capacity of the UHF band and provide more access to the channels. UHF signals can be easily detected and jammed by enemy forces and they are disrupted by natural scintillation. UHF has a relatively low capability to resist jamming of the satellites. Current technology UHF signals are easily detected and intercepted.

The cost of the SHF terminals and the satellites is higher than that for UHF, but many of the systems have already been acquired. Therefore, future costs should be moderate. DSCS III is the military SHF system. Mobility is decreased with DSCS III because of the size of the user terminals and antennas, and the power needed to operate them. Army terminals are deployable but require more than one truck per terminal.

EHF satellite and terminal costs are higher than the other frequency spectrums because it is relatively new technology. A new family of user terminals is needed which will increase the overall cost of the system. The designed capacity of the Block I Milstar satellites is relatively low. EHF is extremely degraded in heavy foliage and rain (rain fade).

Limitations by Type of SATCOM:

Single channel SATCOM has a number of limitations the foremost of which is limited capacity. Current ground terminal limitations include a lack of communications on-the-move capability and difficulty in voice recognition over single channel SATCOM systems. Many single channel terminals use UHF frequencies. Milstar single channel terminals will use the EHF band.

Commercial SATCOM has high costs associated with access and it is often difficult to get host nation approval for use. Commercial SATCOM is not jam resistant or nearly as survivable.

PLANNING CONSIDERATIONS

What are the communications requirements? Can they be satisfied with terrestrial systems?

The warfighter must understand who needs the communications, under what conditions, and in what kind of terrain. SATCOM can fill many of the warfighter's requirements for communications to forward units in remote areas, command and control of mobile units, and to units deployed in areas that do not have telecommunications systems available. However, the type of SATCOM used may be different for each situation. Commercial SATCOM can be used when protection of networks is not a priority or the network is designed to provide administration, logistics, or humanitarian/disaster relief communication support. Single channel UHF can be used in dense foliage where single channel EHF cannot. SHF or EHF multi-channel can support requirements for large volumes of data. UHF can support broadcasted information requirements over the area of operation.

The CJCS "owns" all SATCOM assets and apportions them geographically to each Combatant Commander who then owns that portion of SATCOM within their theater. The COMBATANT COMMANDER then apportions out those resources to the J/CTF and/or component commands depending on the warfighting scenario and priorities. The Army Satellite Communications Architecture

Book and CJCSI 6250.01 give all the necessary information about how to request communications satellite access.

Listed below are some questions for leaders and communications planners. The following sections about capabilities and limitations can be used to determine if SATCOM meets the communications requirements, does it need to be MILSATCOM or will commercial SATCOM suffice, and which frequency range meets the requirements. Requirements should be pushed to J6 for resolution.

- What is the mission?
- What types of circuits are required?
- How critical are each of those circuits?
- What information will be passed over the circuit?
- How much capacity is needed?
- Are there validated requirements to support the mission?
- What allied systems must be supported or interfaced with?
- What kinds of ground terminals are available?
- Are there host nation agreement problems?
- What communications mediums are available during each phase of the operation?
- What can the telecommunications network in the operational area provide?
- What MILSATCOM assets are available and will they fulfill the requirements?
- Are leased satellite communications required and/or available?
- Are there international agreements that prohibit their use?
- Does the military have "first rights of refusal" agreements with commercial satellite providers for service if needed?
- Do marginal or residual capabilities on spare satellites need to be activated? Are there test satellite assets available?
- What kind of terrain, climate, vegetation, and/or buildings may be present that will interfere with terrestrial or SATCOM equipment?
- What are the jamming or interception capabilities of threat forces?

- What are the SATCOM capabilities of the threat forces? How will commercial SATCOM support the threat?

COMMUNICATIONS REFERENCES

The Army Satellite Communications Architecture Book, 2003, Fort Gordon, GA

Websites

http://www.losangeles.af.mil/SMC/MC/ – MILSATCOM Joint Program Office Homepage

http://www.fas.org/spp/military/program/com/gbs_jord.htm - GBS Joint Operational Requirements Document

http://www.military.com/ContentFiles/techtv_update_global.htm - GBS information.

http://catalog.com/hitekweb/iridium.htm – Good historical information about Iridium.

http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/iridium.html – Every link ever wanted to an Iridium site.

www.globalstar.com – Globalstar homepage

http://www.orbcomm.com – Orbcomm Homepage

Chapter 6
Navigation Operations

POSITION, VELOCITY, NAVIGATION AND TIMING

Overview

GPS stands for *Global Positioning System*. It is a space-based radio navigation system sometimes referred to as a satellite navigation system. Users of GPS can calculate their location almost anywhere on the earth. The NAVSTAR GPS, operated by the U.S. Department of Defense, is the first system widely available to civilian users. The Russian space-based radio navigation system, the Global Navigation Satellite System (GLONASS), is similar in operation. Currently these are the only two space-based radio navigation systems available for use.

A space-based radio navigation system uses radio transmissions for location determination. Unlike previous navigation systems using ground based transmitters, satellite based transmitters are used to cover earth with higher accuracy than that of land based systems. The satellites transmit timing information, satellite location and health information. The *Space Segment* is technical term for the satellites that belong to the system. The user requires a special radio receiver to receive the transmissions from the satellite. The receiver contains a specialized computer that calculates the location based on the satellite signals. The user does not have to transmit anything to the satellite, and the satellite does not know the user is there. There is no limit to the number of users that can be using the system at any one time.

The two most significant problems for military use of space-based radio navigation are the civilian demand for unrestricted, accurate signals and the continued threat of jamming/RFI. Despite the positive force enhancement of space-based radio navigation, there still exists a very grave threat of jamming/RFI to the receivers and associated navigation data links for Precision Guided Munitions. During Operations Desert Storm twenty-five percent of A-6 precision strike missions incurred unintentional interference problems, thus preventing final aim point refinement.

Both GPS and GLONASS are space-based radio navigation systems. Both GPS and GLONASS provide two sets of positioning signals. The higher accuracy system is reserved for each country's military use. The lower accuracy system is freely available to civilian users. The GPS system is managed by the NAVSTAR GPS Joint Program Office, located at Los Angeles Air Force Base. The civilian point of contact for GPS information is the U.S. Coast Guard's Navigation Center (NAVCEN). Air Force Space Command’s 2d Space Operations Squadron (2 SOPS) provides day-to-day operations of the GPS constellation. Both 2 SOPS and NAVCEN provide GPS information in the form of a Notice Advisory to NAVSTAR Users (NANU). The point of contact for GLONASS information is the Russian Space Force’s Coordination Scientific Information Center (CSIC). The CSIC presents system status information in the form of a document called a Notice Advisory to GLONASS Users (NAGU).

MILITARY POS/NAV APPLICATIONS

Using lessons learned from Operations Desert Shield and Desert Storm, GPS is integrated into DoD combat forces at all levels, from the hand-held receiver carried by the infantryman to the embedded GPS navigation aids on the most modern aircraft to provide precision location determination and navigation support. GPS is a part of the guidance system in most current and all planned precision-guided munitions being acquired by the Services. GPS is also integrated into military forces worldwide, both friend and foe. Forward air controllers, pilots, tank drivers, and ground troops all use GPS to help ensure victory on the battlefield.

GPS receivers can be used for almost any application that requires accurate position location or navigation. It has been said, "If it moves, it can use GPS." There are many different civilian and military GPS receivers that have been developed and new ones are being introduced all the time. GPS receivers have evolved from stand-alone hand-held devices to units fully integrated into operational systems. Some examples of the use of GPS receivers are:

- Special Forces teams inserted behind enemy lines use GPS to navigate and to report their location and the location of enemy units and facilities.
- Helicopters equipped with GPS know their position accurately at all times and navigate with precision along predetermined routes.
- Reconnaissance forces accurately report on enemy positions and forces. Patrols navigate accurately and with confidence at night without landmarks.
- Tanks and other armored vehicles, using external antennas, know their exact position, direction of movement and speed, even when the hatches are closed to protect the soldiers inside.
- Large formations of combat units conduct coordinated, rapid advances without unwanted dispersion.
- Fire support teams report their positions accurately, even while moving rapidly.
- Field artillery units are accurately positioned with less need for surveyed firing points.
- Accurate indirect fire is provided more quickly with fewer rounds used for adjustment.
- GPS prevents friendly units from erroneously navigating into the sectors of adjacent units or into areas mined by the enemy. Once a breach in an obstacle is made by an advancing coalition force, the location is determined using GPS and reported to the other units that planned to pass through that breach.
- Air support, both close-in tactical support and high altitude bombing is more accurate and timely.

- Attack helicopters navigate at night to planned firing positions to engage precisely located targets.
- Logistics units accurately navigate over long distances to precise locations, thus providing support more quickly.
- The location of casualties is determined using GPS and reported. Medical evacuation teams navigate directly to the exact location of the casualties, thus medical support and evacuation is provided more quickly.

In addition to improved stand-alone receivers, GPS is integrated or imbedded into other battlefield systems such as inertial navigation devices, survey equipment, combat net radios, Army Tactical Command and Control System (ATCCS) equipment, and other systems that have a requirement for position determination, velocity or precise time. Even the space shuttle and some satellites use GPS to report their position to ground controllers rather than having to rely on ground-based space surveillance networks.

Grenadier Beyond Line-of-Sight Reporting and Tracking (BRAT)

Real time situational awareness of friendly forces is the center piece of the Army's battlefield digitization efforts. The Army has worked hard for years to develop systems capable of tracking forces in the close battle. However, until now no viable joint solution for forward line of troops and deep battle visualization existed. Grenadier BRAT makes this concept a reality. Grenadier BRAT has been under development since 1994 and has been demonstrated in numerous exercises.

Using the GPS satellites, the Grenadier BRAT devices continually calculate their own location and transmit position reports at preset intervals (such as every 1, 5, or 15 minutes) or on demand. Each message contains the location, altitude, time of report, and a brevity code status message. The transmitted message is relayed to Collection of Broadcasts from Remote Assets (COBRA) receivers on national systems, on aircraft such as the E-8 JSTARS or other Electronic Intelligence (ELINT) collection aircraft, or a local area tower. The collected signals are then sent to a central processing site and transmitted over UHF SATCOM in an Integrated Broadcast Service (IBS) message format. This broadcast is received on special radios owned by all four services.

Key to the success of the Grenadier BRAT capability is the visual display of the data, made possible by using Graphical Situation Display (GSD) software which is resident on Army TENCAP systems. The unit status and location data is then transferred electronically to Maneuver Control System, Global Command and Control System (GCCS) terminals.

More information about Grenadier BRAT is included in Chapter Six of this text.

TALON HOOK

After the shoot down of Capt Scott O' Grady, the TALON HOOK program received special recognition. The USAF created this program to integrate a GPS receiver into the PRC-117 survival radio to take the "search" out of search and rescue. The downed pilot has the HOOK-112 which acts like a regular survival radio, and the pilot can “data burst” transmit his or her position and other information to those who can help. "Those who can help" include:

- National systems that relay information to the processing station and then back to the theater.
- UAVs and U-2s.
- Airborne assets.
- Friendly troops with interrogator units.

Once the location of the downed pilot has been determined and relayed to rescue forces, SAR forces can use the interrogator unit to guide to the pilot's exact location.

Weapon Systems

There are many weapons systems that are or will be using GPS. Aviation systems employ GPS for better position accuracy. The TLAM uses GPS for mid-course guidance, and then switches to terrain navigation for terminal guidance. If terrain navigation fails, GPS guidance is used for the terminal phase. The addition of GPS guidance saves considerable mission planning as well as national systems assets by minimizing the amount of terrain-following navigation required. GPS enables the ATACMS to position itself and calculate the range and firing solution to the target point.

Combat Survivor/Evader Locator (CSEL)

Most current survival radios rely primarily on line of sight (LOS) communication. CSEL gives the warfighter the capability to communicate over-the-horizon (OTH) directly with search and rescue forces around the globe via a robust, automated C3 system. The radio incorporates the latest-generation GPS receiver which gives CSEL an unparalleled ability to precisely identify the location of the warfighter.

Bomb & Missile Guidance

The EDGE (Exploitation of Differential GPS for Guidance Enhancement) program is developing similar capabilities but with GPS rather than laser guidance. In one test at Eglin AFB, a GBU-15, a 2000 lb glide bomb with a combined INS/GPS seeker successfully hit a target 11 miles from its drop point. A U.S. Air Force F-16 dropped the bomb from an altitude of 25,000 feet. The bomb hit within 6 feet (2 meters) of the target. Four DGPS base stations, located approximately 1,000 nautical miles from Eglin AFB were used to provide corrections to the bomb. The EDGE program has since transitioned to the JDAM (Joint Direct Attack Munitions) program.

The first U.S. shots fired at Iraq at the beginning of Operation DESERT STORM were in fact AGM-86C conventional air launched cruise missiles (CALCM) launched from USAF B-52s. These cruise missiles contained rather crude single-channel GPS receivers which were quickly integrated into the missile's existing navigation system. Development on GPS guidance has continued. In a December 1996 test, a CALCM guided solely by GPS successfully struck it's target after a 4 1/2 hour flight, demonstrating precision strike capability.

Listed below are the presently identified Precision Strike Weapons which do/will employ GPS or data links for weapons guidance:

- Tomahawk BLK III Tomahawk BLK IV
- JDAM
- AGM-130 GBU-15
- ATACMS SLAM Ver 2.42

Artillery Pointing

Artillery batteries can shorten the time needed to survey in guns before they begin operation. This is relatively important in modern warfare because artillery batteries must move often to keep from being hit from counter fire. This principle is demonstrated in the U.S. Army's MLRS surface to surface missile system. The MLRS vehicle can carry up to eight unguided rockets in one tracked vehicle. An inertial guidance system in the vehicle is used to position the vehicle and aim the launch box at the target. A single MLRS vehicle can stop, aim, shoot and leave within four minutes while providing the firepower of an entire battery.

SATELLITE SYSTEMS

NAVSTAR Global Positioning System (GPS)

(http://www.af.mil/factsheets/factsheet.asp?fsID=119)

The NAVSTAR Global Positioning System is a space-based, all weather, continuous operation, radio navigation system. The system provides military, civil and commercial users highly accurate worldwide three-dimensional, common-grid, position/location data, as well as velocity and precision time to accuracies that have not been easily attainable before.

GPS is based on the concept of trilateration (similar to triangulation, but in three dimensions instead of two) from known points similar to the technique of "resection" used with a map and compass except that it is done with radio signals transmitted by satellites. The user's GPS receiver must determine precisely when a signal is sent from selected GPS satellites and the time it is received. The receiver measures the time required for the signal to travel from the satellite to the receiver, by knowing the time that the signal left the satellite, and observing the time it receives the signal, based on the receiver’s clock.

Nothing except a GPS receiver and the signals are needed to use the system so GPS is immediately available to soldiers as they deploy into any theater of operation. In addition, GPS receivers do not transmit any signals and are therefore not electronically detectable. Because they only receive signals, there is no limit to the number of simultaneous GPS users.

Background

Soon after the first satellites to orbit the Earth were launched it was realized that a space based navigation system had many advantages to include better coverage, independence from land based navigation beacons and improved accuracy. In the 1960s, the U.S. Navy developed and operated Transit navigation satellites which supported land and sea operations for many years. Timation was a Navy space based position/navigation program that began in the 1960's. It was intended to provide 2-dimensional navigation data. At the same time, the Air Force conducted concept studies for a 3-dimensional navigation system called 621B. There was concern that these systems were duplicating capabilities. The Air Force was designated as the executive agent to consolidate the Timation and 621B concepts into a comprehensive system which could meet the requirements of all the services.

The result was the NAVSTAR Global Positioning System (GPS). The NAVSTAR GPS Joint Program Office (GPS JPO) was established on 1 July 1973. The Transit system was deactivated in 1996 after the more accurate and versatile GPS had proved its capabilities and dependability. GPS development began in the 1970's. By the mid 1980's a few developmental GPS satellites were in orbit, providing a few hours of coverage. Although the constellation was useful as a partial constellation during DESERT STORM, Full Operational Capability (FOC) did not occur until April 1995 after the constellation had 24 satellites and had completed extensive testing.

The then U.S. Army Space Command acquired about 500 Small Lightweight GPS Receivers (SLGR) and successfully demonstrated the capabilities to Army tactical units around the world. By 1990, the demonstration phase was nearing completion when Iraqi forces invaded Kuwait. The U.S. military response was Operation DESERT SHIELD/DESERT STORM. Many of the units who deployed to Saudi Arabia had used the demonstration SLGRs in training exercises. One look at the trackless desert and the soldiers were demanding GPS receivers to solve their navigation problems. Army Space Command sent all available Army SLGRs, and even some the Air Force had stored in a warehouse, to the theater along with officers and NCOs to train units on how to best use the SLGRs. Soldiers were desperate to get their own GPS receivers. Some even wrote to civilian GPS receiver manufacturers to order one and charged it to their personal credit card. GPS receivers have been key pieces of equipment in all the military services ever since.

Segments

The Global Positioning System consists of three major segments:

- Space Segment
- Control Segment
- User Segment

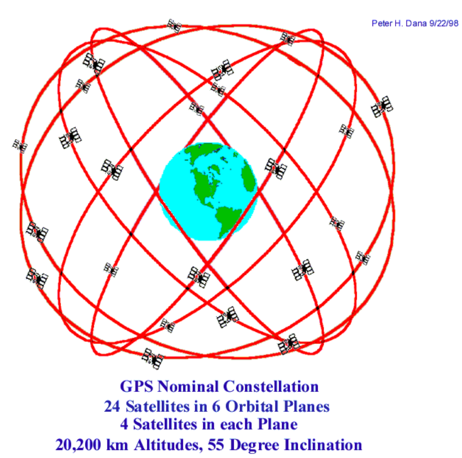

Figure 5-15: GPS Constellation

Space Segment

The space segment has 24 satellites in 6 circular orbital planes with an inclination of 55 degrees. Each plane contains 4 satellites at 10,900 nautical miles altitude with a period of about 11 hours and 58 minutes. These orbital planes maximize coverage of the earth with slight degradation at the poles. The semi-synchronous orbit creates a constantly changing user-to-satellite relation.

The way the satellites are phased within the constellation allows for loss of several satellites with minimal impact on users. This is often called "graceful degradation." As lose satellites for any reason, the constellation capability will "degrade gracefully," meaning should only lose a part of your navigation capability as lose a satellite.

The design life of the current GPS satellites is seven years. Some have continued to function for more than 10 years. The current GPS constellation has 26 operational satellites and 4 operational spare satellites for a total of 30 satellites (as of November 2005). Replacement satellites are launched, as necessary, to replace ones that begin to develop problems or with the design of major modifications to the satellites.

The GPS signals are transmitted continuously by all the GPS satellites. With the fully operational system, users anywhere in the world can receive signals from at least four satellites at all times. Usually, six GPS satellites will be in view. If one satellite should fail to provide accurate data, there are normally sufficient satellites to give total coverage. As a result, availability of the system is estimated at more than 99% of the time. Due to the low GPS signal strength, by the time the signals from the satellites reach the surface of the Earth they are extremely weak. The signals are not able to penetrate more than a few inches of dirt, cannot penetrate through buildings or metal. Terrestrial weather has little effect on the GPS signals. Clouds, rain and snow have little effect. Extremely heavy rainfall will, however, degrade the signal. Very dense, overhead vegetation can block or weaken the signals. In most forests this has not proven to be a significant problem, however, some problems may exist in dense, triple canopy jungle.

Control Segment

The Control Segment works as a system to ensure the overall health and accuracy of the GPS Constellation. It is composed of Monitor Stations, the Master Control Station MCS), Ground Antennas (GA), and people. The Monitor Stations measure the same GPS signals as users. The Monitor Stations are GPS receivers at fixed sites that take accurate measurements from all GPS satellites in view and send them along with satellite clock data to the MCS for processing and error detection. The MCS uses these measurements to calculate errors in the constellation and generate more accurate navigation information for each satellite. Operators in the MCS calculate each satellite's status, ephemeris and clock data which is then sent to transmitting antennas located at the Monitor Stations (except Hawaii) where the data is uploaded to each satellite for inclusion in the navigation message transmitted by the satellites. This is done to maintain the desired system accuracy. The GAs are the interface between the MCS and the Space Segment. They are used to obtain telemetry from the satellites and to transmit commands and navigation information to the satellites. The GAs are located worldwide to ensure we can contact any satellite with minimal delay.

Continuous constellation monitoring is vital for keeping GPS accurate. The constant loop of collecting measurements, processing information, and transmitting to the satellites is all accomplished by the Control Segment.

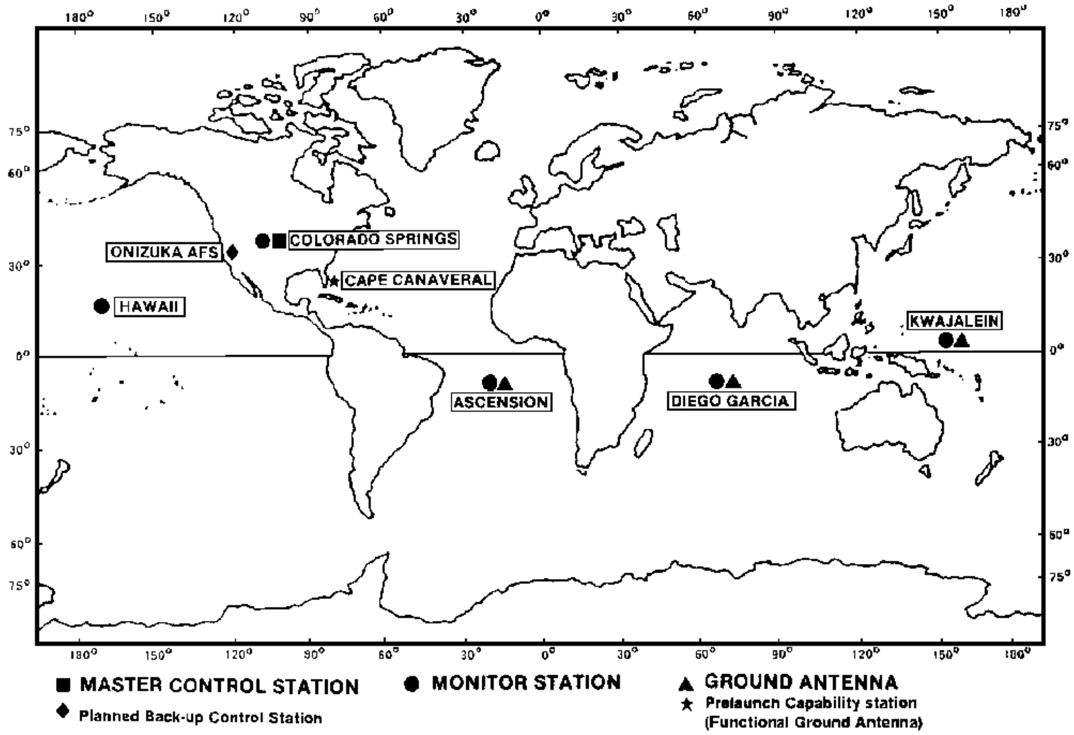

Figure 5-16: GPS Control Segment Locations

The control segment is operated by the 50th Space Wing of Air Force Space Command. The GPS MCS and a Monitor Station are located at Schriever Air Force Base, Colorado Springs, Colorado. Four other Monitor Stations are located in Hawaii, Ascension Island, Diego Garcia and Kwajalein Atoll. The three GAs are located at Ascension Island, Diego Garcia and Kwajalein Atoll. As of 2005, the National Geospatial-Intelligence Agency (NGA) has also tied several of its ground sites into this monitoring/update network for GPS.

Sometimes satellites are taken "off the air" due to maintenance of the atomic clocks, orbital maneuvers, or problems on the satellite. The MCS tries to ensure there is never more than one satellite "off the air." Most maintenance is a scheduled event and a daily notice is published by means of a NANU. It is possible to coordinate maintenance with the MCS so that taking a satellite temporarily out of service floes not have an adverse effect on critical may operations.

User Segment

The User Segment is composed of anyone who can use the navigation signal from space, both U.S. and foreign. Since the signals are broadcast worldwide, the users are worldwide. There are two general categories of users: military and civilian. The growing civilian community's reliance on GPS is becoming a major issue for constellation operations.

How GPS Works

Missions:

GPS has three missions:

- Navigation - primary mission
- Time Transfer - subset of navigation mission
- Nuclear Detonation Detection - secondary mission

Navigation:

The navigation mission is accomplished by broadcasting time-synchronized signals from the constellation of GPS satellites. For a receiver on the ground to determine its 3-dimensional position it must calculate four unknowns: latitude, longitude, altitude and time. For this reason the ground receiver must receive signals from four satellites. If the receiver had a perfect clock, exactly in sync with those on the satellites, three measurements, from three satellites, would be sufficient to determine position in 3 dimensions. Unfortunately, can't get a perfect clock that will fit (financially or physically) in a $300 (or even $3000) receiver, so a fourth satellite is needed to resolve the receiver clock error. Each measurement ("pseudorange") gives the size of a sphere centered on the corresponding satellite. The four satellites generate a solution of the intersection of these four spheres. Due to the receiver clock error, the four spheres will not intersect at a single point, but the receiver will adjust its clock until they do, providing very accurate time, as well as position. To calculate a 2-dimensional position (no altitude) requires three satellites to be in view of the receiver. With a full constellation the receiver can view six satellites from most locations and can view a maximum of twelve satellites from some locations.

A GPS receiver has to acquire and track signals from GPS satellites, achieve carrier and code tracking, collect data from the NAV message included in the signals, and then make pseudorange and relative velocity measurements. From these the receiver can calculate the GPS time, its position and velocity. The results are then displayed on a screen.

To get the best possible accuracy, a GPS receiver will select the satellites that offer the best geometry. This is the same approach that soldiers use in selecting points to sight on when using the technique of resection with a map and compass to determine a location. A more accurate answer is obtained by sighting on two or more points that are far apart. This is also true with GPS. Satellites that appear farther apart in the sky provide a more accurate position solution than ones close together. Since the ephemeris of each satellite is known by the GPS receiver from data obtained from each satellite's navigation message, it is possible to calculate which combination of GPS satellites provide the best geometry at a given time.

The accuracy of GPS receivers is stated in statistical terms. It is important to have some understanding of these terms so that the data, particularly the accuracy of positions, is not misinterpreted. Many GPS receivers can display 10 digits in MGRS grid coordinates which equals to 1-meter resolution. This does not mean that the receiver has 1-meter accuracy. Manufacturers and the military often use different techniques to express accuracy. When comparing performance, the comparison must be made under the same operating conditions and expressed in the same terms. The U.S. Department of Defense commonly uses standards that are stated at the 50% probability. STANAG 4278 states that all navigation system performance figures in NATO documents will be stated at the 95% probability level. The DoD uses 2-dimensional Distance Root Mean Squared (2dRMS) at 95% probability to state accuracies that will be maintained when Selective Availability (SA, discussed later in this chapter) is on. Precise conversion between these different techniques requires a rigorous statistical solution; however, it is possible to give some approximate equivalents. A normal distribution is assumed.

Linear Error Probable (LEP) is defined as the distance from a point on a line within which 50% of the measurements will occur. Usually LEP is used to express the vertical (altitude) error.

Circular Error Probable (CEP) is defined as the radius of a circle containing 50% of the individual measurements. A receiver with an accuracy of 100 meters CEP means that 50% of the time the solution will be correct within a radius of 100 meters and 50% of the time the error will be greater than 100 meters. CEP usually refers to accuracy in the horizontal plane only without regard to vertical (altitude) accuracy.

Spherical Error Probable (SEP) is defined as the radius of a sphere within which there is a 50% probability of locating a point or being located. SEP includes both horizontal and vertical error.

2-Dimensional Distance Root Mean Squared (2dRMS), as defined in STANAG 4278, is the radius of a circle that contains 63% of all measurements. For example, 100 meter (2dRMS) means that 63% of all solutions will be within a circle with a radius of 100 meters. There are, however, some documents that base 2dRMS on a 95% probability level. An accuracy capability of 100 meters (2dRMS @ 95%) is better than 100 meters (2dRMS @ 63%).

Time Transfer

A sub-mission of the navigation mission that is fast becoming critical to communications is the time transfer mission. Time transfer allows users to calculate and synchronize time with great accuracy simultaneously around the world. Each GPS satellite has atomic clocks on board to maintain accurate time. Data on the status and accuracy of these atomic clocks is sent to the MCS. Corrections are sent to the satellites whenever necessary to keep the system within specification. Atomic clocks are not nuclear powered. They get their name because they use the very stable oscillations of certain elements, often rubidium or cesium, to measure the passage of time. The accuracy is very high (+/- 1 second every

360,000 years) but it is not perfect. Since the receiver must adjust its clock to be precisely in sync with GPS time, a GPS receiver can be used as a precise time reference. Some receivers provide a 1 pulse per second output for this purpose.

The atomic clocks are synchronized so that the GPS navigation signal is sent from each GPS satellite at precisely the same time. The specification for accuracy of the GPS atomic clocks provides for time transfer to within 100 nanoseconds of the United States Naval Observatory's (USNO) Universal Time Coordinated (UTC). Although the specification states that the time transfer should be within 100ns, the actual performance of time transfer has been averaging about 10ns. Data in the navigation message tells how far GPS time is off from USNO time so the user can calculate the UTC time to within the 100ns mentioned above.

One of the primary uses of the time transfer is for synchronizing digital communications. There are currently two military radios that use GPS time synchronization: SINCGARS and HAVE QUICK. SINCGARS is a survivable radio used by the Army and the Marine Corps. HAVE QUICK is a radio that employs a frequency hopping scheme for anti jam capability. The "hop'' must occur at the same time as all the other HAVE QUICK radios. This requires accurate time synchronization. GPS can provide the correct time through a GPS user set. The Milstar constellation also uses GPS time synchronization to ensure proper relay of its digitized communications.

All GPS position/navigation receivers calculate the precise time in order to determine location, however, most only display the time to no more than 1/100th of a second. There are special receivers that calculate the time much more precisely.

Nuclear Detonation Detection

The secondary payloads onboard the GPS satellites include a variety of sensors used to detect nuclear detonations (NUDETs). The large number of satellites ensures detection of any event worldwide. A nuclear detonation can be located to within 1.5 km. The system will sense NUDETs and pass the information to the Air Force Technical Applications Center (AFTAC) downlink locations at Buckley AFB, CO (Denver) and Schriever AFB, CO (near Colorado Springs).

Signals, Codes, Services:

There are different signals, codes and services available over GPS. The signals, codes, and services are mutually exclusive entities, yet entirely interrelated. If a user has one, he does not necessarily have the other (e.g., if the user has P-code it doesn't mean he has precise positioning service) but need to know one to explain the other. There are three GPS signals and two codes broadcast at all times. From this there are two basic types of service available.

Signals

The GPS has signals broadcast over three L-Band frequencies L1, L2 and L3). L1 and L2 provide navigation information. L3 is only used to transmit NUDET information and has no impact on navigation users. The primary advantage of getting both frequencies is that can reduce propagation error through the ionosphere. This is done by dynamically measuring differences in refraction caused by the different frequencies. If the receiver does not get both frequencies, it must rely on a less accurate ionosphere model variable factor included in the navigation message.

Codes

The two codes are the Coarse Acquisition Code (C/A-code) and the Precision Code (P-code). As of 7 June 1996, all GPS satellites broadcast both the C/A-code and P-code on L1 and only the P-code on L2.

- The C/A-code consists of a 1023 bit code with a clock rate of 1.023 MHz, hence, it is easy to synch up and acquire. The C/A-code is used to provide Standard Positioning Service. The C/A-code is relatively short and repeats itself every millisecond. A unique C/A-code is assigned to each GPS satellite so that receivers can distinguish among them. A C/A-code-only receiver is less complex and usually less expensive than a P-code receiver. C/A-code is available to all users.

- The P-code is a 267 day long code sequence. Each satellite has a unique seven-day section of the code transmitted with a 10.23 MHz bit rate. The C/A-code is used by P-code users to assist the receiver in reducing the time to acquire the longer P-code. The P-code receivers will generally lock up on C/A-code and read out a handover word to synch up on the P-code. The P-code is more jam-resistant due to the increased bandwidth used for the spread-spectrum scheme. The C/A-code bandwidth is 2.046 MHz, while the P-code bandwidth is 20.46 MHz. The P-code is only available to users authorized by the Department of Defense.

- The Y-code is also only available to authorized users. The P-code is protected against spoofing (i.e., the deliberate transmissions of incorrect GPS information) by encryption of the P-code. When this is done, the P-code is called Y-code. Anti-Spoofing (AS) encrypts the P-code into the Y-code to prevent an enemy from transmitting signals which could mimic a GPS satellite. The same cryptological key used to remove the effects of Selective Availability (SA) is used to decrypt the Y-code into the P-code. SA is implemented on the C/A-code and can also be implemented on the P-code. SA and AS can be implemented independently. Both are discussed in more detail later in this chapter.

Services

The two types of service available are Standard Positioning Service (SPS) and Precise Positioning Service (PPS). Selective Availability (SA) is associated with the services available.

- Standard Positioning Service (SPS). SPS is available to all users around the world. Users do not require any special codes other than standard C/A-code and access to the SPS does not require approval by the U.S. Department of Defense. The accuracy of GPS may be degraded for SPS users, but it is normally within 100m of the horizontal position (2-Dimensional root mean square) 95% of the time. The time transfer function will be within 340ns 95% of the time. In a time of crisis this accuracy can be degraded more significantly to prevent an enemy from using GPS to its advantage. The amount of error induced will be based on DoD policy and decisions. The President will make decisions to change accuracy levels.

- Precise Positioning Service (PPS). Precise Positioning Service (PPS) is a highly accurate position, velocity, and timing service that is only made available to authorized users. Authorized users are those who are designated by the Assistant SECDEF for C3I and who have the crypto keys required to remove SA errors. PPS provides the GPS receiver access to the most accurate signals from the satellites. The 3-D positioning accuracy is guaranteed to 16m Spherical Error Probable at least 50% of the time. This translates to 3-D position within 30m, 95% of the time. The timing accuracy is within 100ns 50% of the time within 197ns 95% of the time. The velocity accuracy is 0.1 meters/second RMS. PPS users have the keys and equipment to decrypt Y-code and remove SA error. PPS users usually have a dual frequency capability based on P(Y)-Code on both L1 and L2.

The key difference between the SPS users and the PPS users is that PPS users have the crypto keys to remove SA errors and decrypt the Y-code. Also of note, most PPS users have a dual L1 and L2 frequency receiver, which allows for better atmospheric error correction and in turn better accuracy. A comparison of SPS and PPS is shown in the table below.

Sources of Navigation Error:

As with any measuring system, GPS cannot provide absolute precision because errors are introduced from a number of different sources. These sources of error are summarized below. The next table shows the typical extent of the error.

The orbits of GPS satellites have been selected to optimize stability, longevity and coverage. The orbits are very stable, therefore it is possible to calculate each satellite's ephemeris with high precision. Even so, slight variations are introduced due to the uneven density of the Earth, magnetic fields in space, fluctuations in solar radiation and other factors external to the satellites. In addition the ephemeris prediction model is not absolutely precise. The monitor stations track each satellite and the GPS control segment updates the ephemeris frequently (usually every four hours) to remove as much error as possible.

GPS ACCURACY

	Standard Positioning Service (SPS)	Precise Positioning Service (PPS)*
Position	76 m SEP 40 m CEP 100 m 2drms @ 95%	16 m SEP 9 m CEP
Velocity	0.5 m/sec	0.1 m/sec
Time	1 millisecond	100 nanoseconds
* PPS is only available to U.S. and allied military, U.S. Government and selected civil users		

specifically approved by the U.S. Government.

Table 5-3: GPS Accuracy

GPS receivers use advanced electronic circuitry to receive, decode and process the data sent by the satellites. The receivers are not, however, perfect so a small amount of error is introduced. If the receiver had a perfect clock, exactly in sync with those on the satellites, three measurements, from three satellites, would be sufficient to determine position in 3 dimensions.

A certain amount of error is caused by reception of multipath signals. Multipath results from signals being reflected off of objects in the vicinity of the receiver. Most receivers employ techniques to minimize the impact of multipath signals.

The ionosphere is made up of charged particles. The size and density of the ionosphere over a particular area is always changing due to sunlight, fluctuations in the Earth's magnetic field, solar radiation and other factors. Radio signals transmitted through the ionosphere are slowed in a manner related to the frequency of the signal and the state of the ionosphere at that instant. The lower the frequency of the signal, the more it is slowed by the ionosphere. Uncorrected ionospheric delay results in significant error in the position solution. PPS receivers receive the P-code on both the L1 and L2 frequencies. Since the same code is transmitted at the same time

SOURCE AND EXTENT OF GPS PSEUDO RANGE ERROR		
	SPS Pseudo Range Error (1σ, or 63%)	PPS Pseudo Range Error (1σ, or 63%)
Satellite clock and navigation stability error	3.0 m	3.0 m
Satellite perturbations	1.0 m	1.0 m
Satellite ephemeris prediction model	4.2 m	4.2 m
Receiver noise	7.5 m	1.5 m
Ionospheric noise	5.0 - 10.0 m	2.3 m
Tropospheric delay	2.0 m	2.0 m
Multipath	1.2 m	1.2 m
Other	1.2 m	1.2 m

User Estimated Range Error (UERE) (calculated by root-square sum)	10.8 - 13.9 m	6.6 m

Table 5-4: GPS Pseudo Range Error

on two different frequencies it is possible to measure the relative difference in the time of arrival and calculate the effect of the ionosphere. SPS receivers cannot process the P-code, therefore an equation is used to estimate the ionospheric delay. This is, however, less accurate than the PPS

SELECTIVE AVAILABILITY MANAGEMENT

The main purpose of Selective Availability Management is to prevent unauthorized users from using the capability of GPS against the U.S. while ensuring that authorized users can use it. The accuracy of GPS may be degraded for SPS users if SA is used, but SA has been set to zero since 1 May 2000 so it is currently not a factor. Normally GPS accuracy should be at least within 100m of the horizontal position (2-Dimensional root mean square) 95% of the time. The Standard Positioning Service (SPS) available to civilian users most likely will give 20 meter horizontal accuracy with SA off. The vertical accuracy is about 1.5 times worse than horizontal, due to satellite geometry. (Satellites are more likely to be near the horizon, than directly overhead.) There are 2 components to Selective Availability Management: Selective Availability and Anti-Spoofing.

Selective Availability

Selective Availability injects known errors into the satellite signal. The injected errors resemble what is required for accurate trilateration. PPS users decrypt corrections to the SA errors to regain high precision accuracy. SPS can provide very good accuracy for most applications. During peacetime, DoD has agreed to keep the error introduced by SA to less than 100 meters (2dRMS) or 76 meters Spherical Error Probable (SEP) at 95% which increases to 300 meters at 99% confidence. This means that 95% of the time the position obtained will be within 100 meters of the "true" (but generally unknown) position and a further 4.99% of the time it will be within 300 meters. However, as the position displayed by GPS receivers is often an average of a number of positions, it could be within about 30 meters or less of the "true" position. The height determined from a GPS receiver in point position mode is even more uncertain. According to the specifications the height will be within 156 meters at 95% confidence, rising to 500 meters at 99.99% confidence.

Users authorized by the U.S. Department of Defense to use GPS are provided with a cryptological key which can be loaded into GPS receivers which are built to store it. The key removes the effects of Selective Availability and allows the receiver to calculate the best solution possible. During a time of crisis, the error caused by SA can be increased to about 2,000 meters, thus making GPS much less worthwhile. SA can be applied to both the C/A-code and the P-code.

Current U.S. policy states we will discontinue the use of GPS Selective Availability (SA) by 2006 in a manner that allows adequate time and resources for our military forces to prepare fully for operations without SA. The President has declared that we will continue to provide the GPS Standard Positioning Service for peaceful civil, commercial and scientific use on a continuous, worldwide basis, free of direct user fees. He stated we would cooperate with other governments and international organizations to ensure an appropriate balance between the requirements of international civil, commercial and scientific users and international security interests. Lastly, we will advocate the acceptance of GPS and U.S. Government augmentations as standards for international use. Implications of this policy are discussed further in this Chapter.

Anti-Spoofing (A/S).

A/S can be implemented to circumvent erroneous impersonation of GPS signals by hostile forces. A/S will replace the normal P-code with an encrypted version called the Y-code. The Y-code can only be decrypted by authorized users. Only the P-code is affected. C/A-code is still subject to spoofing. The table below shows the current GPS Position Error with SA and AS turned off or on.

GPS USER POSITION ERROR				
Selective Availability (SA)	**Anti-Spoofing (AS)**	**Mode**	**SPS**	**PPS**
OFF	OFF	C/A-code	30 m SEP	16m SEP
		P-code	-	16m SEP
OFF	ON	C/A-code	30 m SEP	16m SEP
ON	OFF	C/A-code	76 m SEP	16m SEP
		P-code	-	16m SEP
ON	ON	C/A-code	76 m SEP	16m SEP

Table 5-5: GPS User Position Error

GPS USER EQUIPMENT

The development and acquisition of GPS receivers for the military users is managed by the GPS Joint Program Office (GPS JPO) (http://gps.losangeles.af.mil) located at Los Angeles Air Force Base, California. The GPS JPO is staffed by personnel from the U.S. Air Force, Army, Navy, Marine Corps and Coast Guard along with representatives from the U.S. National Geospatial-Intelligence Agency (NGA), Australia, and many NATO countries. The GPS JPO also provides information to manufacturers of civilian GPS receivers and processors.

Military receivers include two types of portable handsets and an aircraft unit. The SLGR was initially developed as an SPS capable unit as part of the Army Space Demonstration Program. Thousands were eventually bought. Some have been upgraded to accept crypto codes so that they have PPS capabilities. The SLGR was used extensively during DESERT STORM. Most SLGRs have now been turned in and replaced by the Precision Lightweight GPS Receiver. The Precision Lightweight GPS Receiver (PLGR) is the standard PPS hand-held unit. More than 150,000 have been delivered to DoD. The Defense Advanced GPS Receiver will be the follow-on hand held receiver. The MAGR (see below) is the standard receiver for medium and high dynamic aircraft. More receivers are being developed and integrated into weapon systems. The applications for GPS receivers are almost infinite. Extensive information concerning military receivers can be found at http://gps.losangeles.af.mil/user/. Types of military receivers that support/or soon will support Army operations are:

- Precision Lightweight GPS Receiver (PLGR)
- GPS 3A Receiver
- Miniaturized Airborne GPS Receiver (MAGR)
- GPS Receiver Applications Module (GRAM)
- Cargo Utility GPS Receiver (CUGR)
- Special Operations Lightweight GPS Receiver (SOLGR)
- Standalone Air GPS Receiver (SAGR)

In general, the responsiveness and accuracy of GPS receivers is determined by the electronics (hardware) and programs (software) stored in the set. Innovative approaches by manufacturers are common. For military users, the most important feature of a GPS receiver is the ability to use the cryptological code to remove the errors introduced by Selective Availability since this would otherwise be the largest source of position error. Receivers developed solely for military use are able to store the required cryptological key required to compensate for S/A and A-S. The key is loaded by KYK-13 or KOI-18 data loaders. A PPS Security Module (PPS-SM) has been developed so that the cryptological key can be stored in a GPS receiver yet the set remains unclassified.

The number of channels in a receiver determines how many satellites it can receive signals from simultaneously. When not moving, the number of channels in a receiver is not a major factor in determining its position accuracy. When stationary, a 1-channel GPS receiver can be just as accurate as a 5-channel receiver can. More channels do allow a receiver to respond and update position solutions faster. Multiple channels do allow a receiver to remain locked on the satellites in view. A multiple channel set does provide better performance when moving, especially when moving very slowly or very fast. A single channel set does not update its data quickly enough to detect small changes in position. The result can lead to inaccurate direction of movement while moving dismounted in a field environment. A multiple channel receiver detects small changes in position with greater distinction, thus it is able to report a more accurate and consistent direction of movement. A multiple channel set will also reacquire satellites faster following a brief interruption in the signal. The number of channels in a GPS receiver used to be a significant factor in the cost of a set; however, advances in electronics have made sets with five or more channels much more affordable.

Civilian Use of GPS

The civilian market for GPS receivers is expanding rapidly, in many cases faster than the military market. Many companies, both U.S. and foreign, are developing receivers to fill specific needs. Regardless of how many channels and other features to improve performance, all commercially developed sets are C/A-code receivers and are not able to provide PPS because they cannot store the cryptographic codes needed to compensate for SA and cannot decrypt the Y-code AS is turned on. The scientific community and the aviation community are some of the biggest users of GPS. Receivers can cost $100 for a simple SPS receiver with an accuracy of 100m to $15,000 for a L1/L2 carrier phase survey receiver with accuracy up to 0.01m.

Civilian and international users have always been concerned with how they are to depend on a system controlled by the U.S. military. GPS is owned and operated by the U.S. Government as a national resource. DoD is the "steward" of GPS, and as such, is responsible to operate the system in accordance with the signal specification. The March 1996 Presidential Decision Directive, passed into law by Congress in 1998, essentially transferred "ownership" of GPS from DoD to the Interagency GPS Executive Board (IGEB). The IGEB is co-chaired by members of the Departments of Transportation and Defense, and comprised of members of the Departments of State, Agriculture, Commerce, Interior, and Justice as well as members from NASA and the Joint Chiefs of Staff. It allows for both civil and military interests to be included on all decisions related to the management of GPS.

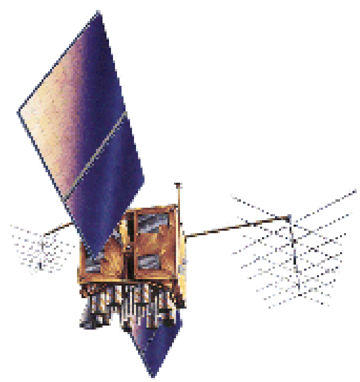

Figure 5-17: GPS Block IIR

U.S. transportation, public safety, economic, scientific, timing, and other users rely on GPS extensively. In aviation and maritime transportation, GPS is used for "safety of life" navigation and it is a critical system for these applications. DOD is the steward of the system, responsible to maintain the signal specification; the IGEB provides management oversight to assure that civil and military needs are properly balanced.

Current Constellation

The operational GPS satellites are designated BLOCK II, BLOCK IIA and BLOCK IIR. The BLOCK II satellites, space vehicle numbers (SVN) 13 through 21, are the first full-scale operational satellites developed by Rockwell International. Block II satellites were designed to provide 14 days of operation without contact from the Control Segment (CS). The Block IIs were launched from February 1989 through October 1990.

The BLOCK IIA satellites, SVNs 22 through 40, are the second series of operational satellites, also developed by Rockwell International. Block IIA satellites were designed to provide 180 days of operation without contact from the CS. During the 180 day autonomy, degraded accuracy will be evident in the navigation message. The design life of the Block II/IIA satellite is 7.3 years; each contain four atomic clocks: two Cesium (Cs) and two Rubidium (Rb); and have the Selective Availability (SA) and Anti-Spoof (A-S) capabilities. The Block II/IIA satellites are launched from Cape Canaveral Air Force Station, Florida, aboard the Delta II medium launch vehicle (MLV).

The BLOCK IIR satellites, SVNs 41 through 62, are the operational replenishment satellites developed by Lockheed Martin and will carry the GPS well into the next century. Block IIR satellites boast dramatic improvements over the previous blocks of satellites, and will have the ability to determine their own position by performing inter-satellite ranging with other IIR vehicles, reprogrammable satellite processors enabling problem fixes and upgrades in flight, and increased satellite autonomy and radiation hardness.

Block IIR

Block IIR satellites are designed to provide at least 14 days of operation without contact from the MCS and up to 180 days of operation when operating in the autonomous navigation (AUTONAV) mode. Full accuracy will be maintained using a technique of ranging and communication between the Block IIR satellites. The cross- link ranging will be used to estimate and update the parameters in the navigation message of each Block IIR satellite without contact from the CS. The design life of the Block IIR satellite is 7.8 years; each will contain three atomic clocks: two Rb and one Cs; and have the SA and A-S capabilities. Additionally, the Block IIR has the ability to be launched into any of the required GPS orbits at any time with a 60-day advanced notice and requires many fewer ground contacts to maintain the constellation. The first launch of a Block IIR satellite, PRN13/SVN43, occurred on July 23, 1997. Launches will continue through the year 2007. Eight of the remaining Block IIR satellites will also be specially modified as GPS IIR-M satellites, the "M" standing for modernized. The first GPS IIR-M was successfully launched on 25 September 2005 from Cape Canaveral, FL. This modernized series offers a variety of enhanced features for GPS users, such as a modernized antenna panel that provides increased signal power to receivers on the ground, two new military signals for improved accuracy, enhanced encryption and anti-jamming capabilities for the military, and a second civil signal that will provide civil users with an open access signal on a different frequency. The new features will not be taken advantage of until receivers are designed and proliferated and there are enough of these satellites in the constellation to take advantage of these new capabilities.

Block IIF and Beyond

Block IIF satellites are the follow-on replacement satellites. The Block IIF satellites are being built by Boeing North America. The first delivery of an early version of the satellites occurred in 2001. Improvements in the Block IIF satellite over previous blocks of GPS satellites include a design life of 15 years, a dramatic increase in the growth space for additional payloads and missions, and provisions for a new high accuracy civilian signal (see below). It will support 3m URE accuracy, crosslink commanding, increased autonomy for reduced ground contacts, and rapid on-orbit reprogramming. The initial contract called for 33 satellites, but there may only be 12 GPS IIFs before GPS III (full modernization) production begins.

Each new satellite will carry multiple cesium-based atomic clocks with current plans which call for Datum to provide 9 clocks, plus an option for an additional 24 clocks. This new program will utilize an upgraded and improved version of the successful cesium clocks, now flying onboard the Block IIA satellites. Datum will utilize the latest design and production techniques in providing this clock technology to Rockwell. The Datum clocks have a long legacy in numerous ground, airborne and shipboard applications, as well as the GPS NAVSTAR.

There will need to be a combination of at least 18 of the Block IIR-M and Block IIF satellites launched, tested and on-station to guarantee availability of the promised second and/or third civil frequencies to the civil user. The earliest anticipated date that we can have 18 of those satellites launched, tested and on station for the second civil frequency is FY 2010.

GLONASS

The Russian Global Navigation Satellite System (GLONASS) is a counterpart to the United States Global Positioning System (GPS). Both systems share the same principles in the data transmission and positioning methods. It is based on a constellation of active satellites, which continuously transmit coded signals in two frequency bands, which can be received by users anywhere on the Earth's surface to identify their position and velocity in real time based on ranging measurements. The GLONASS satellites are similar to the GPS satellites except that they do not have on-board atomic clocks. Precise timing is maintained at ground stations and periodically transmitted to the satellites. In spite of being less complex than GPS satellites, GLONASS satellites have demonstrated an operational life of only a few years; therefore the satellites need more frequent replacement than GPS satellites.

In 1982 the first GLONASS satellites were set into orbit, and the experimental work with GLONASS began. Over this time span, the system was tested, and different aspects were improved, including the satellites themselves. Although the initial plans pointed to 1991 for a complete operational system, the deployment of the full constellation of satellites was completed in late 1995, early 1996. However, since that time, the constellation has degraded and all replacement satellites have not been launched. Current constellation status can be found on the internet using http://www.glonass-center.ru/.

Russia does not degrade the GLONASS signals for any class of users as the U.S. does with GPS signals. The accuracy that GLONASS provides to the general public is actually better than the accuracy GPS currently provides to civil users (but not as good as the accuracy GPS provides to its authorized users). GPS receivers cannot receive data from GLONASS satellites. However, it is possible to buy user sets that receive data from both GPS and GLONASS.

The Russian Federation stated in The Declaration of the Government of Russian Federation, 29 March 1999, the purpose of the GLONASS system is to provide users with continuous coordinate and time information at any point of the globe. The government has declared the provision of a national satellite navigation system GLONASS as a basis for development of international satellite navigation systems. They believe realization of this proposal would promote strengthening confidence and openness in international affairs, upkeep international stability and widen scientific and technical relations between states.

Space Segment

The full space segment of GLONASS would be formed by 24 satellites located on three orbital planes with 8 satellites in each plane instead of the 6 planes of 4 satellites that GPS uses. The three orbital planes are separated 120 degrees, and the satellites within the same orbit plane by 45 degrees. The GLONASS orbits are roughly circular orbits with an inclination of about 64.8 degrees, a semi-axis of 25,440 km and a period of 11h 15m 44s. The 64.8 degree inclination gives the Russians better coverage in the northern latitudes than GPS provides.

Ground Segment

The ground control segment of GLONASS is entirely located in former Soviet Union territory. The Ground Control Center and Time Standards is in Moscow. The telemetry and tracking stations are in St. Petersburg, Ternopol, Eniseisk, Komsomolsk-na-Amure.

User Segment

The user segment consists of GLONASS receivers that automatically receive navigational signals from at least 4 satellites and measures their pseudoranges and velocities. The receivers simultaneously select and process the navigation message from the satellite signals. The receiver processes all the input data and calculates three coordinates, three components of the velocity vector, and precise time.

A few years ago, the first commercial GLONASS two-channel time receivers became available. More recently, companies have developed new GPS+GLONASS multi-channel and multi-code time receivers. Already a number of major timing centers around the globe observe GPS and GLONASS in multi-channel and multi-code mode.

How GLONASS Works

The coordinate system of the GLONASS satellite orbits is defined according to the PZ-90 system, formerly the Soviet Geodetic System 1985/1990. The time scale is defined as Russian UTC. As a difference from GPS, the GLONASS time system includes also leap seconds.

GLONASS uses Frequency Division Multiple Access to broadcast signals from individual satellites as opposed to the Code Division Multiple Access that GPS uses. This means each GLONASS satellite transmits on a slightly different frequency. All satellites transmit simultaneously in two frequency bands to allow the user to correct for ionospheric delays on the transmitted signals. Each GLONASS satellite transmits two types of signals: standard precision (SP) and high precision (HP). SP signal L1 has a frequency division multiple access in the L-band: L1= 1602MHz + n0.5625MHz, where "n" is frequency channel number (n=0,1.2...). This means that each satellite transmits a signal on its own frequency, which is different from the one of the other satellites. These different frequencies allow the user's receivers to identify the satellite. Use of different frequencies for each satellite makes the GLONASS system less vulnerable to interference and jamming than our GPS system.

Superimposed on the carrier frequency, the GLONASS satellites modulate their navigation message. Two modulations can be used for ranging purposes, the Coarse Acquisition code, with a chip length of 586.7 meters and the Precision code, of 58.67 meters. The satellites also transmit information about their ephemeredes, almanac of the entire constellation and correction parameters to the time scale.

GPS Augmentation

Although GPS is, by itself, a very capable system, it is possible to augment the basic system so that the end result is even better. The idea behind GPS Augmentation is to obtain greater accuracies from GPS by using a second source to improve upon the GPS data. This section will give an idea of some of the current augmentation sources. It will also discuss ways to improve upon GPS without outside sources.

There are a variety of sources for GPS Augmentation. Some sources are Differential GPS, Wide Area Augmentation System, Local Area Augmentation System, Exploitation of DGPS for Guidance Enhancement, and GPS Aiding.

Differential navigation (DGPS)

Differential GPS (DGPS) is a means to eliminate the effects of Selective Availability and correct for some GPS errors by using the errors observed at a known location to correct the readings of a roving receiver. The basic concept is that the reference station "knows" its precise position, and determines the difference between that known position and the position as determined by a GPS receiver. The reference stations may be a permanent service, or setup specifically for a project. It measures the distances to each satellite and calculates the errors associated with the satellite. The satellites are so high up, that any error measured by the differential station wall be essentially the same for any receiver in the local area. It then transmits error corrections to any properly equipped GPS differential receiver in the area. When applied at the roving receiver, these corrections greatly enhance its positional accuracy. The correction can be in terms of position, or more often in terms of the observed satellite-receiver distance (the pseudo-range). The corrections may be collected and applied at a later time, or they may be broadcast immediately to the roving receiver by mobile phone, radio or satellite communications.

To use differential GPS must have a local Differential GPS Ground Station and a Receiver Set able to receive and use corrections transmitted from the Differential Station and GPS satellites. DGPS will eliminate the error introduced by Selective Availability, and errors caused by variations in the ionosphere, resulting in reported positions within about 10 meters (33 ft.) of the true position 95% of the time. Better

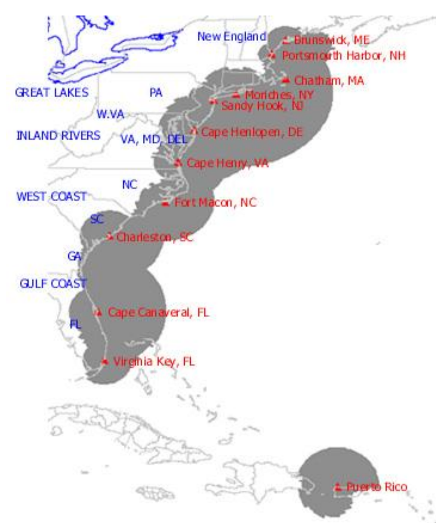

Figure 5-18: East Coast DGPS

receivers can get within 3 meters, or so. The one error correction from the differential station corrects for all the errors in the GPS signal: receiver clocks; satellite clocks; satellite position; ionospheric delays; atmospheric delays. The improved accuracy from differential GPS can bring errors down to within a few feet. The accuracy of DGPS, of the order of a few meters, generally degrades with increased distance from the nearest base station.

For marine use, the U.S. and Canadian Coast Guards (and corresponding agencies in other countries) have established DGPS reference stations that broadcast the correction data over the existing 250 - 350 KHz marine radio beacons. This marine service is available free of charge in the U.S. and Canada, but may only be available by subscription in some countries. The DGPS correction data can be used as far as 1500 KM from the reference station depending on the DGPS setup -- if the DGPS is part of a larger monitoring network.

Differential GPS has potential for applications requiring high accuracy. Some examples are:

- Field artillery and mapping survey.
- Delivery of precision munitions.
- Marking obstacles and cleared paths to follow.
- All weather helicopter operations.
- Non-precision approach for aircraft, particularly into non-instrumented airfields.
- Autonomous operation when the control segment cannot update the satellite ephemeris.
- Instrumented training ranges.

The Coast Guard's maritime Differential Global Positioning Service achieved Full Operational Capability (FOC) on 15 March 1999. NAVCEN operates the Coast Guard Maritime Differential GPS Service, consisting of two control centers and over 50 remote broadcast sites. The Department of Transportation's Nationwide Differential GPS (NDGPS) expansion is underway. The NDGPS plan calls for the conversion of a number of U.S. Air Force Ground Wave Emergency Network (GWEN) sites in their current location and relocation of the remaining sites into desired regions.

More information about DGPS in the U.S. can be found on the Internet at http://www.navcen.uscg.gov/dgps/default.htm.

Wide Area Augmentation System

The Wide Area Augmentation System (WAAS) is an expansion to DGPS. Rather than transmitting corrections within a local area, the corrections will be transmitted across the entire U.S. and potentially worldwide.

WAAS is a safety-critical navigation system that will provide a quality of positioning information never before available to the aviation community. The U.S. FAA is developing this differential GPS system. This system uses a number of reference stations (WRS) scattered around the U.S. These correspond (somewhat) to the differential correction stations of the Coast Guard marine DGPS system, but do not transmit the correction signals themselves. They monitor the GPS signals, ionospheric conditions, and the WAAS correction signal, and transmit the data to the WAAS master stations (WMS). The WAAS master stations take the data, validate past correction signals, and generate a new WAAS correction signal. This correction signal is then transmitted to INMARSAT geosynchronous communications satellites, which retransmit the correction signal to the entire U.S. The INMARSAT satellites transmit the correction signal on the GPS L1 frequency, but use a different pseudorandom (PN) code than any of the GPS satellites. The WAAS beacon receiver could be incorporated directly into a GPS receiver. Any user with a receiver designed to read these corrections could remove the error based on information from the most recently uploaded satellite.

The WAAS is based on a network of approximately 25 ground reference stations that covers a very large service area. Installation of the 25th and final Wide Area Augmentation System (WAAS) Reference Station (WRS) was completed June 3, 1998 at the Federal Aviation Administration (FAA) Air Route Traffic Control Center in Kansas City, Missouri. WAAS will allow a pilot to determine a horizontal and vertical position within 6-7 meters as compared to the 100-meter accuracy available today from the basic GPS service. More information is available at http://waas.stanford.edu/~wwu/WAAS/mops.html.

Local Area Augmentation System

The second augmentation to the GPS signal is the Local Area Augmentation System (LAAS). The LAAS is intended to complement the WAAS and function together to supply users of the U.S. NAS with seamless satellite based navigation for all phases of flight. In practical terms, this means that at locations where the WAAS is unable to meet existing navigation and landing requirements (such as availability), the LAAS will be used to fulfill those requirements.

Similar to the WAAS concept, which incorporates the use of communication satellites to broadcast a correction message, the LAAS will broadcast its correction message via very high frequency (VHF) radio data link from a ground-based transmitter.

LAAS will yield the extremely high accuracy, availability, and integrity necessary for Category II/III precision approaches. It is fully expected that the end-state configuration will pinpoint the aircraft's position to within one meter or less and at a significant improvement in service flexibility, and user operating costs. More information can be found at http://gps.faa.gov/.

Exploitation of DGPS for Guidance Enhancement (EDGE)

EDGE is not truly an augmentation system. The basic concept is to put a GPS guidance package into precision weapons to allow them to hit a target without a man-in-the-loop. By defining the data links that will be used during all phases of employment, EDGE ensures the corrective bias effectively reaches the Precision Guided Munitions. The precision criterion for EDGE is 0.4 meters.

GPS Aiding

GPS Aiding is a form of integrating multiple navigation sources and sensors into the navigation solution. Outside inputs are used to ensure GPS signals are acquired and maintained. In the event GPS signals are lost, these inputs are used to maintain current position until GPS signals can be reacquired. Sources of Aiding include anything that can add to a user's capability to navigate.

Foreign Augmentation Systems

Numerous countries or international organizations believe they cannot afford to depend on, or entrust the security of their people to a system, which is controlled by a single nation, however friendly this nation may be. Therefore, they are designing their own augmentation systems to use with both GPS and GLONASS. The prominent systems that will complement WAAS are the European Geostationary Navigation Overlay System (EGNOS) in Europe and Multi-Satellite Augmentation System (MSAS) in Japan.

FUTURE POS/NAV SYSTEMS

NAVSTAR GPS

In order to improve the accuracy provided by GPS, there are several things that can and are being done. Each of the three segments that make up the GPS system has some part or parts of it that can be improved. As a primary advantage Block IIR and IIF have an autonomous capability with a satellite-to-satellite crosslink.

Current National Policy Impacts

In March 1997 it was announced that two new civilian signals will be provided by the satellite-based U.S. Global Positioning System (GPS). The most immediate benefit of a second civil signal is expected to be in public safety applications, particularly in international aviation, land transportation and maritime uses. Vice President Gore stated that the United States was committed to making this signal available by the year 2005. A lead time of several years was needed because the new signal capability would have to be built into the next generation of GPS replacement satellites (Block IIR-M and up). The addition of a second signal would greatly enhance the accuracy, reliability and robustness of civilian GPS receivers by enabling them to make more effective corrections for the distorting effects of the earth's atmosphere on the signals from space.

To demonstrate commitment to the civil user, the Departments of Defense and Transportation have agreed to identify a second coded civil GPS signal and to develop a plan for providing the signal. Additionally, DoD has agreed not to alter the GPS military coded signal until the second coded civil GPS signal is available. These agreements assist civil users in their constant quest for greater accuracy. The second civil signal will be located at 1227.60 MHZ along with the current military signal, and will be available for general use in non-safety-critical applications. The President's Budget supports implementing this new signal on the satellites scheduled for launch beginning in 2005.

Key to the overall modernization initiative was a recent White House decision on the frequency for a third civil signal that can meet the needs of critical safety-of-life applications such as civil aviation. The third civil signal will be located at 1176.45 MHZ, within a portion of the spectrum that is allocated internationally for aeronautical radio navigation services, and will be implemented beginning with a satellite scheduled for launch in the future. When combined with the current civil signal at 1575.42 MHZ, the new signals will significantly improve the robustness and reliability of GPS for civil users, and will enable unprecedented real-time determination of highly accurate position location anywhere on Earth. This new capability will spur new applications for GPS, further expanding the rapidly growing market for GPS equipment and services worldwide.

Future Management

As GPS moves into its next phase, management and oversight of dual-use aspects of GPS will be provided by the Interagency GPS Executive Board jointly chaired by the Departments of Defense and Transportation, will manage the GPS and U.S. Government augmentations. Other departments and agencies will participate as appropriate. The GPS Executive Board will consult with U.S.

The Department of Defense is required to: acquire, operate, and maintain the basic GPS; maintain a Standard Positioning Service that will be available on a continuous, worldwide basis; and maintain a Precise Positioning Service for use by the U.S. military and other authorized users. From the program's inception in the 1970s, the Department of Defense has been dedicated to successful management of the GPS as a dual-use (civil and military) national information resource. DoD's stewardship of GPS has been instrumental in the growth of a new global industry. The Department will continue working in this new management structure to maintain the delicate balance between global security and economic interests in the operation of GPS.

The Department of Transportation is responsible for serving as the lead agency within the U.S. Government for all Federal civil GPS matters. It is also responsible to develop and implement U.S. Government augmentations to the basic GPS for transportation applications.

Selective Availability

Beginning in 2000, the President has made an annual decision to discontinue use of GPS Selective Availability. To support this determination, the Secretary of Defense, in cooperation with the Secretary of Transportation, the Director of National Intelligence, and heads of other appropriate departments and agencies, has provided an assessment and recommendation on continued SA use. This recommendation has been provided to the President through the Assistant to the President for National Security Affairs and the Assistant to the President for Science and Technology.

GLONASS

Russia continues to have problems maintaining their GLONASS constellation, but pledges to keep trying. The constellation has been incomplete since July 1997. President Boris Yeltsin opened the use of GLONASS to commercial users and offered co-ownership to European countries in exchange for financing. GLONASS M satellites were to be designed as replenishment satellites. Launches began again post-2000 and as of 1 December 2005 there are 13 working satellites in the constellations (about half of what a full constellation).

Galileo

The European Space Agency and the European Commission have signed contracts to build a European rival to the U.S. GPS. The system, called Galileo, will be compatible with GPS. It is envisioned to consist of at least 21 satellites in medium earth orbit at 15,000 miles and possibly complemented by three geostationary satellites at 22,500 miles, and the associated ground control system. The EU also is looking at charging fees for Galileo's services, or at least any expanded services. If built, Galileo may become fully operational as early as 2008.

POS/NAV CAPABILITIES

GPS provides precise navigation and timing signals for hundreds of operations. It has many capabilities that can be relied on during peacetime and warfighting operations. Capabilities we can expect are:

- GPS is there when need it, in all types of weather, 24 hours a day.
- It is worldwide; the signal is sent directly from the satellite.
- Because the system is completely passive, the unit receiving the global broadcast does not radiate and, therefore, is not susceptible to detection.
- Each receiver set can be set to apply many different datums or grid coordinate systems. Sometimes locations on different maps will have slightly different coordinates. By using GPS to specify the correct datum or grid, those minor "coordinate differences" can be resolved. A GPS receiver can be used to translate coordinates from one datum or grid to another.
- It will coordinate time for all units involved in an operation, allowing coordinated attacks.
- It provides precise time for any equipment needing coordinated timing across the battlefield.
- Because access to the P-code is restricted, only those individuals or units with access can use it.
- The GPS constellation is planned for graceful degradation even if the ground segments are taken out. Graceful degradation means that if for any reason the constellation cannot be commanded, the navigation accuracy will worsen slowly over the course of time - it will not be

lost immediately. A Block II vehicle will degrade over 14 days. A Block IIA vehicle will degrade over 67 days. A block IIR vehicle will degrade over 180 days.

- Provides the best position and velocity information available.
- When combined with GLONASS and/or Differential GPS, the timing and location become much more accurate.

GPS accuracy is primarily dependent upon the constellation geometry in relation to the receiver. This geometry can be modeled and used to predict periods of greater and lesser GPS accuracy. Service space professionals are currently using a software package called Space Battle Management Core Systems (SBMCS) for GPS prediction. Information about SBMCS is available from the Army Space Support Teams or the Joint Space Operations Center (JSpOC) located at Vandenberg AFB, CA.

POS/NAV LIMITATIONS

Although GPS is very capable system it also has various limitations. As we become more and more reliant on GPS, it becomes increasingly important to understand its limitations. Knowing the limitations of the system, as well as those of the receiver (which will not be discussed here), the military user can utilize the system to its fullest capabilities without hindering operations. Some factors are limitations of the system, some are limitations of the communications medium and orbit used and some are limitations placed on the system by national policy.

System Limitations

The GPS signal is a low power signal. By the time the signals from the satellites reach the surface of the Earth they are rather weak. The signals are not able to penetrate more than a few inches of dirt, cannot penetrate through buildings or metal. Very dense, overhead vegetation can block or weaken the signals. In most forests this has not proven to be a significant problem, however, some problems may exist in dense, triple canopy jungle. An external antenna must be used when using the GPS receiver in a building, vehicle or aircraft. The GPS signal penetrates Kevlar and canvas with very little loss in power. Weather has little effect on the GPS signals. Clouds, rain and snow have little effect. Extremely heavy rainfall will, however, degrade the signal. Climate, vegetation, and location must all be considered when relying on GPS.

As with all navigation aids, interference, whether intentional or unintentional, is always a concern. GPS signals are communication signals and are subject to the same problems. The signal may be jammed or there may be local interference. The FAA is actively working with the U.S. Department of Defense and other U.S. Government Agencies to detect and mitigate these effects. A number of methods for minimizing interference have been identified and tested and others are being investigated. The FAA is also working to make sure augmentation systems detect and mitigate these effects. The military leader must be aware of the fact that friendly communications systems may interfere with the signal

Any signal can be jammed. The extremely low power levels of the GPS signals transmitted from space can be overwhelmed with local or mobile jammers. We found this out first-hand during Operation IRAQI FREEDOM in 2003 when Iraqi forces used GPS jammers against our forces in Baghdad, albeit with minimal impact in this instance. There are reports of jammers that could jam over a 200-kilometer radius. A company named Aviaconversia announced that it can offer a portable GPS jammer for less than $4000. This jammer is advertised to jam a line-of-sight range of several hundred kilometers. It could realistically be effective at 20 to 40 km.

To maintain its jam resistance, GPS uses two techniques. This combination is difficult, but not impossible to jam. The encrypted GPS frequency on L2 uses a transmission technique called “spread spectrum”. The result of using spread spectrum is that one must jam the entire 10 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. A second method to counter the effects of jamming of the GPS signal is to integrate a GPS receiver into a secondary navigation aid, i.e., combining a GPS receiver and an inertial navigation system (INS).

There is enough concern about GPS jamming that USSTRATCOM has a security program known as Navigation Warfare (NAVWAR). The three principal tenets of NAVWAR are to protect the use of GPS by DoD and allied forces in times of conflict within the theater of operations; prevent the use of GPS by adversary forces; and preserve routine GPS service to all outside the theater of operations. Military users must be aware that the enemy could have the capability to jam the GPS signal at the target location, the friendly locations, or anywhere in the theater AO.

Currently the GPS system is dependent on a ground-based control segment to update each satellite in the constellation. The ground-based control system is susceptible to attacks. Once the Block IIR satellites populate the constellation, there will be a cross-link capability so that only one satellite need be updated. This will reduced the reliance on the ground control segment significantly.

The receiver needs to be in the Line of Sight of at least 4 satellites (hence, it does not work as well in valleys). Most locations will see 6 satellites in line of sight of the receiver but there are still places where the receiver does not have good LOS. Mountainous terrain and urban terrain are among the locations that can cause significant LOS problems. The military user must be aware that line of sight is necessary and consider that fact when using GPS. There are computer programs available that and be used to predict the number of satellites the GPS receiver can see at a given location and at a given time. Using these prediction algorithms can enhance operations that require precise navigation accuracy.

If one is using a differential system, the receiver must also be able to receive the differential signal. The differential signal is different than the satellite signal. The receiver must be designed to receive and utilize both signals.

Communications/Orbit Limitations

The GPS signal is in the UHF spectrum and as such has the same limitations as UHF SATCOM. The UHF frequency range is less jam resistant. It is more susceptible to changes in the ionosphere. Interference is more probable due to the crowded frequency spectrum.

The GPS constellation is located within the Van Allen Radiation Belt. Solar activity (space weather) affects this area more than most layers of space surrounding Earth.

The GPS constellation orbits are in six planes at an approximate inclination of 55 degrees. Although GPS provides worldwide coverage, the coverage in the polar regions is not as good as in more temperate zones. Submarines and aircraft operating at high latitudes may have problems receiving the GPS signals or enough GPS signals to get an accurate position. In addition, the spacing of the satellites in each plane doesn't always give the coverage needed for a specific operation at a specific time. Space tactics have shown what can be done with planned options and creative scheduling techniques to maximize the performance and proper access of the GPS constellation.

Integration discrepancies due to interfaces with host vehicles, embedded systems, power, antenna orientation, output formats, etc. can cause problems.

Other Limitations

Datum

Although the datum is not a true limitation of the system, it is something that military leaders must concern themselves about when using GPS. A datum is the reference framework for the coordinate system, generally consisting of one or more known positions. A geometric model for the Earth's shape (an ellipsoid or spheroid) is usually associated with the reference framework, to allow the computation of geographic coordinates (latitude & longitude). In the past each country established a datum that best fit its region, based on astronomical calculations. Positions in terms of these local datums may be up to many hundred meters different from positions stated in terms of the global coordinate system used by GPS (the World Geodetic System 1984 - WGS84).

Before starting to collect data with your GPS receiver, should select the datum that is compatible with the map, chart or digital data are using. By default, GPS uses the World Geodetic System 1984 (WGS84), but many GPS receivers include a menu of local datums that may select from. may be able to collect the data in terms of WGS84 and transform it later, using a separate software package. The first strategy is preferable if wish to immediately locate your position on a map or chart, but the second method may be better if are uncertain of the local datum, or if wish to later use a better transformation method.

National Policy

The civilian market for GPS receivers is expanding rapidly. Many companies, both U.S. and foreign, are developing receivers to fill specific needs. Regardless of how many channels and other features to improve performance, all commercially developed sets are C/A-code receivers and are not able to provide PPS because they cannot store the cryptographic codes needed to compensate for SA and cannot decrypt the Y-code AS is turned on. However, the current National Policy states that SA will be turned off in the future and that two new civilian frequencies will be added to the future GPS constellation (Block IIF). In addition, Differential GPS has given almost anyone the capability to get near pinpoint accuracy from GPS without PPS.

Countermeasures

In the Master Navigation Plan in May of 1994, the ICS identified the need to develop countermeasures to deny adversaries from using DGPS. The need to develop navigation tactics and countermeasures expanded to include more than just DGPS and resulted in a validated Mission Need Statement (MNS). The MNS covers protection of allied military use and prevention of adversary use of Global Space-Based Navigation Systems. Note that it did not say GPS systems. It is a fairly recent document dated 27 Sep 95.

The best countermeasures for most applications are:

- Accurate user reporting of GPS outages by location and time (e.g. MIJI report) for subsequent G2/ACE analysis.
- Submission of a SIGINT report to identify and geolocate signals operating in the range of 1.5 GHZ and 1.2 GHZ which will cause the GPS receiver to lose position lock.
- Shield the receiver with your body or place it below ground (e.g. in entrenchments). The effectiveness of a GPS jammer that is line-of-sight decreases with shielding.

Recognizing Interference

Receivers differ in the way they react to interference. Sometimes, a unit simply ceases to display position information, or maybe the display freezes, or perhaps the device enters a dead-reckoning mode. Whatever the final outcome, and depending on the equipment, users can look for early warning signs of impending failure. A receiver's displayed measure of signal level or signal-to-noise ratio for example, will indicate deterioration in trustworthiness when an interference signal increases in intensity. The number of satellites tracked may also begin to decline. Some receivers will draw the user's attention by whistling or beeping. However, others may give no warning whatsoever. Users should therefore become familiar with the symptoms of possible interference.

PLANNING CONSIDERATIONS

Q. Does the supported command have sufficient Global Positioning Systems (GPS) receivers? In many units there are an inadequate number of GPS receivers to support sustained operations. A secondary consideration is the type of receiver that is distributed within the unit. If want to use Differential GPS, the receiver must be capable of receiving and using the DGPS signal.

Q. GPS Selective Availability (SA) is currently set to zero (effectively off). Is there a requirement to turn back on the GPS Selective Availability (SA) feature? The GPS SA feature can deny the most accurate GPS navigation/position signal to those who do not have encrypted GPS receivers. Not all military units may be using PPS capable receivers. Turning on SA will affect GPS receivers globally as there is no current way to deny GPS in-theater only. This may affect coalition forces. The authority to turn on the SA feature rests with the POTUS and SECDEF.

Q. Does the command require a capability to jam or deceive (i.e. spoof) commercial GPS receivers? The ability to deny the use of GPS information to any adversary may be a vital military objective.

Q. Does the threat force have the capability to jam or deceive GPS receivers? The GPS signal is a low-level signal and therefore easily jammed. A broadband jammer can effectively hinder our use of GPS. Multiple low watt jammers could also hinder operations or targeting.

Q. Is the threat using GLONASS? If the threat force is using GLONASS (a Russian navigation system) then jamming or denying GPS will not effect their capabilities.

Q. Will the supported command require a GPS differential capability? By using differential techniques, the accuracy of GPS can be significantly improved. This capability can be acquired, but it will require extra equipment, procedures and a fixed location. The GPS receivers must also be capable of receiving the differential signal.

Q. Is there a requirement for knowing "best" GPS coverage times? The satellites in the GPS constellation are constantly moving. Terrain and buildings can mask the signal from the satellites. If specific operations or strike capabilities require accurate GPS, the command must request the capability of identifying those times when the constellation is optimal to support the operation.

Q. What equipment requires the timing signal from GPS? Some communications equipment requires the timing from GPS to maintain frequency hopping and various other operations. GPS jamming or spoofing can effect the timing signal.

Q. Can friendly communications or radar equipment interfere with the GPS signal? Other equipment being used by the friendly forces can jam or interfere with the GPS signal. It is important to know what frequencies all equipment is operating on in order to minimize friendly jamming.

Chapter 7
Intelligence, Surveillance & Reconnaissance (ISR)

INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE (ISR)

The monitoring of air, land and sea targets from space can provide the military information on enemy locations, dispositions, and intentions. This information can provide warning of enemy attack (to include ballistic missile attack), targeting analysis for deep attack, friendly COA development and BDA. This section discusses space support for intelligence, surveillance and reconnaissance, with an emphasis on Imagery (particularly multi-spectral imagery) Intelligence (IMINT) while touching on Signals Intelligence (SIGINT) and Measurement and Signature Intelligence (MASINT). This overall topic may also be referred to as Reconnaissance, Surveillance and Target Acquisition (RISTA). It includes theater ballistic missile detection and warning.

Reconnaissance:

Because space systems have unrestricted overflight of otherwise denied areas, they can gather information about the activities and resources of an enemy or potential enemy.

Surveillance:

Space systems allow commanders to systematically observe and monitor space, surface, or limited subsurface locations or objects at great distances.

OVERVIEW

Analysis of terrain and other environmental factors is a critical step in the Intelligence Preparation of the Battlefield (IPB). The impact of the environment and terrain on the conduct of military operations has been demonstrated throughout history. Without space-based ISR systems, such data can be difficult to obtain, especially in areas where access is limited due to military or political restrictions

Weather and environmental satellites are similar in that they gather information about the nature and condition of the Earth's land, sea and atmosphere by remote sensing. They accomplish this with sensors which observe the Earth in various discrete bands of the electromagnetic spectrum. They are different in that the systems are designed to observe different phenomena and thus have sensors which gather data in different spectral bands with different resolutions. When the data from space systems is merged with that obtained from other ground and airborne sensors, the resultant products are of significantly better quality than those produced from only one source. Weather satellites will be discussed in another chapter.

With the advent of commercial space-based 1-meter resolution imaging capability, there is now a fuzzy distinction between what a remote sensing system is and what a photoreconnaissance system is.

Civilian commercial companies in the United States, Russia, India, and France are selling imagery of various types. Although the commercial companies advertise they are remote sensing programs, the higher resolution images and frequent pass times enables our adversaries access to products that were once only available in the classified national imagery systems. Commercial companies have stated that they will sell as much imagery as is allowed without government intervention. Requesting and buying remote sensing imagery via the Internet is already a growing business. Military commanders and staffs must be aware of what is available to the adversary in peacetime as well as during a crisis.

The Electromagnetic Spectrum

The electromagnetic (EM) spectrum is divided into regions based on wavelength from short gamma rays to long radio waves having a wavelength of many kilometers. All objects transmit, absorb or reflect electromagnetic radiation. These characteristics are different for each type of material; therefore each has its own "signature". For example, healthy vegetation has a strong reflectance of infrared light whereas unhealthy vegetation does not. Both, however, may appear to be the same shade of green.

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. For instance, actively growing vegetation can be easily separated from many other

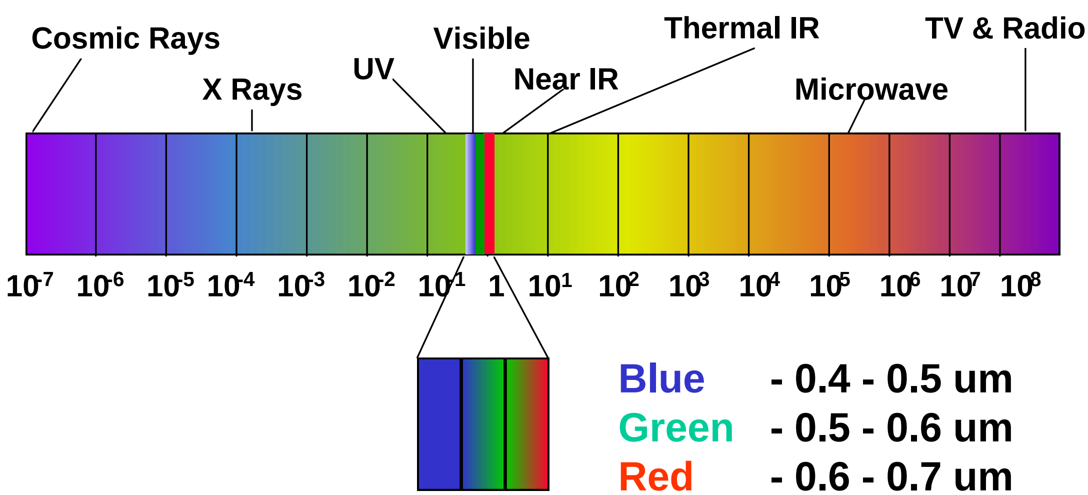

Figure 5-19: Electromagnetic Spectrum

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. Important features like mineral and oil-bearing rock structures are more easily detected using data collected in these longer wavelength IR bands. Emitted or thermal radiance in the mid-wave and long wave regions is also detectable by passive spectral sensors. For ISR purposes, we know that 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.

The human eye can sense electromagnetic waves with a wavelength between only 0.4 μm to 0.7μm (1 μm = 1 micron = 1 x 10^{-6} m = 0.0000001 m). This is visible light. Electronic sensors carried on weather and environmental satellites can sense electromagnetic energy across a much greater portion of the spectrum. Each sensor is designed to detect energy in a specific, narrow band of the spectrum.

Panchromatic Imagery

Black and white imagery that spans the primarily the visual region of the EM (only 2% of the EM spectrum) is called panchromatic imagery. Panchromatic sensors record blue, green and red simultaneously but not separately. Panchromatic imagery displays result in monochrome shades of gray. The human eye can only distinguish approximately 200 shades of gray. Features in panchromatic imagery are interpreted primarily by shape, size, tone, texture, shadow, patter, etc. It is ideal for identifying and analyzing equipment, facilities, and lines of communications. Image manipulation of digital panchromatic imagery can enhance details, sharpen edges, and vary contrast to bring out details which are present, but not evident.

Multispectral Imagery

Spectral imaging systems are digital - they really aren't pictures at all. The multispectral sensors collect data in digital format. A spectral sensor records the intensity of the energy striking it but only in the narrow frequency band that it is designed to detect. Two or more spectral sensors are the core of a multispectral sensing system. Energy outside these spectral bands is ignored. Multispectral sensors simultaneously image a scene in numerous electromagnetic bands ranging from visible light through thermal infrared. Multispectral sensors have a much larger dynamic range than panchromatic sensors, thereby producing higher contrast between objects.

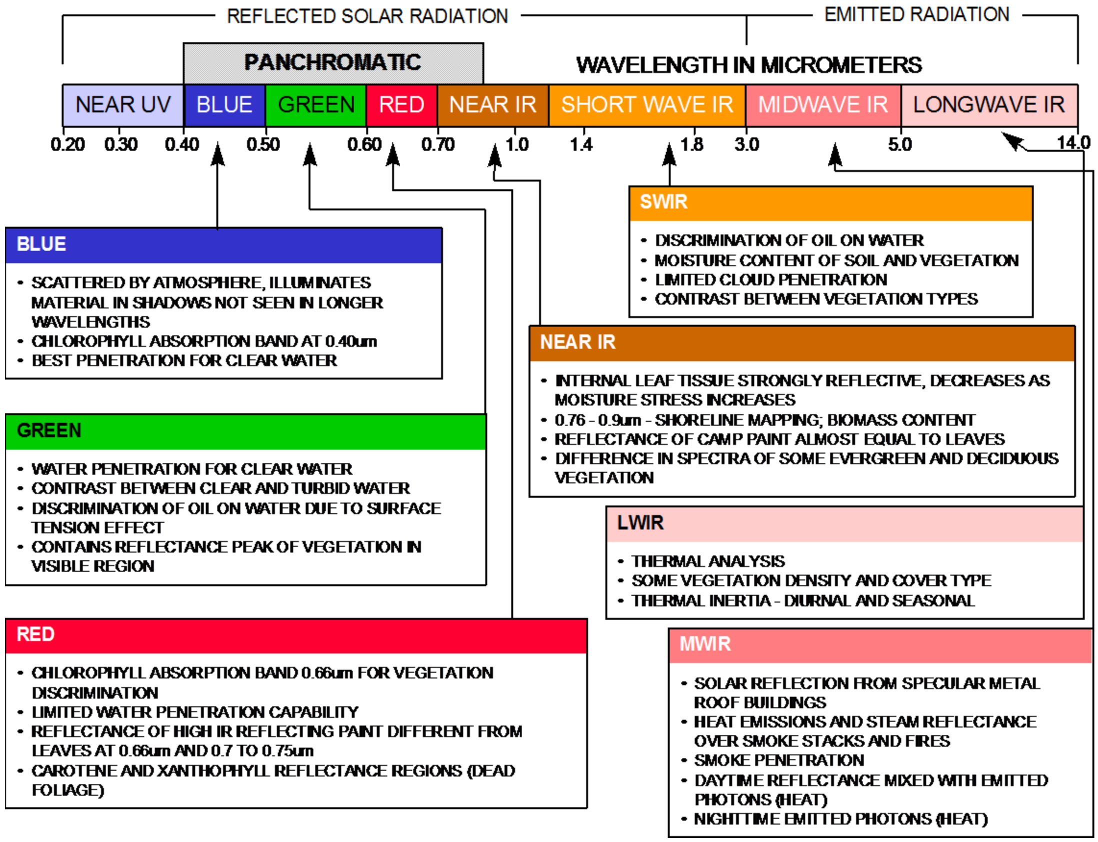

Figure 5-20: Examples of Spectral Regions

The sensors output electronic signals which are converted to digital data. The digital data can be processed in unique ways. For example, haze in an image can be removed by raising the bias level of the signal output. The full dynamic range of the output from the sensors can be digitized and recorded or transmitted to a processing station. After processing, the data from selected sensors are assigned shades of gray or combinations of red, green or blue so that the human eye can see a picture of the data. The resultant image can look significantly different than the normal visible image of the same area. Trained analysts or special computer programs can, however, interpret the image.

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 overlaid electronically with other information, such as slope or land cover data, allowing analysts to derive greater information from the imagery

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. Multispectral sensors are designed to support applications by providing bands that detect information in specific combinations of desirable regions of the spectrum. **Figure 5-20** illustrates the utility of spectral regions. Analysis exploits the spectral separation of reflectance data to detect and identify objects and features.

Each individual object or material has a unique spectral signature based on its reflectance. Spectral imagery records these reflectances and through processing, provides a visual presentation of the reflectance properties. 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.

Three key points to remember are:

- Data is collected simultaneously in defined bands of the spectrum.
- Each object or material has a unique spectral signature.
- Through processing, the data gathered in the selected bands are processed to discriminate the materials of interest.

Key Terms

There are key terms that must be understood when discussing multispectral imagery. Each term gives different parameters of a multispectral system. Many people do not understand what 30-meter or 1-meter spatial resolution actually means and they equate it to the quality of the image and how much detail that can be seen (i.e. equating it to a National Imagery Interpretability Rating Scale (NIIRS) rating used in reconnaissance and surveillance images).

Resolutions

Spatial Resolution

A spectral collection system records electromagnetic (EM) radiation. The EM radiation detected by the collection system may be solar reflected energy or thermal energy (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. A portion of the reflected EM radiation exits through the atmosphere and is received and recorded by the satellite.

This reflected energy is received by the sensor array in the form of individual brightness values for each picture element (pixel). In a digital system, a pixel represents an area on the Earth's surface.

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 also referred to as the Ground Sampling Distance (GSD) and relates to the size of objects that can be detected on the ground from the sensor. 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. An image from the LANDSAT TM sensor, which has a GSD of 30 meters, will not allow for detection of an object that is 5 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

Spectral resolution refers to the spectral position and bandwidth of a sensor. The LANDSAT TM sensor could be said to have moderate spectral resolution (7 relatively wide bands) in contrast to the SPOT panchromatic sensor which 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 will be.

Temporal Resolution

A temporal resolution refers to the time it takes an imaging system to return to an area to collect another image. It is a function of target latitude and satellite orbit. It is essentially a satellite's revisit time to that target. 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, the requested image must wait until that satellite's next pass over the objective area. 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 at the equator.

Radiometric Resolution

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 others.

Viewing Geometries

Viewing geometries for MSI satellites are available in two varieties: off-nadir/ directional viewing and nadir 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. Such systems are excellent for providing images that have minimal geometric distortions. Distortions in nadir imagers are normally due to Earth 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.

Hyperspectral and Ultraspectral Imagery

An outgrowth of multi-spectral imaging is a cross between imaging and spectroscopy known as imaging spectroscopy or hyperspectral imaging. Hyper and ultraspectral sensors split portions of the electromagnetic range of a sensor into hundreds and thousands of bands.

Hyperspectral Imaging (HSI), like MSI, is a passive technique (i.e., depends upon the sun or some other independent illumination source) but unlike MSI, HSI creates a larger number of images from contiguous, rather than disjoint, regions of the spectrum, typically, with much finer resolution. This increased sampling of the spectrum provides a great increase in information. Many remote sensing tasks which are impractical or impossible with an MSI system can be accomplished with HSI. For example, detection of chemical or biological weapons, bomb damage assessment of underground structures, and foliage penetration to detect troops and vehicles are just a few potential HSI missions. A multispectral sensor can detect areas covered with grass. A hyperspectral or ultraspectral sensor can distinguish between Kentucky blue grass and Bermuda grass because the differences in the size of the blades of grass and the differences in chemical composition result in slightly different reflectances.

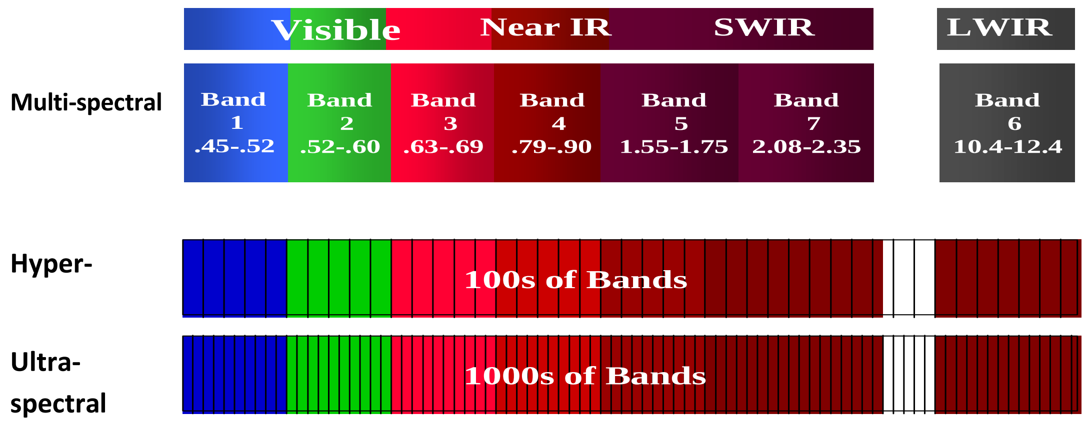

Figure 5-21: Hyper and Ultra-spectral Bands

Hyperspectral remote sensing combines imaging and spectroscopy in a single system which often includes large data sets and requires new processing methods. Hyperspectral data sets are generally composed of about 100 to 200 spectral bands of relatively narrow bandwidths (5-10 nm), whereas, multispectral data sets are usually composed of about 5 to 10 bands of relatively large bandwidths (70-400 nm). This technology is still relatively new. The biggest challenge is the amount of data that must be stored, sent, processed and analyzed. To be able to accurately distinguish subtle differences will require new algorithms and an extensive database of EM signatures of known substances. And even when the technological challenges are resolved, the question of when are 250 bands better than 4 bands will still remain. More bands require more analysis time.

MILITARY IMAGERY APPLICATIONS

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. In recent years, an increasing share of training and equipment resources has been dedicated to field users of MSI, such as USMC and U.S. Army topographic units. USAF and U.S. Navy applications of MSI have also been gaining acceptance, supporting image mapping, mission planning, navigation and targeting. Historically, 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.

DESERT SHIELD/DESERT STORM saw the first wholesale application of MSI. 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.

During operations in Somalia, a large number of organizations pooled resources to acquire and produce MSI products in a coordinated fashion. The Army produced terrain analysis graphics at the U.S. Army Space and Missile Defense 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.

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 U.S. Army Space and Missile Defense Command, featuring an MSI product in the center of a full-sized I-Map, with video snapshots of key points along President Aristede's repatriation motorcade route.

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 separate products 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.

The current information provided by space forces on terrain, surface trafficability, oceanic subsurface conditions, beach conditions, and vegetation permit identification of avenues of approach, specific ingress/egress routes, and other mission parameters. Multi-spectral imagery (MSI) is a contributing source of data for the development and update of Global Geospatial Information and Services (GGI&S) products. 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. Camouflage that couldn't be detected in panchromatic images, such as netting, can be detected using the NIR and SWIR bands. One can also detect vegetation stress and find concealed objects.

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 or the AOR with a picture that is larger than most near-real-time systems.

Image Map or "I-Map" is a common application of Multispectral Imagery and exploit the broad-area coverage capabilities of MSI. An I-Map is nothing more than an image of the area of interest with a commonly understood grid overlaid. Typically, the image is 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 this product is that the user receives a literal image that requires little experience or training to use. This type of image portrays the terrain in near-natural colors, with some enhancements applied to ease use by non-trained personnel. An image map is most useful when a topographic map is not available or when used as a supplement to an older map. Multispectral Imagery provides a means of rapidly updating an older, out-of-date, topographic map with an image map that provides a current, broad-area, synoptic view of the area of operation. The map is 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 that bands selected for the final product appear visually similar.

Perspective Views are a combination of Multispectral Imagery and elevation data such as Digital Terrain Elevation Data (DTED) and Digital Elevation Model (DEM) (produced and maintained under the auspices of the NGA). 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. This can be used to produce 3D perspectives and animated fly-throughs for mission planning or rehearsals.

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 pseudo-color thematic image in which the Multispectral Imagery data has been classified into groups representing different terrain types and land cover. TERCATs are useful in displaying vegetation classes, soil types and hydrology that affect trafficability. 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.

Hydrology and Bathymetry – depths of near-shore channels, reefs, and underwater obstacles can be determined down to about 50 feet in clear water. However, turbid water and submerged vegetation can degrade the accuracy of water depths.

Change detection involves using multispectral imagery over time to record changes in the environment.

REMOTE SENSING AND SATELLITE SYSTEMS

Remote Sensing

Remote sensing and the MSI sensor offer other advantages than just 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.

Remote sensing gives a unique view of the Earth. Remote sensing by satellites, especially multispectral imagery satellites, provides critical information that is of immediate military value over large areas. Remote sensing also has numerous civil and commercial applications which have made it one of the fastest growing areas of space after communications.

Remote sensing is not limited to only satellites nor is it limited to multispectral systems. Remote sensing can be done from virtually any airborne platform. Additional remote sensing capabilities include specific infra-red (IR) sensors and synthetic aperture radar (SAR) capability. SAR uses radar technology in a very specific way. To understand how it works, it is necessary to first understand the basics of radar.

A typical radar (RAdio Detection and Ranging) measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths (in the range 1 cm to 1 m, which corresponds to a frequency range of about 300 MHz to 30 GHz) and polarizations (waves polarized in a single vertical or horizontal plane). For an imaging radar system, about 1500 high-power pulses per second are transmitted toward the target or imaging area, with each pulse having a pulse duration (pulse width) of typically 10-50 microseconds (us). The pulse normally covers a small band of frequencies, centered on the frequency selected for the radar. At the Earth's surface, the energy in the radar pulse is scattered in all directions, with some reflected back toward the antenna. This backscatter returns to the radar as a weaker radar echo and is received by the antenna in a specific polarization (horizontal or vertical, not necessarily the same as the transmitted pulse). Given that the radar pulse travels at the speed of light, it is relatively straightforward to use the measured time for the roundtrip of a particular pulse to calculate the distance or range to the reflecting object. The chosen pulse bandwidth determines the resolution in the range (cross-track) direction. Higher bandwidth means finer resolution in this dimension. The length of the radar antenna determines the resolution in the azimuth (along-track) direction of the image: the longer the antenna, the finer the resolution in this dimension.

Synthetic Aperture Radar (SAR) refers to a technique used to synthesize a very long antenna by combining signals (echoes) received by the radar as it moves along its flight track. Aperture means the opening used to collect the reflected energy that is used to form an image. In the case of a camera, this would be the shutter opening; for radar it is the antenna. A synthetic aperture is constructed by moving a real aperture or antenna through a series of positions along the flight or orbital track of the host vehicle..

Satellite Systems

There are over 15 remote sensing/earth observation satellites owned by the U.S., Russia, France, India, Brazil, China, the European Union, Israel, Japan, and Korea. Many of these countries plan to compete directly with American civil and commercial systems.

The discussion that follows should not be considered all-inclusive.

LANDSAT (U.S.)

The first satellite to use multispectral imagery for Earth remote sensing was the Earth Resources Technology Satellite-A (ERTS-A) which was later renamed Landsat-1. It was the first in a series of satellites designed to provide repetitive global coverage of the Earth's land masses. ERTS-A was launched in July 1972 and finally ceased to operate in January 1978. 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. On April 15, 1999 the latest member of the Landsat family, Landsat 7, was launched into orbit.

The current constellation consists of two satellites, Landsats 5 and 7. They are in sun-synchronous orbits at 438 miles (705 km) altitude and a sun-synchronous 98.2 inclination with ground tracks of 185 km width. This allows a satellite to pass within sensor range of every location on Earth at least once every 16 days. The Landsat system provides for global data between 81 degrees north latitude and 81 degrees south latitude. This final maneuvering process will place Landsat 7 in an orbit consistent with and eight paths offset to the east of Landsat 5 paths. This will result in a Landsat 7 and Landsat 5 overflight of the same location eight days apart during routine operations.

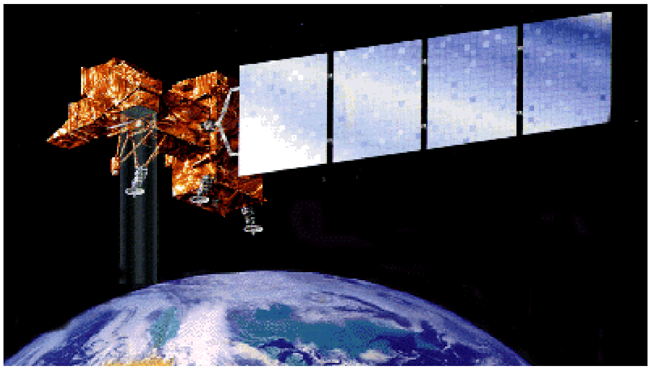

Figure 5-22: LANDSAT

Each LANDSAT satellite carries the Multispectral Sensor (MSS), the Thematic Mapper (TM), and now the Enhanced Thematic Mapper Plus (EMT+). The TM sensor, available on Landsat 5, captures information in seven spectral bands. The EMT+, available on Landsat 7, adds a panchromatic band. The MSS and TM sensors primarily detect reflected radiation from the Earth's surface in the visible and IR wavelengths, but the TM sensor provides more radiometric information than the MSS sensor.

The Multispectral Scanner collects data by continuously scanning Earth from west to east using an oscillating mirror, recording radiation in four different spectral bands in the visible and the near-IR regions with a resolution of 80 m. Bands 1 and 2 are in the visible wavelengths; bands 3 and 4 are in the near-IR portion of the spectrum. In order to present all of the bands in a fashion visible to the human eye, colors or shades of black and white are assigned to each band with the result of creating an image. As an example: band 1 detects green and could be shown as blue; band 2 detects red and could be shown as green; either band 3 or band 4, both of which detect separate bands of IR light, can be used in the construction of an image with bands 1 and 2 and could be shown as red.

The Thematic Mapper receives solar reflected energy covering the entire visible spectrum and the near, shortwave, and thermal-IR spectrums using 7 bands. In this respect, the Thematic Mapper sensor has the greatest spectral discrimination of any sensor platform currently in orbit. This capability allows greater discrimination among a large number of terrain feature types. Six of these bands provide at least 20 basic combinations and 120 permutations for a three-band color image. Each of these combinations has its own unique attributes. An optimum combination is a function of the intended application and a matter of personal band combination for imagery analysis. The TM sensor has a spatial resolution of 30 meters for the visible, near-IR, and mid-IR wavelengths and a spatial resolution of 120 meters for the thermal-IR band.

There are a few differences between Landsat 5 and Landsat 7. One of the Landsat 7 improvements is the Enhanced Thematic Mapper Plus (ETM+). The ETM+ instrument is an eight-band multispectral scanning radiometer capable of providing high-resolution imaging information of the Earth’s surface. It detects spectrally-filtered radiation at visible, near-infrared, short-wave, and thermal infrared frequency bands from the sun-lit Earth. Band 8 is a panchromatic band with a resolution of 15 meters. Band 6 now has both high gain and low gain settings at 60 meter resolution. There are 3 on-board solar calibrators to provide an absolute radiometric accuracy of +/-5%. In addition there is a "cloud cover predict" implemented in the Long Term Acquisition Plan, and a more accurate cloud cover assessment performed on acquired data. Nominal ground sample distances or "pixel" sizes are 49 feet (15 meters) in the panchromatic band; 98 feet (30 meters) in the 6 visible, near and short-wave infrared bands; and 197 feet (60 meters) in the thermal infrared band.

On 31 May 2003 Landsat 7’s ETM+ sensor’s Scan Line Corrector suffered a failure. Without the SLC, some scan lines in the pictures taken by the ETM Plus overlap while others are missing. In total, about 30 percent of data in each picture is lost. Most of the missing regions in the pictures can be filled by interpolation; however, this is an approximation rather than real data.

CHARACTERISTICS OF THEMATIC MAPPER BANDS		
Band	Wavelength, μm	Characteristics
1	0.45 - 0.52	Senses blue-green visible light. Maximum penetration of water which is useful for mapping in shallow water. Also useful for distinguishing soil from vegetation and deciduous from coniferous plants.
2	0.52 - 0.60	Senses green visible light. Matches green reflectance peak of vegetation. Useful in assessing plant vigor.
3	0.63 - 0.69	Senses red visible light. Matches chlorophyll absorption band. Useful in discriminating vegetation types.
4	0.76 - 0.90	Senses reflected near infrared. Useful for determining biomass content and for mapping of bodies of water which appear opaque.
5	1.55 - 1.75	Senses reflected mid-infrared. Indicates moisture content of soil and vegetation. Penetrates thin clouds. Good contrast between vegetation types. Useful for differentiation between snow and clouds.
6	10.40 - 12.50	Senses thermal infrared. Can be used at night. Useful for thermal mapping and estimating soil moisture.
7	2.08 - 2.35	Senses reflected infrared. Wavelength coincides with an absorption band of hydroxyl ions in minerals. Combination of bands 5 and 7 useful for mapping hydrothermally altered rocks associated with mineral deposits.

Table 5-6: Thematic Mapper Band Characteristics

As a commercial system, only licensed ground stations can receive and process Landsat data. The primary ground station, the data handling facility and the archive are located at the USGS/EROS Data Center in Sioux Falls, SD. The ground system can distribute raw ETM+ data within 24 hours of its reception at the EROS Data Center. Secondary USG ground stations for Landsat 7 are located in the Fairbanks, Alaska area and Svalbard, Norway. The secondary station(s) serve as backup for the primary station and ensure that the requirement for scene acquisitions is met. In addition, the Landsat 7 system is capable of transmitting data in real-time to other, non-USG ground stations. These stations will receive direct downlink data upon request.

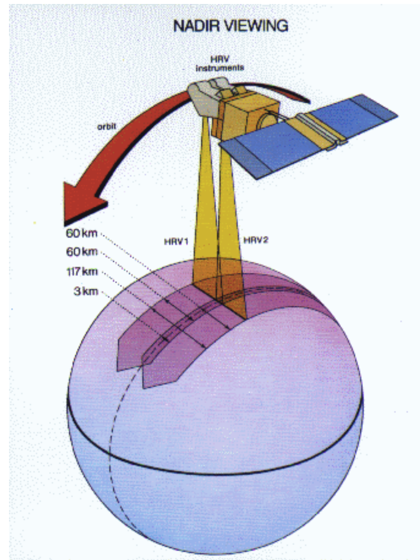

Figure 5-23: SPOT

Systeme Probatoire d'Observation de la Terre (SPOT) (France)

(http://www.spotimage.fr/html/_167_.php)

SPOT satellites are owned and operated by the Centre National d'Etudes Spatiales (CNES), a French governmental organization.

SPOT 1 was launched in 1986. SPOT 1 is still operational but has been placed in an inactive role.

The SPOT 2 satellite was launched on 22 January 1990. Identical to its predecessor, SPOT 2 was the first in the series to carry the DORIS precision positioning instrument.

SPOT 3 followed on 26 September 1993. It also carried the DORIS instrument, plus the American passenger payload POAM II, used to measure atmospheric ozone at the poles. SPOT 3 failed in 1996, having reached the end of its nominal mission lifetime.

SPOT-4, the current satellite, was launched in March 1998. SPOT-4 is designed for a five year life span.

The satellites have the same mission as Landsat but have different capabilities. They are launched into a sun synchronous 822 km high orbit with an inclination of 98.7°. The satellite repeats its ground trace every 26 days. In the panchromatic mode (black and white) visual images with a resolution of 10 meters are possible. The four band multispectral mode has a resolution of 20 meters.

The SPOT 4 satellite carries two identical high resolution sensors, called HRVIR (High Resolution Visible – Infrared), which operate in the visible and near infrared ranges of the electromagnetic spectrum. Each sensor contains a static solid-state linear array of detectors that work together as a "push-broom" scanner. As the spacecraft moves forward, each sensor scans side-to-side by means of a steerable mirror. HRVIR includes a new medium IR channel to support vegetation analysis and harvest forecasting. The Vegetation Monitoring instrument has 1 km resolution in the same bands as the HRVIR.

SPOT 5 was launched in May 2002. The SPOT 5 satellite offers improved ground resolutions of 10 meters in multispectral mode and 2.5 to 5 meters in panchromatic and infrared mode. Higher 2.5-metre resolution is achieved using an innovative sampling concept called Supermode.

SPOT 5 also features a new HRS imaging instrument (High Resolution Stereoscopic) operating in panchromatic mode and able to point forward and aft of the satellite. In a single pass, the forward-pointing camera acquires images of the ground, then the rearward-pointing camera covers the same strip 90 seconds later. HRS is thus able to acquire stereo pair images almost simultaneously to map relief, produce digital elevation models (DEMs) of wide areas and generate orthorectified products of a quality unequalled on the market today. The HRS instrument can acquire up to 126,000 square kilometers of data every day, thus providing a fast turnaround for users.

SPOT 5 also carries a VEGETATION 2 instrument identical to that on SPOT 4.

The HRVIRs are steerable to within 27 deg off-nadir which means they can point to spots on the Earth's surface between +27^{o} and -27 ^{o} from the vertical (extending from the satellite to its ground track) as the satellite moves forward. The maximum ground swath (swath width) for one sensor operating alone is 60 km. The overlap, over the satellite's ground track, of the two swaths is 3 km, giving a total ground swath of 117 km when the two sensors operate at the same time.

Because SPOT has oblique viewing capabilities, stereoscopic imaging is a major feature of the satellite. Stereoscopic pairs of images are commonly used in topographic mapping and geomorphologic and geological studies because they provide high resolution in nearly 3-D images. Two images of the same area acquired on different dates and at different HRV angles can be combined to produce a vertical view that gives very accurate topographic information (i.e., altitude). This capability also allows for viewing of the same area every three or four days although from different angles.

When compared to Landsat, the spatial resolution of SPOT images is higher than that of Landsat; however, Landsat images have more spectral bands. SPOT sensors can also provide stereo image data. Both sets of data can be purchased in the commercial market. During Operation DESERT STORM, France implemented restrictions on the distribution of SPOT data to members or supporters of the coalition of allied forces, of which France was a member. The Army integrated SPOT and Landsat data which resulted in a significantly better product. The SPOT data most frequently used by the DoD is the HRS panchromatic imagery.

The SPOT Mission Center is located in Toulouse, France. A second command center is located at Kiruna, Sweden. At these sites ground operators collect real-time images, within 2500km of the ground stations, and stored images from other parts of the Earth. The two ground stations have the capacity of receiving 500,000 images per year. SPOT Image, the company which runs the SPOT marketing, runs a number of Direct Receiving Stations which receive real-time images only. These stations are located in Canada (2), India, Spain, Brazil, Thailand, Japan, Pakistan, Saudi Arabia, South Africa, Australia, Ecuador, Taiwan, Indonesia, and Israel. Data transmitted in direct mode are received in real time during daytime passes. Data transmitted in recording mode (i.e., via on-board tape recorders) are received during nighttime passes by SPOT's main receiving stations in Toulouse, France, and Kiruna, Sweden. SPOT imagery is sold through Spot Image Corporation in Reston, VA. There are also SPOT commercial sales offices in France, Australia, Singapore, and China.

Indian Remote Sensing (IRS) Satellite (India)

The launching of the first Indian Remote Sensing Satellite, IRS-1A in March 1988, followed by the successful launch, calibration, and initialization of IRS-1B in August 1991, IRS-P2 during 1994, IRS-1C during 1995, IRS-P3 during 1996, IRS-1D during 1997, and IRS-P4 during 1999, has provided India with an unique opportunity to use remote sensing data for the monitoring and management of natural resources and the environment. India sells this data to customers around the world.

These satellites are built by the Indian Space Research Organization (ISRO).

IRS 1A and 1B have a resolution of 117 feet (36 m) by 237 feet (73 m) across. The revisit time is 22 days. Neither satellite has any on-board data storage; therefore the satellite must be within line-of-sight of the receiving station in order to provide any image data

IRS-1C and IRS-1D satellites are identical. Each satellite is equipped with three sensors that collect five-meter resolution panchromatic (black-and-white), 20-meter resolution multispectral (color), and 180-meter resolution multispectral wide-area images. The IRS C and D Panchromatic sensor sacrifices swath width for its higher resolution. However, it can be pointed off the orbit path which allows 2 to 4 day revisits to specific sites. There are on-board recorders for data collection outside the range of ground station, to further increase data availability.

IRS-P4 (OCEANSAT-1) has a Multi-frequency Scanning Microwave Radiometre (MSMR) operating in four frequencies and a nine-band Ocean Colour Monitor (OCM). It was launched in May 1999. The satellite's sensors have a resolution of 250 meters at nadir and have a swath width of 1420 km with a revisit time of two days. The payload is specifically tailored for the measurements of physical and biological oceanography parameters. It will provide valuable Ocean-Surface related observation capability. It has a multispectral spatial resolution of 32 meters and panchromatic spatial resolution of 5 meter. The sensors can steer along the ground track at +/- 20 degrees in steps of 5 degrees.

There is a business alliance between the Indian ANTRIX Corporation which is the commercial Organization and the Lockheed Martin/Space Imaging-EOSAT. Under this alliance, some of the global stations in the U.S., Germany, Thailand etc are receiving IRS data for distribution to the global customers.

The National Remote Sensing Agency (NRSA) is an autonomous organization under Department of Space, Govt. of India engaged in operational remote sensing activities. NRSA has its own ground station at Shadnagar, 60 Km south of Hyderabad to acquire remote sensing satellite data from Indian Remote Sensing satellites, the latest being IRS-P4, and other foreign satellites like Landsat, NOAA, and ERS.

RADARSAT (Canada)

(http://radarsat.space.gc.ca)

RADARSAT is a cooperative program between the Canadian Space Agency, NASA and NOAA. The Canadian Space Agency built and operated the satellite; NASA furnished the launch. In exchange, U.S. government agencies will have access to all archived RADARSAT data and have approximately 15% of the satellite's observing time. RADARSAT was launched in 1995 and is equipped with an advanced Synthetic Aperture Radar (SAR) instrument capable of delivering data from 7 beam modes and 25 beam positions.

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 penetrate through clouds, haze, smoke and darkness, thus providing images of the Earth in all weather conditions, at any time. This ability 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 other ISR satellites.

RADARSAT is in a sun-synchronous polar orbit at 98.6 degrees. It provides the first routine surveillance of the entire Arctic region and accurately monitors disasters such as oil spills, floods and earthquakes. RADARSAT provides radar imagery which is of exceptional value in supporting a wide range of DoD and civilian applications. Fine resolution is 8m, standard resolution is 30m and ScanSAR wide is 100m. The satellite pass is every 24 days but it can provide daily coverage of the artic region and any part of Canada within 3 days. Data can be processed and delivered in less than 4 hours after it has been acquired.

RADARSAT International, Inc. will be the commercial distributor of RADARSAT data worldwide. Lockheed Martin has distribution rights in the United States. For additional information on the current satellites in the constellation, go to the Internet website http://radarsat.space.gc.ca/asc/eng/satellites/default.asp.

RESURS (Russia)

RESURS F and DK

The Soviet Union has launched numerous Resurs-F remote sensing satellites. Russia has continued the program but with infrequent launches. The F2-series satellites has about a 1 month lifetime while the F1 series has only half that. The results of the mission (films) are sent back to earth in a reentry vehicle. This Soviet remote sensing satellite program is operated by the Priroda ('Nature') center of the Russian Central Geodesy and Cartography Agency (GUGK).

The satellites are launched into a low Earth polar orbit. The satellites are used for civil remote sensing photography. Resolution of these images is about 5 meters. The apparent principal use is to monitor the condition of agricultural areas within Russia and other former Soviet republics. The Russians also sell some photographs on the commercial market if the images are not of areas they consider sensitive. Although the resolution is high, the data is difficult to integrate with digital data from other multispectral satellites since the only products are photographs (a form of analog data).

The latest in the series is the RESURS DK vehicle. Information about the series is not widely available, but launching began in the 1990s. There was to be a launch of a RESURS DK in 2005 or 2006.

RESURS O1

The first satellite in the RESURS-O1 series was operational for three years after its launch in 1985. The second, launched in 1988, was switched off after 7 years of successful operation. The third satellite was launched in 1994. It is still partly operational, but it does not receive any transmissions on X-band anymore. The successor was launched in July 1998, but both of the transmitters on-board have failed and we cannot receive any data at all from it.

RESURS-O1 #3 has two remote sensing instruments on board. The MSU-E is comparable with instruments on other satellites, such as Landsat, while the MSU-SK offers perspectives of the Earth that have never been available before. The MSU-E offers three spectral bands and spatial resolution of 45 meters. The MSU-SK is a five spectral band (four visible and one NIR) instrument offering160 meter resolution in the multispectral range and 600 meter resolution in the NIR range.

Through agreements between Satellus and its Distributors, digital Quick Looks and other information are available about the archived RESURS-O1 images. This information can be browsed on the Eurimage on-line service.

Other Imagery Systems

China-Brazil Earth Resources Satellite (CBERS or Zi Yuan 1)(China and Brazil)

(http://directory.eoportal.org/pres_CBERS1234ChinaBrazilEarthResourceSatellite.html)

China and Brazil agreed on July 6, 1988, to start a cooperative program to develop two remote sensing satellites. This satellite was launched in October 1999. The Wide Field Imager has a ground swath of 890 km which provides a synoptic view with spatial resolution of 260 m. The Earth surface is completely covered in about 5 days in two spectral bands: 0.66 mm (green) and 0.83 mm (near infra-red). The high-resolution CCD camera provides images of a 113 km wide strip with 20 m spatial resolution. Since this camera has a sideways pointing capability of ±32 degrees it is capable of taking stereoscopic images of a certain region. The CCD camera operates in 5 spectral bands that include a panchromatic band from 0.51 to 0.73 mm. The two spectral bands of the WFI are also present in the CCD camera to allow complementing the data of the two types of remote sensing images. A complete coverage cycle of the CCD camera takes 26 days. Infrared Multispectral Scanner (IR-MSS) operates in 4 spectral bands such as to extend the CBERS spectral coverage up to the thermal infrared range. It images a 120 km swath with a resolution of 80 m (160 m in the thermal channel). In 26 days one obtains a complete Earth coverage that can be correlated with the images of the CCD camera.

This joint venture has proven very successful. With already 2 satellites launched, there are currently plans for CBERS-2B to launch in 2006 and for CBERS-3 and CBERS-4 in the future.

Earth Remote Sensing Satellite (Europe)

http://earth.esa.int/ERS

The European Space Agency, a consortium of European countries owns and operates the ERS satellites. The last ERS (ERS 2) satellite was launched in 1995. It is designed to produce images and other data on the ocean surface, ocean temperature, ocean bottom in shallow coastal areas, wave patterns, ice conditions, crop development and forest management. The Synthetic Aperture Radar (SAR) instrument is designed primarily to measure ocean wave length and direction but has also been able to detect ocean wave fronts and current shear. ERS 2 operates in the IR and visible spectrum.

ERS-2 is a notable European engineering achievement, reaching the milestone of 10 years in orbit on 21 April 2005 with all instruments still working and providing excellent data. Over this ten year period the satellite has underpinned and supported the development of a unique know-how, a broad range of outstanding Earth Observation science results and a range of operational applications.

Figure 5-24: Ikonos First Image – Denver

Helios (France, Italy, Spain)

Helios is a French military observation program built in concert with Italy and Spain. The Helios 1 payload consists of high resolution optical observation equipment capable of 1m resolution and two tape recorders. It was launched in 1995. Helios 1B was launched in Dec 1999. The Helios 1 satellites cannot observe at night or through clouds. Each country can use the satellite in proportion of its financial participation. Each country can order observations and obtain the results via its Earth station. Each country's results are encrypted so that only the orderer can use the data. However, France may find itself compelled to put images from its Helios-1, and possibly Helios-2, satellite on the commercial market-place to counter a U.S. move to sell commercial images with a resolution of one meter. Both satellites are still operating.

Ikonos (U.S.)

(http://www.satimagingcorp.com/gallery-ikonos.html)

Ikonos 2 was launched in September 1999 into a 680km high sun-synchronous polar orbit. Ikonos 1 had crashed into the Pacific Ocean soon after liftoff in April in what was then perceived as a spectacular failure. It is the first commercial company to offer high-resolution images from space. It is capable of panchromatic images with resolutions of 1m using its unique Kodak digital camera. It is also capable of 4-band multispectral images (red, green, blue and NIR) with resolutions of 4m.

Space Imaging was bought by Orbimage Holdings, Inc., in late 2005. Orbimage now has the rights to sell the images. Newly released images from the Ikonos satellite show cities around the world at a level of detail previously unavailable via commercial imaging satellites.

KITSAT (South Korea)

(http://krsc.kaist.ac.kr/english/SaTReC.html)

KITSAT 3, developed in a university research center, is a micro-satellite that was launched in May 1999 on the Indian PSLV. Previous KITSAT satellites did not include multispectral imaging systems. The current satellite has a remote sensing system capable of acquiring images in three bands – red, green and NIR. Spatial resolution is 15m with a swath width of 50km.

Okean (Russia and Ukraine)

(http://www.okean-o.dp.ua)

The Okean-O satellite was launched in July 1999. The Okean program has been in existence since 1983. The satellites now provide multispectral, radar, microwave and optical images of Earth for the purposes of sea navigation, fishery and coastal shelf usage. The Okean-O has 2 side-looking radars, 2 tracking UHF radiometers. It is capable of collecting information in eight spectral bands with resolutions down to 25m depending on the imager used.

OrbView (U.S.)

(http://www.orbimage.com/corp/orbimage_system/satellite.html)

Successfully launched in April 1995 Orbimage's OrbView-1 satellite contained two atmospheric instruments that improved weather forecasting capabilities around the world. The satellite's miniaturized camera provided daily severe weather images and global lightning information during day and night operations. Its atmospheric monitoring instrument provided global meteorological data useful for improving long-term weather forecasts. OrbView -1 is no longer in service.

OrbView-2, known as SeaWiFS, was launched in 1997 to provide unprecedented multispectral imagery of the Earth's land and ocean surfaces every day. The satellite's imaging instrument has eight channels, six in the visible and two in the near infrared spectrum, with a spatial resolution of 1 km. Its primary mission is to image the oceans. OrbView-2 is particularly good at measuring phytoplankton concentration, sediment concentration and water clarity, which are valuable to support such activities as naval laser-based and SONAR operations.

OrbView-3 satellite is among the world's first commercial satellites to provide high-resolution imagery from space. OrbView-3 produces one-meter resolution panchromatic and four-meter resolution multispectral imagery with a swath width of 8 km. The satellite revisits each location on Earth in less than three days with an ability to turn from side-to-side up to 45 degrees. OrbView-3 imagery can be downlinked in real-time to ground stations located around the world or stored on-board the spacecraft and downlinked to Orbimage's master U.S. ground stations.

ORBIMAGE will continue its tradition of innovation in mapping, monitoring and measuring the Earth's surface with the launch of OrbView-5, its next-generation satellite with the highest resolution and most advanced collection capabilities of any commercial imaging satellite ever developed.

Scheduled for launch in early 2007, OrbView-5 will offer unprecedented spatial resolution by simultaneously acquiring 0.41-meter panchromatic and 1.64-meter multispectral imagery. It can collect in excess of 800,000 square kilometers of imagery in a single day, downlink imagery in real-time to international ground station customers, and can store 1.2 terabytes of data on its

solid-state recorders.

The detail and geospatial accuracy of OrbView-5 imagery will further expand the applications for satellite imagery in every commercial and government market sector.

KOMETA (Russia)

(http://www.sovinformsputnik.com/kometa.html)

Although not a multispectral system, the KOMETA is a space-based mapping system. It is composed of the topographic camera TK-350 and the high resolution camera KVR-1000, integrated with on-board equipment for external orientation elements determination, is designed to provide large scale topographic and digital maps. The satellite operates in near-circular orbit at an average altitude of 220 kilometers and has an orbital duration of 45 days. The entire system is retrieved from orbit and landed at the preliminary defined location. The film is then retrieved from the descending module, processed, converted into digital form using precise scanners, and orthorectified. The digital products are delivered to customers on CD-ROM.

The SPIN-2 is a trademark for Russian digital orthorectified geo-coded two meter resolution satellite imagery data. SOVINFORMSPUTNIK, Aerial Images, Inc., and Central Trading Systems, Inc. have contracted to jointly market high resolution panchromatic Russian satellite imagery data. This unique project brings to the civilian market, for the first time, cartographic quality, high resolution image data collected from formerly classified Russian military satellite systems. The imagery is archived and available at http://terraserver.com.

SUNSAT (South Africa)

(http://www.sarl.org.za/public/local/sunsat.asp)

SUNSAT is a low earth orbit (LEO) micro satellite designed and built almost entirely by postgraduate students from the University of Stellenbosch. It was launched in February 1999 from Vandenberg AFB. The primary purpose of SUNSAT is to take low cost, high resolution (5m) photographs of South Africa. The satellite has the capability of imaging three bands – red, green and NIR. A high resolution camera, also referred to as a push-broom imager, has been developed by the university in conjunction with the Council for Scientific and Industrial Research (CSIR) and forms the main payload of SUNSAT. The types and quality of images that SUNSAT hopes to produce promises to be exceptional for such a low cost university micro satellite and should approach that of large and expensive commercial satellites like SPOT and LANDSAT. The camera design has, in fact, been so successful that Korea and South Africa have already signed a technology co-operation agreement which will allow Korea to use a similar camera on board their next KITSAT-3 satellite. The second satellite is scheduled to be launched in 2006.

Terra (EOS-AM1)

(http://terra.nasa.gov/)

Terra (formerly known as EOS-AM1) is a NASA scientific research satellite launched in December 1999. The instrumentation package includes a MODIS Moderate Resolution Spectro-radiometer (MRS) which is capable of imaging in 36 spectral bands from visible to thermal infrared. It can view the entire earth’s surface every 1 to 2 days.

A second multispectral instrument on board is the Multi-angle Imaging Spectro-Radiometer (MISR). MISR is a new type of instrument designed to view the Earth with cameras pointed at nine different angles. One camera points toward nadir, and the others provide forward and aftward view angles, at the Earth's surface, of 26.1°, 45.6°, 60.0°, and 70.5°. As the instrument flies overhead, each region of the Earth's surface is successively imaged by all nine cameras in each of four wavelengths (blue, green, red, and near-infrared). MISR data can distinguish different types of clouds, aerosol particles, and surfaces.

The third multispectral instrument is the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). ASTER will obtain high-resolution (15 to 90 m) images of the Earth in the visible, near-infrared (VNIR), shortwave-infrared (SWIR), and thermal-infrared (TIR) regions of the spectrum. ASTER consists of three distinct telescope subsystems: VNIR, SWIR, and TIR. It is a high spatial, spectral, and radiometric resolution, 14-band imaging radiometer. All three ASTER telescopes (VNIR, SWIR, and TIR) are pointable in the crosstrack direction and the telescopes do not have a zoom capability. The pixel resolution is fixed within each telescope, but varies between the telescopes. Given its high resolution and ability to change viewing angles, ASTER will produce stereoscopic images, such as 3-D terrain.

Tubsat (Germany)

(http://www.ilr.tu-berlin.de/RFA/DLR-TUBSAT/DLR-TUBSAT.htm)

The DLR-Tubsat was launched in May 1999. It is a nanosatellite mainly used for high resolution earth observation tasks. This is done in a live TV mode with a three head camera system with different focal lengths, resulting in a resolution of 370 meter down to six meter per pixel. The pictures can be received with a standard satellite dish with a minimum of three meter diameter.

UoSAT (United Kingdom)

(http://www.tbs-satellite.com/tse/online/sat_uosat_12.html)

UoSAT-12 is a mini-satellite that carries payloads for multi-spectral and panchromatic Earth imaging as well as other payloads. It was launched in April 1999. It has a multispectral imager capable of imaging in the red, green, blue and NIR bands with a 32.5m spatial resolution and a high-resolution imager capable of providing haze penetration panchromatic images with 10m spatial resolution.

QuickBird and Worldview (U.S.)

(http://www.digitalglobe.com/about/index.shtml)

EarthWatch built two QuickBird 1-meter resolution satellites. EarthWatch later became DigitalGlobe. This constellation is designed to provide a constant digital stream of earth imagery, received and distributed by a global network of ground stations and telecommunications-based distribution networks. As a predecessor to the QuickBird series of satellites, the company had constructed a 3-meter resolution satellite: EarlyBird 1. This satellite was launched successfully on December 24, 1997, but failed on orbit four days later due to a problem with the on-board power system. QuickBird-1 was launched in November 2000 but failed to achieve orbit. QuickBird-2 was launched in October 2001 and is operational. It can provide less than 1m panchromatic and 4m 4-band multispectral images.

Scheduled to launch no later than 2006, the follow-on to Quickbird, named WorldView, will be the world's only commercial satellite to snap pictures of the Earth at 50-centimeter resolution. The WorldView system will include more efficient image processing systems and multi-satellite collection planning, shorter tasking timelines, and an expanded network of remote ground terminals. DigitalGlobe's imaging constellation combining WorldView and QuickBird will be capable of collecting more than 4.5 times the imagery of any current commercial imaging system. By late 2006, WorldView alone will be capable of collecting nearly 500,000 square kilometers (200,000 square miles) per day of half-meter imagery.

Indian Remote Sensing (India)

Indian Resource Satellites IRS-P5, IRS-2A, and IRS-2B have the new LISS-4 sensor suite. IRS-P5 is also known as the Cartosat. It is intended for cartographic applications and is reported to have a pan camera with a resolution of 1- 2.5 meters.

IRS-P6 (RESOURCESAT-1), launched in 2003, has is a state-of-art satellite mainly for agriculture applications and has a 3-band multispectral LISS-IV camera with a spatial resolution better than 6 m and a swath of around 25 km with across track steerability for selected area monitoring. An improved version of LISS-III with four bands (red, green, near IR and SWIR), all at 23 m resolution and 140 km swath provides the essential continuity to LISS-III. Together with an advanced Wide Field Sensor (WiFS) with 80 m resolution and 1400 km swath, the payloads will greatly aid crop/vegetation and integrated land and water resources related applications.

The IRS-2 series (OCEANSAT-2/CLIMATSAT-1/ATMOS-1) will be an integrated mission that will cater to global observations of climate, ocean and atmosphere. IRS-3 will have all weather capabilities with multi-frequency and multi polarization microwave payloads and other passive instruments.

FUTURE IMAGERY SYSTEMS

OrbView

As mentioned in the previous section, ORBIMAGE will continue its tradition of innovation in mapping, monitoring and measuring the Earth's surface with the launch of OrbView-5, its next-generation satellite with the highest resolution and most advanced collection capabilities of any commercial imaging satellite ever developed.

Scheduled for launch in early 2007, OrbView-5 will offer unprecedented spatial resolution by simultaneously acquiring 0.41-meter panchromatic and 1.64-meter multispectral imagery. It can collect in excess of 800,000 square kilometers of imagery in a single day, downlink imagery in real-time to international ground station customers, and can store 1.2 terabytes of data on its

solid-state recorders.

The detail and geospatial accuracy of OrbView-5 imagery will further expand the applications for satellite imagery in every commercial and government market sector.

OrbView-4's high-resolution camera will acquire one-meter resolution panchromatic and four-meter resolution multispectral imagery. In addition, OrbView-4 will acquire hyperspectral imagery. OrbView-4's imaging instruments will provide one-meter panchromatic imagery and four-meter multispectral imagery with a swath width of 8 km as well as 280 band, 8-meter resolution hyperspectral imagery with a swath width of 5 km.

RADARSAT 2

(http://www.mda.ca/radarsat-2)

The RADARSAT-2 satellite incorporates state-of-the-art technology and features the most advanced commercially available radar imagery in the world. The RADARSAT-2 program ensures the continuation of the original RADARSAT program and the development of Canada's Earth Observation business sector.

RADARSAT-2 is a unique cooperation between the Canadian Space Agency (CSA) and MacDonald Dettwiler. The CSA is providing approximately 75% of the funding for the development of the satellite and MacDonald Dettwiler is investing the difference. MacDonald Dettwiler will own and operate the satellite and the CSA's investment will be recovered through the supply of imagery to a number of government agencies during the mission lifetime.

The design of RADARSAT-2 has been driven by the needs of the emerging Earth Observation market, to provide users around the world with high-quality data products. RADARSAT-2 will be capable of imaging at spatial resolutions ranging from 3 to 100 meters with swath widths ranging from 20 to 500 kilometers. RADARSAT-2 is also the first commercial radar satellite to offer multi-polarization capability that aids in identifying a wide variety of surface features and targets. The satellite is scheduled for launch in 2006 and has a design life of 7 years.

RADARSAT-2 is a truly world-class mission and the next step in MacDonald Dettwiler's goal to being a world-leading company in the delivery of a broad range of information products and services to manage the scope of human activities on our planet.

SPOT (France)

CNES is currently working on the SPOT 6 with a planned launch possibly as early as 2006. It's technology will be similar to SPOT 5.

TerraSAR (Germany and UK)

The TerraSAR program is being developed by Matra Marconi Space UK and Dornier Satellitensysteme GmbH (DASA). TerraSAR (SAR: synthetic aperture radar) is a sun-synchronous satellite orbiting at an altitude of 600 km. The prime contractors estimate its life span at five years. Its maximum resolution will be 1.5 meters and its launch is scheduled for 2006.

SkyMed/COSMO (Italy)

The SkyMed/COSMO (Constellation of Small satellites for Mediterranean basin Observation) program is composed of three optical and four radar-sensing satellites and funded by the Italian Space Agency (ASI). Each satellite in the constellation will have a mass of 600 kg. The orbit will be sun-synchronous (480 km altitude for radar satellites, 500 km for optical satellites). The maximum resolution of the optical component will be 2.5 meters. The high-resolution radar images provided by SkyMed/COSMO would be an excellent complement to the optical images from Helios.

IMAGERY CAPABILITIES

Satellite systems are vital for providing earth remote sensing data because of their global coverage and periodic updates. This is especially necessary when gathering information about the environment of a hostile area, remote area or an area we don't have access to.

Multi-spectral imagery can provide information about the environment that can't be detected with the human eye.

Space systems provide broader area coverage than aircraft or UAV systems. One scene from Landsat 5 covers an area of 185km by 170km.

Commercial and civil remote sensing systems provide unclassified imagery. This means it can be used and shared with any coalition partner and does not require stringent handling.

IMAGERY LIMITATIONS

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 which makes them effective imagers only during periods of sunlight. In addition, the usefulness of Multispectral Imagery 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 but also prohibits "24 hour" coverage of a specific area. It may be a few days or a few weeks before the satellite covers the area again.

The resolution of the images is not as high as imagery taken from an aircraft or UAV. However, this is rapidly changing.

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. Terrestrial weather also affects multispectral and IR-only sensor systems. They cannot "see" through clouds, smoke, haze etc.

Multispectral data typically takes significant processing and is converted to prints (photographs, film, and computer compatible storage media which delays distribution to theater users. Turn around time is normally greater than 24 hours.

Currently, most remote sensing space systems are commercially owned and operated. In times of conflict, these systems could provide products to the enemy. The products from these commercial satellites are for sale unless otherwise restricted. In addition, products can be expensive to purchase.

NATIONAL GEOSPATIAL-INTELLIGENCE AGENCY (NGA)

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. In October 2003, NIMA was re-designated the National Geospatial-Intelligence Agency (NGA).

NGA incorporates the former Defense Mapping Agency (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 (NPIC). Also included in NGA 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 being put into 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 means.

Although NGA and COLISEUM represent a major change in terms of support to DoD, the process in the Army and the other services for acquiring MSI is still through intelligence channels. As a result, the Collection Manager remains the best starting point for operational and intelligence driven imagery intelligence (IMINT) requirements at the unit level.

PLANNING CONSIDERATIONS

Q. Is there a requirement for IMINT products? Is there an imagery analysis and dissemination infrastructure in place to support rapidly developing operations? New MSI products, because of satellite pass opportunities, may take days to months to obtain. Without a central analysis and dissemination infrastructure, components may have requested and obtained MSI products that are critically required by others.

Q. Are there areas in the supported command's AOR/JOA that require an imagery dissemination infrastructure to be in place for MSI analysis to support rapidly developing operations? MSI products may have to be obtained via contract. Some products may require acquisition lead times to be available when required.

Q. Does the supported command require MSI products for surveillance and strike planning purposes? MSI products typically require lead times (hours to weeks) for delivery which can limit their tactical utility for surveillance and strike. Supporting mechanisms need to be in place to expedite the delivery of MSI products for mission planning, target analysis, terrain categorization, etc.

Q. What is the threat force capability to receive commercial imagery products? Are commercial production facilities or downlink sites in the AO? Commercial imagery products will be available to threat forces in the same manner they are available to friendly forces. They may be direct purchase or through a third party. There may be a commercial imagery downlink and processing station in the threat force country that may want to deny him access to.

TACTICAL EXPLOITATION OF NATIONAL CAPABILITIES (TENCAP)

History

From initial development through to the early 1990s, overhead reconnaissance systems were highly classified and protected by numerous special compartments. Each National Reconnaissance Program (NRP) satellite had its own layer of caveats. The Cold War was on going, and the fact of overhead reconnaissance and the existence of the NRO were classified. The systems were designed to support the POTUS and SECDEF, and Imagery and SIGINT products derived from these sensors remained compartmented to protect the capabilities of the platforms.

TENCAP evolved from an Army recognition that national overhead systems developed for the POTUS and SECDEF had potential to support the tactical warfighter. Throughout the early and mid-‘70s, the Army explored the tactical applicability of national systems at corps-level and initiated an office under the Deputy Chief of Staff for Operations (DCSOPS) to develop and field the tools needed to leverage those systems. Congress considered the program so successful that in 1977 it directed the other Services to create similar programs. By the early ‘80s, TENCAP offices had been established within the Services, the DIA, the National Security Agency (NSA), and the Joint Staff J-3. As the single point conduit into the NRO, the Defense Support Project Office (DSPO) was established under the auspices of OSD, to provide overt oversight of the Defense Reconnaissance Support Program (DRSP) on behalf of the Director, NRO. Through the DRSP, DSPO provided service insight into NRO technologies, facilitated service exploitation of NRO capabilities, and funneled service funding into the NRO for DoD unique capabilities. Throughout the early years of TENCAP, national overhead reconnaissance systems remained focused on support to the national community. Although the DoD TENCAP community made tremendous strides in leveraging national systems for the tactical user, it wasn’t until after Operations DESERT SHIELD/DESERT STORM that the military customer really became a critical consideration when evaluating requirements for future NRO systems. The DRSP was renamed the Defense Space Reconnaissance Program (DSRP) in 1994 as an element of the Joint Military Intelligence Program (JMIP).

With decompartmentalization and declassification within the overhead reconnaissance community over the past 5 years, roles and functions of TENCAP-related organizations have evolved. Several services have reorganized to encompass both “white” and “black” space responsibilities. Support to military operations has become a major driver in the requirements process for new overhead architectures. The recent openness of the NRO has led to better dialogue with the military customers across the board. Requirements for emerging NRP satellites are now addressed by the Joint Requirements Oversight Council (JROC), a situation totally unheard of just three years ago. Even though much has changed in the way the DoD and the national community do business, the value placed by the Services on their TENCAP Programs is reflected by the fact the funding for these efforts has remained relatively consistent in a period of declining resources.

Army TENCAP

The Army Space Program Office (ASPO) has been developing, acquiring, fielding, and maintaining Army TENCAP systems for 25 years. It is the largest service TENCAP Program, and is unique in its life cycle approach to TENCAP. From the program's inception, the Army recognized the need to normalize TENCAP like any other weapons system. By incorporating it as an element within the U.S. Army Training and Doctrine Command's (TRADOC) Intelligence and Electronic Warfare (IEW) Battlefield Operating System (BOS), TENCAP systems have been fully integrated into the division, corps, and echelon above corps (EAC) intelligence infrastructure. With the consolidation of space functions in 1994, ASPO transferred to the U.S. Army Space and Missile Defense Command (SMDC), and the SMDC Acquisition Center. In 2003, the mission of the Program Executive Office (PEO) for Air and Missile Defense was expanded to include the Army Space Program Office.

The Army TENCAP program baseline has undergone a major transition, with migration to a modular, downsized baseline system called the Tactical Exploitation System (TES). The TES is a split-based, scaleable, single-integrated, multi-disciplined, all-source, preprocessing family of systems.

Legacy systems include the Advanced Electronic Processing and Dissemination System (AEPDS), the Enhanced Tactical Radar Correlator (ETRAC), the Modernized Imagery Exploitation System (MIES), the Mobile Integrated Tactical Terminal (MITT), and the MITTs functional twin, and the Forward Area Support Terminal (FAST). The baseline and transition program descriptions can be confusing because the systems are in either of two accounts--Tactical Intelligence and Related Activities (TIARA) or Joint Military Intelligence Program (JMIP). Adding to the confusion are numerous baseline components and

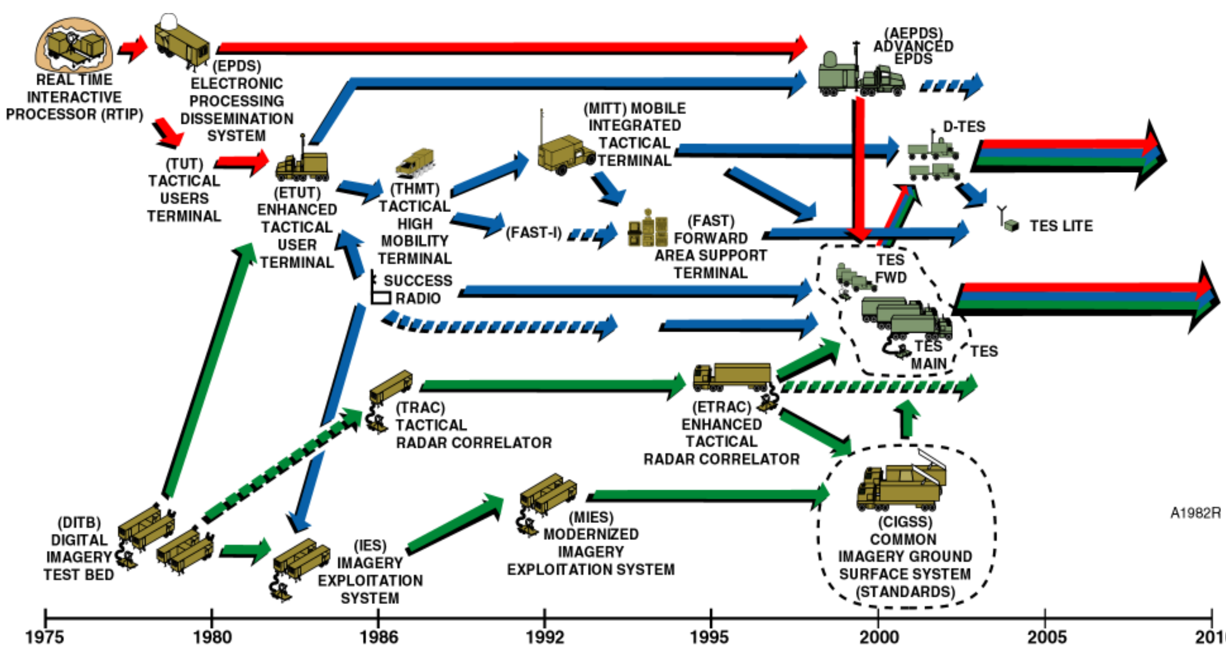

Figure 5-25: Army TENCAP Evolution

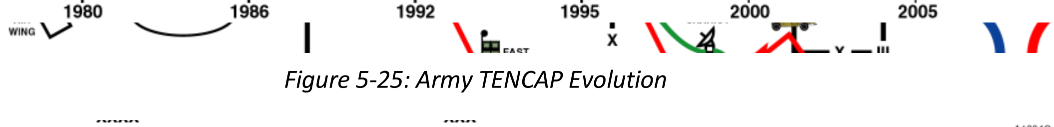

Figure 5-26: Army TENCAP Architecture

subsystems common to the legacy systems that are retrofitted and incorporated into the TES.

Army TENCAP also executes an aggressive technology insertion and advanced demonstration program that exploits the tactical potential of national and commercial space systems as well as select theater assets and integrates those capabilities into the TENCAP baseline.

Army TENCAP Programs

Army Common Imagery Ground/Surface System (CIGSS - components)

CIGSS is a joint program. All systems support theater combatant commanders through the Army component or through standing unified and specified joint command's CONPLANS and OPLANS. The purpose of CIGSS is to provide the Army ground commander with timely, assured, reliable, and accurate national and theater imagery intelligence to support military missions, in all-weather, 24-hours daily. Programmatically, TES is the Army component of CIGSS joint service imagery baseline.

Migration to the Army common imagery ground station, includes continued engineering and technology insertion upgrades to the processors, and processing tools. Army will maintain the Common Imagery Processor (CIP) baseline program capability to receive and process data from all DOD imagery collection platforms. Efforts include: ASARS Improvement Program (AIP) sensor implementation; automatic target recognition (ATR) projects, like the Semi-automated IMINT Processor (SAIP) ACTD; upgrades to the common data link (CDL) for the TES.

Tactical Exploitation System (TES)

TES is the Army's objective TENCAP system for the 21st century, and it replaces the AEPDS, the ETRAC, and the MIES. TES combines all TENCAP functionality into a single, integrated, scaleable system, designed for split-based, disbursed operations. TES development includes joint CIGSS components, CIP development, compliant and compatible communications systems and sub-systems, and acquisition of a TES system (Littoral Surveillance System (LSS)) by the Navy Reserves.

TES is a multi-disciplined processing system that will provide the tactical and operational commander with timely and assured access to imagery and signals intelligence from national, theater, and select organic tactical collectors. TES will perform the preprocessor functions for forward and main elements, as well as the division-TES (D-TES) and TES-light configurations. TES is designed for split-based and extended battlespace operations. The TES baseline consists of the All-Source Analysis System (ASAS), the common ground station (CGS), and the Digital Topographic Support System (DTSS).

The TES forward is a highly mobile, HMMWV-based system that can be multiple mission configured in one of five options to meet the tactical situation. This is a fly-away (C-130 drive-on drive-off, quick set-up tear-down, rapid deployment, early-entry) system.

The TES main is housed in vans and will operate from sanctuary, or can be deployed if the United States enters into sustained theater military operations, like Operations DESERT SHIELD/STORM.

The D-TES and TES-light will be a downsized TES forward configuration, fielded to the current Mobile Integrated Tactical Terminal (MITT) and Forward Area Support Terminal (FAST) force baseline.

The Army acquisition objective is for six TES (XVIII ABN Corps, 513th MI BDE, III Corps, 501st BDE, V Corps, and I Corps). The Army procurement objective will include a mix of full and TES (-) configurations to be acquired and fielded over the POM. D-TES and TES-light will be fielded at the division and separate BDE level. The basic order of issue (BOI) requirement for TES is one Main or Forward per MI BDE at Corps and EAC, and one DTES or TES-light per MI BN at division and MI CO at separate maneuver BDE.

Grenadier BRAT (GB)

GB is the enabling technology that links the Army's digitized and non-digitized ground forces. The GB WRAP initiative is directed toward procuring a limited go-to-war, blue force tracking and messaging system (BFU MS). GB began to be fielded in FY 2003 as a digital feed to the common operating picture (COP) for the GCCS, Global Command and Control System-Army (GCCS-A), and maneuver control system (MCS). The primary goal of the GB program is to minimize the time and cost of satisfying the Army's GCCS COP, while providing the tactical Army an enhanced warfighting capability.

GB extends the commander's view beyond the limits of the tactical Internet to the entire battlespace. GB solves the early entry and beyond line-of-sight force tracking, feeding the force commander with a COP for Joint, coalition, and other non-digitized forces. The system uses a small, lightweight transceiver with a user interface unit. The device transmits a low probability of detection, low probability of intercept (LPD/LPI) signal (Collection of Broadcasts from Remote Assets (COBRA)), containing a unique device identification, spread spectrum, burst transmission, GPS location and time, and a user selected brevity code that operates in the military UHF band. The system uses a tiered architecture (national, aircraft, UAVs, aerostats, and towers) to receive and relay the signal to a ground processing center, which then retransmits the data through the TDDS broadcast to Tactical Receive Equipment (TRE), or through SIPRNET, to the tactical user. Ultimately, the data will be displayed in GCCS-A, MCS, or other command and control systems. Worldwide interpretability is provided through the use of common messages and data elements.

The GB system can be man-packed or easily mounted on military or commercial vehicles, helicopters, or aircraft. It leverages the Combat Survivor Evader Locator (CSEL) radio technology used by the Air Force. The man-portable version will be similar to a “brick” radio transmitter. The vehicle mounted system will include a ruggedized transceiver and hand-held device with a display. National systems will provide the communications backbone and provide the vital communications interfaces between GB, GCCS-A, and MCS. The contract for GB was awarded in April 1999 with delivery of receivers starting in 2001.

GB will be supported by the Standard Army Logistics System. The maintenance concept may be a two-level concept based on the variant mission for ground, air, or sea. Standard Test, Measurements and Diagnostic Equipment (TMDE) will be utilized. Operator level maintenance will be limited to basic care and cleaning, and the replacement of basic components such as batteries, fuses, and filters. Depot level maintenance will be responsible for all repairs.

The program has been jointly developed. The COBRA waveform is a common Service-Agency standard technology supporting COP and various tracking and tagging programs, projects, and demonstrations. The system has been demonstrated in several All Services Combat Identification Evaluation Team (ASCIET) exercises, as well as in JWID, in Korea (FOAL EAGLE), and in Germany. GB has been supported by the national intelligence community. GB has been incorporated as an Initiative in JCS

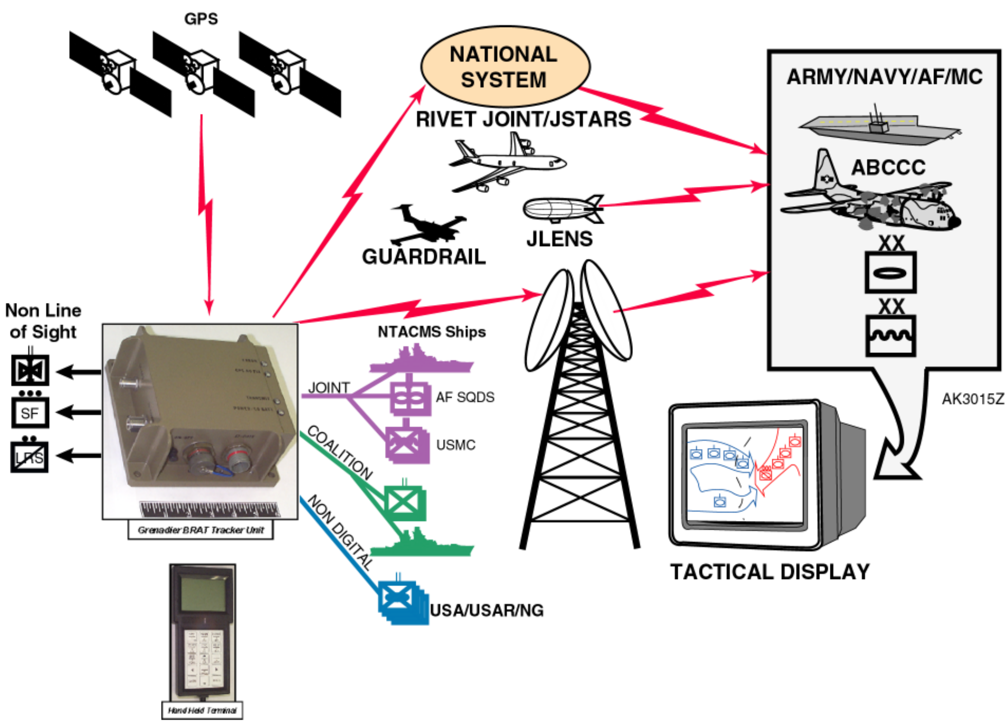

Figure 5-27: Grenadier BRAT End-to-End Architecture

Special Project SOUTHERN EYE.

TES-LITE

TES-LITE accepts, correlates, and integrates SIGINT reports from national, theater, and corps collection and dissemination assets to include the AEPDS. Receives, integrates and disseminates national and theater imagery from various processors and sources. The objective Tactical Exploitation System-Light (TES-LITE) will incorporate the functionality of the FAST. The TES-LITE is a transportable, modular, survivable, stand-alone, UNIX system. It provides MITT functionality in transit cases. The TES-LITE will be fielded in the 2006 timeframe.

SIGINT & IMINT Preprocessing Architecture (S&IPA)

The S&IPA provides a framework for the TES and the Guardrail Common Sensor (GRCS) Integrated Processing Facility (IPF) and its follow-on, the Aerial Common Sensor (ACS) Ground Processing Facility (GPF) to become interoperable, achieve selective commonality of processors and methods, and to operate as an integrated system-of-systems. The S&IPA will also provide the flexibility for split-based operations, that support deployable and deployed forward and main headquarters elements of the joint task force or ground component commander (at corps or detached to the division or brigade echelons coincident with the contingency operation). The S&IPA reflects a transition from autonomous TENCAP and GRCS IPF system operations to a state of interoperability and selective commonality for TES and ACS GPF. The S&IPA will support national security objectives and assist in the planning and execution of strategic, operational, and tactical deployments. It becomes part of contingency operations as an element of an Army, joint, or combined force for stability and support operations or for war across the spectrum of conflict.

The S&IPA will provide a single preprocessing resource and focus for the commander, G-2, and G-3. It will leverage the synergy of collocated analysts and their methods, techniques, and tip-offs. These characteristics will achieve a timely coherent data stream to the G-2 and G-3, so that the data may be fused to form a common picture of the battlefield for dissemination. The A&IPA supports dynamic tasking, retasking, and synchronized collection, processing, and exploitation of national, theater, and organic platforms and sensors.

Eagle Vision II (EVII)

EVII is a proof-of-concept experiment to help determine the utility of timely civil and commercial imagery as a responsive combat enabler. The goals are: 1) to assess the usefulness of commercial high-resolution imagery to support military operations; 2) to develop technical and operational architectures for use with existing military infrastructure, to determine best fit (separate system or integrated into existing or developing systems); 3) formulate concepts for dissemination of unclassified imagery within joint and collation force structures and architectures.

EVII is a joint Army and NRO effort. Operational demonstration and evaluation will be conducted by the Army. An EVII integrated product team (IPT) is the mechanism by which changes to the system and the concept of experiment (CONEX) are proposed, evaluated, and prioritized by the CCB. The ASPO Project Officer chairs the EVII IPT, which includes representatives from the NRO, SMDC, HQDA, USARSTRAT, TRADOC, and TRADOC Battle Labs. The NRO will chair the CCB, which include ASPO, TEC, and ARSTRAT. Eagle Vision II has been incorporated as an Initiative in JCS Special Project SOUTHERN EYE.

Due to funding and schedule constraints, a phased development plan is being executed to provide this experimental capability. The EVII program is structured into two phases. Phase I will develop, build, test, and operate the prototype mobile satellite commercial imagery ground receive and processing system. Phase Ia will deliver a system capable of ingesting data from SPOT 1,2, and 4 and RADARSAT 1.

Phase 1b will provide a field upgrade to add the capability to ingest data from one U.S.-built high-resolution system. Additionally, Phase 1 will include a Joint Collection Management Tool (JCMT) based EV Mission Manager (EVMM) that will provide a common commercial imagery planning tool. Phase II is the planned incorporation of one additional high-resolution system and an upgrade and license to receive LANDSAT 7.

The Army has a continuing need to evaluate evolving commercial imagery operations against specific Army criteria. Inherent to this effort is the need to study, test, and evaluate the capability and performance of individual commercial imaging satellite systems. EVII will test the entire tasking, processing, exploitation, and dissemination (TPED) for commercial imagery. The results from EVII will help define the role of commercial imagery for strategic, operational, and tactical users. EVII will provide a deployable mobile ground station that is not dependent on a foreign controlled downlink and processing facility.

EVII will be certified for air transport on C-130 or larger military airlift. The system will consist of a diesel tractor, a 34-foot double-expandable semi-trailer, and a separate, towable, 5.4 meter antenna. The dual push-out design of the van provides extra workspace, and the system is equipped with a remote operating position (ROP) that can be set up in the supported organizations operations center. The system uses a COTS-GOTS open architecture.

The EVII network and communications subsystem will provide connectivity between the multiple internal computer systems, and to external military and commercial networks. The network includes an asynchronous transfer mode (ATM) for large data transfers and an Ethernet. The subsystem supports both unclassified commercial and classified voice and fax data communications. It will employ standard area communications, and commercial communications capable of worldwide commercial connectivity, used as primary military backup, and for interfacing with commercial vendors.

FOREIGN RECONNAISSANCE AND SURVEILLANCE

Much of the information about foreign reconnaissance and surveillance systems is classified. In the past, Russia was the only country with considerable reconnaissance and surveillance space systems. China has now become a player in space-based reconnaissance and surveillance along with a few other countries. However, with the advent of space-based commercial 1-meter and sub-meter remote sensing systems, many foreign countries will now have access to reconnaissance capabilities that were typically limited to two or three countries. See the Remote Sensing chapter for more information.

To date, no other country besides the U.S. has a fully operational space-based missile warning system.

Russia

There are several opinions concerning the capability of Russia to continue developing and launching the number of reconnaissance and surveillance systems that it has in the past. The name normally associated with Russian reconnaissance and surveillance satellites is Cosmos (or Kosmos). Recently the number of satellites maintained in orbit has fallen. The gap between the de-orbiting of Cosmos 2320 in 1996 and the launching of Cosmos 2343 in 1997 was unprecedented since the photoreconnaissance satellite program began in 1962.

Reconnaissance Satellites

The Russians are currently flying four types of photoreconnaissance satellites on a semi-regular basis. They have program names such as Yantar, Orlet and Arkon. Most are film return systems although some are now digital data return systems. Typical lifetimes do not exceed one year before they are de-orbited. In the past, the Soviet Union would launch up to 30 photoreconnaissance satellites a year. Over the last few years, there have been periods when Russia has had no record of space reconnaissance capability. The last reported launch was Cosmos 2359 in June 1998. Russia has also started to describe some of their photoreconnaissance satellites in open literature and has sold some of the imagery under the SPIN-2 imaging program.

Electronic Intelligence (ELINT) Satellites

Unlike the photoreconnaissance satellites, many of the ELINT systems are still classified. Russia's capability to maintain a constellation of ELINT satellites has also taken a fall in the past few years. Best know are the ELINT Ocean Reconnaissance Satellites (EORSAT). This program has been in operation since 1974. They have been typically flown to detect, identify and track naval forces that might threaten Russia. Typically two satellites operate simultaneously for a year.

Early Warning Satellites

Russia's early warning space systems for detecting missile attacks is deteriorating. Russia has negotiated with the U.S. during the past year to gain access to some of the U.S. missile warning data. The Russian missile warning space system required several passes over missile site areas and therefore needed several satellites. The current constellation has a gap for several hours. The "Oko" constellation needs at least nine operational satellites in Molniya orbits to provide global overlapping coverage. Russia has not been able to maintain this constellation in the recent years although launches still continue. Russia probably has partial coverage of the U.S. and China. There is also a constellation named Prognoz flown in geosynchronous orbit.

China

Once again, much of the Chinese reconnaissance and surveillance capabilities are classified. China seems to have no long term constellation of military satellites deployed. However, it is possible for the Chinese military to use "civilian" satellites such as the Feng Yun-1 meteorological satellites and Fanhui Shi Weizing (FSW) series of remote sensing satellites. A more capable FSW-3 series will give the Chinese greater capability in the photoreconnaissance arena.

SPACE RECONNAISSANCE AND SURVEILLANCE CAPABILITIES

The prime advantage of reconnaissance and surveillance space systems is their ability to provide worldwide, quick-reaction coverage of areas of interest. They can observe areas that we do not have access to with other sensors. They also enhance planning capabilities, providing updated information regarding enemy force locations. Often the product of a space or terrestrial system can cue a space system to survey an area of interest, enhancing accuracy and reaction times to the user.

Space-based reconnaissance and surveillance systems can provide near-real time information in many cases. TBM warning timelines have decreased significantly with the use of space-based systems.

SPACE RECONNAISSANCE AND SURVEILLANCE LIMITATIONS

The key limitation of these systems is simply based on limitations dictated by the satellite orbit. As discussed with remote sensing and environmental satellites, the LEO orbit gives the best resolution of Earth but it is not a geostationary satellite. The cost of reconnaissance and surveillance satellites currently prohibits a proliferation of satellites as we have with communications satellites. Therefore, the satellites do not cover a particular area 24 hours a day. Commanders and their staffs must know satellite coverage times to effectively enhance their operations.

In addition to the access limitations dictated by the satellite orbit, some satellite systems may be affected by a variety of atmospheric disturbances such as fog, smoke, electrical storms and clouds. These affect the ability of some imaging systems to detect enemy activity and missile launches.

Another problem associated with space-based reconnaissance and surveillance systems is the fact that they are national systems designed to meet the requirements of the POTUS and SECDEF. As such, the priority of effort is at the strategic level and not necessarily at the tactical level of war. Requests for support are based on priority of need.

TBM warning may produce some false events depending on how accurate the commander wants the information. TBM warning systems still experience some correlation problems with other radar systems or with multiple events.

PLANNING CONSIDERATIONS

Reconnaissance and Surveillance

Q. What area do I need information from and what kind of information do I need? The space systems have limitations as to when, where, and what kind of information they can sense.

Q. What kind of information do I need and at what resolution? Can another system such as UAV provide the information I need? The higher the resolution, the longer the tasking will take to get a space system applied against it. The commander must consider whether he has the assets available to get the information he needs before tasking a satellite system.

Q. What priority am I willing to place on the request? How quickly do I need the information? Satellite requests are based on priority of need. Strategic and Operational users frequently have higher priorities than tactical users. It may be hours before your request is processed and then the satellite may not be in position to fulfill your request immediately.

Q. When I get the information, how old is it? Can I use archived information or information that someone else has requested? The commander must always consider the time the information was gathered. If already requested imagery can be used, the time to get the information will be significantly shortened.

WEATHER AND ENVIRONMENTAL MONITORING

Overview

The field of meteorology entered the space age on April 1, 1960 with the launch of TIROS 1 (TIROS stands for Television and infrared Observation Satellite). Some would argue that weather satellites date back to 1959, when NASA's Vanguard 2 photographed the weather on the Earth's surface. Since that time, numerous satellites with ever increasing capabilities and sophistication have been deployed.

Weather satellites provide valuable real-time cloud photographs. Most importantly, coverage includes the 70 percent of the earth's surface covered by water where few surface observations can be made. Before the deployment of weather satellites, many areas had no advance warning of impending severe storms. Today satellites can spot and accurately track hurricanes and typhoons while they are still far out in the ocean. Modern satellites also carry many instruments used to measure various environmental variables, providing vital information to not only meteorologists, but farmers, geologists, fishermen, foresters and others.

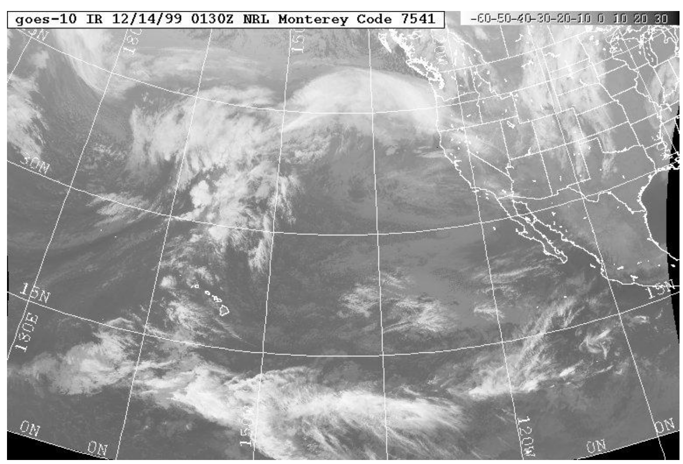

Figure 5-28: GOES-West Image of Pacific Ocean

Satellite based systems do not try to replace surfaced based instruments, but rather to compliment and augment them. Surface based weather reporting instruments are critical to characterizing current weather conditions. Only surface based instruments on land, floating in the oceans, or carried aloft by balloons provide direct precise measurement of environmental conditions. The problem is that there just aren't enough of them. Weather sensors carried on satellites designed to measure current weather conditions and environmental factors that influence the weather are the only alternatives to having many hundreds of thousands of monitoring stations around the world on land and at sea. Obviously weather satellites do not measure environmental conditions directly. Instead, they carry a variety of instruments that either take visible and infrared pictures or take readings, called soundings, of the area within view of the sensors.

Some people refer to weather satellites as environmental satellites because they can tell us something about the air, water and land in which we live. Weather and environmental satellites are similar in that they gather information about the nature and condition of the Earth's land, sea and atmosphere by remote sensing. They accomplish this with sensors that observe the Earth in various discrete bands of the electromagnetic spectrum. They are different in that the systems are designed to observe different phenomena and thus have sensors that gather data in different spectral bands with different resolutions. When the data from space systems is merged with that obtained from other ground and airborne sensors, the resultant products are of significantly better quality than those produced from only one source. For military purposes and for purposes of this text, we will differentiate between weather and environmental satellites. Weather satellites are those designed to assess meteorological phenomena. Environmental satellites are those designed to assess information about the status of the land and changes made over time.

Weather Satellites in General

Most weather satellites are civil systems, even in the case of foreign weather satellites. The United States, Russia, Japan, China, Europe, and India currently have weather satellites in operation. The Defense Meteorological Satellite Program (DMSP) is the only DoD weather satellite system and now is merging with NOAA, a civil system. By international agreement the data sent from civil weather satellites is not encrypted and can be received and processed by anyone with the proper type of equipment. Most civil weather satellites transmit data from their sensors in an unencrypted, publicly available format. A number of companies make weather satellite receivers that can receive data directly from the satellites, process it, and display it on a local display. The data rate from some instruments is high so a large antenna may be required to receive all data. To reduce costs, it is common to have central weather satellite receivers with high speed computers to process the data into a variety of weather products. The products are then distributed by radio or over landlines. The organizations operating the civil weather satellites routinely share data. This shared data is available over the Internet to anyone.

The wide-ranging view afforded from satellites makes it possible to observe weather over a large area from an overhead perspective. Weather satellites can be found in two types of orbits: geostationary to give the “big picture” and polar sun-synchronous to collect data closer to the earth. The advantages of using low Earth orbiting satellites and high altitude geostationary orbiting satellites counterbalance the disadvantages of each type of orbit. Using satellites that are in both types of orbits, it is possible to keep 100% of Earth almost constantly under observation and provide the most accurate data available to merge with the ground weather system data.

Various types of sensors are used on board to detect weather phenomena and its changes. Visual sensors on the satellites take pictures of the cloud formations, land and water below. The size and shape of clouds can tell a meteorologist the type of weather in the area of interest. A series of pictures over time can reveal changes in the weather, the speed and direction of movement of storms and other aspects of the weather. Infrared sensors on the satellites can provide digital data on the temperatures of the water, land and clouds in the frame of view. It is even possible to determine the temperature of the atmosphere at various altitudes by a technique called "atmospheric sounding." Sensors on weather satellites can detect the temperature of specific gases that make up the Earth's atmosphere which when merged with other data results in information on wind speed and direction and atmospheric pressure.

Although civil weather satellites have performed extremely well in space for long periods of time, they are not hardened against hostile action or nuclear effects. Only the U.S. military has weather satellites that are hardened to enhance their survivability. They transmit encrypted data which cannot be used by anyone other than approved users who have been provided with the current COMSEC codes. The U.S. military uses weather data provided by the Defense Meteorological Support Program satellites along with U.S. and foreign civil weather satellites in low Earth polar sun-synchronous and geostationary orbits

Chapter 8
Space-Based Weather

MILITARY WEATHER APPLICATIONS

Weather is considered in every facet of military planning, global deployment, and system design and evaluation. In 2003, Peter B. Teets, Undersecretary of the Air Force, testified that "the nation's unparalleled ability to exploit weather and environmental data gathered from space is critical to the success of military operations." With improvements in environmental situational awareness, the U.S. military is rapidly shifting its tactical and strategic focus from "coping with weather" to anticipating and exploiting atmospheric and space environmental conditions for military advantage.

Analysis of weather is a critical step in the Intelligence Preparation of the Battlefield (IPB). Weather and its effects on the environment and terrain have impacted the conduct of military operations throughout history. Knowledge of the current weather and terrain in an area of operations along with accurate predictions of what future conditions is a definite advantage. Timely and accurate 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 field 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.

Weather data plays a crucial role in planning and conducting all military operations ranging from locating cloud gaps for aerial refueling to determining site visibility prior to reconnaissance flights. We use satellite weather pictures for forecasting when weather conditions will be favorable for friendly forces and the impact of weather on the effectiveness of weapons and the mobility of forces. 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.

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.

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.

Satellite-based remote sensors provide situational awareness of environmental conditions and allow geographical access to areas that otherwise would not be directly available. Weather satellites cover areas that the military does not have direct access to. Weather data from these areas can be critical. For example, weather conditions developing in and around China have a strong influence on the weather that will occur on the Korean peninsula. Although China currently reports some weather conditions from the area through international civil weather reporting channels, the reports may be discontinued during a conflict in Korea. Satellites give us a way to gather weather data quickly over large areas using our own sensors but without violating a country's airspace.

Part of the success of the air campaign in Operation Iraqi Freedom was attributed largely to good weather (for aircraft operations) throughout the period. However, nearly 65% of all air sorties that were cancelled were due to weather during a 3-day period at the end of March 2003.

The ground war commenced on March 20, 2003, and the Third Infantry Division began its furious race through the desert toward Baghdad. As a front swept east across the Mediterranean, forecasters warned to prepare for "the mother of all fronts."

The largest sandstorm to hit southern Iraq in decades engulfed a 300-mile-wide area and blasted tremendous walls of dust into the atmosphere. Meanwhile, the Saddam Fedayeen (Saddam's "Men of Sacrifice") used the cover of the blinding storm to attack the stalled Army convoys.

The same system that blinded troops in southern Iraq created a different set of weather challenges for operations in northern Iraq. Sleet, snow, and heavy cloud cover over Bashur Airfield jeopardized a large and daring combat jump.

SATELLITE SYSTEMS

The DMSP and National Oceanographic and Atmospheric Administration (NOAA) satellites have evolved from the first TIROS weather satellites. Russia maintains Meteor weather satellites in low Earth orbit. NOAA also operates the Geostationary Orbiting Environmental Satellites (GOES). The European Meteorological Satellite (EUMETSAT) organization, a consortium of European civil weather reporting agencies, operates the METEOSAT satellites. Japan operates the Geostationary Meteorological Satellite (GMS) system. Russia operates the Geostationary Orbiting Meteorological Satellite (GOMS). India operates the constellation of Indian Satellites (INSAT). INSAT satellites have a multipurpose mission to

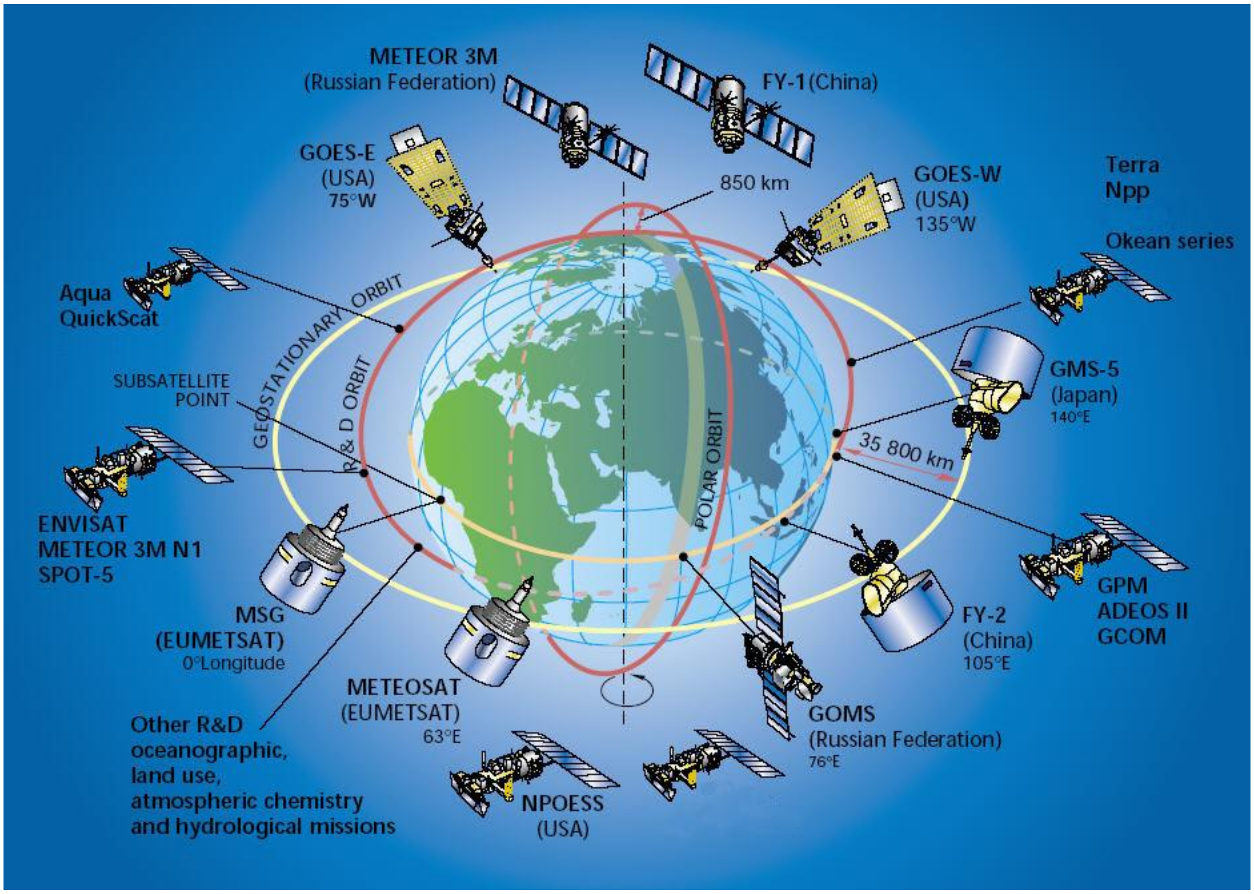

Figure 5-29: Commercial/Civil Weather Satellites

provide communications and weather data. China launched some Feng Yun low Earth orbiting weather satellites but they are no longer operational. Each of these systems will be explored in more detail.

Polar Orbiting Satellites

Sun-synchronous, polar orbiting, low Earth orbiting (LEO) weather satellites provide daily, full world coverage and higher resolution imagery than that available from geostationary satellites. Polar satellites have the advantage of photographing clouds directly beneath them. Geostationary satellite images of the Polar Regions are distorted because of the low angle the satellite sees the region. Polar satellites also circle at a much lower altitude (about 530 mi., 850 km) providing more detailed information about violent storms and cloud systems. Only the United States, Russia and China operate polar, low Earth orbiting, sun synchronous weather satellites. A sun-synchronous orbit is one in which the satellite passes over a particular part of the Earth at the same time every day.

The U.S. has two polar, LEO, sun-synchronous satellite weather systems:

- Defense Meteorological Satellite Program (DMSP). DMSP provides weather data through all levels of conflict and disseminates global visible and IR cloud data and other specialized meteorological and oceanographic data to support DoD operations. DMSP is operated by the U.S. Air Force.
- National Oceanic and Atmospheric Administration (NOAA) Advanced Television infrared Observation Satellite (Advanced TIROS). The NOAA/TIROS satellites provide images of cloud cover, snow, ice, and sea surface, plus temperature and moisture at various levels in the atmosphere for weather analysis and forecasting.

Defense Meteorological Satellite Program (DMSP)

(http://www.af.mil/factsheets/factsheet.asp?fsID=94)

Space Segment

The DMSP mission is to generate terrestrial and space weather data for operational forces worldwide. The Air Force is the Department of Defense's executive agent for this program. The DMSP satellites design aims at meeting unique military requirements for worldwide weather information. Through these satellites, military weather forecasters can detect developing patterns of weather and track existing weather systems over remote areas. DMSP has been accomplishing this mission for more than 40 years. In that time, the Air Force has successfully orbited more than 35 satellites.

Figure 5-30: DMSP

DMSP satellites are in a sun-synchronous orbit at an altitude of approximately 833 km (450 nautical miles or 518 statute miles) with an approximate inclination of 98.7º. At all times at least two operational DMSP satellites are on orbit. Each satellite crosses any point on earth up to two times a day and has an orbital period of about 101 minutes. Their particular orbits allow one satellite to pass overhead in the early morning and the other to pass in the late morning. The satellite encrypts all data transmitted, except when over the north and south poles.

Each DMSP satellite monitors the atmospheric, oceanographic and solar-geophysical environment of the Earth. The visible and infrared sensors collect images of global cloud distribution across a 3,000 km swath during both daytime and nighttime. The coverage of the microwave imager and sounders are one-half the visible and infrared sensors coverage, thus they cover the Polar Regions above 60º twice daily but the equatorial region once daily. The space environmental sensors record "along track" plasma densities, velocities compositions, and drifts.

The last three Block 5D-2 satellite act as back ups to the two primary satellites. The primary sensor on-board is the Operational Linescan System that observes clouds via visible and infrared imagery for use on worldwide forecasts. A second important sensor is the Special Sensor Microwave Imager (SSM/I), which provides all-weather capability for worldwide tactical operations and is particularly useful in classifying and forecasting sever thunderstorms, hurricanes, and typhoons. Additionally, the SSM/I helps Army operations by getting data on soil moisture, land surface characteristics and vegetation type. The DMSP satellites also measure local charged particles and electromagnetic fields to assess the impact of the ionosphere on surveillance, detection and communications (HF and UHF) systems. Additionally, space weather forecasters use this data to monitor global auroral activity and to predict the effects of the space environment on military satellite operations.

The two primary operational satellites are Block 5D-3 series, which accommodate upgraded and larger sensor payloads. They also feature a larger power supply; a more powerful on-board computer with increased memory allowing greater spacecraft autonomy and increased battery power that extends mean mission duration.

Control Segment

NOAA's Office of Satellite Operations in the National Environmental Satellite, Data and Information Service exercises primary command and control of the DMSP constellation. In May 1994, the President of the United States ordered the Departments of Commerce (DOC) and Defense (DoD) to converge their current polar-orbiting environmental satellite systems into a single National program. Under this directive satellite control authority passed from Air Force Space Command to the tri-service (DoD, DOC, NASA) National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Program Office (IPO). As part of the agreement the DoD

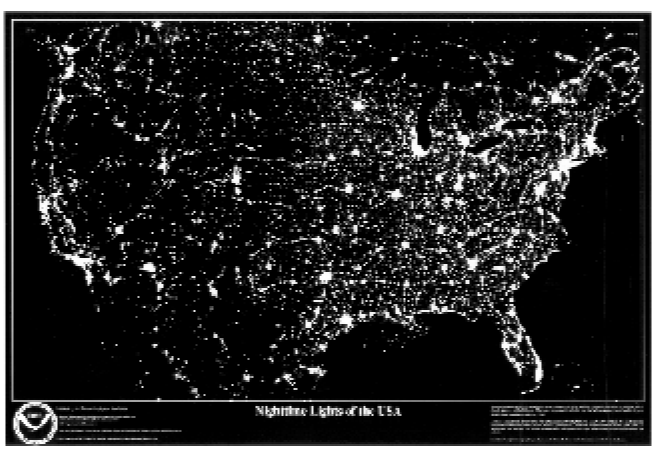

Figure 5-31: DMSP "Night Shot"

transferred day-to-day operations of the DMSP constellation to DOC's NOAA. However, the DoD kept the right to transfer C^2 back to the Air Force in case of extreme national emergencies and exercises oversight through the NPOESS IPO's Directorate of Operations. Additionally, in October 1998, the Air

Force Reserves activated the 6th Satellite Operations Squadron (6 SOPS) at Schriever Air Force Base, Colorado to act as a hot backup to the DOC Satellite Operational Control Center (SOCC) in Suitland, Maryland. SOCC and 6 SOPS routinely alternate primary C2 responsibilities to maintain proficiency in DMSP operations.

The control segment makes use of ground stations for command and control of the satellites. There are four DMSP-enhanced ground stations in Thule AB, Greenland; New Boston AS, New Hampshire, Kaena Point, HI; and Fairbanks, AK. These sites collect and route environmental data to the DMSP user community. Through specialized communications equipment, 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 the satellite orbit. Operators access stored data once every orbit when the satellite is within the Field-of-View (FOV) of a DMSP compatible ground station.

The DMSP Program Office, which is part of Air Force Space Command's Space and Missile Center at Los Angeles AFB, California manages the sustainment of the constellation. The last four satellites remain in clean rooms at Lockheed Martin facilities in California awaiting launch.

User Segment

A long list of users comprises the user segment of the DMSP constellation. The biggest DMSP data users are the Air Force Weather Agency (AFWA) and the Navy's Fleet Numerical Oceanography Center (FLENUMOCEANCEN). These two agencies serve as the central distribution points for much of the DSMP generated environmental data. AFWA products include: meteorological advice, aviation, terminal and target forecasts prediction of sever weather; automated flight planning; exercise and special mission support; and computations for ballistic missile systems, as well as the collection and dissemination of environmental data. FLENUMOCEANCEN receives and processes DMSP visible, infrared and microwave imagery and distributes products to the Navy's operational forecasting community on-shore and afloat.

The DMSP User Segment also has a tactical component. This component consists of fixed and mobile land and ship-based tactical terminals operated by Air Force, Navy and Marine Corps personnel. The Air Force provides all meteorological support to the Army. These terminals are capable of recovering direct readouts of real-time visible, microwave and IR cloud cover data from the satellites. The biggest advantage of tactical users having their own receivers and processors is that they can concentrate on their particular areas of interest. Tactical receiver terminals do not, however, receive all of the data received at AFWA or FLENUMOCEANCEN because the satellites transmit it at such a wide bandwidth and at such a high data rate that the size of the terminals

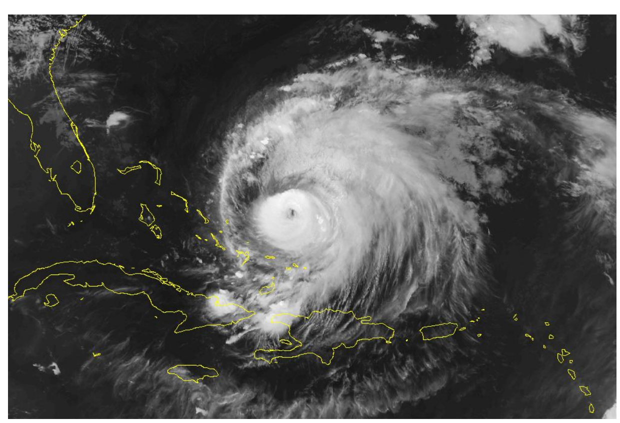

Figure 5-32: IR Picture of Hurricane Bonnie

would be prohibitively large.

The tactical terminals (TACTERM) have been part of DMSP since the early 1970s. The latest TACTERM is the Mark IV terminal, a transportable satellite terminal designed for worldwide tactical deployment in hostile environments. Mounted on standard shelter, the Mark IV can be towed over virtually any terrain or transported on C-130 or C-17 aircraft and be operational within 8-10 hours. 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, and 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. Additionally, DMSP satellites provide environmental data directly in real time to Air Force, Army, Navy and Marine Corps tactical ground stations and Navy ships worldwide.

IMETS is a mobile, tactical automated weather data receiving, processing and dissemination system designed to provide timely weather and environmental effects forecasts, observations, and decision aid information to multiple command elements at echelons where U.S. Air Force Weather teams provide weather support to the Army. The IMETS is an Army furnished system (standard shelter/vehicle, ACCS common hardware/software and communications) is operated by Air Force Staff Weather Officer personnel and maintained within planned Army support for system hardware components. The system is capable of receiving weather data from all available sources such as weather satellites, local and remote weather sensors, meteorology, theater forecast units, and Air Force Global Weather Central

The STT (Small Tactical Terminal) is a two person portable satellite data receiver and analysis system. It receives visual and infrared imagery and mission sensor data directly from the satellites. A Basic STT can receive up to 3 streams of satellite data simultaneously. Allows RDS data from DMSP, APT data from NOAA satellites, and WEFAX from geostationary weather satellites to be received and processed at the same time.

NOAA

Space Segment

The POES Program is a cooperative effort between NASA and the National Oceanic and Atmospheric Administration (NOAA), the United Kingdom (UK), and France. The Goddard Space Flight Center (GSFC) is responsible for the construction, integration and launch of NOAA satellites. Operational control of the spacecraft is turned over to NOAA after it is checked out on orbit, normally 21 days after launch. The NOAA satellites carry seven scientific instruments and two for Search and Rescue.

Currently, the POES mission is composed of two polar orbiting satellites part of the Advanced Television Infrared Observation Satellites (TIROS) - N (ATN). NOAA-M and NOAA-N operate as a pair and primarily provide data used for long-range weather forecasting ensuring that infrared and non-visible data for any region of the Earth are no more than six hours old.

POES data provides economic, humanistic, and environmental benefits on a continuous, reliable basis. The benefits that directly enhance the quality of human life and protection of Earth's environment include:

- Over 50% of the U.S. public utilizes 3-to-5 day weather forecasts for planning recreational and business activities.
- City, state and federal government agencies utilize TIROS data products to manage resources, plan civic and industrial expansion, schedule services, and monitor population growth.
- Countless lives and properties have been saved by monitoring severe storm movement and forecasting national disasters.
- From monitoring ozone levels and animal migrations patterns to forecasting and detecting forest fires, TIROS is a vital tool of environmental research and protection.
- Global data collected about the earth is used to monitor the environment and trend changes over time.
- Search and Rescue instruments carried on POES satellites contributed to saving over 17,000 lives.

The satellites are a three-axis-stabilized spacecraft that are launched into an 830-870 km, circular, near-polar, sun synchronous orbit. The circular orbit permits uniform data acquisition by the satellite and efficient command and control of the satellite from ground stations located near Fairbanks, AK, and Wallops Island, VA. The constellation consists of two satellites in sun-synchronous orbits. One satellite crosses the equator at 7:30 a.m. local time, the other at 1:40 p.m. local time. Each satellite orbits the Earth 14.1 times per day. Operating as pair, these satellites ensure that data for any region of the Earth are no more than six hours old.

The NOAA satellites are built using the same basic design as DMSP satellites, therefore, they look alike. Sensors carried on the NOAA satellites have different names and different technical characteristics but they perform the same general functions as those on DMSP satellites. The suite of instruments is able to measure many parameters of the Earth's atmosphere, its surface, cloud cover, incoming solar protons, positive ions, electron-flux density, and the energy spectrum at the satellite altitude. As a part of their mission, the satellites can receive, process, and retransmit data from Search and Rescue beacon transmitters, and automatic data collection platforms on land, ocean buoys, or aboard free-floating balloons. The primary instrument aboard the satellite is the Advanced Very High Resolution Radiometer or AVHRR which is similar to DMSP’s OLS.

The latest POES satellite, NOAA-N, launched in May 05, is the first in a series of polar-orbiting satellites to be part of a joint cooperation project with the European Organisation for the Exploitation of Meteorological Satellites (EUMESTAT).

Control Segment

NOAA/NESDIS operates two Command and Data Acquisition (CDA) stations, one in Wallops Island, Virginia and one in Fairbanks, Alaska (formerly Gilmore Creek before 1984), to receive both recorded and direct readout environmental data from the satellite and send these data to Suitland, Maryland, via satellite relay. A receive only CDA station is also set up in Lannion, France at the Centre National d'Etudes Spatiales (CNES), France's national space center. The satellites send more than 16,000 global measurements daily via NOAA's CDA station to NOAA computers, adding valuable information for forecasting models, especially for remote ocean areas, where conventional data are lacking.

User Segment

Some commercial weather receivers can receive POES transmissions. The Army uses POES data for both current weather determination and forecasting to support operations. The POES satellites provide data which enhances data that is provided by geostationary weather satellites. They also provide weather data of the polar areas not covered by geostationary satellites. It is also possible to receive data from civil weather satellites that are operated by other countries.

Geostationary Weather Satellites

Another group of weather satellites is maintained in geostationary orbit to provide a continuous watch of the weather on the Earth below them. Each geostationary weather satellite is able to continuously scan approximately one third of the Earth, collecting visual and IR data. This positioning allows continuous monitoring of a specific region. Geostationary satellites measure in "real time", meaning they transmit photographs to the receiving system on the ground as soon as the camera takes the picture. A succession of photographs from these satellites can be displayed in sequence to produce a movie showing cloud movement. This allows forecasters to monitor the progress of large weather systems such as fronts, storms and hurricanes. Wind direction and speed can also be determined by monitoring cloud movement.

The United States, Europe, Japan and India operate geosynchronous weather satellites. The system operated by the United States is the Geostationary Orbiting Environmental Satellites (GOES). There are no military geostationary weather satellites.

Geostationary Operational Environmental Satellite (GOES) (U.S.)

Space Segment

Over the past 30 years, environmental service agencies have stated a need for continuous, dependable, timely, and high-quality observations of the Earth and its environment. The average time it takes to get a DMSP/TIROS product to its user is 15-415 minutes depending on satellite overpass and priority of the tasking. The Geostationary Operational Environmental Satellites (GOES I through M) provide half-hourly observations to fill the need. The instruments on board the satellites measure Earth-emitted and reflected radiation from which atmospheric temperature, winds, moisture, and cloud cover data can be derived.

The GOES constellation is also operated by NOAA. GOES is a series of meteorological geostationary orbiting satellites that provide weather prediction data for the Western Hemisphere and particularly for the U.S. GOES imagery is accessible to over 10,000 ground stations in 120 nations. Because they are in a geostationary orbit, they provide a constant vigil for the atmospheric "triggers" of severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop the GOES satellites are able to monitor storm development and track their movements. GOES satellite imagery is also used to estimate rainfall during the thunderstorms and hurricanes for flash flood warnings, as well as estimates of snowfall accumulations and overall extent of snow cover. Such data helps meteorologists issue winter storm warnings and spring snow melt advisories. Satellite sensors also detect ice fields and map the movements of sea and lake ice. Lastly, they can monitor solar flare activity.

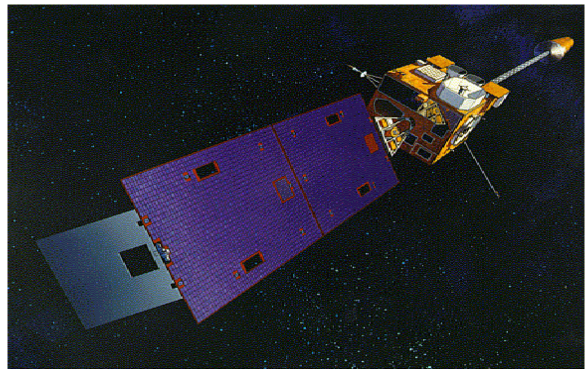

Figure 5-33: GOES

The National Aeronautics and Space Administration (NASA) manages the design, development, and launch of the spacecraft. Once the satellite is launched and checked out, NOAA assumes responsibility for the command and control, data receipt, and product generation and distribution. During NASA's construction and launch phases, the satellites have alphabetical designations: GOES-I, GOES-J, etc. Once the satellites are deployed, they get a serial number in orbit, i.e. GOES-I became GOES-8, GOES-J became GOES-9, GOES-K became GOES-10, etc. The GOES I-M mission is scheduled to run from the mid-1990s into the first decade of the 21st century. Each element of the mission has been designed to meet all in-orbit performance requirements for at least five years.

Each satellite in the series carries two major instruments: an Imager and a Sounder. These instruments acquire high resolution visible and infrared data, as well as temperature and moisture profiles of the atmosphere. The three-axis, body stabilized spacecraft design enables the sensors to image clouds, monitor earth's surface temperature and water vapor fields, and sound the atmosphere for its vertical thermal and vapor structures. GOES-8 and GOES-10 also introduce two new features: flexible scanning that allows small-area imaging *plus simultaneous and independent imaging and sounding*, allowing continuous gathering of data from both instruments. They continuously transmit these data to ground terminals where the data are processed for rebroadcast to primary weather services both in the United States and around the world, including the global research community. The processed data are received at the control center and disseminated to the National Weather Service's (NWS) National Meteorological Center, Camp Springs, Maryland, and NWS forecast offices, including the National Hurricane Center, Miami, Florida, and the National Severe Storms Forecast Center, Kansas City, Missouri. Department of Defense installations, universities, and numerous private commercial users also receive processed data. Color is added to indicate areas of severe weather, along with latitude and longitude lines and country outlines so users can relate the weather to the ground below. More information about the sensor packages can be found at the Internet site http://www.etl.noaa.gov/et6/satres/env_satellite.html.

Imager

The imager detects different wavelengths of energy through different channels. This allows the imager to capture visible light, emitted long wave radiation and other radiation wavelengths. The imager has five "channels" which monitor radiation at a specific wavelength per given channel. Channel and product descriptions are given below:

> 0.52 - 0.72 micrometers (visible) - at 1 km, useful for cloud, pollution, and haze detection and severe storm identification.
>
> 3.78 - 4.03 micrometers (short wave infrared window) - at 4 km, useful for identifying fog at night, discriminating between water clouds and snow or ice crystal clouds, detecting fires and volcanoes, and determining sea surface temperatures.
>
> 6.47 - 7.02 micrometers (upper level water vapor) - at 4 km, useful for estimating regions of mid-level moisture content and advection plus tracking mid-level atmospheric motions.
>
> 10.2 - 11.2 micrometers (long wave infrared window) - at 4 km, familiar to most users for cloud-drift winds, severe storm identification, and location of heavy rainfall.
>
> 11.5 - 12.5 micrometers (infrared window more sensitive to water vapor) - at 4 km, useful for identification of low-level moisture, determination of sea surface temperature, and detection of airborne dust and volcanic ash.

Sounder

The GOES Sounder is a 19-channel discrete-filter radiometer covering the spectral range from the visible channel wavelengths to 15 microns. It is designed to provide data from which atmospheric temperature and moisture profiles, surface and cloud-top temperatures and pressures, and ozone distribution can be deduced by mathematical analysis. It operates independently of and simultaneously with the imager, using a similarly flexible scanning system. The sounder's multi-element detector array assemblies simultaneously sample four separate fields or atmospheric columns. A rotating filter wheel, which brings spectral filters into the optical path of the detector array, provides the infrared channel definition.

The GOES I-M system performs the following basic functions:

- Acquisition, processing, and dissemination of imaging and sounding data.
- Acquisition and dissemination of Space Environment Monitor (SEM) data.

- Reception and relay of data from ground-based Data Collection Platforms (DCPs) that are situated in carefully selected urban and remote areas to the NOAA Command and Data Acquisition (CDA) station.

- Continuous relay of Weather Facsimile (WEFAX) and other data to users, in dependent of all other functions.

- Relay of distress signals from people, aircraft, or marine vessels to the search and rescue ground stations of the Search and Rescue Satellite Aided Tracking (SARSAT) system. A dedicated search and rescue transponder on board GOES is designed to detect emergency distress signals originating from Earth-based sources. These unique identification signals are normally combined with signals received by a low-Earth orbiting satellite system and relayed to a search and rescue ground terminal.

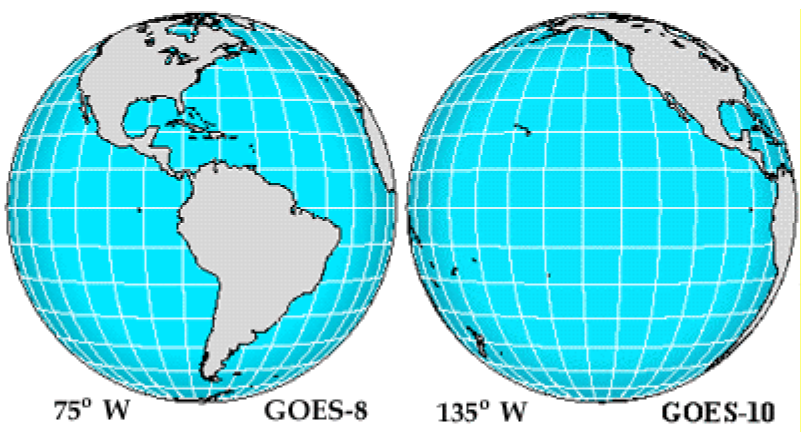

Figure 5-34: GOES 8 and 10

The GOES I-M system serves a region covering the central and eastern Pacific Ocean; North, Central, and South America; and the central and western Atlantic Ocean. Pacific coverage includes Hawaii and the Gulf of Alaska. This is accomplished by keeping two satellites in orbit at all times. Currently the constellation consists of GOES-10 (or GOES West) located at 135ºW longitude and GOES-8 (or GOES East) at 75ºW longitude. Coverage extends approximately from 20ºW longitude to 165ºE longitude. GOES 10 was launched in 1997 to keep an operational spare on orbit. It replaced GOES 9 in August 1998 and GOES-9 is the current spare, although not fully operational. GOES-L (GOES-11) was to be launched in May 1999 but was delayed until

Figure 5-35: COSPAS-SARSAT Emblem

October/November 1999. It will go into cold on-orbit storage to replace GOES 8 when necessary.

A common ground station, the CDA station located at Wallops, Virginia, supports the interface to both satellites. The NOAA Satellite Operations Control Center (SOCC), in Suitland, Maryland, provides spacecraft scheduling, health and safety monitoring, and engineering analyses.

COSPAS-SARSAT

(http://www.sarsat.noaa.gov)

Although not a weather system, several of the weather satellites carry a package on board to aid Search and Rescues efforts. The COSPAS (Cosmicheskaya Sistyema Poiska Avariynich Sudov) - SARSAT (Search And Rescue Satellite) system is an International, humanitarian satellite-based search and rescue system which can detect and locate transmissions from emergency beacons carried by ships, aircraft, or individuals. It has helped save over 9025 lives worldwide since its inception in 1982. There are 25 other participating nations in the COSPAS-SARSAT program.

The GOES satellites carry a Search and Rescue (SAR) module that listens for emergency distress signals from special transmitters on the ground. There are a few basic models of these emergency transmitters or beacons but the concept for all of them is to transmit a signal that identifies the transmitter.

The GOES geosynchronous altitude vantage point gives the GOES SAR the capability to detect distress signals from one entire hemisphere of Earth 24 hours a day but the GOES satellites are too far away to pinpoint the location. Upon detection of a distress signal, other satellites in LEO with SAR equipment are used to pinpoint the location of the distress signal with an accuracy of one to two km. LEO satellites with SAR systems include U.S. NOAA 14, NOAA 15, Russian Meteor satellite and the Russian Nahezda civil navigation satellite constellation. INSAT-2A also carries a COSPAS-SARSAT package on board.

The COSPAS-SARSAT ground network includes the U.S., Canada, France, Russia, Norway, and Brazil. The U.S. portion of the COSPAS-SARSAT System is operated by the NOAA SARSAT Office in Suitland, Maryland. Rescue services around the world have responded to save the lives of hundreds of civilians injured in aircraft accidents and distress at sea. Some military aircraft carry COSPAS-SARSAT emergency beacon transmitters for use during peacetime.

NON-U.S. WEATHER SYSTEMS

The United States is not the only country operating weather satellites. Weather is important to all countries and several have satellites in either polar, geostationary or both types of orbits. The United Nations formed the World Meteorological Organization (WMO) in 1951. The purposes of WMO are to facilitate international cooperation in the establishment of networks of stations for making meteorological, hydrological and other observations; and to promote the rapid exchange of meteorological information, the standardization of meteorological observations and the uniform publication of observations and statistics. As of June 1996, there were 185 Members, comprising 179 Member States and six Member Territories, all of which maintain their own Meteorological and Hydrological Services. For more information about this organization go to http://www.wmo.ch.

Polar Satellites

Meteor (Russia)

(http://sputnik.infospace.ru/meteor/engl/meteor.htm)

Since the inception of the Soviet meteorological program in 1964 and the official debut of the Meteor 1 spacecraft in 1969, the USSR/Russian Federation has operated a single, integrated space-based network designed to meet all civilian, military, and governmental requirements.

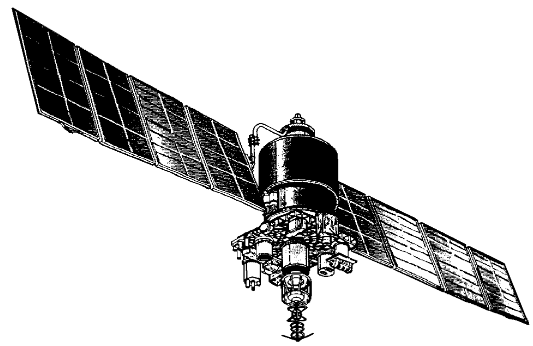

Figure 5-36: Meteor

Russia has continued the Meteor weather satellite program. Meteor satellites are in an approximately 900 km circular orbit with an inclination of 82.5 degrees. The design lifetime is two years.

Meteor satellites provide sensor data that is used for meteorological observations, measurement of sea surface temperatures, extent of sea ice and snow cover and data on the condition of vegetation in the field of view. It also has the mission to observe, on a regular basis, information on radiation conditions in near-Earth space A scanning telephotometer transmits infrared images as the satellite pass overhead. No encryption is used and the format is the same format as POES satellites. Most civilian weather satellite receivers that can receive data from the POES satellites can also receive data from the Meteor satellites. The resolution is about 2 km with a swath width of about 2,000 km.

The scientific instrument package onboard the Meteor-3 spacecraft provides for regular instant acquisition of images of cloudiness and Earth surface in visible and infra-red bands, data on air temperature and humidity, sea surface temperature and clouds temperature. Acquired data on corpuscular and X-ray irradiance and total emitted radiation energy are supplied to geophysical division. The ozone layer is being monitored. Beyond regular scientific hardware, the Meteor-3 spacecraft is often equipped with experimental and research instruments.

The Meteor-3 satellite No.5, which was launched in 1991, carries a scanning spectrometer for global ozone distribution mapping (TOMS instrument, developed and produced by NASA). Meteor-3 satellite No. 6 was the most recent satellite launched. It was launched in January 1994. The launch of Meteor 3 included the small German satellite Tubsat which was separated from the Meteor 3 on the second orbit.

Meteor-3 satellite No. 7 was launched in December 2001. It carries visible and IR sensors and NASA's SAGE III instrument. The latter delayed the launched by 6-months as it had to be returned to manufacturer after satellite integration. Sage 3 studies aerosols and the ozone layer. In December 2003 all transmitters suddenly failed and the satellite is no longer in service.

Feng Yun 1(China)

The Feng Yun 1 is a Chinese weather satellite in a sun-synchronous polar orbit with an altitude of 849 km and an inclination of 98.7 degrees. The satellite has four sensors in the visible light band and one in the infrared band. The highest resolution is about 1 km. Each image covers an area about 1,600 km wide (east-west) and 3,200 km long (north-south). It continuously transmits data in analog format for Automatic Picture Transmission (APT) and in digital format for High Resolution Picture Transmission (HRPT). These signal formats are compatible with U.S. NOAA satellites; therefore, receivers capable of receiving NOAA data can also receive Feng Yun data.

Figure 5-37: Feng Yun 1

A Feng Yun 1C was launched in May, 1999 at an altitude of 870 Km with an inclination of 98.85 degrees. It carried the Shi Jian 5 research satellite as a secondary payload to study the radiation belts. Besides improving the reliability and extending the life of the satellite the number of channels of the scan radiometer increased from 5 to 10. The major sensor package of the FY-1 C is the Multichannel Visible and IR Scan Radiometer (MVISR). The total number of channels of the sensor is increased from 5 channels in FY-1 A and B to 10 channels in FY-1 C. These channels include 4 VIS channels, 3 near IR channels, 1 short wave IR channel and 2 long wave IR channels. The FY-1D is the next satellite.

The meteorological satellite data receiving and processing system consists of three ground stations located in Beijing, Guangzhou, Urumqi respectively and a data processing center in NSMC. The system has successfully accomplished the tasks of data receiving, transmitting, processing and product distributing for the FY-1A and FY- 1B satellites. The system also holds responsibility for receiving and processing the data from NOAA satellites.

A PC based polar orbiting meteorological satellite data receiving and processing system has been developed by the NSMC. The hardware of the system includes a data ingestor for the HRPT data of FY-1 and NOAA satellites, a personal computer (PC 486, PC586), a color image card and a monitor. Other equipment such as tape recorder and video converter etc. is selectable for the system. This PC based system is good at receiving and processing the AVHRR and TOVS data from polar orbiting meteorological satellites.

Geostationary Satellites

METEOSAT (EUMETSAT)(Europe)

(http://www.eumetsat.de/en/area1/topic1.html)

METEOSAT weather satellites are owned and operated by EUMETSAT, a consortium of 18 European States (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey and the United Kingdom). EUMETSAT also has six Cooperating States (Croatia, Hungary, Poland, The Slovak Republic, Slovenia and Romania). Additionally, an agreement has been signed with Serbia and Montenegro, and upon ratification by its government, Serbia and Montenegro will become the latest Cooperating State. These States fund the EUMETSAT programs and are the principal users of the systems. Since July 1999 EUMETSAT also has had two Cooperating States, Slovakia and Hungary. EUMETSAT took over formal responsibility for the Meteosat system in January 1987 and 1991 had initiated a new program to ensure the continuation of Meteosat operations until the year 2000. The Meteosat Second Generation program will ensure continuity of operations until at least 2012 with major improvements to the data.

Since December 1995, EUMETSAT has operated its Meteosat satellites from a new purpose-built control center in Darmstadt. This center is part of a new ground system that includes a Primary Ground Station in Fucino, Italy, and data up-link stations in Bracknell, Toulouse and Rome.

EUMETSAT's Meteosat system is intended primarily to support the National Meteorological Services (NMS) of Member States. The NMS in turn distribute the image data to other end users, notably through the provision of forecasts on television several times a day. Through this particular distribution system it could be said that most of the population of Europe makes direct use of Eumetsat's imagery. Second priority is given to the NMS of non-Member States. These are given privileged access to Meteosat data in the continuing tradition of data exchange between meteorological services. They too use the data for the preparation of forecasts and for distribution to television audiences.

Meteosat-7 is has been the primary operational spacecraft since June 1998. It is in geostationary orbit above the equator at 0º longitude off the west coast of central Africa.

The first Meteosat Second Generation satellite, MSG-1, was launched into geostationary orbit in August 2002. After successfully being placed in orbit the satellite was renamed Meteosat-8. It is position over the eastern Atlantic Ocean at about 3.5º west longitude.

Meteosat-6 is positioned in geostationary orbit at about 9º east longitude. It is in a stand-by mode.

Meteosat-5 is now positioned in geostationary orbit over the Indian Ocean at about 63º east longitude.

Meteosat sensors are similar to GOES. The Meteosat system provides continuous and reliable meteorological observations from space to a large user community. In addition to the provision of images of the earth and its atmosphere every half an hour in three spectral channels (Visible, Infrared and Water Vapor) a range of processed meteorological parameters is produced. Meteosat also supports the retransmission of data from data collection platforms in remote locations, at sea and on board aircraft, as well as the dissemination of meteorological information in graphical and text formats.

INSAT (India)

(http://209.207.236.112/spp/guide/india/earth/insat2_eo.htm)

India's INSAT series of geostationary spacecraft perform the dual missions of communications and meteorology. These unique satellites carry telephone, and television transponders along with weather sensors.

INSAT satellites carry a Very High Resolution Radiometer (VHRR) with 2-km resolution in the visible band and 8-km resolution in the IR band. The sensors are similar to those on GOES. Like many GEO meteorological satellites, INSAT spacecraft require 30 minutes to complete a full Earth scan. In addition to full Earth images, the VHRR can be commanded to scan very limited regions for more rapid return of time-critical data, e.g., during the approach of cyclones to the sub-continent. Each vehicle is also capable of receiving (on 402.75 MHz) meteorological, hydrological, and oceanographic data from remote data collection platforms for relay to central Indian processing centers.

The INSAT 2 program was inaugurated in 1992 with the launch of INSAT 2A, followed by INSAT 2B in 1993. INSAT 2 satellites also carry the Data Relay Transponder system for collection and retransmission of data. The current constellation includes INSAT 2B/2C at 93.5E and INSAT 2E, which was launched in 1999, at 83E.

INSAT-3B was launched in March 2000. INSAT-3C, carrying Fixed Satellite Services (FSS) transponders, Broadcast Satellite Services (BSS) transponders and Mobile Satellite Services (MSS) transponders is intended to continue the services of INSAT-2D and INSAT-2C which are nearing their end of life besides improving and augmenting the INSAT system capacity. INSAT-3C is the second satellite of the INSAT-3 series. Another three satellites INSAT-3A, INSAT-3D and INSAT-3E are planned to be launched under INSAT-3 series in the coming years.

Launched into the geosynchronous transfer orbit by the European Ariane launch vehicle, the liquid apogee motor on board, INSAT-3C is used to lift the satellite to its final geosynchronous orbit, which is about 36,000 km above the equator. The satellite is finally positioned at 74° east longitude.

The satellites are controlled from the INSAT Master Control Facility at Hassan, Karnataka, India. In compliance with the international agreement on weather satellites, the data are not encrypted, however, the signals from the satellite are transmitted on a narrow spot beam to the Delhi Earth Station. The spot beam limits reception of the data to a small area. India did not share data from this satellite until 1991 and then the data was 3 years old. The probable reason for the narrow transmission beam and the lack of sharing of the data is to keep certain neighboring countries from getting the information. The data is relayed to the Meteorological Data Utilization Center in New Delhi where the data is processed. The meteorological products are then relayed through an INSAT satellite to 22 Secondary Data Utilization Centers throughout India.

Geostationary Meteorological Satellite (GMS) (Japan)

(http://daac.gsfc.nasa.gov/PLATFORM_DOCS/gms_source.html)

(http://209.207.236.112/spp/guide/japan/earth/gms.htm)

The Geostationary Meteorological Satellite (GMS) Program consists of a series of satellites operated by the Japan Meteorological Agency. The satellite is also known as Himawari. They are in geostationary orbit at 140°E longitude which allows the satellite to image the Pacific Basin. The first satellite in the series was launched in 1977 and the last in 1995. The satellites have been used for the World Weather Watch Program. The satellites consist of a despun section which houses the earth-oriented antennas and the 100 revolution per minute (rpm) rotating spin section which houses the Visible and Infrared Spin Scan Radiometer (VISSR), the primary instrument aboard GMS.

The VISSR provides visible and infrared images of the Earth and its cloud cover through the use of an optical telescope and detector system. The current satellite, GMS-5, also carries a search and rescue package. The functions of GMS include 1) Observation of meteorological phenomena by the visible and infrared spin scan radiometer; 2) Collection of weather data from various stations; 3) Distribution of weather data to earth stations, and; 4) Monitoring of solar particles.

Japan's National Space Development Agency (NASDA) and Japan's Meteorological Agency (JMA) operate the GMS. GMS data are received at the Command and Data Acquisition Station in Hatoyama, just north of Tokyo. The data is relayed to the Data Processing Center where Stretched VISSR and WEFAX images are created. These are then retransmitted to users through the GMS. The products are also relayed to NESDIS in Maryland where NOAA uploads them as WEFAX on the U.S. GOES weather satellites. Data from these satellites is transmitted in formats similar to GOES and Meteosat.

After some initial glitches, Japanese weather forecasters have started using data from the U.S. GOES-9 geostationary weather satellite. The U.S. weather bird will help Japan track typhoons and other systems in the Western Pacific at least until its weather agency can replace its malfunctioning Geostationary Meteorological Satellite-5. Under a May 2002 deal with the National Oceanic and Atmospheric Administration, the Japanese Meteorological Agency paid to upgrade NOAA's ground station in Fairbanks, Alaska, while the U.S. agency brought GOES-9 out of on-orbit storage for use by Japan. Launched in 1995, the satellite had been mothballed because it wasn't up to the latest NOAA specs. At first, NOAA's satellite control center in Suitland, Md., suffered some dropped commands on a leased high-speed data connection with the Fairbanks facility. But engineers were able to work around the problem by shifting the command-generating function to a computer in Fairbanks. Gregory W. Withee, assistant NOAA administrator for satellites and information, said the arrangement could pave the way for a standing agreement between the two weather agencies to back each other up with satellite data in the Pacific. Japan plans to launch its Multifunctional Transportation Satellite, with sensors to replace those on GMS-5.

GOMS (Elektro) (Russia)

(http://209.207.236.112/spp/guide/russia/earth/goms.htm)

(http://sputnik.infospace.ru/goms/engl/goms_s.htm)

The year 1994 witnessed the long-awaited debut of the Geostationary Operational Meteorological Satellite (GOMS) system of Elektro spacecraft. GOMS was launched 31 October 1994 and placed into a geostationary orbit at 76.61 degrees E. The GOMS network will eventually consist of three spacecraft spaced 90 degrees apart in the geostationary ring: at 14 degrees W, 76 degrees E, and 166 degrees E. Each 2.6-metric-ton spacecraft will have an estimated operational lifetime of at least three years. The satellites are a 3-axis-stabilized platform.

Onboard instruments package allows:

- obtaining in real time visible and infrared images of the Earth surface and cloud cover within a radius of 60° 50' centered at sub-satellite point;
- providing continuous observation of the dynamics of varying atmospheric processes;
- detecting, on an operational basis, hazardous natural phenomena;
- determining wind velocity and directions at several levels, sea surface temperature;
- obtaining information on fluxes of solar and galactic particles, electromagnetic ultraviolet and X-ray radiation, variations in the vector of magnetic field.

Twelve communications channels link the spacecraft to the receiving and processing centers, the independent data receiving center, and the data collection platforms. The main data receiving and processing center is in the Moscow region while two regional centers are located at Tashkent and Khabarovsk.

FengYun 2 (China)

(http://www.cma.gov.cn/fy2/chnsmc.htm#m4)

(http://209.207.236.112/spp/guide/china/earth/fy-2.htm)

The Chinese Meteorological Administration (CMA) launched FengYun 2B FY-2B to 105 degrees East longitude on 10 June 1997. Feng Yun means Wind and Cloud in Chinese. The satellite was located above the equator of 105^{o}E on 17 June 1997 and acquired the first visible image on 21 June 1997. On 8 April 1998, FengYun 2B was moved from 105^{o}E to 124^{o}E in anticipation of the launch of FengYun 2C.

Fengyun-2C was launched in October 2004. The satellite is in geostationary orbit above the equator at 105^{o}E. The transmission of the first image came on 29 October 2004.

FY-2C is the replacement satellite for FY-2B, which has been in space since June 2000 and has operated beyond its design life of three years.

FY-2C is a spin-stabilized satellite that rotates at 100 rpm to maintain its attitude. The satellite is 1.6 m tall and 2.1 m in diameter, with an initial on-orbit mass of approximately 623 kg. FY-2C has a design life expectancy of three years.

The primary payload on FY-2C is the Visible Infrared Spin-Scan Radiometer (VISSR); an imaging instrument consists of a scanning system, a telescope, and infrared and visible sensors.

Through step action of the scan mirror VISSR produces cloud cover pictures in five channels, which is two additional channels than its predecessor on FY-2B. The spectral coverage includes the three conventional channels in the wavelength bands of visible (0.55-1.05 micrometer), infrared (10.5-12.5 micrometer) and water vapor (6.2-7.6 micrometer).

Using sensors to sense radiant and reflected solar energy from sampled areas of the Earth, VISSR can make daytime and nighttime observations of cloud, and determine cloud heights, temperatures and wind fields.

FY-2C produces a cloud image once every half an hour, with a nadir resolution of 1.25 km in the visible channel. Nominally FY-2C transmits 28 cloud images daily. During the flood season, FY-2C can increase the transmission to 48 or more images per day.

The satellite also carries instruments to monitor solar activities such as emission of x-rays, and measure particle radiation in the orbital environment.

The new metsat achieved "first light" on Oct. 29. From 11 a.m. to 11:25 a.m. [0800-0825 UTC] VISSR moved its scanning system from west to east and north to south to make the first full disk image of the Earth, centering on China.

The complete image, measuring 9,164 by 9,164 pixels, shows a large cloud-free area that extends south of the Yangtze River to the southern Guangdong Province and Guangxi Zhuang Autonomous Region. The image also shows a cloud system developing in the western area near the Tibetan Plateau, and snow accumulation in the northeast highland.

Xu Jianmin, Chief Engineer of the FY-2C ground application system, said that based on the first image there was "an obvious improvement" in the quality of the imagery compared to that returned from FY-2B.

The improvement is in resolving structures in cloud cells over sea and in land features such as lakes and deserts; a wider dynamic range in grayscale level display in high-, medium-, and low-level clouds, snow cover, vegetation and water bodies; and a greater level of suppression of scattered light in visible images.

Under the current plan FY-2C will start transmitting observations to clients in January 2005 year, and reach commercial operation status by June 2005.

Another key technical improvement on FY-2C is an increase in battery capacity from 17 ampere-hour to 30 ampere-hour. This would further ensure that the metsat maintains normal operation during periods of eclipse when the satellite goes into the Earth's shadow.

NSMC, a scientific research and operational facility affiliated to the China Meteorological Administration (CMA), receives, processes, and distributes metsat data to users. FY-2C climatic information of western Asia and the Indian Ocean will be distributed to the international community.

FY-2C will continue the surveillance of changing weather conditions that spans the Indian Ocean in the west and the western Pacific Ocean in the east. The metsat monitor development and movement of typhoons in the Pacific Ocean and cyclones in the Indian Ocean, watch weather changes at the Tibetan Plateau, survey the land and seas, detect grassland and forest fires, and observe sandstorms and fog formation.

FUTURE WEATHER SYSTEMS

Polar Satellites

NPOESS

(http://npoesslib.ipo.noaa.gov)

On 5 May 1994, President Clinton approved the convergence of the civil POES/TIROS and military polar orbiting satellite (DMSP) systems into a single operational program. This satellite system will be designated National Polar-Orbiting Operational Environmental Satellite System (NPOESS). The converged system on-orbit architecture will consist of three low earth orbiting satellites. This is a reduction from the current four satellites (two civilian and two military). The orbits of the three satellites will evenly space throughout the day to provide a sufficient data refresh rate. The nominal equatorial crossing times of the satellites will be 5:30, 9:30, and 1:30. This converged system can accommodate international cooperation, including the open distribution of environmental data. The program will be operated by the NPOESS Integrated Program Office (IPO).

The DMSP/POES Convergence Implementation Plan outlines two key efforts for convergence: operations transition and the procurement of a follow-on for DMSP and POES. Beyond the current POES polar-orbiting satellite capabilities, the NPOESS satellites will meet the Department of Defense's requirements derived from DMSP. Additional civil requirements that will be met include increased sensitivity in moisture and temperature profiles and ozone mapping and profiling. Additional DoD requirements that will be met include increased imagery requirements, data availability, and data access. In addition, the NPOESS satellites will be designed with a seven year life versus the current two year life.

The first NPOESS satellite (designated C-1) is to be available in 4Q FY 08 with the first launch tentatively scheduled for 1Q FY 09.

The military value of weather data is directly linked to timely delivery of "fresh" and accurate products to mission planners and battlefield commanders. The constellation of three equally-spaced (in time) NPOESS satellites, combined with larger swath-widths will ensure complete contiguous global coverage with refresh rates (local average time interval between consecutive measurements of a parameter at the same location) of four hours at the equator with faster rates in polar latitudes.

Ground forces are frequently at the mercy of the weather. Troops exposed to the elements are hampered by extreme temperatures, winds, dust, rain, and snow. With accurate weather forecasts and warnings, ground troops can prepare in advance for the extremes or camouflage themselves appropriately. The ability of the mechanized Army to move its weapons and equipment cross-country depends upon soil and vegetation type, soil moisture, precipitation, snow and ice cover. The CMIS instrument on NPOESS will provide leading-edge measurements of surface wetness and soil moisture. Combined with data on vegetation and soil type derived from VIIRS, these measurements will allow the Army to plan maneuvers more effectively for tactical advantage and safety.

Detailed real-time data on ocean surface winds from the CMIS instrument on NPOESS will help U.S. Navy task forces choose operating areas with favorable conditions for air operations. These capabilities will help ensure that range-limited aircraft can complete strike missions and get back to their ship safely. Real-time data from CMIS on ocean surface winds, as well as other oceanographic products that will be derived from other NPOESS instruments or from prediction models that will use the surface winds fields derived from CMIS will assist the Navy in planning amphibious operations that depend critically on sea state. Water clarity and underwater visibility are becoming increasingly important to the Navy as SEAL Teams operating in the littoral regions of the world. Water clarity and turbidity in regions like the head of the Persian Gulf are being mapped today from the multi-spectral data from MODIS on NASA's EOS Terra and Aqua satellites and from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS). These remote sensing capabilities will be carried forward with VIIRS.

The Navy uses ocean surface wind and wave fields for routine ship routing as well as to direct fleet sorties in emergency situations. Accurate, time-critical forecasts of hurricane tracks, strike probabilities, and landfall are essential to the Navy at home and overseas. Microwave and multi-spectral imagery as well as sounding data from NPOESS, combined with higher resolution Numerical Weather Prediction (NWP) models are expected to improve the accuracy of hurricane track and landfall forecasts. With better data and forecasts, the Navy will avoid costly unnecessary sorties and have more time in areas of certain impact.

Weather affects every air mission, from an air drop of humanitarian aid to bombs on targets. While the effects of weather on ground-based aircraft can be serious, carrier-based air wings often have more critical problems. Launching aircraft from the deck of a carrier is highly dependent on wind speeds.

The high-spectral fidelity imagery that will be available from VIIRS will present information in ways that will be more useful directly to the warfighter and allow Combat Weather Teams to answer tactical questions with more confidence. For example, improved cloud information will help make decisions regarding aerial refueling, the operation of infrared-guided missiles, and the formation of contrails, which can reveal stealth aircraft.

The high spatial, temporal, and spectral resolution of the instruments on NPOESS would be wasted if the data were not coupled with an equally fast delivery system. The NPOESS SafetyNet data relay network and the NPOESS ground processing system will improve delivery of data processed to users by a factor of five to seven compared to DMSP and POES. Current tests of the prototype system are demonstrating that nearly 80% of the global NPOESS data will be available to users within 15 minutes and 95% of the data will be available within 24 minutes. According to John Cunningham, System Program Director for the NPOESS Integrated Program Office, "this jump in data latency means you'll actually be observing the weather while it's still fresh." Rapid ingest of new data into numerical weather prediction models will also facilitate improved nowcasts and forecasts.

NPOESS data will also be broadcast in real-time directly to combat units in the field or to carrier battle groups equipped with field terminals. Weather warriors attached to these units will receive NPOESS imagery and data for their area of interest as the satellite passes in range overhead. As technology improves, "net-centric" solutions may allow deployed units to be tied electronically into a larger infrastructure.

Improved weather information will significantly enhance the success of the Nation's global and "at home" military operations. Better global environmental observations can also help prevent new or renewed strife worldwide. Today, nations are increasingly vulnerable to environmental catastrophes that can threaten people, economic or political stability, and lead to regional conflicts over scarce environmental resources. Movement of populations from rural to urban centers, particularly in coastal regions, has created increased competition for resources such as water and arable land. These changes demand improvements in precipitation forecasts for food production, warnings of natural disasters, and seasonal climate and drought forecasts.

Meteor (Russia)

Meteor 3-8 will be the follow-on satellite.

EUMETSAT Polar System (EPS) (Europe)

(http://www.eumetsat.int)

The EUMETSAT Polar System (EPS) is conceived as an integrated end-to-end data system, serving user needs on an operational basis. The initial EPS program consists of a series of three Metop satellites, to be flown successively in the years from 2005, together with the relevant ground facilities. Central facilities include provision for spacecraft command and control, for the reception and central processing of global data, for generation of other products at application centers, and for the exchange of data from the corresponding USA satellites. The satellite itself broadcasts regional data to user stations throughout the world.

The EUMETSAT Polar System is designed as an integrated end-to-end concept embracing the Metop spacecraft, the payload, command and control functions, data processing and data delivery. It is designated as an operational system with the intention to ensure data continuity over an initial period of at least 14 years.

The EUMETSAT Polar System satellites, also called Metop satellites, will broadcast two data streams continuously to user stations throughout the world. By this means users will receive local data in real-time from the satellite each time it passes overhead or close to the station. The orbit is such that most recipients can expect to gather high resolution regional data extending up to about 1500 km radius of the user station, receiving images and other information from at least three consecutive orbits twice each day.

The two data streams will be coordinated with those of the NOAA satellites of the USA, but due to the evolving technology and different phasing of the systems the transmission details will differ. Metop will use a state-of-the-art packetized data transmission standard conforming to the recommendations of the Consultative Committee for Space Data Systems (CCSDS). For the time being, the NOAA satellites will continue to use their current transmission standards. As a consequence, users of Metop direct broadcast transmissions will need new frame synchronizers, reception hardware and software packages for data ingest.

The Metop High Resolution Picture Transmission (HRPT) system will provide data for large scale user stations. This system will carry data from all Metop instruments, including those provided by the USA, but will not be compatible with the system of the same name currently flown on NOAA satellites.

The Low Resolution Picture Transmission (LRPT) system will provide data for relatively small user stations and will be the long-term replacement, using digital technology, for the analogue Automatic Picture Transmission (APT) system currently used on NOAA satellites.

GEOSTATIONARY SATELLITES

GOES NO/PQ

(http://rsd.gsfc.nasa.gov/goes/text/goesnopq.status.9701.html)

(http://rsd.gsfc.nasa.gov/goes/text/goesnext.html)

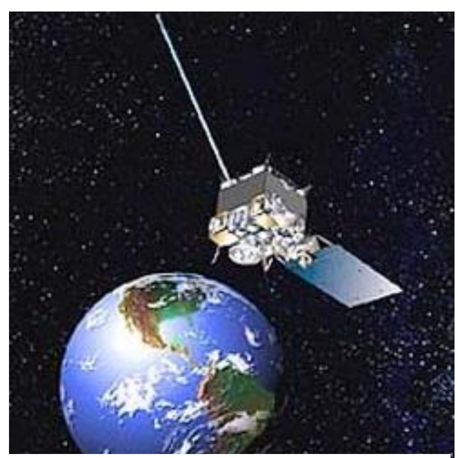

Figure 5-38: GOES NO/PQ

NASA and the National Oceanic and Atmospheric Administration (NOAA) have awarded a $423 million contract to Hughes Space and Communications, El Segundo, CA, for the manufacture, launch and delivery on-orbit of up to four weather-monitoring Geostationary Operational Environmental Satellites (GOES). The contract includes the design, manufacture, integration and launch of two Geostationary Operational Environmental Satellites, GOES N and GOES O, with options for GOES P and GOES Q.

The new spacecraft will be used to continue and enhance the functions of the current GOES I-M series of spacecraft. The first spacecraft purchased under this contract is awaiting launch most likely in 2006. GOES N-Q will carry an Imager and a Sounder to provide regular measurements of Earth's atmosphere, cloud cover and land surfaces. Two of them also will carry a Solar X-ray Imager and Space Environment Monitor instruments. A new solar X-ray imager will monitor the sun's X-rays for the early detection of solar flares. This early warning is important because these solar flares affect not only the safety of humans in high-altitude missions, such as the Space Shuttle, but also military and commercial satellite communications. They will have an on-orbit life of seven years.

GOES-Next

GOES-R is in the planning stages to be the first in a series of the most advanced environmental observation satellites dedicated to supporting weather and water, ecosystems and coasts, climate and commerce. Planned for launch in 2012, GOES-R will scan the Earth nearly five times faster than the current GOES satellites on orbit today. The satellites will provide about one hundred times the amount of data currently provided.

Major new innovations in the spatial, temporal, and spectral resolution of data and image products are planned, including the capability to:

- View the whole Western Hemisphere every 15 minutes; currently we can see the Western Hemisphere every three hours;
- View the U.S. every five minutes; currently every 15 minutes;
- Provide targeted scans every minute simultaneously; currently cannot be done;
- Operate well calibrated instruments, suitable for climate monitoring; current limitations on GOES image navigation do not allow for significant climate monitoring;
- Provide imagery in 16 spectral channels at 0.5-2 km resolution (see Figure 3); currently 5 spectral bands;
- Provide high-resolution atmospheric soundings (more than 1,000 spectral channels) at 10 km resolution; not currently available;
- Provide lightning detection continuously over the hemisphere at 10 km resolution; currently not available from space;
- Provide enhanced space weather and solar information; currently done on a limited basis.

Meteosat Second Generation (MSG)

Figure 5-39: Meteosat Second Generation

(http://www.eumetsat.int/msg2/spacecraft.htm)

There are already two MSG satellites on orbit. MSG-2 will be launched 21 December 2005 and placed in a parking orbit until needed to take over its sister satellite's duties, waiting in the wings to ensure seamless continuity of service. Collectively, four total MSGs are projected to provide more than 20 years of meteorological coverage.

These next generation Meteosat satellites are to be significantly enhanced. They are being designed in response to user requirements and will serve the needs of nowcasting applications and Numerical Weather Prediction in addition to provision of important data for climate monitoring and research.

The space segment will be comprised of four satellites being manufactured by a European industrial consortium led by France, under the responsibility of the European Space Agency (ESA). The new satellites will be spin-stabilized like the current generation, but with many design improvements including a new radiometer which will produce images every fifteen minutes, in twelve spectral channels. The more frequent and comprehensive data collected by MSG will also aid the weather forecaster in the swift recognition and prediction of dangerous weather phenomena such as thunderstorms, fog and explosive development of small but intense depressions which can lead to devastating wind storms.

The Spinning Enhanced Visible and Infrared Imager (SEVIRI) will bring major improvements in the service to meteorologists, climate monitoring and other related disciplines through:

- Twelve spectral channels (three on the current system) will provide more precise data throughout the atmosphere.
- Fifteen-minute cycle of imaging (30 minutes on the current system) will provide more timely data for nowcasting, improving the accuracy in forecasting of severe weather such as thunderstorms, heavy rain, snow or fog.
- Improved horizontal image resolution for the visible light spectral channel (1 km as opposed to 2.5 km on the current Meteosat) will also greatly aid weather forecasters in detecting and predicting the onset or cessation of severe weather.
- An additional humanitarian payload on MSG satellites will be a Search and Rescue transponder that will relay distress signals from ships, aircraft and others in peril.
- MSG satellites will have a nominal life in orbit of seven years (two more years than the current system), this leading to an extended and more cost-effective life-span.

Feng Yun 3 (China)

A second-generation LEO observation satellite called Feng Yun 3 is reportedly under development with substantially advanced multispectral imaging systems.

INSAT (India)

Another three satellites INSAT-3A, INSAT-3D and INSAT-3E are planned to be launched under INSAT-3 series in the coming years.

WEATHER SUPPORT

Air Force Weather Agency was formed on Oct. 15, 1997, as part of a reengineering effort to streamline and improve the structure of the former Air Weather Service. This was a result of the realignment of Air Weather Service headquarters staff from Scott AFB, Ill. and the former Air Force Global Weather Center, DOD's primary centralized weather production facility at Offutt.

The Air Force Weather Agency mission is to enhance our nation's combat capability by arming our forces with quality weather and space products, training, equipment and communications -- anytime, anywhere. AFWA's production operation involves gathering over 140,000 weather reports per day from conventional meteorological sources throughout the world and relaying them to AFWA by the Automated Weather Network (AWN). By combining these data with information available from military and civilian meteorological satellites, AFWA constructs a real-time, integrated environmental database. A series of scientific computer programs model the existing atmosphere and project changes. AFWA is responsible for providing technical advice and meteorological assistance to Air Force weather units supporting Active or RC Army units.

AFWA exchanges data and meteorological products with the National Weather Service and the Naval Oceanography Command. AFWA is the backup agency for two National Weather Service centers. Support to the National Meteorological Center includes products transmitted on the Digital Facsimile (DIFAX) circuit and aviation winds for civilian users. Support to the National Severe Storms Forecast Center includes severe weather forecasts to the civilian community. Products and services provided by AFWA include meteorological advice; aviation, terminal and target forecasts; prediction of severe weather; automated flight planning; exercise and special mission support; and computations for ballistic missile systems, as well as the collection and dissemination of environmental data.

There are a number of ways to get weather satellite support. The DMSP terminals discussed can receive a direct downlink although they will not receive the same amounts of information that AFWA receives. Users can dial-into AFWA and FNMOC. It is possible to set up an account and dial in, using a modem over a telephone line. A SATCOM link can be established to AFWA to receive The Automated Weather Dissemination System (TAWDS) broadcasts. There are many sites on the World Wide Web that provide weather information from around the world. Almost all of it is processed data converted into an image or low resolution data. Some sites give weather information for specific cities or regions.

Most homepages are operated by civilian agencies or even civilian individual citizens. Lastly, special support can be coordinated by the theater staff meteorologist.

WEATHER SATELLITE CAPABILITIES

A prime advantage of environmental satellites is their ability to gather data regarding remote or hostile areas, where little or no data can be obtained via surface reporting stations. Weather satellites rely on gathering data in the visual, infrared, and microwave spectral bands. Infrared sensors provide images which are based on thermal characteristics of atmospheric features, such as clouds, and earth features, such as land masses and water bodies. This data can be used to calculate the altitude of cloud tops and ground or water surface temperatures. This data can be gathered during light or dark hours.

Thermal and visible images together provide the coverage and extent of clouds at various levels, as well as other physical phenomena such as ice fields and snow. Microwave sensors are used to measure or infer sea surface winds, ground moisture, rainfall rates, ice characteristics, atmospheric temperatures, and water vapor profiles.

Weather satellites can gather information about the magnetosphere and ionization of the atmosphere. This data can be used by the space weather forecasters to predict communication outages and to alert operators to look for possible satellite problems.

Current polar-orbiting satellites provide high resolution imagery and can image weather over the poles. Geosynchronous satellites provide a constant look at the same area with an updated weather picture every 30 minutes. Geosynchronous satellites have a large field of view and are utilized to track large weather systems and provide environmental warning.

WEATHER SATELLITE LIMITATIONS

Weather satellites have a limited multi-spectral capability. Some meteorological parameters needed by forecasters for operational support cannot currently be accurately determined from satellites, including, heights of cloud bases, visibility restrictions, and lower level winds.

Current polar-orbiting satellites have limited data-refresh rates. A constellation with two satellites will give a picture of the same area at least every 6 hours (except for the poles which get covered more often). Geostationary satellites provide lower resolution images. The image quality degrades as distance and angle from the point directly under the satellite increases. The resolve of an increased angle is poor coverage as polar latitudes are approached and no coverage at the poles.

PLANNING CONSIDERATIONS

Understanding the capabilities and limitations of weather satellites and the orbits they are in is crucial to effective operational planning. Weather affects all operations in one way or another. The weather data obtained from ground systems is effective in determining the current situation. Satellite data is necessary for accurate forecasting. Satellite data from polar, sun-synchronous orbiters is different than data from geostationary orbiters.

Typically, weather satellite information is broadcast worldwide. Anyone with a PC and Internet connection can obtain a current weather picture. What we see is what the enemy also can see. DMSP is the only encrypted weather signal and therefore its information can be denied to the enemy. However, there are instances now and there could be instances in the future when weather data is denied. India has denied its real-time weather information in the past. Meteosat has encrypted its data and then sold access to the data to secondary and other partners. An example of the effects of denying weather data would be in a hostile engagement in Korea. The weather patterns over China greatly affect the future weather over Korea. China could deny its weather data. If India and Russia do the same, we would have a gap in coverage that could lead to inaccurate forecasting.

Q. What quality and frequency of satellite imagery, forecast products and communications equipment are required? Are civilian weather satellites adequate or is there a need for encrypted data from military satellites or a mix of both? Is "CNN" type weather forecasting adequate? The frequency and quality of required weather forecasts will determine what kind of receive equipment need.

Q. Does the command require the capability to prevent an adversary from receiving meteorological transmissions? Due to treaty limitations, political considerations, and the impact on U.S. and friendly forces, denial of transmissions may not be a desirable option. Targeting enemy earth terminals remains an option.

Q. Are the current available transmission times for DMSP and civil meteorological satellites adequate? In a highly maneuverable, fast-paced conflict, timely weather data is important. Current military weather systems do not provide full-time coverage. However, a mix of military and civil assets can provide increased coverage.

Q. Does the supported command require rapid or near-real-time access to recorded DMSP data? Microwave imagery data is available in a recorded format, and through a real-time direct downlink. ARSTRAT can provide the necessary equipment for direct downlink. The Air Force can provide the weather analyst. Prior coordination for both is necessary.

Chapter 9
Missile Warning

SPACE-BASED MISSILE WARNING

Theater Ballistic Missile (TBM) Detection and Warning:

Theater Ballistic Missile proliferation is becoming an ever-increasing problem in the world in the 21st Century. Many nations possess theater ballistic missiles and some have made this technology available for purchase. Today, proliferation poses a significant threat to U.S. field commanders in overseas locations and this threat will continue to grow in the future. Detection and warning of enemy ballistic missile launches allow commanders to take appropriate passive missile defense, attack operations, and active missile defense actions. TBM warning is a subset of Surveillance and involves the sensor satellites (Defense Satellite Program, or DSP), communication links and verbal command directions. These satellite sensors also accomplish nuclear detonation (NUDET) detection and can be used to detect other IR events. Ground stations such as Joint Tactical Ground Stations (JTAGS) and the Space Based Infrared System (SBIRS) Mission Control Center gather, process and disseminate early warning information.

Theater Ballistic Missile Warning

One of the primary missions of the United State Strategic Command is to provide space-based theater ballistic missile warning to U.S. forces worldwide. This warning provides the troops in the field the opportunity to defend themselves or take the necessary precautions in the event of a missile threat. Those precautions could include intercepting the missile when combined with the current and future theater missile defense systems and the evacuation of buildings in the threatened area. The command performs this mission with a variety of ground-based and space-based systems as part of the Theater Event System (TES).

The Theater Event System consists of the Defense Support Program satellite constellation, SBIRS, JTAGS, and Tactical Detection and Reporting System (TACDAR). The data from these sources is disseminated world wide via Integrated Broadcast Service (IBS).

A brief description of key Theater Event Systems and sensors follows.

Figure 5-40: DSP Satellite

Defense Support Program (DSP)

(http://www.af.mil/factsheets/factsheet.asp?fsID=96)

DSP satellites are a key part of North America’s Early Warning System. In 22,000 mile geosynchronous orbits, DSP satellites serve as the continent’s first line of defense against ballistic missile attack and are often the first system to detect world-wide missile launches. Defense Support Program satellites use an infrared sensor to detect heat from missile or booster plumes against the relatively cool background of the Earth's surface. These satellites have provided uninterrupted warning since the early 1970s when they were first launched. These satellites were designed to detect strategic ballistic missiles in the early stage of launch of their flights. However, during Desert Storm, prior to the start of the air campaign, the detection software was upgraded and refined to detect short-range theater ballistic missiles such as the SCUD missile. In addition to missile launches, the DSP system also has numerous sensors on board to detect nuclear detonations.

During Operation DESERT STORM, a DSP satellite was able to detect the launch of Iraqi SCUD missiles toward Saudi Arabia and Israel. The satellite sensor data was transmitted to a CONUS processing station. Computers analyzed the data to determine when a launch occurred. If the operator confirmed the computer analysis, a launch detection alert was issued. This alert message was relayed over satellite communications to the headquarters in Saudi Arabia. The alert message provided early warning to military and civilian personnel in the target area and provided cueing information to the Patriot missile batteries providing point defense. This procedure was relatively expedient for its time. It was in fact using what had been designed as a strategic missile warning system via Cheyenne Mountain and NORAD for tactical purposes. It was used operationally for the first time during Operation DESERT SHIELD/STORM. The TES was created post DESERT STORM to allow for better, timelier missile warning data to flow to theater. TES now allows for theater commanders to take action without having to wait for CINCNORAD’s North American threat assessment.

Space Segment

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.

The DSP satellites are launched into a geostationary orbit from which the sensors on the satellite monitor the Earth below for the launch of ballistic missiles. Although three satellites could cover the Earth, there are generally five satellites in orbit. Most areas of the Earth have at least two satellite coverage and some have three satellites.

The primary mission of DSP is to detect, characterize and report in real time, missile and space launches occurring in the satellite Field Of View. DSP satellites track missiles by observing infrared (IR) radiation emitted by the rocket's exhaust plume. The principal sensor subsystem is the Infrared (IR) Telescope. Infrared energy given off by hot sources on the Earth is detected by an array of photoelectric cells located in the IR Telescope. Sensor data is transmitted to control segment ground stations for processing. The DSP satellites also carry RADEC sensors capable of detecting and quantifying nuclear explosions on the Earth's surface, in the atmosphere and in near Earth space.

The sensor and the spacecraft, which together comprise the satellite, are placed in geosynchronous-equatorial orbit so that the telescope is pointed toward the earth and rotated at six revolutions per minute. To provide a scanning motion for the infrared (IR) sensor, the satellite is spun about its Earth-pointing axis.

Over the last 30 years, there have been 22 satellite launches with five major design changes. The last DSP satellite, DSP Flight 23, is scheduled to launch on an EELV during the second half of 2006.

The follow-on to the Defense Support Program is the Space Based Infrared System (SBIRS).

Control Segment

The DSP satellites are operated and controlled by the Air Force Space Command's 460th Space Wing's 2nd Space Warning Squadron located at Buckley AFB, Colorado. DSP ground support consists of a Mobile Ground System (MGS) consisting of six fully deployable units (tractor-trailer rigs) and the fixed-site SBIRS Mission Control Station (MCS) that receives, processes, and reports mission data to the users.

SBIRS is presently being developed from the ground up to detect theater ballistic missiles. The SBIRS MCS represents a transformational step in the evolution of the nation's space-based infrared systems. The MCS centralizes global command, control, and communications for strategic and tactical warning into a single modern peacetime facility. Emerging from a heritage of over 30 years of early warning and the lessons of the 1991 war with Iraq, the consolidated facility provides warfighters with timely, unambiguous missile warning reports.

The MCS operates the Defense Support Program satellites today and will have the capability to operate SBIRS High and the Space Tracking and Surveillance System from the consolidated location in the future. Following the 1991 Gulf War, a need was recognized to deliver to the theater commanders a single, unambiguous report on missile activity in their area.

While DSP proved very effective, the fact remained that it had been designed for strategic missile warning. In response, the program office launched Talon Shield Phase 1, which quickly fielded an operational system known as Attack and Launch Early Reporting to Theater (ALERT) in March 1995. ALERT was a high-confidence operational system that provided assured theater missile warning to warfighters worldwide. ALERT was deactivated in September of 2002 and the MCS team now performs the ALERT mission. The first step toward a more robust infrared capability in space was taken December 18, 2001 with the declaration of the MCS at Buckley AFB as operationally capable. The MCS consolidates command and control and data processing elements from dispersed legacy systems into a single modern facility. The MCS saves 58% in manning and up to 25% in operations and maintenance costs over the legacy systems. The MCS is also designed to accommodate new SBIRS capabilities.

User Segment

Data from the DSP satellites are processed at the SBIRS MCS and a warning is transmitted to users. The warning information consists of an assessment of the time and place of launch, the type missile launched and an estimated course of the missile. The systems that process DSP data for theater ballistic missile warning are JTAGS and TACDAR.

JTAGS

The Joint Tactical Ground Station (JTAGS) is a transportable information processing system which receives and processes in-theater, raw, wideband infrared data downlinked directly from Defense Support Program sensors. The system disseminates warning, alerting, and cueing information on Tactical Ballistic Missiles (TBM), and other tactical events of interest throughout the theater using existing communications networks, primarily IBS broadcast.

Figure 5-41: JTAGS

Developed and built by Aerojet for the U.S. military, JTAGS determines the TBM source by identifying missile launch point and time, and provides an estimation of impact point and time. Since the system is located in-theater, it reduces the possibility of single-point-failure in long-haul communication systems and is responsive to the Theater Commander. It also fulfills the in-theater role of the Air Force Space Command's Theater Event System (TES).

JTAGS maximizes the use of commercial off-the-shelf (COTS) and government off-the-shelf (GOTS) equipment. The system is housed in a NBC protected standard military shelter, equipped with a standard wheeled mobilizer that permits tow speeds up to 55 mph by a 5-ton truck. It is air transportable by a C-141 or larger aircraft.

JTAGS can be a key link for the Theater Commander's situational awareness. Operational benefits include:

- Cueing of active theater missile defense systems for missile intercept
- Cueing attack operations assets to find and destroy enemy launch capability
- Timely warning for the protection of friendly forces and population

JTAGS receives direct down linked data from up to three Defense Support Program sensors and follow-on space-based sensors. Features include:

- Threat Tactical Ballistic Missile infrared data
- 3-D stereo processing of multiple sensor downlinks
- Real-time reporting
- Robust multi-networks capability
- In-theater data/voice

The high resolution JTAGS displays include:

- Estimated launch point and time
- Predicted impact point and time
- Trajectory parameter
- Multi-track capability

TACDAR

Tactical Detection and Reporting system is a system based on the combined ability of a variety of space-based assets to provide warning data.

Space Based Infrared System (SBIRS)

(http://www.losangeles.af.mil/SMC/is/SBIRS.htm)

The SBIRS program provides the nation with critical missile defense and warning capability well into the 21st century. SBIRS is one of Air Force Space Command's highest priority space systems. SBIRS will consist of three individual space constellations and an evolving ground element: The Defense Support Program (DSP), SBIRS High, and the Space Tracking and Surveillance System (STSS). These systems are independent yet will complement each other by providing global infrared coverage. The program supports four mission areas: Missile Warning, Missile Defense, Technical Intelligence, and Battlespace Characterization.

SBIRS High

SBIRS High features a mix of four geosynchronous earth orbit (GEO) satellites, two highly elliptical earth orbit (HEO) payloads, and associated ground hardware and software. SBIRS High will have both improved sensor flexibility and sensitivity. Sensors will cover short-wave infrared like its predecessor, expanded mid-wave infrared and see-to-the-ground bands allowing it to perform a broader set of missions as compared to DSP. Currently in the engineering, manufacturing, and development phase, the first SBIRS High HEO payload were scheduled for delivery in 2003 but technical delays and cost overruns delayed delivery until 2005. The first GEO satellite is expected to launch in 2008.



Space Tracking and Surveillance System (STSS)

Originally, SBIRS was to have a low earth orbiting component that was referred to as SBIRS Low. The SBIRS Low program was cancelled and the Space Tracking and Surveillance System was implemented to meet operational requirements. STSS is managed by the Missile Defense Agency (MDA). STSS will build a few satellites at a time with later satellites being more capable than earlier ones. The program will be fully integrated into the nation's ballistic missile defense system architecture, contribute to MDA's ballistic missile testbed, and focus resources on highest leverage technologies. Using the advantage of a lower operational altitude, STSS will track tactical and strategic ballistic missiles. The satellite's sensors will operate across long and short-wave infrared, as well as the visible light spectrum. These wavebands allow the sensors to acquire and track missiles in midcourse as well as during the boost phase, substantially improving the performance of ballistic missile defenses.

STSS is proceeding in a series of biennial "blocks." According to MDA's FY2006 budget documents, STSS' Block 2006 is the launch of what is referred to two legacy satellites; Block 2008 is an improvement of the ground system; and, in Block 2012, operational satellites

will be integrated into the program.

Theater Ballistic Missile Warning

Q. What is the threat? Does the enemy have TBM capability?

Q. For what purpose will the command use the warning data received? The timeliness and accuracy required of the warning data provided depends on why the command needs the data and how it will be used. Cueing TMD forces requires quick and accurate data.

Q. How quickly do I need the information at my Operations Center and how quickly do I need to get the information disseminated? This is important because TBM warning information is broadcast to only to certain locations with the necessary receiver equipment. It is the responsibility of the Theater Commander to disseminate the information. Therefore, warning networks must be considered.

Q. What communications networks are available in the AO that can handle voice or data warning reports? Does the command need a separate voice/data system for TBM warning? The proliferation of medium to long-range ballistic missiles and their potential impact on operations may necessitate a separate and more responsive warning network than the normal communications network can provide.

Q. JTAGS needed in theater or can will information from the broadcast networks (TRAP and TIBS) be sufficiently timely and reliable?

Q. Are there areas that would benefit from having terrestrial radar capable of providing theater missile warning? Are resources available to correlate terrestrial radar and satellite warning data? Dual phenomenology provides dual verification and increased accuracy of launch data and refinement of the impact point.

Q. What is the tolerance for false missile warning reports? Missile warning data is gathered from a variety of sources and is then assessed. The results of the assessment can include launch and impact point predictions and a confidence level. The supported commander must consider whether it is more important to have warning of all events (with the possibility of false events) or no false reports with some events not reported.

Q. Will warning reports be provided to allies for broadcast to civilian populations? Dissemination of warning reports to allies is determined by the Theater Combatant Commander or Secretary of State and the Joint Staff in coordination.

Chapter 10
Space Lift

OVERVIEW

Space systems can be divided into two categories: the launch vehicle and the spacecraft. The launch vehicle, commonly called the booster, propels the spacecraft and its associated payload(s) into space. Typically for military missions, a specific spacecraft is 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.

This chapter will discuss launch systems, launch sites and the three segments of space systems. Spacecraft and payloads will be discussed separately in the next chapters.

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.

LAUNCH SYSTEMS

There are only a few countries that have launch vehicles. Most launch vehicles are now available for commercial and military satellite launches.

U.S. Launch Vehicles

Athena

The Athena program was begun in January 1993. The first operational mission of the Athena, an Athena I, successfully launched the NASA Lewis satellite into orbit from Vandenberg Air Force Base (VAFB), Calif., on Aug. 22, 1997. The first Athena II was successfully launched from Cape Canaveral Air Station (CCAS), Fla., on Jan. 6, 1998, sending NASA's Lunar Prospector spacecraft on its mission to study the moon. An Athena I also successfully launched the Republic of China's ROCSAT-1 satellite from CCAS on Jan. 26, 1999.

The Athena I is a two-stage launch vehicle with the performance to place up to 1,750 lbs into a low earth orbit. The Athena II, a three-stage vehicle, more than doubles the payload capacity of the Athena I and has the performance to place up to 4,350 lbs into low earth orbit.

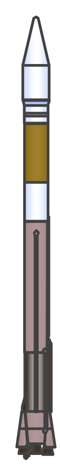

Figure 6-1: Atlas

Atlas

The Atlas was developed in the early 1950's and became the United States' first operational Intercontinental Ballistic Missile (ICBM). Although fitted with newer upper stage engines, the missile has changed only slightly over the years. The Centaur or Centaur II advanced upper stage has been added as a second stage to allow much larger payloads to be placed into orbit. Current Atlas boosters provide a medium lift capability. The Atlas can be launched from Vandenberg AFB or Cape Canaveral Air Force Station. The current configuration can place 18,000 lbs. into LEO orbit, 8,000 lbs. into geostationary transfer orbit, or 1,800 lbs. into a polar orbit. Atlas I and II models provided a medium lift capability for the DSCS III. It is also used to put DoD and NOAA weather satellites into low Earth, sun-synchronous (polar) orbits and to put a variety of DoD, NASA, and commercial satellites into low, medium or geosynchronous orbit. Atlas II has also been used to launch some communications satellites for foreign customers.

With a 100 percent success rate and 63 consecutive successful launches, the Atlas II family has a reliability record unmatched in the industry.

The Atlas IIA was retired on December 4, 2002 and the Atlas II was retired in March 1998. The last Atlas IIAS was successfully flown out on August 31, 2004.

The Atlas 5 program includes a family of newly designed launch vehicles capable of carrying payloads weighing up to 45,200 pounds into LEO, up to 19,114 pounds into geotransfer orbit, and up to 14,000 pounds to geosynchronous orbit. The first launch of Atlas 5 was in August 2002.

Additional information about the Atlas V Evolved Expendable Launch Vehicle (EELV) can be found at the following internet site: http://www.astronautix.com/lvfam/atlas.htm.

Delta

The Delta launch vehicle evolved from the Thor intermediate range ballistic missile (IRBM). It was first launched to carry satellites into orbit in May 1960. The Delta family of launch vehicles has gone through many upgrades and is available in a variety of configurations, depending on the needs of the customer. There are launch facilities at Vandenberg AFB and Cape Canaveral. The current configuration has a payload capacity of about 11,100 lbs. (5,045 kg) into LEO or up to 4, 120 lbs. (1,800 kg) into geostationary transfer orbit. The Delta II is the primary launch vehicle for the Navstar GPS satellites, a variety of U.S. DoD, civil and foreign communications satellites such as Globalstar and some scientific payloads. In 1993, the Air Force designated the Delta II as its Medium Launch Vehicle (MLV-3).

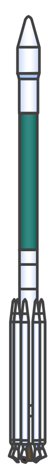

Figure 6-2: Delta

Additional information about the Delta IV EELV can be found at: http://www.boeing.com/defense-space/space/delta/deltahome.htm.

Pegasus

Pegasus is a winged, three-stage rocket, launched from under the wing of an aircraft. It weighs about 41,000 lbs. and is 50.9 feet long with a 22-foot wingspan. The first launch was in 1990. The Pegasus launch vehicle is carried aloft by the L-1011 “Stargazer” aircraft to a point approximately 40,000 feet over open ocean areas, where it is released and then free-falls in a horizontal position for five seconds before igniting its first stage rocket motor. With the aerodynamic lift generated by its delta wing, the small rocket achieves orbit hundreds of miles above the Earth in approximately ten minutes. Most recently it has been used to launch the ORBCOM communication satellites. Advantages of using the Pegasus include:

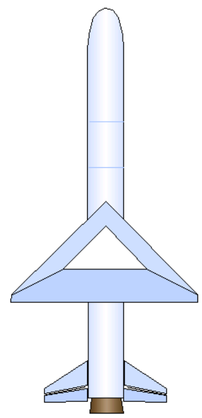

Figure 6-3: Pegasus

- Flexibility - Capable of being launched from virtually anywhere in the world with appropriate range facilities
- Cost **-** Approximately half the cost of equivalent ground-based launchers
- Performance **-** Equatorial orbit up to 1,100 lbs., polar and sun synchronous orbits up to 750 lbs., geosynchronous transfer orbit up to 400 lbs., and Earth escape up to 300 lbs.
- Applications**-** Supports a wide range of missions, including space technology validation, Earth science and space physics experiments, hypersonic flight research, Earth imaging, communications, and planetary exploration

Orbital Suborbital Program Space Launch Vehicle (OSPSLV or Minotaur)

The OSPSLV is also known as the Minotaur. It is combination of the first and second stages of the Minuteman II. The third and fourth stages are from the Pegasus XL launch vehicles. The rocket is part of an Air Force effort to use surplus Minuteman II components for sub-orbital and orbital spacelift. As of January 2004 the Air Force has about 350 Minuteman II ICBMs in storage. The vehicle is capable of launching several payloads of up to 750 lbs to a 400 nm, sun-synchronous orbit which is roughly 1.5 times the Pegasus XL capability. The first launch was in January 2000 when the OSPSLV was used to launch several microsatellites and picosatellites into orbit.

Taurus

Taurus is a four-stage vehicle. It is capable of launching a 2,100-lbs. payload into polar orbit. Taurus fills the cost and performance gap between our Pegasus rocket and the industry's much larger, more expensive launch vehicles. In March 1994, the Taurus rocket made its debut, placing two satellites for the Defense Advanced Research Projects Agency (DARPA) into near-perfect orbits. It is compatible with the USAF's Western Range (WR) and Eastern Range (ER) and NASA's Wallops Island Range; 30-day on-pad hold capability. The Taurus was most recently launched in March 2000.

Titan

The first Titan I launch occurred on February 6, 1959. In 1962, the Titan I was replaced with the larger and more powerful Titan II. Following the Shuttle Challenger disaster, initiatives to develop a family of reliable expendable launch vehicles with Shuttle payload capabilities have resulted in the creation of a variety of Titan configurations: Titan III, Titan 34D, and Titan IV. These are base configuration identifiers; each of these types can be modified with various upper stages and solid rocket boosters strapped on the first stage to accomplish specific missions. The Titan III and Titan 34D boosters were launched from Cape Canaveral. They were used by DoD and also for commercial launches. The Titan IV is now the United States' heavy lift vehicle, capable of injecting in excess of 10,000 into geosynchronous Earth orbit (GEO), up to 39,000 lbs. into LEO and 31,100 lbs. into polar orbit. It is available in three different configurations. There is one Titan IV launch pad at Vandenberg AFB and two at Cape Canaveral. Planned upgrades to the solid rocket boosters and upper stages will raise the lift capacity to almost that of the Shuttle. Launch preparation of the Titan IV is about 6 months. The Titan IV has been retired.

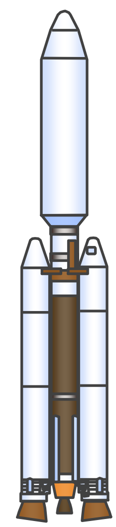

Figure 6-4: Titan

Space Transportation System (STS)

The Space Transportation System (STS) includes the space shuttle fleet, boosters and upper stages, launch and landing facilities, and training and control facilities. There are currently three shuttle spacecraft: Discovery, Endeavor, and Atlantis. The shuttle is capable of carrying eight astronauts (normally seven) and approximately 22.5 metric tons into 28.5° inclined LEO from its two launch pads at Kennedy Space Center.

The first launch was in 1981. It can be used to place a 53,500 lb. payload into LEO orbit or a 13,000 LB payload into a geostationary transfer orbit (GTO).

On 28 January 1986, the Space Shuttle Challenger exploded during launch, killing the crew of the orbiter. NASA was forced to suspend all Shuttle launches while it investigated the cause of the explosion and assessed its implications. Military payloads as well as civilian payloads scheduled for the Shuttle had to obtain launches on expendable boosters or wait. Shuttle flights did not resume until 29 September 1988. Development of the Shuttle facilities at Vandenberg ended after the disaster because of deficiencies in the design of the launch pad and because of national policy changes in favor of returning to expendable launch vehicles for national security missions.

On 1 February 2003, the Space Shuttle Columbia was destroyed over Texas while returning from orbit. All crewmembers were killed and further Space Shuttle flights were suspended. Space Shuttle flights resumed in the summer of 2005 with the successful return to flight of the Space Shuttle Discovery. All future flights will be to support the International Space Station.

Four primary landing sites have been constructed for the shuttle: Edwards AFB, White Sands, Vandenberg AFB, and Kennedy Space Center. For safety reasons, the preferred landing facility is Kennedy Space Center, but there have been landings at all of these sites except Vandenberg AFB. The shuttle system allows humans to interact directly with LEO satellites. Satellites can be checked out before they are released to go into orbit, defective satellites can be repaired while they are in orbit, adjustments can be made to orbits of satellites, and orbiting satellites can be retrieved and returned to Earth for repairs or study. All of these capabilities have been demonstrated.

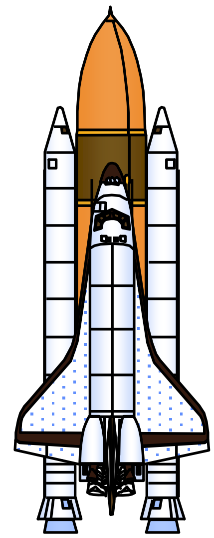

Figure 6-5: STS

FUTURE LAUNCH SYSTEMS

Evolved Expendable Launch Vehicle (EELV)

The Evolved Expendable Launch Vehicle is the Air Force space lift modernization program. The EELV program is intended to reduce the cost of launching by at least 25 percent over current Delta, Atlas, and Titan launch systems. In addition, EELV improves space launch operability and standardization.

The EELV program's two primary objectives are to: 1) increase the U.S. space launch industry's competitiveness in the international commercial launch services market and 2) implement acquisition reform initiatives resulting in reduced government resources necessary to manage system development, reduced development cycle time, and deployment of commercial launch services.

The EELV system will be used to deploy Government payloads. The EELV system consists of the Launch Vehicle (LV) Segment and the Ground Segment. The EELV system includes all equipment, facilities, and launch base infrastructure necessary to launch a payload, place it in the required delivery orbit, provide specified environments, provide EELV system maintenance, and perform any necessary recovery/refurbishment operations. The program office completed its Source Selection in October 1998 and awarded Development and Initial Launch Services contracts to Boeing and Lockheed Martin.

In July 2003, a second EELV purchase was made for 4 additional launches. A third purchase is currently in the planning stages.

Both launch vehicle systems employ a number of design features providing for a family of vehicles to meet the national mission model while achieving a significant reduction in life-cycle cost. These design features include: a common booster core, common engine, common structure, common adapters, simplified launch pads and streamlined operations. In addition, the Lockheed Martin vehicle uses an existing Centaur upper stage. The various launch vehicle configurations are capable of lifting 50,000 lbs to low earth orbit, 13,100 lbs to geostationary orbit and 18,080 lbs to geo-transfer orbit.

The first EELV launch was a Lockheed Martin Atlas V Medium Lift Vehicle which carried a commercial Eutelsat Hotbird 6 payload to orbit on 21 August 2002 from Space Launch Complex (SLC) 41 at CCAFS.

The inaugural launch for Boeing was a Delta IV Medium+ launch vehicle, which successfully placed a Eutelsat W5 payload into orbit on 20 November 2002 from SLC-37 at CCAFS. Both vehicles demonstrated superb orbital insertion accuracy within 20 km and within less than one degree of the customer's target parameters.

These new systems demonstrated the capabilities of two new launch sites, two new launch operation centers, new production facilities, and new launch vehicle and payload processing strategies.

The first DOD payload for the Delta IV was a satellite from SMC's Defense Satellite Communications System Phase III (DSCS III) program, which the launcher placed into a nominal geosynchronous orbit from Cape Canaveral on 11 March 2003.

To date, there have now been more than 10 successful EELV launches. There are some technical issues with the Heavy Lift Vehicle, but the main issues should be worked out by the mid-2006 timeframe.

Reusable Launch Vehicle (RLV)

NASA is responsible for developing the Reusable Launch Vehicle (RLV) that will eventually replace the aging Space Transport System (STS). The program has dual objectives: to demonstrate technologies leading to a new generation of space boosters capable of delivering payloads at significantly lower cost, and to provide a technology base for development of advanced commercial launch systems that will make U.S. aerospace manufacturers more competitive in the global market. Launched in 1994, the RLV program moved ahead on two fronts in 1996 with a restructuring of the X-34 air-launched small booster project.

X-33

The X-33 contract was awarded to the Lockheed-Martin Skunk Works on July 2, 1996. X-33 was the advanced technology demonstrator for the Reusable Launch Vehicle (RLV). The X-33 configuration was a lifting-body design using linear aerospike engines. Flight testing began in 1999. The vehicle was to be launched from Edwards AFB and land at one of several sites in the western U.S. A prime objective of the X-33 was to mature the technologies required for the next-generation of reusable launch vehicle (single-stage-to-orbit is a goal). The program ran into trouble in 1999 when there was damage to one of the two fuel tanks. The X-33 was cancelled in 2001.

X-34

X-34 was a reusable technology demonstrator designed to reach Mach 8 and 250,000 feet altitude. It was to be dropped from a modified Lockheed 1011 aircraft. Orbital Science Corporation was awarded a $60,000,000 contract in June 1996 to design, develop, build and test the X-34. This low-cost testbed vehicle was designed specifically to demonstrate new operational approaches that will dramatically reduce the time, cost and number of personnel required to process and launch future reusable launch vehicles. The program was cancelled by NASA in 2001.

X-37

The X-37 is a third testbed for RLV technologies, which officially got under way in July 1999. The X-37 is unpiloted, autonomously operated and will be the only X-vehicle capable of conducting on-orbit operations and collecting test data in the Mach 25 (reentry) region of flight. The X-37 will be launched into orbit and will have the capability to remain in space for up to 21 days. It will also serve as a test bed for 40 airframe, propulsion and operation technologies designed to make space transportation and operations significantly more affordable. Potential new commercial and military reusable space vehicle market applications for these technologies range from on-orbit satellite repair to the next-generation of totally reusable launch vehicles.

The X-37 concept permits testing of a wide variety of experiments and technologies, including a highly durable, high-temperature thermal protection system; storable, non-toxic liquid propellants; and important new aerodynamic features, all of which are applicable to future reusable space vehicles. The vehicle's modular design, including a seven foot by four foot experiment bay, will also allow testing of both current and future technologies within the same vehicle, providing long-term cost savings.

Advanced Space Transportation Program

NASA's Advanced Space Transportation Program (ASTP) looks beyond the Reusable Launch Vehicle to develop technologies for potential use after the year 2008. NASA, in a venture with industry, is seeking innovative launch system technologies that could markedly reduce the cost of launching payloads to orbit. NASA and industry are developing technologies for advanced propulsion systems starting with combined air-breathing and rocket engines. The ASTP is developing technologies for air-breathing rocket engines that could help make future space transportation like today's air travel. Powered by engines that "breathe" oxygen from the air, the spacecraft would be completely reusable, take off and land at airport runways, and be ready to fly again within days. ASTP is also supporting long-term technology research in advanced chemical and non-chemical propulsion systems.

Other New Space Vehicles

AirLaunch

Boeing Co. is developing a new rocket called AirLaunch as a "quick response" vehicle that can carry spacecraft form Earth to LEO within days of a request. The AirLaunch would come in two models both of which would be carried aloft on the back of a modified 747 jet. One model could place a 2,000 pound payload into LEO and returns home with an airplane-style landing. This model is being designed to cater to the military Space Maneuver Vehicle program. The second model would be a one-use only version that could carry private satellites up to 7,500 pounds into LEO. The thought is that AirLaunch could be ready to fly on short notice therefore deleting the need for on-orbit spare satellites.

Russian/Common Wealth of Independent States (CIS) Launch Vehicles

The Commonwealth of Independent States, formerly what was most of the Soviet Union, has a variety of capable launch systems. The Soviet Union's approach to space launcher design and construction was to build for simplicity and reliability, while incorporating technological advances if they substantially improved launcher performance. Their launch systems typically are large for the amount of on-orbit payload delivered. This is partly due to the extra weight that the use of older technology entails and partly to the use of less efficient liquid, non-cryogenic propellants for many of their main engines. Another reason for the relatively large size of their space launchers is that most were derived from military missiles built to carry massive nuclear warheads, and had to be proportionally large to do so.

The Soviet Union developed an impressive array of space launchers, most derived from ICBMs. On more than one occasion, the ability to conduct multiple launches within a short period has been demonstrated.

Soyuz

The Soyuz was developed from the Vostok Launch Vehicle, which was originally derived from the SS-6 ICBM. It made its debut in 1963. It has been used to launch every former Soviet Union piloted spacecraft since 1964. It has also been used to launch photoreconnaissance satellites, earth resource satellites, and progress resupply missions to the Mir space station. It is launched from Plesetsk, Russia and Baikonur, Kazakhstan. It is capable of placing 15,400 lbs. in LEO orbit and 5,500 lb. in a 760 nm circular orbit. This launcher is now available commercially. The assembled Soyuz, with the payload already mated to the launcher, is normally brought to the launch pad in a horizontal position and erected less than 48 hours before launch. The launcher has an extremely high reliability rate with a success rate of 1,064 out of 1,098 attempts. It has repeatedly demonstrated the ability to be launched during severe weather conditions including extreme cold, high winds and rain. It is now used to support commercial launches such as Globalstar.

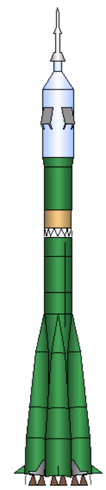

Figure 6-6: Soyuz

Molniya

The Molniya launcher (SL-6/A-2-e) is the most powerful of the SS-6 Sapwood derivatives. It uses an even more capable upper stage engine than the Soyuz. Its principal use has been to place payloads (principally Molniya communications satellites and Cosmos military payloads) into highly inclined, highly eccentric orbits. It is also used to launch many of the former Soviet Union's early interplanetary space probes. The first satellite placed into this highly eccentric, highly inclined orbit was called a Molniya; from this both the orbit type and launcher have drawn their name. This launcher has not flown any geostationary missions. The Molniya launcher is also available commercially.

Proton

There have been over 185 Protons launched. It is the largest currently available space launcher from the former Soviet Union. It was first launched in 1965. The

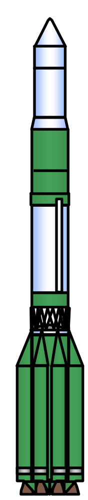

Figure 6-7: Proton

SL-12 variant has four stages and the SL-13 variant has three stages. The first stage has six strap-on rocket engines. The second stage has four rocket engines and the third stage has one rocket engine. The Proton is used to launch satellites into GEO, interplanetary spacecraft, and manned space stations such as Salyut and Mir. The SL-12 variant has a lift capacity of about 5,500 lbs. (2,500 kg) into GEO. It has been used to launch numerous scientific payloads to the Moon and Mars, and to put communications satellites into geostationary orbit. The three stage SL-13 variant can put about 46,200 lbs. (21,000 kg) into LEO. It has only been used to launch components of the Mir space station. The SL-12 Proton has been marketed commercially as a launcher for geostationary commercial communications satellites, such as INMARSAT.

Tsyklon (Cyclone)

The Tsyklon is a derivative of the SS-9 Scarp ICBM. It was introduced in 1966 as a two-stage launcher for space payloads, typically ocean surveillance satellites. There is no known Soviet name for this launcher. The SL-11/F-1 has a lift capacity of about 7,900 lbs. into LEO. In 1977, a third stage was added. The resulting launch vehicle, the Tsyklon, was given the designation of SL-14/F-2. The SL-14/F-2 assumed many of the missions previously performed by the Kosmos SL-8 such as ELINT, Meteor weather satellites, LEO communications satellites and some scientific payloads. The SL-14/F-2 has only been launched from Plesetsk.

Zenit (Zenit-3SL)

The Zenit is a modern booster with capabilities between those of Soyuz and Proton. Flight testing began in 1985, and since becoming operational it has been used primarily for launch of ELINT satellites. Standard versions can place 30,300 lbs. into a moderately inclined LEO, or 1320 lbs. into GEO. It is also used in a slightly different configuration as a strap-on booster for the Energia heavy-lift launch system. This booster has been proposed as a candidate for the Cape York (Australia) Space Agency venture as the booster of choice for heavy payloads, as it is capable, with modification, of lifting up to 52,800 lbs. (24,000 kg) to LEO. It is used quite frequently as a Sea Launch vehicle and successfully launched INMARSAT-4 in November 2005.

Energia

The Energia was a huge Saturn V-class booster. It took over 13 years to develop, and has great potential as a very heavy booster with flexible configurations, depending on mission. It can be configured with from two to eight SL-16 (see Zenit, above) liquid fueled strap-on boosters that are capable of being recovered, giving it a range of lift capabilities from 143,000 lbs. (65,000 kg) up to 440,000 lbs. (200,000 kg) to LEO. Its central core engine is the region's first dual cryogenic main stage, using liquid hydrogen and oxygen for its energy. Second stages are of two types: a low-energy, long mission duration (up to two years) second stage fueled by liquid oxygen and kerosene, and a high energy dual cryogenic upper stage with a mission duration of four days. Both upper stages are capable of multiple, although finite, restarts. Energia is being marketed commercially by NPO Energia. Several were built but have not been maintained and, therefore, are considered unusable.

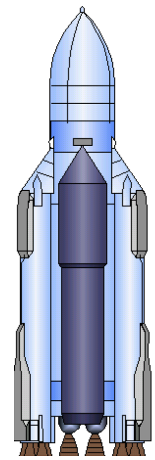

Figure 6-8: Energia

Rokot

The Rokot is the newest addition to the Russian space launch fleet. It originated as the SS-19 two-stage ICBM in the l970's. It is advertised to launch payloads up to 4,400 lbs. into LEO. The first launch was in December. The Rokot is marketed internationally by the German Space Agency (DARA) as a commercial launch vehicle for small satellites.

Start

The Start made a test flight in November 1993. It is a five-stage solid propellant vehicle based on the SS-25 mobile ballistic missile. It will be launched from Plesetsk, Russia and will place 1,260 lbs. in circular polar orbit. The first commercial launch of the Start-1 was in March 1997 and was also the initial launch from the Svobodny Cosmodrome.

Republic of China

Like the Soviets and the U.S., the Chinese satellite launchers derive from strategic ballistic missile (IRBM and ICBM) systems. The approach to development has concentrated on maximizing the utility of developed, reliable systems. Their systems are simple and reliable, factors which the Chinese have exploited to promote their commercial marketing of satellite launch services worldwide. In November 1999, the Chinese launched its first successful test of a spacecraft (Shenzhou) for manned flight. China is the third country with the capability of manned spacecraft.

Chang Zehn (CZ) - Literally, "Long March"

There are 16 models of the Long March launch vehicle. The Long March (LM) family is also known as Chang Zheng (CZ). Information about each can be found at http://www.geocities.com/CapeCanaveral/Launchpad/1921/launch.htm. Launch vehicles are referred to as "CZ" or "LM". The Long March 1 is a derivative of the DF-4 (Dong Feng, or East Wind) IRBM known in the West as the CSS-3. This launcher placed China's first satellite in orbit in 1970. The first launch of the CZ-2 was in 1975. It was developed in parallel with the CSS-4 ICBM. It can place 1,650 lbs. into sun-synchronous polar orbit, 3,175 lbs. into GTO, and 7,040 into LEO. The CZ-2 has functionally replaced the CZ-1, and is available commercially in a variety of configurations, including GEO delivery. The CZ-2D variant is capable of 2,750 lbs. to GTO. The eight-engine CZ-2E variant can launch 19,400 lbs. to LEO or 7,430 lbs. to GTO.

The CZ-3 series of launchers closely resemble the CZ-2. It evolved from Chinese surface-to-surface (CSS) series IRBMs. The CZ-3B is capable of launching 29,900 lbs. to LEO, 9,900 lbs. to GTO, or 4,950 lbs. to geosynchronous orbit. The CZ-4 is an enhanced version of the CZ-3. The CZ-4A is able to deliver 5,500 lbs. payloads into a sun-synchronous orbit or 8,200 lbs. to LEO.

Shenzhou

China completed its first unmanned test of a spacecraft meant to carry astronauts in November 1999. It was controlled by China's newly built space control network. The craft orbited the earth 14 times and touched down as planned in central Inner Mongolia. Most of the spacecraft was built from Russian technology.

China's first manned spacecraft Shenzhou 5 lifted off from Jiuquan Satellite Launch Center in northwest China's Gansu Province Wednesday, Oct. 15, 2003. China became the third country to send an astronaut toward orbit, four decades after the Soviet Union and the United States.

European Space Agency

The European Space Agency (ESA) is a consortium of European countries. The members contribute money and are, in turn, awarded contracts for work on ESA programs. The ESA is responsible for development of new versions of Ariane, Columbus (ESA's contribution to the Space Station Freedom effort), and Hermes (a reusable space plane), as well as providing test launches. The ESA also participates with other nations in space science activities. ESA's charter provides that its activities be strictly commercial or scientific, and that it may not conduct military space programs. 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.

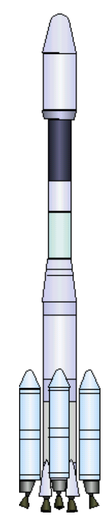

Figure 6-10: Ariane

Ariane and all associated launch services are provided under contract by Arianespace, a private French company in which the French government holds 32% of the voting stock.

Ariane

The Ariane 1 rocket was designed from the beginning to be a commercial launch vehicle, and has no direct military roots. Its first flight was in December 1979, and had an initial capability of 9,700 lbs. into LEO. Ariane 2 and 3 followed within five years, providing greater capability, up to 13,200 lbs into LEO. The Ariane 4 replaced the Ariane 2 and 3 and is currently the most widely used. This system has been designed for maximum flexibility and reliability with the capability to place 13,230 lbs. to LEO orbit, 7,495 lbs. to sun-synchronous polar orbit, and 6,460 lbs. to GTO.

The Ariane 5 is a completely new design and depends on a strap-on assisted dual cryogenic propellant main stage and a hypergolic (nitrogen tetroxide and monomethylhydrazine) second stage. It is capable of delivering 39,600 lbs. into LEO, 26,400 lbs. into polar orbit, 15,000 lbs. to GTO.

India

ASLV (Augmented Satellite Launch Vehicle)

The ASLV is an Indian produced four-stage launcher. It is nominally capable of placing 330 lbs. (150 kg) into LEO with a 46.5° orbital inclination. The first launch was a failure in 1987. The first successful launch was 20 May 1992.

PSLV (Polar Satellite Launch Vehicle)

In keeping with its effort to achieve self-reliance, India desires a capability to perform their own remote sensing. To accomplish this, they must make use of the coverage available only from sun-synchronous sensor platforms. The PSLV is designed to deliver the 2,200-pound India Remote Sensing (IRS) satellite into sun-synchronous orbit. It is capable or launching 6,610 lbs. to a 215 nm circular orbit, 43 degrees inclination, 2,200 lbs. to a 490 nm sun-synchronous orbit, or 990 lbs. to GTO.

Israel

Israel is striving to develop a limited space program using internal capabilities. Israel builds its own launchers and satellites, seeking to avoid the problems inherent in dealing with other countries for space technology and launch services.

Shavit

The Shavit is a two or three-stage launch vehicle derived from the Jericho 2 missile. It is capable of launching 334 lbs. On 19 September 1988, the Shavit launched the Offeq-1 ("Horizon") satellite into moderately inclined retrograde (westward) orbit.

Japan

The Japanese space industry is, like the Indian and Israeli space industries, progressing toward self-sufficiency. Their national space administrative structure is made up of two organizations: the Institute of Space and Astronomical Science (ISAS), which is part of the Ministry of Education, and the National Space Development Agency (NASDA), which has links to the Ministry of Posts and Telecommunications, the Ministry of Transport, and the Science and Technology Agency. Japanese orbital experience began in 1975, when they orbited their first satellite using an N1 rocket as the launcher. Since then they have orbited over 40 satellites and even sent payloads to explore Halley's Comet and the Moon.

Currently Japan's space program is facing numerous problems. Recent costly failures, sky-high costs and competition between the two space organizations as well as tough overseas competition have not made it easy for their space program.

M-3S-II

The M-3S-II was first launched in 1985. It is at three-stage launch vehicle with strap on boosters. It is capable of launching 1,720 lbs. to LEO or 440 lbs. to GEO. It and variants have been used since 1970 to launch a variety of probes, small satellites, the Halley's Comet probe, and the Muses-A payload to the Moon. The M-3SII is a relatively small all solid-fuel rocket system, comprising up to four stages with solid strap-on booster rockets.

M-5

The M-5 is a three stage solid propellant satellite launcher with an optional kick motor for an extra fourth stage. It was developed as the successor to the M3SII and has a Low Earth Orbit payload capability is more than twice that of the M-3 SII. It is ISAS's vehicle to compete with NASDA's H2 rocket. The first M5 was launched in February 1997. The second launch was in July 1998 for a Mars space probe making Japan the fourth nation to launch to Mars. The third launch failed in February 2000.

H-Series

The H-series of launchers were designed for Japan to enter the commercial market with their own booster. The H-1 was launched in 1986. It is also a three-stage launch vehicle with strap on boosters. It is capable of launching 4,840 lbs. to LEO or 1,210 lbs. to GEO. Japan began development of this launch vehicle in April 1985 with its first launch in 1994.

Based on experience gained through the H-1, NASDA developed the H-2 launch vehicle entirely with Japanese technology. It is a two-stage vehicle with two strap-on solid boosters. It is capable of placing

23,000 lbs. into a 100 nm circular orbit, 14,000 lbs. into a 100 nm polar orbit, 8,800 lbs. to GTO, and 4,410 lbs. to GEO. However, the program as had problems. There was an unsuccessful launch in February 1998 and a flagship H-2 launched in November 1999 had to be blown up eight minutes into flight when the rocket failed to follow its proper path. The H-2 is Japan's first large indigenous launcher.

J-I

NASDA began developing the J-1 solid propellant launcher to lift payloads too small for the H-2 launcher. Japan began a conceptual study in 1991 for development of a new launch vehicle. The first launch of the J-1 was in 1996. It has the capability to launch 1,980 lbs into LEO.

Brazil

Brazil is poised to become the ninth nation to achieve an indigenous space program. In 1994, the Brazilian Space Agency (AEB, Agencia Espacial Brasilera) was established to coordinate and plan Brazil's space program.

Brazil is developing its own space launch vehicle, based on the Sonda series 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. The first launch of the VLS on 2 November 1997 was a failure. It was launched from its launch complex at Alcantara. There have been no other launches.

LAUNCH SITES

There are at least 24 launch sites world wide including Sea Launch. Many of these sites are not commonly used or are used for sounding rocket launches only. Some of the sites are still under development. This section will discuss a few of the sites shown in **Figure 6-11**. The below list is not all-inclusive.

Figure 6-11: World Wide Launch Sites

1 – Vandenberg AFB	9 – Andova	17 – Xichang
2 – Edwards AFB	10 – Plesetsk	18 – Taiyuan/Wuzhai
3 – Wallops Island	11 – Kapustin Yar	19 – Svobodny
4 – Cape Canveral/KSC	12 – Palmachim/Yavne	20 – Kagoshima
5 – Kourou	13 – San Marco Platform	21 - Tanegashima
6 – Alcantara	14 – Baikonour/Tyuratam	22 - Woomera

7 – Hammaguir 15 – Sriharikota (SHAR) 23 – Sea Launch

8 – Torrjon AB 16 – Jiuquan 24 – Kodiak Island, AK

U.S. Launch Facilities

Eastern Space and Missile Center

The Eastern Space and Missile Center (ESMC), is located on the east coast of Florida (28.5° N, 80° W). The ESMC includes Cape Canaveral Air Force Station where most of the launch pads are located, Patrick AFB where the headquarters is, the Eastern Test Range and other supporting facilities in east central Florida. The Eastern Test Range (ETR) extends from Cape Canaveral, across the Atlantic Ocean and Africa into the Indian Ocean. The ETR includes tracking stations on Antigua and Ascension Island.

The United States' largest space launch facility is located at Cape Canaveral Air Force Station. Since 1950, more than 40 launch complexes have been constructed. Some of the launch pads were built to test ICBMs and Submarine Launched Ballistic Missiles. Many launch complexes are now obsolete and some have been torn down or destroyed because of corrosion from the salty sea air.

Cape Canaveral is located at 28.5° north latitude. The optimum launch (most fuel efficient or heaviest payload) is attained by launching directly to the east (azimuth of 90°) to take maximum advantage of the Earth's rotational speed, thus the minimum inclination of a satellite's initial orbit is 28.5°. Safety considerations limit the launch azimuth to a minimum of 35° to a maximum of 120° for an initial orbit inclination of 57° and 39°, respectively.

Kennedy Space Center

Kennedy Space Center is located on Merritt Island (28 N, 80 W), just to the north of Cape Canaveral. It is NASA's primary launch base for the space shuttle. It is operated by the National Aeronautics and Space Administration (NASA). Considerable support is provided by the Air Force Space Command's Eastern Space and Missile Center. The Space Shuttles are launched from Space Launch Complexes 39A and 39B

Western Space and Missile Center

The Western Space and Missile Center (WSMC) is located at Vandenberg AFB, California (35° N, 121° W). It is responsible for the missile and space launches from Vandenberg AFB and the Western Test Range which extends westward over the Pacific Ocean and into the Indian Ocean where it meets the Eastern Test Range. The nearest landmass directly to the south of Vandenberg is Antarctica. For this reason, launches to the south into polar orbits can be safely made. Surveillance satellites, low earth orbit (LEO) weather satellites, and environmental and terrain monitoring satellites like Landsat are launched from this facility. The safety limit of the launch azimuth is from 158° to 201° for an initial orbit inclination of 70° to 104°, respectively. There are approximately 52 launch pads, silos, and other sites to support launching the entire family of military and commercial rockets and missiles. The principal launch vehicles supported are the Delta, Atlas, Titan, and Scout.

Wallops Flight Facility

The National Aeronautics and Space Administration operates the Wallops Flight Facility (38° N, 76° W), located on Wallops Island on the Atlantic coast, a few miles south of the Maryland and Virginia border. The principal activity now is the launch of sounding rockets although 21 satellites have been launched using the Scout launcher. Italian missile crews who launched Scouts from their facility off the coast of Kenya were trained here. Privately funded launches for commercial lifters (such as Scout and Conestoga) have been negotiated.

Poker Flats, Alaska

Poker Flats Research Range (65° N, 147° W), located northeast of Fairbanks, is owned and operated by the Geophysical Institute, University of Alaska, Fairbanks. It has the distinction of being the world's only university-owned launch range. Established in 1968, the range launches between ten and fifteen major sounding rockets, and a number of meteorological rockets, annually. Total launches to date are approaching three hundred. It also supports continuous ozone measurements and observations. NASA provides various range support radar and tracking systems and facilities.

Kodiak Island Alaska Spaceport

Alaska Spaceport (57.5° N, 153° W) is a commercial launch facility on 3,100 acres of Kodiak Island, Alaska, that can launch small satellites into polar orbit. It also provides a backup launch facility for Vandenberg Air Force Base for satellites needing delivery to polar orbit.

White Sands Missile Range, N. M.

Located at 32° N, 106° W. White Sands Missile Range was established July 9, 1945, as White Sands Proving Ground. It was the site of the July 16, 1945, Trinity shot, the world's first test of atomic bomb, and of postwar test and experimental flights with captured German V-2 rockets. It was also the scene of the February 24, 1949 launch of a Bumper rocket, whose second stage achieved altitude of 244 miles--becoming the first man-made object in space. White Sands is now used for launches of suborbital sounding rockets and some anti-ballistic missile testing. New Mexico is in the process of establishing a spaceport adjacent to White Sands for conducting commercial orbital launches.

Space Ports

The FAA has issued licenses for four spaceports at Cape Canaveral, Vandenberg, Alaska and Wallops Island. All were established on or near existing military or NASA bases, except for the Alaskan site. Spaceport Systems International (SSI) in California is the first privately-owned commercial spaceport in the United States. Its first launch was in January 2000 with the Orbital Suborbital Program rocket, informally known as the Minotaur. The Alaska spaceport has already been tested by a pair of suborbital rocket launches. Seven more spaceports are under active development at the time of this writing. In addition to Texas and Oklahoma, they include Montana, Nevada, Utah and a proposed base in Australia.

Russian/Common Wealth of Independent States (CIS) Launch Facilities

The breakup of the former Soviet Union (FSU) into the Commonwealth of Independent States (CIS), and following that the Russian Federation, 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. 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 (Russian name) or Tyuratam (U.S. name) 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 newest Russian spaceport called Svobodny Cosmodrome.

Tyuratam (TT)/Baikonur Cosmodrome

Sputnik, the first man-made satellite, was launched from TT in October 1957. This site has been the location of all manned Soviet and CIS launches as well as most lunar, planetary and geostationary orbit launches. Due to range safety restrictions at other launch sites, TT is the only Russian/CIS site that can launch directly into retrograde orbits. With the exception of the Start series space launch vehicles (SLV), all Russian/CIS SLVs can be launched from TT. 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.

Kapustin Yar (KY)

Kapustin Yar Space and Missile Test Center (48.4ºN, 45.8ºE) is located on the banks of the Volga River, about 120 Km east of Volgograd and less than 48 Km west of Kazakhstan. In the past, this facility was the site of numerous sounding rockets and small orbital payload launches using the SL-8/Kosmos, but is infrequently used now, with the last space launch taking place in 1987. Kapustin Yar's proximity to Kazakhstan now precludes eastward launches without prior approval of that government.

Plesetsk (PK) Cosmodrome

Plesetsk Cosmodrome (63.8ºN, 40.7ºE) is about 640 Km northeast of St. Petersburg. Although used for civilian communications, meteorological and international launches; most launches from PK have military roles. Orbital inclinations attained from PK range from 63º to 83º. It typically is used to deliver most (if not all) Russian polar orbiting sensor payloads and many Molniya orbit payloads. 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.

Svobodny Cosmodrome

When the breakup of the Soviet Union left Russia's largest spaceport of Tyuratum in Kazakstan, 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.

China

China's growing indigenous space industry has spawned three major launch complexes. These are located at Shuang Cheng-tzu, Xichang, and Taiyuan (Figure 6-16). Although by Western standards the facilities are austere and make limited use of advanced technologies, they appear to be functional and adequate to support the Chinese space programs as they currently exist.

Shuang Cheng-tzu (also known as Jiuquan)

Shuang Cheng-tzu (40.6° N, 99.9° E) is located in the Gobi Desert, 1,000 miles (1,600 km) west of Beijing. This is China's first launch site. There are two primary launch pads, only about 300 m apart. Long March 1 and 2 rockets have been launched from this facility. Launches are restricted to the southeast, resulting in a 57° to 70° inclined orbit. Most payloads lifted from here are military and civil remote sensing, materials processing, or other scientific payloads.

Xichang

The Xichang launch facility (28° N, 102° E) is located in a canyon at the foot of a mountain. Weather conditions are generally favorable for launches throughout the year. The first launch from the facility was conducted in 1984. There is one CZ-2E launch pad and one CZ-3 launch pad. Each can accommodate about five launches per year although there have not been any attempts to achieve the maximum launch rate. All launches from this complex have been attempts to place communications payloads into geostationary orbit. China's first commercial launch mission (Hong Kong's Asiasat 1 on a CZ-3) was made from this facility in April 1990.

Taiyuan

In 1988 the Chinese opened Taiyuan (38° N, 112° E) by launching their first polar orbiting weather satellite, Feng Yun 1. To date, the few payloads lifted from Taiyuan have been polar orbiting weather satellites.

ESA Space Launch Facility

Kourou (also known as Centre Spatial Guyanais)

ESA has one operational spaceport located near Kourou, French Guiana in South America (5.2°N, 52.8°W). Arianespace provides for the launch site and also the launch vehicles. 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. 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 launch pads at the site.

Italy

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 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 site is well suited to put satellites in an equatorial orbit. The site became operational in 1966. By 1976, eight small satellites had been launched into low Earth orbit (4

Italian, 3 U.S., 1 British). No other space launches were conducted until 1988, when a Scout rocket was used to launch an Italian/German/U.S. small scientific satellite into low Earth orbit. The last Scout rocket was launched in 1994.The launch platform is only configured for Scout rockets and also for some sounding rockets.

India

SHAR Center

SHAR Center is located on Sriharikota Island (13° N, 80° E) on the east coast of India. Facilities include assembly, checkout and launch complexes for the PSLV and ASLV launchers. From here, payloads bound for GEO, LEO, or polar orbits climb out over the Bay of Bengal.

Israel

Palamchim

Israel has one launch facility located near Palamchim Air Force Base (31.0° N /035.0° 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.

Japan

Tanegashima Space Center

The Tanegashima Space Center, operated by NASDA, is Japan's primary space launch facility. It is located on the southeast end of Tanegashima Island (30° N, 131° E) about 600 miles (1,000 km) south of Tokyo. There are launch complexes and support facilities for the Japanese N1, N2, H1 and the H2 space launch vehicles. Launch windows have been a major concern for the Japanese space program. Launches are normally restricted to two 45-day windows; January/February and August/September. This restriction is because of range safety procedures and an influential fishing industry lobby.

Kagoshima Space Center (Uchinoura)

The Kagoshima Space Center is located at Uchinoura, on the southern tip of Cache Island (31° N, 131° E) near the extreme southern tip of Japan. Japan's first launch of a satellite into orbit was conducted from this facility. The facility now primarily supports the launch of scientific payloads. Launches can be into 32° inclined orbits, or Earth escape trajectories. Kagoshima is restricted by government directive to all-solid propellant launch vehicles. Like Tanegashima, this facility must operate under the same launch window restrictions imposed by range safety and the fishing industry.

Brazil

Alcantara

With further development, Alcantara is capable of serving as a world class commercial space port and has a geographical advantage that few other launch sites possess. The Alcantara Launch Center (CLA, Centro Lancamentos de Alcantara) is located on the northern coast of Brazil (2.2° S /044.2° W). The formal opening of Alcantara, as a sounding rocket facility, was in February 1990. Between July and October 1994, NASA conducted a joint campaign with Brazilian space agencies to study the Earth's magnetic equator from Alcantara. A total of 33 sounding rockets were launched during the program. The VLS pad was added and used in 1997.

Because it is 3 degrees south of the equator, the greater rotational speed of the earth at that latitude gives each rocket an added boost, requiring less fuel to escape the earth's gravity. Brazilian authorities estimate fuel savings of over 30% for launches into equatorial orbit. That would put Alcântara at a competitive advantage over today's most dominant commercial satellite launch facility, the Europeans' "space port" at Kourou in French Guyana.

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. 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 serves 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 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. Modified to a three-stage configuration, the Zenit was selected due to its highly automated launch procedures. In October 1999, Sea Launch made its first commercial launch using a Zenit-3SL.

European Launch Vehicles

A European aerospace and defense conglomerate designed to compete with U.S. giants Boeing and Lockheed Martin was formed 2 December 1999 in a signing ceremony attended by the leaders of France, Germany and Spain. The merger brings together CASA of Spain, Aerospatiale Matra of France and DASA, the aerospace unit of Germany's DaimlerChrysler, as founding members of the European Aeronautic Defense and Space Co. The deal, which began to take shape in October, creates Europe's biggest aerospace company and the third largest in the world behind Boeing and Lockheed Martin.

SPACE SYSTEM SEGMENTS

Space systems have three distinct segments:

- Space Segment: The satellites placed into orbit or components used to launch the satellites.
- Control Segment: The personnel, equipment and facilities responsible for the operation and control of the satellite and, in many communications systems, control of users' transmissions through the satellites.
- User Segment: The personnel, equipment and facilities that use the capabilities provided by the satellite payload.

Space Segment

There are numerous types of space systems providing a wide variety of capabilities and services. In spite of this diversity, there are similarities among all satellites because they all must operate in the environment of space. All satellites have two principal subsystems:

- The platform
- The payload

Platform

The platform is the basic frame of the satellite and the components which allow it to function in space, regardless of the satellite's mission. The control segment on the ground monitors and controls these components. The platform consists of the following components:

Structure of the Satellite

The structure or body of a satellite holds all of the components together as an integral unit and provides the interface with the launch vehicle. The structure must be strong enough to withstand the rigors of launch yet light enough to not unduly restrict payload weight. Many different shapes and materials have been used. Most satellites are built in low quantities. Each is designed to accomplish specific functions using technology and materials available at the time. As technology develops, new or improved materials and components are used to build new replacement satellites. It is not uncommon, therefore, that follow-on systems are significantly different in design and configuration even though they perform functions identical to earlier systems.

Power

Satellites require power to operate the electrical equipment that is on board. Satellites which have high power sensors or transmit strong or continuous signals require more power than those which have low power sensors and radios. For example, a satellite with a radar emitter and receiver requires a significant amount of power. Communications satellites which receive, process, amplify, and retransmit signals sent from users on the Earth or from other satellites require more power than a scientific satellite with only few sensors and a small radio to transmit the data to researchers on the ground. There are three types of energy sources:

- Solar Energy.
- Chemical Energy.
- Nuclear Energy.

Propulsion

Most satellites have an on board propulsion system which is used to achieve initial orbit and to make position changes. Shortly after reaching the initial, or transfer, orbit the satellite is separated from the final stage of the launcher. The final orbit is achieved by firing a kick motor to move the satellite into the final desired orbit and position. Some satellites are designed so that they can be repositioned. In general, changing the orbital plane requires more force than changes within the orbital plane. The kick motor is used to make major changes in the satellite's orbit. Sufficient propellant must be carried on board to last the lifetime of the satellite system. After a satellite's payload is no longer useable, the kick motor is often used one last time to either increase or decrease its orbital velocity. Increasing the speed raises the altitude of the orbit. Decreasing the speed lowers the altitude, sometimes enough so that the satellite is deliberately destroyed reentering the Earth's atmosphere. Either technique allows a replacement satellite to assume the same orbital position.

Stabilization and Attitude Control

Stabilization and attitude control are necessary to ensure that the satellite maintains the proper attitude. Satellites are subjected to a number of forces in space such as particles streaming from the Sun, meteorites, atmospheric drag, gravity from the Moon, gravity gradients and other perturbations. These forces cause satellites to wobble, spin, drift, or move in other ways not desired. Most satellites which provide visual or electronic images of the Earth or its environment maintain three axis stabilization (roll, pitch and yaw). Many communications satellites are designed to rotate about their longitudinal axis (roll) and thus have only two axis stabilization. Two and three axis stabilization allow sensors and antennas to be pointed in specific directions. Devices such as momentum wheels on the satellite help to stabilize the satellite while in orbit. Position, velocity and attitude data from on-board sun sensors, star trackers, horizon scanners and other devices is transmitted to ground control stations. When momentum wheels and other such passive devices cannot compensate or adjust the orbit, the satellite controllers send signals to the satellite to fire thrusters in short spurts to control roll, pitch, yaw and to make corrects in orbital altitude. To reduce size, mass, complexity and cost some small satellites are designed to tumble freely through space without any stabilization or attitude control.

Thermal Control

The temperature in a satellite must be controlled so that components do not become too hot or too cold. The temperature in a satellite is affected by both internal and external sources. On board electronic equipment and other devices which consume power generate heat. The sun is a source of a vast amount of radiant energy. Radiant energy absorbed by the satellite heats the satellite surfaces and components unless it is dissipated. The ambient temperature of space is a few degrees above absolute zero (-459 degrees F) however, since there is almost no atmosphere, heat transfer between the satellite and the space around it by convection or conduction is almost nonexistent. In very low Earth orbit, however, there can be significant heat generated from friction as the satellite moves at very high speed through the outer reaches of the atmosphere. The most common heat transfer device is the passive radiator which radiates heat from the satellite into space to maintain temperatures within design parameters. A satellite may also require a liquid or gas filled cooling system to transfer heat from internal components to the passive radiator.

Environmental Control

Manned spacecraft require precise environmental control to ensure that air quality, humidity, water and temperature are maintained within operating limits. Most unmanned satellites do not require environmental control.

Telemetry, Tracking and Command (TT&C)

The TT&C subsystem monitors and controls all of the other systems on the spacecraft, transmits the status of those systems to the control segment on the ground, and receives and processes instructions from the control segment. Telemetry components include sensors throughout the satellite to determine the status of various components, the transmitters and antennas to provide the data to the control segment and even the data itself. (In some documents TT&C stands for Telemetry, Tracking and Control. The tasks are, however, the same).

Payload

The function and capabilities of the payload are the reasons a satellite is placed in orbit. The payload provides space-based capabilities to the users. The payload distinguishes one type of satellite from another. The general types of satellite systems are:

- Communications
- Position/Navigation
- Reconnaissance, Surveillance and Target Acquisition (RSTA)
- Early Warning
- Weather and Environmental Monitoring
- Scientific/Experimental
- Manned

Control Segment

The control segment is responsible for the operation of the overall system which includes platform control, payload control and network control. The control segment consists of personnel, ground satellite control facilities and systems on the satellites.

Platform Control

Platform control involves satellite station keeping, relocation maneuvers and the proper functioning of onboard systems. Platform control must be accomplished for almost all satellites. The tasks involved are accomplished through telemetry, tracking and commanding (TT&C).

Payload Control

Payload control involves operation and control of the payload on the satellite. Data is provided by the satellite and commands are sent to the satellite through TT&C.

Network Control

In general, there are two types of networks involved with a satellite system, both of which must be controlled:

- The network of satellite control and monitoring stations. Control and monitor stations are strategically located around the world to perform platform and payload control.

- The network of user terminals. Satellite systems which receive and process transmissions from multiple users (such as DSCS III, FLTSATCOM and AFSATCOM) require a controlled earth terminal segment (users) to insure that the system provides service to authorized users according to established priorities and within the operating parameters of the system. These systems can provide service to a limited number of users at any one time. Satellite systems which only transmit signals to users (such as GPS, DMSP and GOES) may have an unlimited number of users and do not require control of user terminals. More information on network control of user terminals is contained in the sections of this chapter pertaining to specific systems.

Telemetry, Tracking and Commanding (TT&C)

Satellites are controlled through TT&C. Some TT&C is required for all satellites, regardless of the payload they carry.

Telemetry

After the satellite has been placed in the desired orbit, there must be a way to make the data, which the sensors detect, available to the engineers or operator users in order for it to be meaningful. Such a method does exist and is referred to as telemetry. Telemetry is information transmitted to a ground station over a radio link that evaluates the satellite performance or provides mission data.

General spacecraft health and status data is fairly consistent, regardless of the type of mission. This data consists of pressure, temperatures, flow rate, voltages, current and events present throughout the satellite system, subsystems and components. Housekeeping instruments indicating switch positions are digitized, designating the “ON” or “OFF” modes as "1" and "0,” respectively. These switches reflect satellite health and status information. Note that, when communicating with spacecraft, space holding bits ("S" bits) are sent whenever "1s" or "0s" are not being sent.

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 the process whereby the tracking observations are used to determine the spacecraft's orbital characteristics and its position in space.

Commanding

Controlling a satellite and its functions from the ground is a crucial task, and is performed for most satellites. This task is accomplished by transmitting specially coded instructions from the ground station over radio frequency carrier, referred to as the uplink, to the satellite's receiving equipment. This entire process is known as satellite commanding and, depending on the manner in which the command is structured, will determine what functions will be performed.

Commands may be sent for accomplishing any of the following functions; ascent control, orbit adjust, reentry by separation, engine ignition or cutoff, control of internal systems, on-off, switchover, control of sequential events that must operate in a predetermined manner, or control of a space-borne timer which in turn controls a predetermined sequence of events. Commands falling into this latter category control such things as start time, orbital position for start, rate or event occurrence and on-off and reset of the timer.

Commands can be identified as either Real-time Commands (RTC) or Stored Programs Commands (SPC). The primary difference between these commands is the time of execution. RTC causes events within the satellite to occur upon command receipt while the satellite is still within sight of a ground station. The SPC is 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.

It is significant to note, that on spacecraft which contain no self- sustaining reference package, the capability to be commanded is an absolute necessity. Vehicles in this category undergo continuous telemetry monitoring and rely solely upon commands sent from the ground, the bulk of them being of a station-keeping nature.

Air Force Satellite Control Network

The Air Force is the designated service responsible for platform control of DoD satellites. The organizations and facilities involved are organized into the Air Force Satellite Control Network (AFSCN). The principal organization in the AFSCN is the 50th Space Wing of the Air Force Space Command with headquarters at Schriever Air Force Base, Colorado.

The Air Force Satellite Control Network (AFSCN) provides support for the operation, control and maintenance of a variety of DoD and some non-DoD satellites. This involves continual execution of the tasks involved in TT&C. In addition, the AFSCN provides pre-launch simulation, launch support and early orbit support while satellites are in initial or transfer orbits and require maneuvering to their final orbit.

The AFSCN provides tracking data to help maintain the catalog of space objects and distributes various data such as satellite ephemeris, almanacs, and other information.

LAUNCH REFERENCES

Websites:

http://www.tbs-satellite.com/tse/online/thema_lanceur.html – Information about launch vehicles.

http://www.boeing.com/defense-space/space/sealaunch – Sea Launch home page.

http://www.orbital.com/SpaceLaunch/Pegasus/ -Pegasus and Taurus information.

http://www.boeing.com/defense-space/space/delta/deltahome.htm – Delta homepage as well as Delta IV EELV information.

http://www.astronautix.com/lvfam/titan.htm - Titan launch vehicle information.

http://www.astronautix.com/lvfam/atlas.htm - Atlas launch vehicle information.

http://www.spacetoday.org/Rockets/Spaceports/LaunchSites.html#USA – Space Launch Sites Around the World.

http://www.fas.org/spp/guide/index.html – Information on world launch vehicles and capabilities. Sometimes outdated but still good information.

Chapter 11
Space Control

THREAT TO SPACE SYSTEMS

Overview

The nation's dependence on space capabilities in the 21st century rivals its dependence on electricity and oil in the 19th and 20th century. Military operations depend critically on space capabilities. In the 21st century they'll rely even more on such services as global communications, reconnaissance and surveillance in near real time, accurate missile warning, and position/navigation. Space capabilities are critical for integrating the effects of widely dispersed weapons platforms and forces.

In the civilian sector, space has become even more critical to industry and international business operations. The failure of Galaxy IV (May 1998) and the loss of TV and pagers gave us a taste of how dependent the civil sector has become on space capabilities.

As the U.S. economy moves from an industrial-focused nation to an information-focused nation, space becomes a vital national interest. The recent National Security Strategy and National Space Policy have indicated that freedom of action in space is a U.S. interest. Space has or will soon emerge as a center of gravity for DoD and the nation. Space and Information Dominance have already become key tenants for future warfare. We must commit enough planning and resources to protect and enhance our access to, and use of, space.

Various sources such as USSPACECOM's Long Range Plan and SMDC's Vision 2010 have addressed the threat to ensuring our freedom of action in space. Most of the information addressing the actual threat can only be found in classified sources. This chapter will give a brief overview of what is envisioned to be the future strategic environment that will affect space interests, some current threat offensive capabilities and the offensive measures we may have available. When discussing threats to space it is important to remember that space systems include both satellites and ground facilities along with command, data, and communications links between them.

FUTURE STRATEGIC ENVIRONMENT

There are a number of assumptions or key judgments that are made about the future strategic environment that will influence how wars may begin and be fought. The assumptions listed below are just a few. Threats to our national interests will continue to emanate from these sources.

- Nation-states will continue to fragment, sparking regional unrest.

- Main causes of warfare will be nationalism, ethnic separatism, religious extremism, and scarce resources.
- Non-state actors (e.g. terrorist organizations, multinational corporations, etc) will become more important. Some of these organizations may have access to weapons of mass destruction.
- Temporary alliances will emerge as expedient ways to address various political situations.
- The U.S. will remain a global power but won't always be able to forward base its forces. It is unlikely; however, the U.S. will face a global military peer competitor through 2020.
- The global economy will rely more on information and information processing.
- The global economy will continue to become more interdependent and economic alliances will blur security agreements.
- The gap between "have" and "have-not" nations will widen which will create regional and possibly global unrest.
- Rapid advancement of technology will create revolutionary breakthroughs. Commercial interests will drive most technology development, especially with space and information processing.
- More nations and non-state actors will access space and information technologies and products. Rapid integration of information enabled by space capabilities will be the key to successful operations.
- Advanced ballistic missile warheads and stealth technology will become more common in ballistic missiles.
- The precision and lethality of future weapons will lead to increase massing of effects rather than massing of forces.
- Technology will proliferate for weapons of mass destruction and delivery systems.
- Asymmetrical attacks will be the norm.
- Rapid and dynamic U.S. military operations will increasingly depend on an information-networked environment.

- Space capabilities will proliferate at a faster pace.
- The shift will continue from the military to the commercial sector as the dominant receiver and provider of space services.
- Military, civil and commercial space sectors will continue to converge.
- Achieving space superiority or denying space to the adversary during conflicts will be critical to any military's success.
- Sovereignty will remain a concern and space "basing rights" will become a bigger issue.
- Space capabilities will be increasingly important to our society and economy and they will become vital U.S. national interests.

THREAT CHARACTERISTICS

Threats will be tactically and technologically diverse. Armed conflict will remain a vicious, lethal business. Opposing forces may appear in regular or paramilitary structures, transnational military organizations, and single or widespread domestic and international terrorist cells. Criminal elements of various sizes and means can probe our geographical, human, electro-magnetic, and cyber borders. They may threaten U.S. interests abroad or populations, critical infrastructure, or territory at home. Some adversaries will enhance their C4ISR with international or commercial space systems and the global information infrastructure. Adversaries will wield technologically advanced niche capabilities, and develop asymmetric capabilities for waging computer network and information warfare. Some may employ precision fires or massed fires to put our forces or partners at risk during mobilization, deployment, and operations or redeployment. The threat of nuclear, chemical and biological warfare will persist, as will the specter of attack with strategic or intercontinental ballistic and cruise missiles.

Many adversaries will be politically astute and innovative. Adversaries will attempt to undermine the national will to conduct operations and fracture the cohesion of coalitions and alliances. This approach is now enabled by the worldwide proliferation of telecommunications and information technology. Traditional foreign intelligence collection against the U.S. will remain a concern. However, the effort will evolve in new directions, stemming from reliance on computer systems for processing and storing sensitive information. Space systems allow the U.S. to monitor and report on global activities, observing early indications of crises, providing planning information, reducing many uncertainties characterizing conflict situations, and supporting information sharing with partners and allies. Space operations can do much to preclude such threats, but our adversaries can put space systems at risk.

Adversaries may put at risk all elements of space systems. Adversaries may alter the space environment, on-orbit assets, communications links, ground stations, terminals, or the associated information infrastructure. A variety of direct ascent and co-orbital anti-satellite (ASAT) techniques will be possible. On the ground, aerospace industrial facilities and launch sites may come under attack, as well as boosters during ascent. If vulnerable, ground stations, control facilities, and terminals will be attacked by enemy special forces, terrorists, theater missiles, electronic warfare means, cyber-attack, or conventional forces. Electronic attacks will aim to degrade satellite communications; telemetry, tracking, and control (TT&C) links; and ground stations. Low power signals such as GPS are particularly susceptible to localized interference.

Space systems will be in the IO target set, and the linkage between information operations and space operations has been forged by the assignment of selected IO responsibilities to U.S. Strategic Command. Commander, USSTRATCOM, must prepare to counter computer hacking aimed at tampering with streams of data moving to and from satellites. If vulnerable, space systems will come under computer network attack (CNA). Left unprotected, links will be jammed, monitored, or pirated by adversaries.

Adversaries will also use space. Commercial and international space is expanding our capabilities, as well as our adversaries'. Twelve hundred new commercial satellites will be on orbit in the next decade. The majority will be communications systems, but thirty or more imaging satellites are likely to be operating. As a result, states, transnational organizations, factions, or individuals will be able to buy militarily significant space products or services. In fact, 1-meter resolution imagery, sufficient for tactical targeting (if timely) will be internationally available. Other purchases will include radar imagery, precision navigation and timing services, and a multitude of highly mobile, highly capable communications. While licensing and international pressure will impose some restrictions, this burgeoning space industry has been termed the new *El Dorado.*[1] The lure of a space gold mine, coupled with the rise of the global economy, will dampen voluntary controls.

The systems are not all commercial, however, as more than 40 nation-states have national space programs of varying sophistication. So, military operations must assume an adversary will have limited access to overhead intelligence capabilities and telecommunications capable of operating in remote, undeveloped areas, as well as in urban environments.

OFFENSIVE COUNTERSPACE MEASURES

Advanced technology will help develop counterspace weapons aimed against U.S. or Ally space systems. Although improved satellite systems will depend less on ground infrastructures for TT&C, they will still be susceptible to directed-energy weapons that can permanently or temporarily disable critical satellite functions. Keep in mind that space systems consist of space (mission and data relay satellites), ground (supporting ground facilities), and user segments. The sophisticated enemy's hostile capabilities may include kinetic, electronic, and direct-energy systems to negate U.S. satellites. A lesser nation state or other non-state actors may prefer jamming or attacks against ground and user systems. Deception and information operations against our C4I systems may also be use.

Offensive counterspace operations neutralize space systems or the information they provide through attacks on the various elements of those systems. They involve the use of lethal or non-lethal means for negation (deception, disruption, denial, degradation, and destruction). Deception, disruption, denial, degradation, or destruction of space systems and services may seriously effect the U.S. commercial, civil and military environment. Most countries already have the capability (but not necessarily the will) to affect the space environment. There are four types of offensive counterspace operations that could be used.

Denial and Deception

These techniques are used to limit or corrupt information obtained by an intelligence collection satellite. This is a highly attractive counterspace alternative because of the low level of difficulty. Denial and deception involves the employment of camouflage, concealment, and deception techniques. Many countries have denial and deception practices to impede the collection of intelligence by an adversary. A significant advantage of denial and deception is that it can be conducted in peacetime.

In order to conduct effective denial and deception operations, one must know when intelligence satellites will be overhead. Such information can be obtained in many ways. Amateur observers post what they believe to be intelligence collection satellite data on several Internet sites. Countries more acutely concerned about satellite overflights can implement their own observing program. The accuracy of publicly available software to predict satellite orbits means some actors can use satellite warning as part of a plan for denial and deception (see the Commercial Satellite section below for examples of software available).

Ground Segment Attack/Sabotage

Physical attacks and/or sabotage can be used against critical satellite ground facilities such as control stations or data processing stations to disrupt, deny, degrade, or destroy the space system. The greatest advantage of this method is that it can be accomplished using existing military systems. Most potential adversaries could attack the ground and user facilities associated with a space system. Critical ground facilities include TT&C facilities, launch facilities and assembly plants, satellite assembly plants, and key data processing or data downlink facilities. There can be mobile ground facilities as well as fixed facilities. Most fixed satellite ground facilities are described in open source materials and are therefore easy to identify and target.

Electronic Attack

Electronic warfare is not a new capability to many countries and can be used to disrupt or deny such things as satellite communications, position/navigation/timing data, and command links. All satellites use some form of communication link to pass information. These electronic signals can be neutralized by jamming or spoofing the electronic equipment on the satellites or at the receiving ground facility. 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 that are received and processed along with desired signals.

It is relatively easy to jam signal uplinks and downlinks. The jammer must operate in the same radio band as the signal to be jammed. However, transmit power becomes an issue in determining how easy it is to jam the uplink or the downlink. In general, uplink jammers must be roughly as powerful as the emitter associated with the link being jammed. Since downlink jammers have a significant range advantage over the space-based emitter with which they are competing, they can often be much less powerful and still be effective.

Targets of downlink jammers are ground-based satellite data receivers ranging from large sites to handheld GPS user sets. Systems using low power receive (downlink) signals, such as GPS and some communication systems, are relatively easy to jam and are jammed many times through the use of other RF transmitters in the area. Jamming is normally local (from tens to hundreds of miles).

Targets of uplink jammers are the satellites’ radio receivers, including their sensors. Uplink jamming is more difficult since considerable jammer transmit power is required. However, if effective, it can deny information globally. If false commands can be sent to the satellite, it could cause the spacecraft to destroy itself. Vulnerability of satellite systems to jamming depends strongly on particular designs.

Two areas of great concern to the military are communications and GPS. The military has become more reliant on commercial communications that are not hardened against jamming. During Desert Storm 45% of all communications passed between the U.S. and the Persian Gulf were over commercial satellite systems such as INTELSAT and could have been jammed with existing communications equipment

Space Segment Attack (Anti-satellite)

Direct attack against a satellite has historically been a capability only the U.S. and former Soviet Union possessed. China may also have the capability to deploy anti-satellite (ASAT) weapons. However, global technology will lead to the proliferation of ASAT threats especially as threats against LEO systems.

ASATs can be grouped into two generic categories, interceptors and directed-energy weapons. The ASAT interceptor category consists of low-altitude direct-ascent interceptors; low-altitude co-orbital interceptors; high-altitude, short duration interceptors; and long-duration orbital interceptors. Directed-energy ASAT weapons consist of ground-based high-power lasers; low-power anti-sensor lasers; airborne high-power lasers; space-based lasers; and RF weapons.

Vulnerability of satellite systems to component damage from directed energy weapons depends on the design and orbit of the satellite. LEO satellites are close to the earth allowing an enemy to concentrate large amounts of energy on them. Since imagine optical systems must concentrate incident light on a small sensitive detector, laser attacks against these sensors can be highly effective.

Enemy nations that can track satellites and fire significant payloads into space can place important satellites at risk using inexpensive direct-ascent weapons. But this ability will belong only to the most advance countries because of the cost of research, development, and implementation. Russia had previously tested a co-orbital interceptor and had developed a concept for space-to-space missile platforms. Other countries have boosters that could be used for direct-ascent ASAT weapons but not necessarily the ASAT technology.

High Altitude Nuclear Device

A high-altitude nuclear detonation would create electromagnetic interference against satellite communications. Satellites in LEO or MEO orbits would be most affected (such as Iridium, UFO, and GPS). Prompt nuclear effects include electronic upset, electronic burnout, and mechanical damage. Delayed nuclear effects include the same effects due to trapped radiation. The detonation of a single nuclear weapon above the atmosphere could have severe, long-term consequences.

Only a few nations have the capability to launch a nuclear weapon and most nation-states wouldn’t be willing to accept fratricide of their own satellite systems. However, some nation-states that don’t rely heavily on space capabilities may be willing to reduce U.S. military and industrial capabilities at the risk of nuclear fratricide.

Information Operations

Offensive information operations are cheap relative to the cost of developing, maintaining, and using direct energy or nuclear devices. Many information operations tools are readily accessible to third world nations or non-state actors. Information attacks could consist of creating false information, manipulating information, and inserting malicious, logic-based weapons in space-based, globally shared infrastructures for telecommunications and computing.

U.S. CAPABILITIES

Control of Space is the ability to ensure uninterrupted access to space for U.S. forces and our allies, freedom of operations within the space medium and an ability to deny others the use of space, if required. We must protect our space assets and be able to deny adversaries from gaining an advantage through their space systems. The ability to gain and maintain space superiority will become critical to military operations. Control of space requires USSTRATCOM to achieve five interrelated objectives: (1) *assure* the means to get to space and operate once there; (2) *surveil* the region of space to achieve and maintain situational understanding; (3) *protect* our critical space systems from hostile actions; (4) *prevent* unauthorized access to, and exploitation of, U.S. and allied space systems and, when required, (5) *negate* hostile space systems that place U.S. and allied interests at risk.

This section will discuss current ways the U.S. is looking at negation systems. Negation will be executed when prevention fails. Negation is the ability to deny, disrupt, deceive, degrade, or destroy an adversary's space systems or services. Actions that can be taken range from temporarily disrupting or denying hostile space systems to degrading or destroying them. Jamming, attacks against ground segment systems and information operations are always applicable as negation tools. When considering the options, the commander must consider third-party use of a satellite, plausible deniability and how actions may add to debris or otherwise affect the environment. Some of the technologies being explored are listed below.

The space-based systems that the U.S. is looking at are for space control and force application. All are new technology systems and there is not much information about them in open source materials.

Directed Energy Weapons

Directed energy weapons include high-energy laser and high-power microwave.

Radio Frequency (RF) Weapons

High Power Microwaves may be able to disrupt, degrade, and destroy electronics in communication and information systems. They would use bandwidths at high peak power to damage electronic information processing and communication or bandwidths at high average power to disrupt systems. These RF weapons would be deployed in GEO orbits and use large antennas to direct RF energy against enemy electronic systems.

Laser Weapons

Space based lasers appear to be the most versatile in providing for options for temporary effects on anticipated targets. The potential for using lasers has been recognized since the technology was discovered in 1960 but producing beams with enough power has been problematic. The type of laser currently being developed is the chemical laser.

Although Congress cut the Department of Defense's Space-Based Laser (SBL) acquisition program in 2000, the Missile Defense Agency (MDA) maintains an active interest in developing the technology necessary for space-based missile defense, and work within the Directed Energy Directorate of the *Air Force Research Laboratory* continues at the basic and applied research levels. SBLs present unique challenges for laser developers. The requirements of autonomous operation, minimal logistics, low weight, and radiation-hardened materials are very significant basic research and engineering issues. To date, only chemical lasers appear to have the potential to generate the requisite power levels and beam qualities to meet mission requirements. Furthermore, researchers have been able to scale only the chemical oxygen iodine laser (COIL) and hydrogen fluoride (HF) chemical lasers to very-high-energy systems.

The Army manages HELSTF (High Energy Laser System Test Facility) as the DoD National Test Facility for High Power Lasers. HELSTF is located at White Sands Missile Range and is capable of testing lasers over a broad range of wavelengths. HELSTF is the home of the Mid Infrared Advanced Chemical Laser (MIRACL), the United States' most powerful laser, which is a CW, megawatt class deuterium-fluoride laser operating in a band from 3.6 to 4.2 microns. In a test to determine laser capabilities against satellites, the Army fired the MIRACL against the MSTI-3 satellite on the evening of Oct. 17, 1997. The laser hit the target camera, which recorded data now being evaluated at White Sands. The point of the test was to show that lower-intensity lasers might be able to disable the information-gathering equipment, such as infrared sensors, mounted on U.S. military satellites. Information about HELSTF and various projects being worked there is available at the following internet sites: http://helstf-www.wsmr.army.mil/; and http://www.cnn.com/US/9710/20/pentagon.laser/.

Direct Impact Weapons

These are weapons that use either kinetic energy (KE) or ones that pass close enough to a satellite for an exploding fragmentation device to destroy it.

KE-ASAT

According to The Boeing Company, the Kinetic Energy Anti-Satellite (KE-ASAT) program is intended to provide the United States with the capability to neutralize hostile satellites. The objective of the KE-ASAT program is to define, develop, integrate and test the necessary Kill Vehicle (KV), weapon control subsystem component and subsystems technologies to demonstrate hit-to-kill performance, including debris mitigation against hostile satellites.

Boeing won the demonstration/validation program contract in 1990 to develop the kinetic kill vehicle (KKV). A follow-on development contract was awarded in 1996. The current program finalizes development of the KKV on-board processor and seeker, performs hardware-in-the-loop and hover testing, and builds three flight test units. Boeing is the prime contractor responsible for development and demonstration testing of the KE-ASAT Kill Vehicle and Weapon Control Subsystem. More information is possible by following links from the Internet site http://www.boeing.com/defense-space/ic/keasat/.

Development of this technology into deployable offensive or defensive systems will still take a number of years. However, some of the systems the United States is currently developing to intercept ballistic missiles would have considerable inherent capability to be used as ASAT weapons. Current-generation satellites are not equipped to defend themselves. While future satellites might include defenses of some type, it will be difficult to overcome the advantages inherent to an attacker.

Co-Orbital ASAT

A co-orbital ASAT is one that closes slowly with its target. It uses an exploding warhead to destroy the satellite. The feasibility of a co-orbital ASAT weapon was demonstrated successfully by Russia in 1982.

COMMERCIAL/CIVIL SPACE

Space-based systems and products will increase our adversaries' potency and level the military battlefield. The explosive commercial development of space capabilities will make space products accessible to any organization with resources. Amplifying the potential threat is the compression of time from "intent to use" because future space systems will operate in near real time.

As described in several instances above and throughout this text, our adversary has access to many space products and capabilities. The proliferation of space products throughout the commercial environment gives the enemy access to communications, high-resolution imagery, current weather, and accurate position/navigation/timing. National policy attempts to resolve some of the problems associated with the U.S. commercial space products but does not go far enough. The commander of a military operation must be aware of what is available to his adversary, how it might be used, and what can be done to protect his own use of commercial assets while denying it to the enemy.

Communications

Technology advances provide unparalleled capability and access to potential adversaries in the form of higher bandwidths and a proliferation of global communications. An adversary's ability to command and control forces will gain much from dynamic, global, communication networks such as Iridium and Globalstar.

There are mechanisms that are being considered to give industry incentives to increase protection levels and decrease an adversary's access.

Imagery

There is concern about the availability of what formerly was highly classified imagery with very high resolution. But already on the market is one-meter resolution multispectral and optical imagery. It is not available typically in near-real-time because it can take hours to image, receive and process the product. Had near-real-time capabilities been available in 1991 and if Iraq had had access to the capabilities, the left hook that the Coalition set up in DESERT STORM might not have worked because Iraq would have had imagery of the troop formation.

Anyone with Internet access will get highly accurate imagery almost instantly. A potential enemy can order archived imagery from any number of commercial agencies. He can even request specific imagery be taken over any area of the earth. Some of the websites available to him are:

- Space Imaging: http://www.spaceimaging.com/
- Canada Centre for Remote Sensing: http://ccrs.nrcan.gc.ca/index_e.php
- Google Earth: http://earth.google.com/
- Landsat Program: http://geo.arc.nasa.gov/sge/landsat/landsat.html
- Radarsat: http://radarsat.space.gc.ca

- EROS: http://edc.usgs.gov/
- Other: http://terraserver.com

There is commercial satellite tracking software available that anyone can purchase to track the path of any satellite have the ephemeris data for. Most data is available on-line also. Some of the software packages available are:

- J-Track: http://liftoff.msfc.nasa.gov/realtime/jtrack
- Northern Lights: http://www.nlsa.com
- Satellite Toolkit: http://www.stk.com

Weather

All geostationary weather imagery is available to anyone via WEFAX or the Internet. Most of the polar orbiting satellites also produce weather imagery that is available to anyone. Depending on equipment the enemy has in theater, he may very well be receiving and analyzing the same weather picture that we are. DoD has passed management of national weather satellites to the National Oceanic and Atmospheric Administration. Cable and satellite television stations now routinely market satellite weather information.

Position/Navigation/Timing

Current U.S. policy states we will give the commercial and civil sector more accurate position and navigation data and that GPS will be a global satellite system. GLONASS is as of December 2005 about a half-full constellation. Galileo is the European community's space-based navigation system of the future. Until then, GPS is essential to such things as global transportation systems. Potential enemies will use all of these systems to enable their own precise military operations.

GPS jammers can be built for a relatively small amount of money. There are also jammers being advertised for sale. One 4-watt jammer being advertised states it has an effective jamming area of 150-200K.

SPACE THREAT REFERENCES

Air Force Space Command Strategic Master Plan FY06 and Beyond

http://www.peterson.af.mil/hqafspc/library/AFSPCPAOffice/Final%2006%20SMP--Signed!v1.pdf

USSPACECOM Long Range Plan, March 1998

Army Space Master Plan (Draft)

Threats to U.S. Military Access to Space, National Air Intelligence Center, 1998

Websites:

http://www.au.af.mil/au/awc/awcgate/saas/spacy_wl.pdf – CADRE Paper, Maxwell AFB, Does the United States Need Space Based Weapons? Excellent resource for information about the problems with the various kinds of space control issues and weapon systems.

Chapter 12
Space Force Application

Joint Publication 3-14, Joint Doctrine for Space Operations, states, “The application of force would consist of attacks against terrestrial-based targets carried out by military weapons systems operating in or through space.” Army FM 3-14, Space Support to Army Operations, uses the basic JP 3-14 definition that states space force application is “Combat operations in, through, and from space to influence the course and outcome of conflict. The space force application mission area includes ballistic missile defense and force projection.” Currently, there are no force application assets operating in space.

BMD doctrine is beyond the scope of this manual and is not addressed here. Other than BMD, the Army currently provides no space force application weapons systems. This is a potential mission of the future when space-based platforms can add an accurate and immediate third-dimensional sensor and shooter capability.

Chapter 13
Military Space Personnel, Education and Training

OVERVIEW

USSTRATCOM, as the integrating organization for space forces and as a full partner in the joint fight, has the ultimate responsibility to ensure that the space needs of the combatant commanders are met. Commander, USSTRATCOM (CDRUSSTRATCOM), is the functional combatant commander who has COCOM authority of assigned DoD space forces. USSTRATCOM has service component commands through which it exercises control of the space forces. These are AFSPC, NETWARCOM and ARSTRAT.

The USSTRATCOM Space Operations Center (SPOC) is manned 24 hours a day and has been the focal point for obtaining space support. It ensures the correct agency provides the needed assistance. The SPOC, the component commands and the National Reconnaissance Office (NRO) maintain an extensive library of information that can be accessed via GCCS. Current constellation status and threat information is just an example of what can be found on the USSTRATCOM SPOC website.

Under CDRUSSTRATCOM is the Joint Functional Component Command for Space and Global Strike (JFCC-SGS). This is the USSTRATCOM JFCC responsible for space operations missions. Commander JFCC-SGS is dual-hatted as the 8th Air Force Commander (8 AF/CC) and is located at Barksdale AFB. The Joint Space Operations Center (JSpOC), located at Vandenberg AFB, is the actual joint operations center for JFCC-SGS with OPCON of all assigned forces. Commander, JSpOC, is dual-hatted as the 14 AF/CC. 14 AF is AFFOR (Air Force Forces) for JSpOC, which plan and execute AF space operations as tasked by JSpOC. ARSTRAT's 1st Space Brigade fulfills the ARFOR (Army Forces) role under JSpOC, and NNSOC fulfills the corresponding NAVFOR (Naval Forces) role.

Unity of command is ensured when space forces are presented to a theater via OPCON, TACON, or support. At SECDEF direction, CDRUSSTRATCOM can transfer control of space forces or capabilities to another combatant commander. For example, a Joint Tactical Ground Station (JTAGS) detachment could deploy and then attach, normally with OPCON, to another combatant commander. If needed by a Joint Force Commander (JFC), OPCON of those forces can be delegated to that JFC, who could then delegate that authority to a service component commander. The JFC may, for instance, delegate OPCON of assigned and attached Air Force space forces to the COMAFFOR. To ensure unity of command of theater DoD space forces, a JFC may designate a supported commander for joint theater space operations. The appropriate Service or functional component commander should then exercise TACON of those theater space forces made available by the Services.

The service with the preponderance of space capability and the capability to command and control should normally be designated supported commander for joint theater space operations. This normally is the COMAFFOR, or COMAFFOR/ joint force air and space component commander (JFACC) (when COMAFFOR is dual-hatted as the JFACC), if established.

If the space force's operation only impacts that individual theater, the SECDEF may direct USSTRATCOM to transfer the space forces to the geographic combatant commander. The command relationship the gaining commander will exercise is specified by the SECDEF. The normal relationship will be OPCON, however, a TACON or support relationship may be appropriate depending on the ability of the theater commander to conduct space operations planning.

JOINT AND SERVICE SPACE SUPPORT TEAMS

Each level of Army and Joint organizations now has space officers assigned or attached for working actions involving space operations and support. ARSTRAT and NNSOC, as service components, also have Space Support Teams (SST) that can deploy to assist combatant commanders' subordinate commands. These SSTs should be requested early in the planning process to ensure effective and efficient use of space assets. In general the teams support the following customers:

- ***IMPORTANT NOTE:*** Joint Space Support Teams (JSST) are no longer provided by USSTRATCOM. That space expertise is now resident via positions on each combatant commander's staff. The same is true for the old Air Force Space Support Teams (AFSST), since that expertise can now be found on the air and space commander's staff as well.

- Army Space Support Teams (ARSST) support ARSTRATCOM Army Organizations and can still be sent to support Land Component Commanders, Staff and Organizations and to support Army Corps level staffs. Space Support Elements (SSE) are now part of Army Divisions

- Naval Space Support Teams (NSST) support NETWARCOM Navy Organizations, Sea and Maritime Component Commanders, Staff and Organizations

Space support teams provide expertise, advice and liaison regarding the application of space systems capabilities for Theater Commanders, Joint Task Forces, and theater component commanders. Space Support Teams (SST) emphasize staff contact and coordination regarding USSTRATCOM's assigned missions in order to make space systems' capabilities understandable, and useful for warfare. A component's support teams or the assigned staff space officers will also provide briefings and information back to USSTRATCOM identifying theater problems and issues, current theater operational plans, current intelligence, and recommendations to improve theater space support.

Air Force Space Support

As mentioned, the Air Force no longer has Space Support Teams that are deployed from Air Force Space Command. The USAF has chosen to imbed assigned space operations officers into its Air Operations Center (AOC) components of the Expeditionary Air force and directly on combatant commanders' staffs. These personnel perform integration of space products and space force capabilities into the air campaign planning process. Examples of space support provided to Air Force operational units are as follows:

- Provide predicted GPS navigation signal accuracy models for planning of precision guided munitions strikes.
- Provide radio frequency spectrum propagation forecasts for terrestrial and space communications to airborne sensor, strike and C2 platforms.
- Provide national and threat system orbitology predictions for determining vulnerabilities to U.S. aircraft on the ground and opportunities for strike operations.
- Operate equipment that accesses and retrieves space support information.
- Provide national and commercial satellite imagery fusion for mission fly-through of target areas.
- Provide contingency communications via INMARSAT and Iridium terminals.
- Provide space TTP advice to support aerial strike warfare.
- Maintain OPFOR space order of battle and tactics.
- Provide contingency weather imagery reception and with battlespace imagery capabilities for forecasting over target areas.

Naval Space Support Team (NSST)

NETWARCOM's Naval Space Support Teams (NSSTs) are an important source of information and training for the naval warfighter. These teams take tailored support at all operational levels directly to the "waterfront." The teams provide on-site training, exercise support, staff augmentation and other assistance. Training packages highlight not only the "what," but the "how" of space support to the warfighter. The focus of the NSSTs is to take the mystery out of space and put space capabilities in the hands of the warfighter. Through direct on-site contact with Naval and Marine forces, NSST members provide a wide variety of services ranging from technical systems assistance to pre-deployment briefings tailored to specific areas of operation.

The NSSTs form a cadre of highly trained space-smart personnel providing expertise on space systems capabilities to deployed users. 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 be responsive to the needs of its customers. NETWARCOM deploys space support teams to provide space-based information, publications, and products to the warfighter.

NSST support is available on a 24-hour basis. However, because of the limited space aboard ship, the team normally does not deploy with the naval forces. Support includes:

- Deployed Forces Support command and control warfare (C2W) cell augmentation and tactical receive equipment- tactical related applications (TRE-TRAP) training.
- Exercise support.
- Electronic Support (via Joint Deployable Intelligence Support System (JDISS)).
- School House Support (early warning, communications, weather, remote sensing, navigation)
- Publications and Products

National Space System Support

The Operational Support Office (OSO) of the NRO is the national organization that orchestrates and delivers tailored support to combatant commands and other operational users by providing national overhead reconnaissance system information where and when needed. OSO provides equipment and personnel. Host units may be required to cover consumables such as commercial satellite air time and commercial imagery costs. Response time varies depending on the situation and support requested.

ARMY SPACE SUPPORT TEAMS AND SPACE SUPPORT ELEMENTS

Army Space Support Teams (ARSST)

ARSSTs are the land-based warfighter's primary interface to space-based capabilities. The ARSSTs provides rapidly deployable space-based operational support as well as expertise, advice and liaison regarding the application of space capabilities for the joint force land component commander (JFLCC). The ARSSTs, elements of the U.S. Army 1st Space Battalion, are deployed for contingency missions and exercises by the 1st Space Brigade commander in coordination with U.S. Strategic Command (USSTRATCOM). The mission states the ARSST will:

- Provide space expertise.
- Offer operational support to the warfighter.
- Actively participate in the evolution of prototype space technologies.

Army Space Support Teams rapidly deploy worldwide to provide space operations and operational support to land forces to achieve advanced full spectrum dominance. ARSST elements typically will provide direct support to units where FA-40s are not assigned as part of the warfighter's staff.

The ARSST can be deployed in less than 48 hours. It is tailored to meet the needs of the supported commander with each deployment being unique. The typical team is composed of soldiers who have widely varying military specialties. ARSST members, because of their training, level of expertise and unique positions as special staff members, impart knowledgeable feedback directly to the 1st Space Brigade commander and through appropriate channels, to USSTRATCOM. Team member comments assist and encourage the identification of operational needs and requirements for space-associated capabilities.

During contingency operations, a JFLCC request for deployment of an ARSST is normally routed through USSTRATCOM to 1st Space Brigade. Component missions process through Headquarters Department of the Army (HQDA), Deputy Chief of Staff for Operations (DCSOPS) to ARSTRAT for support of contingencies. Upon notification of a potential mission, ARSTRAT establishes communications with the supported unit and coordinates final mission planning and support.

Space Support Elements (SSE)

SSEs composed of Army space operations officers (FA40), are located at Army Division level and will be the primary focal point for leveraging space capabilities.

The SSE integrates and synchronizes space assets in support of operations; coordinates the enhanced access to joint, national, civil and commercial space systems; provides space input and recommendations to division planning activities; and coordinates the protection of friendly space capabilities and the negation of enemy space capabilities. As a special staff element, the SSE maintains active communications and data links with several space-related organizations within the theater or Joint Operational Area.

An SSE at a division level consists of four FA40 space operations officers and two MOS 31S NCOs. These six soldiers will serve in the force applications cell at each of the two tactical command posts and the plans cell of the main command post.

The SSE ensures the planning, integration and coordination of the space mission areas into division plans, orders and operations. *The SSE*:

- Provides the commander and staff expertise, experience and professional knowledge to ensure the space portion of the battlespace is fully understood.
- Provides assured access to all available space-based products and services to support current and future operations.
- Ensures full use of space-based capabilities for intelligence, focused surveillance, area reconnaissance, communications, early warning/battlespace characterization, position, velocity, navigation, time, Blue Force Tracking (BFT), combat identification and precision engagement, integrated tactical warning and attack assessment, environmental monitoring, and dynamic tasking and re-tasking of space platforms with direct downlinks to enhance the warfighting effectiveness of combatant commanders.
- Facilitates augmentation by specialized space forces when required and ensures reachback to all supporting space forces and organizations.
- Supports division operations in conjunction with joint, interagency and multinational organizations and non-governmental organizations across the full spectrum of operations.

ARSST and SSE Space Products

An ARSST or SSE deploys with state-of-the-art automated data processing equipment that it uses to complement and augment the resources of the local topographic unit. Image maps provide staffs and soldiers the most current maps of areas where no maps exist, or are out of data. The ARSST or SSE can reach back to the Multi-spectral Imagery (MSI) laboratory at its headquarters in Colorado Springs. It 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 SIPRNET, GBS and overnight mail. These products include videotaped fly-throughs in VHS format; 3-D images, perspective views and image maps in various resolutions. ARSST and SSE software tools provide the capability to monitor the health status of the GPS constellation.

ARSST and SSE Space Services

ARSSTs and SSEs can aid staffs in making optimal use of Satellite Reconnaissance Advance Notice (SATRAN) data, which provides overflight information on potential threat satellites. The information includes satellite capabilities to monitor friendly operations.

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. ARSSTs and SSEs obtain and provide 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. They can also provide advice on counter measures to enemy efforts to jam or spoof GPS.

On the sun’s surface, numerous phenomena affect Ultra-High Frequency (UHF) and SATCOM communications, GPS signal reception and radar. The ARSSTs and SSEs complements the SWO’s efforts by obtaining advance forecasts of these events and assessing which friendly systems will be degraded, the degree of degradation and when the systems could be degraded.

The ARSST or SSE can aid intelligence personnel in conducting space intelligence preparation of the battlefield (IPB), respond to space related requests for information (RFI), provide assessments of how the enemy will use its space systems, and provide expertise on friendly force space-based intelligence capabilities. The ARSTRAT G2 maintains a web site that details threat space potential and ARSST/SSE members access it through the SIPRNET when deployed. Additional support to intelligence includes providing expertise on enemy and friendly availability to employ commercial satellites, enemy and friendly space vulnerabilities, and recommendations to support the targeting process.

ARSST/SSE members use the Multi-source Tactical System (MSTS) to augment the assets of the supported Intelligence staff. The MSTS is similar to the corps’ Forward Area Support Terminal (FAST). The MSTS receives Information Broadcast Service (IBS) broadcasts.

The ARSSTs and SSEs can provide a limited supplement to the unit’s early entry communications connectivity using International Maritime Satellite (INMARSAT) hand-carried terminals providing secure fax, data, telex, and voice.

Summary of Support for Army Forces

ARSTRAT counts on ARSST and SSE soldiers to use their specialized knowledge and distinct training to provide space subject matter expertise in:

- Space-based analysis – The ARSST/SSE uses its particular knowledge, equipment and reachback capabilities to identify and track ongoing events in space, translate their significance, and relate their impact on task force operations.

- Space intelligence estimate – The ARSST/SSE uses its unique knowledge to complete the space intelligence preparation of the battlefield (IPB).

- Space weather – The ARSST/SSE, through attachment of an ARSTRAT government civilian, can provide a unique weather resource and can brief the impact of space weather on military systems and equipment.

- GPS – The ARSST/SSE provides information and briefings on the health and status of the GPS constellation, and supplies GPS accuracy prediction graphs.

ARSTRAT plans to make available enhanced support to commanders' staffs and special staffs by:

- Augmenting imagery processing through use of its organic computers, printers and plotters.

- Providing the Deployable Weather Satellite Workstation (DWSW), a direct satellite to ground terrestrial weather capability.

FA40 and 3Y Space Staff Officer

FA40 Space Staff Officer

The Space Operations Officer (FA40) is a Functional Area within the Information Operations Career Field resulting from the OPMS XXI working group. Many issues are still being worked defining his role and responsibilities within various units. The FA40 Space Staff Officers will normally be found at Division and above. Space and Missile Defense Command (SMDC) is responsible for defining the role of the FA40. The following paragraphs generally explain the expected role of the FA40.

Mission

Various battlefield functions will generate demands on the space infrastructure. It is the responsibility of the FA40 officer to ascertain the scope of the command's need for space support, prioritize competing demands IAW the commander's priorities, coordinate the provision of space support, monitor execution and recommend actions in all staff areas affected by space [e.g. OPSEC, IO (especially IW), logistics, communications, imagery, ELINT and SIGINT]. The FA40 officer is primarily responsible for integrating and monitoring support from USSTRATCOM and its units attached in theater.

Functions of the Space Operations Staff Officer

FA40 officers deal with activities regarding warfighting implications of space operations from communications, command and control (C2), position & navigation, weather, terrain, and environmental monitoring satellites, to satellite-based intelligence collection and surveillance operations, to theater missile defense, national missile defense, joint space activities, information operations, and future applications for space and space support as they are developed.

FA40 officers are experts in the capabilities of space and ground-based sensors, processors, and software for dissemination networks. They will learn to fully leverage the capabilities of these systems. Duties of these officers entail planning and a moderate amount of analysis; however, there may be critical periods where the ability to focus, assimilate diverse information, and make rapid decisions is extremely important. Understanding how space capabilities can enhance operations and an understanding of the commander's need for the information and data derived from space capabilities (e.g. number and type of systems employed, system capabilities, and operational status) is a significant capability of the FA40.

3Y Space Activities Officer

Until the advent of the FA40 Officer Specialty there was only the Additional Skill Identifier (ASI) of 3Y to identify those officers that had additional training and experience in the space field. This ASI will continue to be a vital part of the Army Officer skills. There are several positions throughout the Army that require the 3Y ASI. Some of those positions were converted to FA40 positions but many remain 3Y positions. In particular Signal and Intelligence Officer positions may be coded 3Y.

The duties of the 3Y Officer are similar to the FA40 duties. In those units where an FA40 is not assigned, the 3Y becomes the primary Space Staff Officer. In units that have FA40 positions, the 3Y is an additional space officer with expertise in his primary specialty.

The current position of Space and Missile Defense Command is to continue the 3Y Additional Skill Identifier in an effort to "operationalize" and "normalize" space functions as quickly as possible. To that end, the U.S. Army Command and General Staff College has continued to provide 3Y instruction to more and more officers.

Chapter 14
Space Planning and Operations

OVERVIEW

Military forces must address space forces and space force enhancement issues during the planning process. The commander must determine what space support is needed in the form of personnel, products and connectivity; how and when it will be used; and allocation of space assets (if required). At a minimum, each Joint Forces Command (JFC), Joint Land Component Command (JFLCC), Army Force (ARFOR), Corps and Division has missions that utilize space systems and therefore must address space as part of the OPLAN or OPORD. Each of the Battlefield Operating Systems uses space to enhance operations. Many of the subordinate units require some kind of space support and must know how to get the space products or services that they need.

The Space Operations Annex is the tool that the commander uses to identify threat space systems and friendly space requirements to be provided by space forces. It is the coherent plan for space support in the theater or area of operation. This annex should provide the over-arching requirements, guidance, space order of battle and basic information for the staff and subordinate commander to understand what space systems are supporting him during each phase of the operation, what space systems the adversary is using, and how he can request further space support. Army and Naval Space Support Team personnel as well as other embedded space support personnel should be included in deployments rosters (i.e. USAF UTCs, Army battle rosters, etc.). The Space Operations Annex is not a repeat of previous annexes such as Annex B (Intelligence), Annex C (Operations) or Annex K (Command, Control, and Communications). It is important to cross-reference these Annexes.

This Appendix provides a format for the Space Operations Annex and an example of a Space Operations Annex (labeled Annex N) written for the Joint Force Land Component Commander for a Pacific scenario. Much of the Space Operations Annex is classified and therefore is not included in the example given.

PLANNING THE ANNEX

Currently each Corps is authorized an FA40 Space Operations Officer. It is this officer on the staff that is responsible for preparing and submitting the Space Operations Annex. If the unit does not have an FA40 available, they may contact USASMDC/ARSTRAT for support and assistance in preparing the annex.

Each of the chapters about Space Force Enhancement systems lists limitations, capabilities and planning questions for each system. System capabilities and limitations must be considered when determining how and when to use it to support operations. The planning questions should be answered during the planning process. The planning questions are not all inclusive.

FM 3-14, Space Support to Army Operations, dated May 2005 is an excellent source for planning space support. Chapter 4 provides good ideas for planning considerations at the strategic, operational, and tactical levels of war. It gives examples of applications of system capabilities to support various phases of operations from Predeployment through Redeployment. TRADOC Pam 525-60, Space Support to Land Force Operations, is another source for examples and considerations for employment of space support for various phases of an operation.

ANNEX N FORMAT

Copy no___ of ___copies

Issuing Headquarters

Place of Issue

Date/Time Group

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. Also list the respective USSTRATCOM supporting plans and any respective ARSTRAT supporting plans

(X) Time Zone Used Throughout the Order:

(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. Refer to Annex B, Intelligence, for amplifying information.

(b) (X) Estimate the enemy's use of commercial space systems to support their operations. These should also be listed in Annex B, Intelligence.

(c) (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 the enemy's capability to impact friendly space systems. This includes the enemy's capability to deny or negate friendly space systems. 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 USSTRATCOM, ARSTRAT, DISA, DIA, NIST, 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 Space Operations Annex of the next higher command and adjacent commands. Address any treaty limitations that impact commercial space assets.

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-references 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 meteorological, oceanographic, geodetic and other environmental support information provided by space assets. List receivers and processors that are available to receive DMSP 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, mult-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 effects 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 (should not be a factor unless POTUS changes policy to again use this capability). 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 and GPS can not *adequatel*y support operations, 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, Surveillance and Target Acquisition (RSTA). 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 elements of the Theater Event System (TES) architecture. 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 separate 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. Include C2 agreements for both global systems (that require established support agreements with joint organizations such as USSTRATCOM) and theater-based systems. Include support (such as DIRLAUTH) agreements with "reachback" agencies. 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

Appendixes: 1 - Communications

2 – Environmental (may include Remote Sensing)

3 - Navigation

4 - Reconnaissance, Surveillance and Target Acquisition (may include Remote Sensing)

5 - Tactical Warning

6 - Space Control

7 - Space Support

(Complete Appendixes only as required for amplifying details)

EXAMPLE ANNEX N

NOTE: *This example is based on an unclassified scenario using a threat with very little space system or space system negation capabilities. An actual annex must always address the breadth of enemy space considerations such as satellites (indigenous and commercial), launch capability, any ground stations, and how the enemy is actually using space to support his operations. This is an example only and is scenario driven and dated. An actual annex must address current space doctrine and systems. You may refer to classified USSTRATCOM or ARSTRAT OPLANs for other examples of annexes.*

HQ, MNF PACIFICA

05 APR XX

ANNEX N, SPACE OPERATIONS, TO MNF PACIFICA OPLAN XX-02, PACIFIC STRIKE 1.

(U) <u>REFERENCES</u>: Operational Chart Series, Sheets J-12, K-11, L-12. Current Edition 1:1,000,000 (U)

a. World Map, Southeastern Asia and lndonesia, Series II06X##WT, Sheets 8-9, Current Editions, 1:5,000,000 (U)

b. USPACOM OPORD XX-01 (U)

c. USSTRATCOM Supporting OPLAN XX-01 (U)

d. JP 3-14, Joint Doctrine for Space Operations, Aug 02 (U)

e. AFDD 2-2, Space Operations, Aug 98 (U)

f. AFDD 2-2.1, Counterspace Operations, Aug 04 (U)

g. FM 3-14 Army Space Operations, May 05 (U)

1. (U) <u>TIME ZONE USED THROUGHOUT THE OPLAN:</u>

2. (U) SITUATION.

a. (U) General. This annex with its appendices lists the required space assets and operational support requirements for use in support of MNF PACIFICA OPLAN XX-02, PACIFIC STRIKE. Planned space support includes communications; environmental (weather and terrain); position and navigation; reconnaissance, intelligence, surveillance, and target acquisitions (RISTA); and Theater Ballistic Missile (TBM) warning. Planned space assets support several crucial areas enabling USPACOM to conduct military operations to destroy Surranian forces ability to conduct and sustain military operations, and support restructuring as directed by NM PACIFICA. All support is available upon execution of this plan and is provided in increments or as a complete space support package.

b. (U) Enemy Forces.

(1) (U) Enemy is capable of disrupting friendly space capabilities through destruction of the ground segments of space systems located in the PACIFICA Area of Responsibility (AOR). Potential satellite threat systems, which may provide support to Surranian forces, include those of the Eastland and Russia. These potential space capabilities include surveillance satellites capable of collecting signals, environmental and monitoring data. Eastland and Russia control these systems and may cooperate and share information with Surranian forces. Both Eastland and Russia have operational space launch capabilities for replacement and/or refurbishment of space vehicles. Surran has the potential to purchase commercial imagery (SPOT, HUS etc.), however, economic hardships and lack of hard currency may make it difficult, but not necessarily prohibitive, for Surranian forces to affect these purchases.

(2) (U) Enemy space capabilities will have some impact on friendly operations. Although Surranian forces do not control any space systems nor do they have an operational space launch capability they can obtain space support systems using Eastland, Russian, and/or other commercial international satellites. The following satellites and capabilities would probably be used:

(a) (U) Communications

Eastland Chinastar communications satellite

- C and Ku band transponder
- Geosynchronous orbit

The Eastland Sinosat

- C and Ku band transponder

- Geosynchronous Orbit

The DFH-3 (Dong Fang Hong)

- C and Ku band transponders
- Geosynchronous Orbit

AsiaSat

- C and Ku Band
- Geosynchronous Orbit

Asia Pacific Telecommunications Satellite (APT)

- C and Ku Band
- Geosynchronous Orbit

International Maritime Satellite (INMARSAT)

- L/C band transponders
- Geosynchronous Orbit

Iridium

- L band
- Low Earth orbit

(b) (U) Environmental: Possible weather satellite access includes the Geosynchronous Operational Meteorological Satellite (GOMS), and the Geostationary Meteorological Satellite (GMS).

(c) (U) Navigation: Russia's Global Navigation Satellite System (GLONASS), and the Global Positioning System (GPS).

(3) (U) Additional information on Eastland and Russian enemy space activities will be provided to supported units, after determination of the effects and the potential for adverse impact on friendly operations. See Annex B, (Intelligence), to MNF PACIFICA OPLAN XX-02, for amplifying information.

(4) (U) Surranian forces possess very little capability to effectively interfere with any friendly space systems. A limited capability to jam selected UBF frequencies do exist. Surranian forces will most likely target ground stations in theater and/or worldwide to disrupt

friendly force us of space systems. Surranian forces do not have any reconnaissance and surveillance systems. However, they could request assistance from Eastland, Russia or other international commercial space systems to provide information for targeting. Friendly forces should take appropriate countermeasures when notified that enemy space surveillance activities are directed to assigned areas of operations. The Surranian forces could have commercial GPS receivers, and GLONASS receivers.

c. (U) Friendly.

(1) CDR, USPACOM and CDR, USSTRATCOM are responsible for all theater space support requests. The JSpOC will provide space force enhancement to MNF/JFC staffs during Operation PACIFIC STRIKE. The JSpOC in conjunction with the JFC's Space Coordinating Authority (as assigned) will coordinate with component commands, component space support teams, joint and service commands/agencies for all space activities and functions in the AOR. (See appendices for friendly space capabilities and assets.)

(2) ARSTRAT will deploy an ARSST to support the JFLCC, and if requested, the Corps. The ARSST will coordinate with the JSpOC and/or ARSPOC for space assets supporting the ground forces.

d. (U) Assumptions.

(1) (U) Support to PACIFA will be provided by U.S. Government space agencies and programs, specifically NASA and NOAA.

(2) (U) Commercial satellite capabilities of corporations owned by U.S. and Allied nations will support U.S. and United Nations forces supporting PACIFICA.

(3) (U) Commercial space capabilities owned by international consortia may be available to support the PACIFICA Theater of Operations, as well as Surranian forces.

(4) (U) Countries not directly involved in the conflict will allow the U.S. to establish communications nodes or relays.

(5) (U) Commercial satellite companies will allow MNF PACIFICA forces to share data at one cost (example spot imagery).

(6) (U) Chinese and Russian civil weather satellites will continue to operate in normal (unencrypted) transmission mode in support of Surranian forces.

3. (U) MISSION. When directed USSTRATCOM provides maximum space support to PACIFICA and combatant commanders to enhance warfighter capabilities.

4. (U) EXECUTION.

a. (U) Concept of Operations. See Basic Plan

(U) General. USSTRATCOM will support the PACOM AOR directly via the JFCC-SGS support through the JSpOC. Support includes direct space systems support for communications, environmental information and analysis, multi-spectral imagery, mapping, RISTA, and tactical warning. USSTRATCOM also will provide space systems support services for operational command and control communications and position/navigation. The term USSTRATCOM includes all of its subordinate component commands. Priority for space support will be mission dependent and determined by the MNFC.

(a) (U) Phase I-Pre-Hostilities. CDR, USSTRATCOM conducts military space operations in support of CDR, USPACOM through USSTRATCOM components to achieve Phase I conditions listed in the MNF PACIFICA OPLAN, Pacific Strike Number XX-02 Basic Plan. Space Operations will support CDR, USPACOM intent to accumulate early, unambiguous warning of Surranian force intentions. If requested, USSTRATCOM, AFSPACE, ARSTRAT, and/or NAVSPACE will provide space support teams or personnel that may be integrated into the MNF Pacifica battle staff and/or component battle staff operations.

(b) (U) Phase 2-(Decisive Combat Operations). CDR, USSTRATCOM will continue to conduct military space operations in support of MNF PACIFICA to achieve Phase 2A (Shape the Battlespace) and phase 2B (Decisive Maneuver) listed in the basic plan. USSTRATCOM will support USPACOM via JFCC-SGS through JSpOC operations. Component space support teams (Army Space Support Team (ARSST), and Naval Space Support Team (NSST)) will be provided as necessary. Theater Event System (TES) for missile warning, positional and navigational support, and Military Satellite Communications (MILSATCOM) system support will be provided. Space operations will provide surveillance and reconnaissance to assist in the destruction of Surranian force projection capability as well as defeating Surranian and PRA ground forces on Luzon.

(c) (U) Phase 3-(Follow through Operations). CDR, USSTRATCOM will continue to conduct military space operations in support of MNF PACIFICA to achieve Phase III conditions listed in the basic plan. USSTRATCOM will provide space support operations in the areas of RISTA, communications enhancement, environmental (weather and terrain) information, position and navigation support, and theater tactical missile warning to assist in operations to overwhelm Surranian forces and disrupt its ability to concentrate its combat power.

(1) (U) Employment. Services/Components will deploy with their associated space operations and space support planning equipment. The ARSST will deploy, at the

minimum, INMARSAT communications terminals; High Resolution Satellite Weather Receiver; and a Mission Planning Rehearsal System and Multispectral Imagery processor (MSIP). Teams/units will be in theater and prepared to conduct operations or provide support NLT 72 hours after notification. USSTRATCOM will provide additional mission and logistical support specific to the space capabilities via the JSpOC.

b. (U) Space Support.

(1) (U) Communications: See Appendix 1, Communications.

(2) (U) Environment (Weather and Terrain): See Appendix 4. Both Military and civilian satellite systems will provide weather and supplemental data for operational support.

(3) (U) Position/Navigational: See Appendix 5. Satellite borne position and navigation (POSNAV) systems support tactical, operational, and strategic forces.

(4) (U) Reconnaissance, Intelligence, Surveillance and Target Acquisition (RISTA): Priority is to provide intelligence data and intelligence products based on the Commanders Priority Intelligence Requirements (PIRs). RISTA is conducted from terrestrial, as well as spaced-based platforms, and is generally classified.

(5) Tactical Warning/ JTAGS: See Appendix 2.

5. (U) SERVICE SUPPORT.

a. (U) All deployed USSTRATCOM personnel will be attached to the supported unit for administration and logistics support to include rations, quarters, and UCMJ.

b. (U) Supported unit will provide local transportation and movement assistance in support of USSTRATCOM personnel and equipment.

c. (U) Supported unit will provide organizational and direct support maintenance for individual equipment and weapons for USSTRATCOM deployed personnel.

d. (U) Space support equipment maintenance.

(1) (U) Deployed USSTRATCOM personnel will conduct first echelon maintenance.

(2) (U) Supported unit will provide maintenance support as available and required.

6. (U) COMMAND AND CONTROL.

a. (U) Command and Control.

(1) (U) See Annex J, Command and Control, MNF PACIFICA OPLAN XX-02

(2) (U) USSTRATCOM personnel and capabilities deployed in support of this OPLAN will be under the TACON of the supported unit headquarters.

b. (U) Command, Control, and Communications (C3) Systems.

(1) (U) See Annex K, Communications-Electronics, MNF PACIFICA OPLAN XX-02.

(2) (U) The CFLCC, CFACC, or the CFMCC will not have operational control of space forces. OPCON of space forces will be through USSTRATCOM for all DOD space satellite systems. CDR, USSTRATCOM will delegate to component commands requirements and requests.

(3) (U) Deployed USSTRATCOM personnel will have access to the supported unit's communications systems for transmittal of voice, recorded and data traffic to HQ USSTRATCOM using IMMEDIATE precedence.

XXXXXXXXX

Brigadier General, USA

Multi-National Forces Commander

Appendix 1 Communications Support

Appendix 2 Tactical Warning/JTAGS

Appendix 3 Environment (Weather/Terrain)

Appendix 4 Position/Navigation

(NOTE: Other possible appendixes could include Space Control or ISR)

HEADQUARTERS, MNF PACIFICA

5 April XXXX

APPENDIX 1, TO ANNEX N, TO MNF PACIFICA OPLAN XX-02, PACIFIC STRIKE COMMUNICATIONS SUPPORT (SPACE) (U)

(U) Purpose. This appendix is provided to inform the MNF PACIFICA of the capabilities and different types of communication satellites available. The DoD currently uses the Military Satellite Communication (MILSATCOM) systems, and U.S. and foreign civilian commercial communications satellites. Satellite communication (SATCOM) systems carry the bulk of inter-theater and intercontinental DoD traffic and a significant portion of intra-theater or tactical communications.

1. (U) Procedures. Each COMBATANT COMMANDER will consolidate, validate and prioritize all requests for use of SATCOM systems within their Area of Responsibility (AOR) and forwarded to USPACOM J6S. Because of the limited number of channels/bandwidth, priority of usage will be in accordance with CJCSI 6250.01, Satellite Communications, 20 October 1998.

2. (U) Defense Satellite Communication Systems.

   (U) Defense Satellite Communications System Phase III (DSCS III). DSCS III satellites, tracking, telemetry and control (TT&C) agent is AFSPACE. Payload control is ARSTRAT. Users on the ground, at sea, or in the air can receive DSCS III communications.

   (1) (U) DSCS III provides SBF voice and data communications for intra and inter-theater communications. Two (2) primary and three (3) reserve geosynchronous satellites are positioned to provide support.

   (2) (U) The capacity of the two primary satellites includes six independent SHF transponder channels covering a 500 Hz bandwidth.

   (3) (U) The following DSCS III satellites are available in the AOR:

Primary Satellites	GEO location	
B-10	Indian Ocean:	60 degrees east
B- 13	Western Pacific:	175 degrees east

Reserve Satellites	GEO Location

A-2	Indian Ocean	57 degrees east
B-5	Western Pacific	180 degrees east
B-9	Western Pacific	180 degrees east

3. (U) UHF Follow-on system (UFO). This system replaces FLTSAT satellites. The AFSATCOM mission has transferred to Milstar. TT&C agent and payload control is NETWARCOM via NNSOC. There will be eight (8) geosynchronous satellites in the full constellation, providing secure voice and data communications service.

   (U) Each UFO provides one Fleet Broadcast and 38 UHF channels in each of the four FLTSAT primary coverage areas, which allow 16 Kbps voice for Vinson communications; data and voice up to 2.4 Kbps with the Advance Narrowband Digital Voice Terminal (ANDVT). UFO's 4 thru 10 provide Low Data Rate (LDR) (75 bps to 2.4 Kbps) EHF channels. Four Global Broadcast Service (GBS) transponders are on UFO - 8 and can provide up to 24 Mbps broadcast service at Ka band.

   a. (U) The following are the UFO satellites available in the AOR.:

Satellite	GEO location	Channels
U-2	Indian Ocean 72.5 E	1 - Fleet Bcst
		17 - 25 kHz UHF
		21 - 5 kHz UHF
U-5	Indian Ocean 72 E	Same as U-2, and
		11 - EHF LDR channels
U-4	Pacific Ocean 177 E	Same as U-5
U-8	Pacific Ocean 172 E	Same as U-2, and
		20 - EHF LDR channels
		4 - 24 Mbps GBS capable transponders

4. (U) Milstar.

   a. (U) Milstar is the next generation military satellite communications system. It provides highly survivable, jam resistant, secure communications to strategic, operational, and tactical forces. Milstar primarily uses EHF, but also has some UHF capability for fleet broadcast communications. EHF enables the military to use smaller, more mobile terminals that will be installed on aircraft, ships and land vehicles. The Milstar capabilities are:

(1) (U) Secure and enduring communications

(2) (U) Data Storage

(3) (U) Joint, Army, Navy, and Air Force terminals interoperability

(4) (U) Encrypted voice, data, teletype and facsimile communications

(5) (U) Crosslinks: Communications from one satellite to another without ground stations.

b. (U) Deploying CONUS units may use Milstar initially then transition to the EBY package on UFO once in theater.

5. (U) International Maritime Satellite (INMARSAT)

a. (U) INMARSAT is an internationally owned satellite consortium that provides mobile satellite communications services. Service supported by SAT includes direct-dial telephone, telex, FAX, e-mail, and data connections. This is a fee for service system, units win be billed for airtime as required.

b. (U) The following are the INMARSAT satellites available in the AOR:

Satellite type	GEO location
INMARSAT II	Indian Ocean 64.5 E
INMARSAT II	Pacific Ocean 179 W

(U) International Telecommunications Satellite (INTELSAT). INTELSAT Is internationally owned, and provides wideband communications in the C/Ku frequency range. This system is used to augment the DSCS III for wideband communications.

c. (U) DISA is responsible for the leasing of transponder and or bandwidth for the DOD under the Commercial Satellite Communication Initiative (CSCI) program.

d. (U) The following satellites are the GEO locations of INTELSATs in the AOR. Note that not all satellites may have leased services contracted through the CSCI program. (see Annex K)

<u>Satellites</u>	<u>GEO location</u>
Six satellites	Indian Ocean: 72, 66, 63, 60, 57, and 33 E
Five satellites	Pacific Ocean: 157, 174, 177, degrees E,/177, 180 W

6. (U) Iridium. Iridium is an internationally owned consortium of 66 satellites in a low earth orbit. It provides commercial voice, data, paging, FAX, and messaging service. Iridium voice handsets are similar to a cellular phone**.** Iridium is a fee for service system and units will be billed for airtime. (see Annex K)

HEADQUARTERS, MNF PACIFICA

5 April XXXX

APPENDIX 2, TO ANNEX N, TO MNF PACIFICA OPLAN XX-02 PACIFIC STRIKE TACTICAL WARNING

1. (U) Purpose. This appendix provides information on spaced based early warning that is carried out by orbiting Defense Support Program (DSP) satellites and their associated ground sites. Tactical warnings include launch vehicle type, launch time, launch location, launch azimuth, estimated impact time, and location. The information provided is used for Force Protection and is available via the Integrated Broadcast Service (IBS). Data is provided by the Theater Event System (TES) and composed of the SBIRS MCS, JTAGS and TACDAR.

   a. (U) TES provides HQ's PACIFICA a continuous 24 hour capability to receive and processes in-theater, direct downlink data from the DSP sensors in order to disseminate early warning, alerting and cueing information on Tactical Ballistic Missiles (TBM) throughout the theater using existing communications networks. USSTRATCOM maintains COCOM of TES, with OPCON of JTAGS exercised through Commander, ARSTRAT and OPCON of ALERT exercised through Commander, AFSPACE.

   b. (U) TES provides a reliable and redundant information processing system that receives and processes, raw, wideband infrared data. Data is down linked from DSP satellites to determine launch points, state vectors, and predicted impact points for TBM'S. This system supports all Theater Missile Defense (TMD) pillars (attack, operations, active defense, and passive defense) and battle management/command, control, communications, computer and intelligence (BM/C41).

   c. (U) Capabilities. TES provides position information to support Air Defense cueing, early warning of units in the impact area, and targeting requirements.

   d. (U) Timely launch warning information allows the following:

      - (U) Personnel to take cover and assume appropriate MOPP.
      - (U) Warnings to be selectively focused using impact area prediction.
      - (U) Launch point information with sufficient accuracy and timelines sensor hands-off to support attack operations.

      (1) (U) Evaluation and selection of appropriate response using launch times.

(2) (U) The strengths of TES are:

- (U) Ability to provide rapid, reliable reporting on tactical missile launches and other events.
- (U) Ability to provide rapid, reliable reporting on tactical missile launches and other events.
- (U) Connectivity to a variety of tactical networks.
- (U) Close relationship with theater
- (U) Responsiveness to theater requirements.

2. (U) <u>Defense Support Program (DSP)</u>. The DSP is a survivable and reliable satellite-borne system that uses infrared detectors to sense heat from missile plumes against the earth background to detect and report in real-time missile launches, space launches and nuclear detonations.

   a. (U) Two DSP satellite positioned over the area of operations is critical to support MNF PACIFICA military operations.

      (U) The satellites are placed in a circular, equatorial, geosynchronous orbit.

   b. (U) The DSP sensor detects and locates sources of IR radiation which are then processed via the different ground stations comprising the TES architecture. Reports are then transmitted into theater via IBS along with an accompanying voice report.

3. (U) <u>Advanced Party</u>

   a. (U) The successful and rapid in-theater reception and integration of JTAGS of TES depends largely on two factors: 1) the maturity of the theater to integrate JTAGS based upon a previously conducted advanced party site survey; and 2) the successful accomplishment of a current advanced party site survey. Either way, the theater must make the reception and integration of JTAGS a priority for successful accomplishment of the JTAGS mission.

4. (U) <u>Deployment</u>. The normal sequence is a 72-hour deployment timeline.

HEADQUARTERS, MNF PACIFICA

5 April XXXX

APPENDIX 3 TO ANNEX N, TO MNF PACIFICA OPLAN XX-02, PACIFIC STRIKE ENVIRONMENT (WEATHER/TERRAIN SUPPORT) (U)

1. (U) Purpose/Situation. This appendix will provide PACFICA theater commanders with information on both military and civil satellite systems that provide weather/terrain and supplemental data for operational support. Satellite borne environmental monitoring provides meteorology, oceanography, and mapping support for tactical, operational and strategic operations. Defense Meteorological Satellite Program (DMSP) satellites provide global environmental coverage necessary to support worldwide DOD operations and other high-priority programs. Timely global visible and infrared (IR) cloud cover and other specialized environmental data are provided to Air Force and Navy weather centers, as well as numerous tactical and direct-readout terminals.

2. (U) Mission. To provide MNF PACIFICA forces with an enduring and survivable capability, through all levels of conflict consistent with the survivability of the supported forces, to collect and disseminate global visible and infrared cloud data, and other specific meteorological, oceanographic and solar-geophysical data. Weather satellites have advantages over ground based systems because data can be obtained on an entire weather system at one time.

3. (U) Execution

    a. (U) Concept of Operations. CDR, USSTRATCOM is assigned combatant command (COCOM) of space and control segments of DMSP and shall act as final approval authority for any changes that affect operational on-orbit mission capabilities.

    b. (U) Employment. U.S. Strategic Command is responsible for monitoring the health, status, and maintenance of the on-orbit DMSP constellation. DMSP data is down linked to Air Force and Navy weather centers, and direct-readout tactical terminals controlled by the CDR, USPACOM. The JSST can assist @ PACIFICA with all issues regarding receipt and application of meteorological satellite data.

4. (U) Weather. The current U.S. weather satellite system is composed of polar and geosynchronous orbiting satellites. Polar orbiting satellites have greater resolution than geosynchronous orbiting satellites because of their lower altitude. The geosynchronous

weather satellites are able to view large areas of the earth continuously due to their orbital characteristics.

a. (U) System Description.

(1) (U) The Defense Meteorological Satellite Program (DMSP). DMSP is a meteorological sensing system that transmits environmental and meteorological data to both fixed and mobile terminals. The ARSST has transportable DMSP receivers and can support the theater.

(a) (U) The space systems normally consist of two (2) operational satellites in Low Earth Orbit and will make two each optimum passes over the theater of operation each day.

(b) (U) DMSP visual (daytime), infrared and other sensors provide data on cloud cover, vertical atmospheric temperature profile , water vapor, and precipitation. Tactical terminals can receive real-time pictures of local weather data (visual and infrared cloud cover) as the satellites pass within view of the terminal. Weather data will be received, integrated, processed, analyzed and provided by attached JSST personnel.

(2) (U) Geostationary Operational Environmental Satellite (GOES) System. Geostationary Operational Environmental Satellite (GOES) data is received at the Air Force Global Weather Central where it is processed. The civil GOES provides supplemental meteorological information to military forecasters. The GOES carries two major instruments, an Imager and a Sounder. These instruments acquire visible and infrared data as well as temperature and moisture profiles of the atmosphere. GOES covers the majority of the Pacific Ocean.

(a) (U) This system provides continuous high resolution visual and infrared imaging of the atmosphere and earth surface every 30 minutes. The primary function of the GOES program is to provide timely atmospheric environmental information, including advance warning of developing storms. GOES provides information on cloud cover, wind conditions, sandstorms and thunderstorm locations, sea surface temperature, and ground snow and ice coverage.

(b) (U) GOES data is combined with DMSP and NOAA TIROS data at the Air Force Global Weather Center.

(3) (U) NOAA Television Infrared Observation Satellites (TIROS) supplements DMSP, and provides continuous measurement of the earth's surface and atmosphere, using high resolution.

(a) (U) Two satellites in Low Earth Polar Orbit will make two (2) each optimum passes over the theater of operations each day. Automatic Picture Transmission, low resolution images are broadcast in real time directly from the satellites. Weather data will be received, integrated, processed, analyzed and provided by attached JSST personnel.

(b) (U) Weather data from TIROS is combined with DMSP data to provide a precise weather picture of the world. Information gathered by TIROS includes precise visible and infrared images of land, snow, ice, sea-surface, cloud conditions and sea-surface temperature profiles. This information is provided to subordinate units through the Staff Weather Officer and the U.S. Air Force Air Weather Service Detachment.

(4) (U) Meteorological Satellite (METEOSAT). METEOSAT is a geostationary satellite located at 0 degrees longitude over the equator. The theater of operations is in the quadrant of the satellite's view. Low resolution images are generated every minute. The infrared sensor measures atmospheric temperatures in daylight and darkness. Civil weather receivers, portable DMSP receivers, and High Resolution Satellite Weather Receivers (HRSWR) can receive the transmissions.

5. (U) <u>Weather Equipment</u>

a. (U) High Resolution Satellite Weather Receivers (HRWSR). When tasked, the JSST can deliver data from direct downlink, high resolution satellite weather receiver (DMSP capable) to MNF PACIFICA and deploying units. The HRSWR automatically acquires and archives data from both civil and DOD polar-orbiting weather satellites. These satellites provide images of the earth in the five regions of the visible and infrared electromagnetic spectrum with a ground resolution of .6 KM with hard copy output. Additional instruments on the satellite can sense critical weather elements such as atmospheric winds, surface and upper-air temperatures, pressure fields and humidity. Software enhancements provide rendering of real time, three-dimensional clouds over terrain and spatial location of soil moisture.

b. (U) Deployable Weather Satellite Workstation (DWSW) can provide real time high resolution weather satellite imagery to situational awareness. The benefit to the

Warfighter is that it provides the commanders the timely and accurate weather data needed to plan military operations.

6. (U) LANDSAT MULTISPECTRAL IMAGERY (MSI) SUPPORT

a. (U) MSI systems described include LANDSAT and SPOT.

b. (U) System Support.

(1) (U) LANDSAT satellites are launched into sun-synchronous polar orbit and provide complete earth coverage. LANDSAT provides multiple image scanning and heat (infrared) sensor data with resolutions of 30-80 meters. Changes on the earth's surface can be readily detected with LANDSAT. Examples of these changes would include vegetation change, location of recent manmade structures, or changes in oceans and surface waters (to include temperature changes). LANDSAT is particularly useful in terrain analysis to determine different terrain types and surface conditions affecting mobility. A typical use of LANDSAT data would be in support of mobility planning for ground and amphibious operations. Additionally, LANDSAT is used extensively in support of mapping, charting, and geodesy (MC&G).

(a) (U) LANDSAT data are provided to topographic units and intelligence staffs and units for exploitation using the MSI Processor (MSIP). Additional MSI support for the preparation of mapping products and terrain analysis is provided by the JSST with their Multispectral Imagery Processor (MSIP).

(b) (U) Tasking of LANDSAT is accomplished by EOSAT Corporation, with military requirements handled by the NGA.

(c) (U) Currently two (2) low earth orbit satellites provide LANDSAT MSI data to fixed ground stations.

(2) (U) SPOT is a French owned and operated satellite constellation. SPOT is an environmental space system used to simultaneously collect imagery (panchromatic or MSI mode) in the visible and infrared portions of the electromagnetic spectrum. (SPOT is an acronym for Systeme Probatoire D'Obsrevaition de la Terre.)

(a) (U) Currently two (2) SPOT satellites are in low earth, polar, sun synchronous orbits and provide imagery and limited MSI data to fixed ground stations.

(b) (U) SPOT data can be provided to topographic units, intelligence units, and an ASSC/ARSST for processing and preparation of mapping products and terrain analysis.

(3) (U) Ikonos and other commercial imaging systems should be their availability,

their usefulness, and capabilities to support this mission.

7. (U) Procedures. USSTRATCOM will assist MNF PACIFICA in obtaining, processing, and producing MSI. MSI support via USSTRATCOM will include terrain analysis, mapping products, and tailored MSI exploitation for products directed by PACIFICA.

8. (U) Products. Currently LANDSAT and SPOT provide MSI and panchromatic data sets to U.S. forces. Normally, the NGA will broker the purchases of imagery with funding provided by MNF PACIFICA, and/or CDR, USSTRATCOM. At times, USSTRATCOM will purchase the imagery through . Available products include:

a. (U) LANDSAT Image Map (LIM). A colored map used for area familiarization. NGA can produce a LIM within 72 hours (JCS approved crisis). Normal LIM production by NBM takes two (2) or more weeks.

b. (U) Terrain Categorization (TERCAT). An analysis of major surface features. Used for route planning, trafficability, assessments and force employment. Analysis and production takes several days once imagery is available.

c. (U) Precise Positioning. Applies highly accurate, known control points to increase the physical accuracy of a map product. Precise positioning is normally used for targeting and takes several days once imagery is available.

d. (U) Soft-copy exploitation combines MSI products and digital terrain evaluation data. The following are examples of these products:

(1) (U) 3-D Analysis. Allows a walk or fly through of the terrain. Various service mission rehearsal/planning systems use 3-D analysis.

(2) (U) Change detection. An analysis of a given area using two or more images taken at separate times to identify areas of activity/change.

9. (U) Benefits to OPERATION PACIFIC STRIKE. LANDSAT/SPOT MSI can be

procured and exploited to support the following activities:

a. (U) Update geographical data

b. (U) Support Mapping requirements

c. (U) Analyze trafficability

d. (U) Develop predictive models

e. (U) Display situation

f. (U) Support Mission Planning and Rehearsal

g. (U) Training

10. (U) Space Environmental Effects. The space environment can possibly degrade satellite navigation and communications missions. Systems relying on the VBF or UHF bands are especially susceptible from local sunset to midnight due to ionosphere scintillation.

HEADQUARTERS, MNF PACIFICA

5 April XXXX

APPENDIX 4, TO ANNEX N, TO MNF PACIFICA OPLAN XX-02, PACIFIC STRIKE POSITION/NAVIGATIONAL SATELLITES (U)

1. (U) General. Satellite borne position and navigation (POSNAV) systems support tactical, operational, and strategic forces as well as civil authorities. The Global Positioning System (GPS) is a spaced based, all weather, jam resistant continuous operation radio navigation system that provides warfighters highly accurate worldwide position and location data, as well as velocity information and precision time. A minimum of four satellites will be in view of users at all times to provide three-dimensional coverage through out the theater. These satellites provide military users the ability to locate themselves to within IO meters anywhere on earth. GPS can also enhance targeting and employment of weapon systems requiring precision geolocational guidance.

2. (U) Mission. The GPS constellation now consists of 29 operational satellites. 24 operational satellites assure 24 hour worldwide 3-dimensional coverage. System Effectiveness Model software programs calculate this coverage and also provide actual expected accuracy for any specified location.

3. (U) Support: Space experts in theater, via SBMCS, can support MNF PACIFICA in obtaining any necessary measurement for GPS Accuracy.

4. (U) Selective Availability (SA): This feature limits the accuracy of GPS for users not specifically authorized by DOD. Currently SA has been set to 0 in 2000. However, CDR PACIFICA may request through USPACOM that the error be increased to degrade accuracy to unauthorized users of GPS. (This request is not automatic, and will require approval from the POTUS)

(U) Space Environmental Effects. The space environment can possibly degrade satellite navigation and communications missions. Space environmental support is available to support the mission via the JSpOC.

Appendix A
Abbreviations and Acronyms

3D	Three Dimensional
3Y	Additional Skill Indicator for Space Activities
AAN	Army After Next
AAMDC	Army Air and Missile Defense Command
ABCS	Army Battle Command System
ABL	Airborne Laser
ABM	Antiballistic Missile
ACOM	Atlantic Command
AF	Air Force
AFB	Air Force Base
AFFOR	Air Force Forces
AFS	Air Force Station
AFSATCOM	Air Force Satellite Communications System
AFSCN	Air Force Satellite Control Network
AFSPACE	Air Force Component to USSTRATCOM (14th Air Force)
AFSPC	Air Force Space Command
AJ/AS	Anti-Jam/Anti-Spoof
ALCOR	ARPA Lincoln C-Band Observation Radar
ALRPG	Army Long Range Planning Guidance
ALERT	Attack, Locate and Early Report to Theater

ALTAIR.	ARPA Long-range Tracking and Identification Radar
AOI	Area of Interest
AOR	Area of Responsibility
ARFOR	Army Forces
ARPA	Advanced Research Projects Agency (Now DARPA)
ARSST	Army Space Support Teams
ARSTRAT	Army Forces Strategic Command
ARTS	Automated Remote Tracking System
A-S	Anti-Spoofing
ASARS	Advanced Synthetic Aperture Radar System
ASAS	All Source Analysis System
ASAT	Anti-Satellite
ASCC	Alternate Space Control Center
ASEDP	Army Space Exploitation Demonstration Program
ASEWG	Army Space Executive Working Group
ASI	Additional Skill Indicator
ASMP	Army Space Master Plan
ASP	Army Space Policy
ASPO	Army Space Program Office
ASSC	Army Space Support Cell
ATD	Advanced Technology Demonstration
ATM	Asynchronous Transfer Mode

ATMDE	Army Theater Missile Defense Element
AV 2010	Army Vision 2010
AWE	Advanced Warfighting Experiment
AWS	Advanced Wideband System
BCBL	Battle Command Battle Lab
BDA	Battle Damage Assessment
BFT	Blue Force Tracking
BLOS	Beyond Line of Sight
BM	Battle Manager
BMC	Ballistic Missile Center/Battle Management Cell
BMC3	Ballistic Missile Command, Control and Communications
BMD	Ballistic Missile Defense
BMDO	Ballistic Missile Defense Office
C2	Command and Control
C4I	Command, Control, Communications, Computers, and Intelligence
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CALL	Center for Army Lessons Learned
CASCOM	Combined Arms Support Command
CCD	Coherent Change Detection
CC&D	Camouflage, Concealment and Deception
CCIS	Civil/Commercial Imagery Systems
CECOM	Communications and Electronic Command

CENTCOM	Central Command
CEP	Circular error of probability
CFJO	Concept for Future Joint Operations
CG	Commanding General
CGS	Common Ground Station
CIA	Central Intelligence Agency
CIGSS	Common Imagery Ground/Surface System
CIP	Common Imagery Processor
CJCS	Chairman, Joint Chiefs of Staff
CJTF	Combined Joint Task Force
Cm	centimeter
CMAFB	Cheyenne Mountain Air Force Base
CMAS	Cheyenne Mountain Air Station
CMO	Commercial Satellite Communication Initiative Management Office
CMOC	Cheyenne Mountain Operations Center
CNO	Chief of Naval Operations
COA	Course of Action
COCOM	Combatant command
COIL	Chemical Oxygen-Iodine Lasers
COMAFSPACE	Commander, Air Force Space Command (14th AF)
COMARSTRAT	Commander Army Forces Strategic Command
COMM	Communications

COMSAT	Communications satellite
COMSEC	Communications Security
CONOPS	Concept of Operations
CONR	CONUS NORAD Region
CONUS	Continental United States
COP	Common Operating Picture
CoS	Control of Space/ Chief of Staff
COTS	Commercial-Off-The-Shelf
CSLA	Commercial Space Launch Act
CSCI	Commercial Satellite Communications Initiative
DAMA	Demand Assigned Multiple Access
DARPA.	Defense Advanced Research Projects Agency
DAWE	Division Advanced Warfighter Experiment
DNI	Director of National Intelligence
D & D	Denial & Deception
DDS	Defense Dissemination System
DDNI	Deputy Director of National Intelligence
DDL	Direct Downlink
DE	Directed Energy
DEW Line	Distant Early Warning Line
DGPS	Differential GPS
DISA	Defense Information Systems Agency

DISN	Defense Information Systems Network
DITP	Discriminatory Interceptor Technology Program
DMA	Defense Mapping Agency
DMS	Defense Message System
DMSP	Defense Meteorological Satellite Program
DNRO	Director of the National Reconnaissance Office
DOC	Department of Commerce
DOCC	Deep Operations Coordination Cell
DoD	Department of Defense
DOT	Department of Transportation
DSCS III	Defense Satellite Communications System Phase III
DSCSOC	DSCS III Operations Center
DSNET	Defense Security Network
DSP	Defense Support Program
DTD	Digital Terrain Data
DTES	Division Tactical Exploitation System
DTED	Digital Terrain Elevation Data
DTSS	Digital Topographical Support System
DTSS-D	Digital Topographical Support System-Division
DTSS-H	Digital Topographical Support System-Heavy
DTSS-L	Digital Topographical Support System-Light
DUSD(Space)	Deputy Under Secretary of Defense for Space

DWSW	Deployable Weather Satellite Workstation
EAC	Echelons Above Corps
ECB	Echelons Corps and Below
EELV	Evolved Expendable Launch Vehicle
EAM	Emergency Action Message
EGI	Embedded GPS Inertial
EHDR	Extreme High Data Rate
ELINT	Electronic or Electromagnetic Intelligence
ELV	Expendable Launch Vehicle
EMP	Electro Magnetic Pulse
EMUT	Enhanced Manpack UHF Terminal
E/O	Electro-Optical
EOSAT	Earth Observation Satellite
EPLGR	Enhanced PLGR
EPLRS	Enhanced Position, Location, Reporting System
ERM	Earth Resource Monitoring
ERS	Earth Resourcing Satellite
ESA	European Space Agency
ETRAC	Enhanced Tactical Radar Correlator
ETUT	Enhanced Tactical Users' Terminal
EUCOM	European Command
EW	Electronic Warfare

EWE	Early Warning Experiment
EWR	Early Warning Radar
FA 40	Functional Area 40 (Space Operations Officer)
FAA	Federal Aviation Administration
FAR	Federal Acquisition Regulation
FAST	Forward Area Support Terminal
FCC	Federal Communications Commission
FDIC	Force Development Integration Center
FDO	Flexible Deterrent Options
FEP	FLTSAT EHF Program
FLTSAT	Fleet Satellite
FLTSATCOM	Fleet Satellite Communication System
FOC	Future Operational Capability
FOV	Field of View
FY	Fiscal Year
FYDP	Five Years Defense Program
G-B	Grenadier-Beyond Line of Sight Ranging and Tracking System
GBE	Ground-Based EMP
GBI	Ground-Based Interceptor
GBL	Ground-Based Laser
GBS	Global Broadcast Service
GCCS	Global Command and Control System

GCN	Ground Communications Network
GCSS	Global Command Support System
GDIN	Global Defense Information Network
GE	Global Engagement
GEO	Geosynchronous Earth Orbit/Geostationary Earth Orbit
GEODSS	Ground-Based Electro-Optical Deep Space Surveillance
GIS	Geographic Information System
GLOBALSTAR	Commercial Name of System
GMF	Ground Mobile Forces
GMPCS	Global Mobile Personal Communications Satellite
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOMS	Geostationary Orbiting Meteorological Satellite
GPS	Global Positioning System
Grenadier-BRAT	Grenadier-Beyond Line of Sight Range and Tracking System
HA-UAV	High Altitude Unmanned Aerial Vehicle
HDR	High Data Rate
HEMP	High Altitude Electro-Magnetic Pulse
HEO	Highly Elliptical Orbit
HQDA	Headquarters, Department of the Army
HSI	Hyper-Spectral Imagery
IADS	Integrated Air Defense System

IBS	Integrated Broadcast Service
IC	Intelligence Community
ICBM	Intercontinental Ballistic Missile
ID	Identification/Identify
IFSAR	Interferometric Synthetic Aperture Radar
IGEB	Interagency GPS Executive Board
IMETS	Integrated Meteorological Systems
IMINT	Imagery Intelligence
INFOSEC	Information Security
INSCOM	Army Intelligence Security Command
IO	Information Operations
I/O	Input/output
IPB	Intelligence Preparation of the Battlespace/Battlefield
IPL	Integrated Priority List
IR	Infrared
IRS	India Remote Sensing satellite
ISR	Intelligence, Surveillance, and Reconnaissance
ISS	International Space Station
ISSN	Integrated Space Surveillance Network
ITSO	International Telecommunication Satellite Organization
ITW/AA	Integrated Tactical Warning and Attack Assessment
JAOC	Joint Air Operations Center

JCAPA	Joint/Combined Arms Precision Attack
JCS	Joint Chiefs of Staff
JFACC	Joint Force Air Component Commander
JFLCC	Joint Force Land Component Commander
JFMCC	Joint Force Maritime Component Commander
JFS	Joint Feasibility Study
JFSCC	Joint Force Space Component Commander
JP	Joint Publication
JPO	Joint Program Office
JROC	Joint Requirements Oversight Council
JRSC	Jam Resistant Secure Communications
JSIC	Joint Space Intelligence Center
JSIMS	Joint Simulation System
JSMB	Joint Space Management Board
JSpOC	Joint Space Operations Center
JSST	Joint Space Support Team
JSTARS	Joint Surveillance Target Attack Radar System
JTAGS	Joint Tactical Ground Station
JTF	Joint Task Force
JTF/CC	Joint Task Force Component Commander
JTIDS	Joint Tactical Information Distribution System
JV 2010	.Joint Vision 2010

Kbps	Kilobits Per Second
KE	Kinetic Energy KE
KE ASAT	Kinetic Energy Anti-satellite
KHz	KiloHertz
km	Kilometer
KW	Kinetic Weapon
LADAR.	Laser Detection and Ranging
LAN	Local Area Network
LANDSAT	Land Satellite
LCC	Land Component Commander
LDR	Low Data Rate
LEO	Low Earth Orbit
LEOCOMM	Low Earth Orbit Communications
LIDAR	Laser Identification Detection and Ranging
LNO	Liaison Officer
LO	Low Observable
LoD	Launch on Demand
LOS	Line of sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept/Launch and Predicted Impact
LWIR	Longwave IR
m	meter

MABS	Missile Alert Broadcast System
MAGR	Miniaturized Airborne GPS Receiver
MAP	Mission Area Plan
MAPS	Mission Area Planning System
MASINT	Measurement and Signals Intelligence
MAST	Meteorological Automated Sensor and Transceiver
MCG	Mapping, Charting, and Geodesy
MCS	Maneuver Control System
MDR	Medium Data Rate
MDSTC	Missile Defense and Space Technology Center
MEO	Mid Earth Orbit
METL	Mission Essential Task List
METEOSAT	Meteorological Satellite
METOC	Meteorological and Oceanographic
METT-T	Mission, Enemy, Own Troops, Terrain, and Tim
MGES	Mobile Gateway Earth Station
MGS	Mobile Ground Station
MIC	MILSATCOM Iridium Communications
MIDAS	Miniaturized Data Acquisition System
MIES	Modernized Imagery Exploitation System
MILSATCOM	Military Satellite Communications

MIL-STD	Military Standard
MIRACL	Mid IR Advanced Chemical Laser
MIST	Multiband Integrated Satellite Terminal
MITT	Mobile Integrated Tactical Terminal
MMBL	Mounted Maneuver Battle Lab
MOA	Memorandum of Agreement
MSE	Mobile Subscriber Equipment
MSI	Multispectral Imagery
MSS	Mobile Satellite Services/Multispectral Scanner
MSTS	Multi-Source Tactical System
MWC	Missile Warning Center
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAV	Navigation
NAVFOR	Naval Forces
NAVSOC	Naval Satellite Operations Center
NAVSPACECOM	Naval Space Command
NAVSPASUR	Naval Space Surveillance System
NAVWAR	Navigation Warfare
NBC	Nuclear, Biological, and Chemical
NCO	Noncommissioned Officer
NEMSS	National Environmental Monitoring Satellite System

NETWARCOM	Network Warfare Command (Naval)
NGA	National Geospatial-Intelligence Agency
NGO	Non-Governmental Organization
NIIRS	National Imagery Interpretability Rating Scale
NIMA	National Imagery and Mapping Agency
NIR	Near Infrared
NMD	National Missile Defense
NMS	National Military Strategy
NNSOC	Naval Network and Space Operations Command
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NPOESS	National Polar Orbiting Environmental Satellite System
NRO	National Reconnaissance Office
NRT	Near Real-Time
NSA	National Security Agency
NSC	National Space Council/National Security Council
NSP	National Space Policy
NSSMP	National Security Strategy Master Plan
NSS	National Security Strategy
NSSA	National Security Space Architect
NTC	National Training Center
NUDET	Nuclear Detonation

NVG	Night Vision Goggles
OCONUS	Outside of Continental United States
ODA	Optical Data Analysis
ODOC	Objective DSCS III Operations Center
O&M	Operations and Maintenance
OLS	Operational Linescan System
OOTW	Operations Other Than War
OPSEC	Operations Security
ORD	Operational Requirement Document
OSA	Office of the Space Architect
OSD	Office of the Secretary of Defense
OSF	Operational Support Facility
P-code	Precision Code
PACOM	Pacific Command
PAFB	Peterson Air Force Base
PAM	Pamphlet
PCP	Precision Code Protected
PCS	Personal Communications Services
PD	Presidential Directive
PDD	Presidential Decision Directive
PLGR	Precision Lightweight GPS Receiver
POC	Point of Contact

POES	Polar Orbiting Environmental Satellite
POS/NAV	Position/Navigation
POTUS	President of the United States
PPBE	Planning, Programming, Budgeting and Execution System
PPS	Precision Positioning Services
PPS-M	Precision Positioning Services-Security Module
PSM	Portable Space Model
PVO	Private Volunteer Organization
R&D	Research and Development
RBV	Rapid Battlefield Visualization
RDEC	Research, Development, and Engineering Center
RDT&E.	Research Development Test and Evaluation
REG	Regulation
RFI	Radio Frequency Interference
RIDSN	Radar Imaging and Deep Space Network
RISTA	Reconnaissance, Intelligence, Surveillance, and Target Acquisition
RLV	Reusable Launch Vehicle
R&S	Reconnaissance and Surveillance
RT	Real Time
SA	Situational Awareness/Selective Availability
SAGR	Standalone Air GPS Receiver
SAR	Synthetic Aperture Radar

SATCOM	Satellite Communications
SATRAN	Satellite Reconnaissance Advance Notice
SBC	Synthetic Battle Center
SBE	Synthetic Battlefield Environment
SBI	Space-Based Interceptor
SBIRS	Space-Based Infrared System
SBIRS-H	SBIRS- High
SBJ	Space-Based Jammer
SBL	Space-Based Laser
SBP	Space-Based Platform
SBR	Space-Based Radar
SCAMP	Single Channel Anti-Jam Man Portable
SCC	Space Control Center
SCI	Sensitive Compartmented Information
SECARMY	Secretary of the Army
SECDEF	Secretary of Defense
SEL	Space Education and Literacy
SEP	Spherical Error Probability
SHF	Super High Frequency
SIAM	Space and Information Analysis Model
SID	Secondary Imagery Dissemination
SIGINT	Signals Intelligence

SINCGARS	Single Channel Ground and Air Radio System
SIPRNET	Security Internet Protocol Routing Network
SLBM	Sea-Launched Ballistic Missile
SLEP	Service Life Extension Program
SLGR	Small Lightweight GPS Receiver
SLV	Space Launch Vehicle
SMART-T	Secure Mobile Anti-Jam Reliable Tactical Terminal
SMDBL	Space and Missile Defense Battle Lab
SMDC	Space and Missile Defense Command
SOB	Space Order of Battle
SOC	Space Operations Center
SOCOM	Southern Command
SOF	Special Operations Forces
SOI	Space Object Identification
SOLGR	Special Operations Lightweight GPS Receiver
SOS	System of Systems
SPACECOM	Space Command
SPAWAR	Space and Naval Warfare Systems Command
SPIN	SATCOM Planning Information Network
SPIRIT	Special Purpose Integrated Remote Intelligence Terminal
SPOC	Space Operations Center (USSTRATCOM)
SPOT	Satellite Probatoire d’Observation de la Terre

SPS	Standard Positioning Service
SRBM	Short Range Ballistic Missile
SSDC	Space and Strategic Defense Command
SSN	Space Surveillance Network
STS	Space Transportation System
STAR-T	SHF Tri-band Advanced Range Extension Terminal
STEP	Standardized Tactical Entry Point
STRATCOM	Strategic Command
STO	Science and Technology Objective
STT	Small Tactical Terminal
SUCCESS	Synthesized UHF Computer Controlled Equipment Subsystem
SWC	Space Warfare Center
SWIR	Shortwave Infrared
TAC v2	Tactical Communication Protocol version 2
TACDAR	Tactical Detection and Reporting
TACON	Tactical Control
TBM	Theater Ballistic Missile
TD	Technology Demonstration/Training Development
TDDS	TRAP (TRE- Tactical Receive Equipment—and Related Applications) Data Dissemination System
T&E	Test and Evaluation
TEC	Topographical Engineering Center
TENCAP	Tactical Exploitation of National Capabilities

TEL	Transporter Erector Launcher
TES	Theater Event System/Tactical Exploitation System
THAAD	Theater High Altitude Air Defense
THEL	Tactical High Energy Laser
TIBS	Tactical Information Broadcast Service
TM	Thematic Mapper
TMD	Theater Missile Defense
TOC	Tactical Operations Center
TP	TRADOC Pamphlet
TRANSCOM	Transportation Command
TRAP	Tactical and Related Applications
TRADOC	Training and Doctrine Command
TRE	Tactical Receive Equipment
TRI-TAC	Tri-Service Tactical Communications
TT&C.	Telemetry, Tracking and Commanding
TTP	Tactics, Techniques, and Procedures
TW/AR.	Threat Warning/Attack Reporting
UAV	Unmanned Aerial Vehicle
UCP	Unified Command Plan
UFO	UHF Follow-on
UHF	Ultra High Frequency
U.S.	United States

USA	United States Army
USAF	United States Air Force
UAV	Ultralight Aerial Vehicle
USD (A & T)	Under Secretary of Defense for Acquisition and Technology
USEUCOM	United States European Command
USMC	United States Marine Corps
USN	United States Navy
USI	Ultra-Spectral Imagery
USSPACECOM	United States Space Command (became part of USSTRATCOM in 2002)
USSTRATCOM	United States Strategic Command
WAAS	Wide Area Augmentation System
WAGE	Wide Area GPS Enhancement
WEFAX	Weather Facsimile
WMD	Weapons of Mass Destruction
WRAP	Warfighting Rapid Acquisition Program
WSMC	Western Space and Missile Center
WTEM	Weather, Terrain, and Environmental Monitoring
WIN-T	Warfighter Information Network-Terrestrial
WWMCCS	Worldwide Military Communication Command and Control System
WWW	World Wide Web

Appendix B
Glossary of Terms

Access	A channel allocated to a specific user for a specific period of time.
Anti-Jam	Resistant to signals which would interfere with reception of the desired communications. Jamming is not necessarily hostile and an be caused by unintentional use of the system or improperly tuned equipment.
Anti-satellite (ASAT)	Any weapon designed to destroy satellites.
Apogee	The point in a satellite's orbit where it is farthest from the Earth and its velocity is slowest.
Argument of Perigee	The orbital element of the angular measurement from the right ascension of the ascending node along the orbital path, in the direction of satellite motion, to the perigee point.
Ascending Node	The point where a satellite crosses the equator in a south to north direction.
Assured access	Allocation of the necessary satellite resources to form communication slinks or networks when needed throughout the strategic, operational and tactical areas of operations.
Asynchronous Transfer	
Mode (ATM)	This is the new form of super-fast packet switching. In the 21st century ATM networks will operate at speeds of gigabits per second.
Atmospheric drag	Resistive forces caused by gases in the atmosphere acting on an orbiting satellite.
Band (channel)	As it refers to remote sensing, a band is a slice of wavelengths from the electromagnetic spectrum.
Bandwidth	The width of a given band or spectrum of frequencies of interest, expressed in hertz. The lowest usable frequency subtracted from the highest usable frequency for a communication channel gives its bandwidth. Generally, higher bandwidth channels have greater capacity to convey signals modulated with higher data rates of information.
Baud	The number of pulses per second or the number of times per second that a signal on a communication circuit changes.

Beamwidth	The angle of the conical shaped beam that an antenna radiates. Large antennas have narrower beamwidths and can pinpoint satellites in space or dense traffic areas on the Earth more precisely. Tighter beamwidths deliver higher levels of power and thus greater communications performance.
Bent Pipe	A non-regenerative non-processed channel that does nothing to the signal received by the satellite, except to relay it toward Earth.
Bus	Everything on a satellite except the payload itself. Normally includes the structural frame, TT&C subsystems, power, attitude control, thermal management systems, etc.
Channel	As it refers to communications, a frequency bandwidth available as a communications path. A channel will normally be the operating frequency and bandwidth of a satellite transponder.
Circular Orbit	Any orbit that has an eccentricity of zero. Since all satellites are subject to perturbations, no orbit can achieve and maintain an eccentricity of exactly zero. Common practice is to call orbits with very low eccentricities circular.
Constellation	A number of like satellites that are part of a system. Satellites in a constellation generally have the same type orbit, although that is not a requirement.
Control Segment	That portion of a space system that controls the satellite platform, payload, and network. This segment provides for station-keeping, orbital changes, attitude and stabilization changes, and other satellite maintenance and housekeeping activities.
Countermeasure	Any action or measure employed by a threatened or targeted system to avoid detection, destruction, or neutralization.
Corona	The outermost layer of the Sun's atmosphere. The corona is very hot, up to 1-1.5 million degrees centigrade, and is the source of the *solar wind*.
Coronal mass ejection	A huge cloud of hot plasma, expelled sometimes from the Sun. It may *accelerate ions* and *electrons*, and may travel through interplanetary space as far as the Earth's orbit and beyond it, often preceded by a *shock* front. When the shock reaches Earth, a *magnetic storm* may result.

Coverage	The portion of the earth's surface over which satellite services are provided.
Crosslink	A communications link between satellites, usually a microwave, millimeter wave, or laser signal with a narrow beamwidth. Crosslinked satellites provide connectivity to satellites that are out of view of ground stations.
DAMA	Demand Assigned Multiple Access. An efficient method of managed channel access allowing the sharing of one or more channels by multiple users. A control system providing satellite access to customers on a priority and need basis. DAMA reduces the amount of unused (wasted) satellite channel availability time.
Decay	Uncontrolled reentry of a satellite as a result of atmospheric drag.
Dedicated sensor	Sensor owned and operated by AFSPACECOM whose primary mission is space surveillance.
Descending node	A point at the intersection of the equatorial plane and the orbital plane of a southbound satellite.
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.
Downlink	A communications channel from a satellite to an Earth station.
Eccentricity	The amount by which an orbit varies from perfectly circular. As this value approaches one, the shape becomes more elongated. As this value approaches zero, the shape becomes more circular.
Electromagnetic field	The regions of space near *electric currents*, magnets, broadcasting antennas etc., regions in which electric and magnetic forces may act. Generally the EM field is regarded as a modification of space itself, enabling it to store and transmit energy.
Electromagnetic perturbation	Magnetic drag caused by the interaction of the Earth's magnetic field and the satellite's electromagnetic field.

Electromagnetic radiation	Energy transfer in the form of electromagnetic waves or particles that propagate through space at the speed of light.
Electromagnetic spectrum	The entire range of electromagnetic radiation. The spectrum usually is divided into seven sections. From the longest wavelengths to the shortest: radio, microwave, infrared, visible, ultraviolet, x-ray, and gamma ray radiation
Elliptical orbit	Any orbit that is not perfectly circular is elliptical. The term is normally used to describe orbits that vary significantly from circular.
Ephemeris data	Information needed to establish a link to a satellite, including look angles in elevation and azimuth.
Epoch Time	A particular instant in time for which satellite measurements of position are made.
Equatorial Orbit	Satellites in equatorial orbit are, by definition, inclined at zero degrees. All geostationary orbits are also equatorial orbits.
Footprint	A satellite's footprint is that area on the Earth's surface covered by the satellite antenna's beam pattern or within the field of view of the satellite's transmitters or sensors.
Frequency	How frequently an electromagnetic signal completes one complete cycle in one second, expressed in Hertz.
Frequency Hopping	Discrete jumping of a signal's transmitted frequency over time. Used to counter jamming or other interference.
Full Duplex	Able to communicate both ways (transmit and receive) simultaneously.
Gapfiller	A commercial satellite capability leased by the Navy to provide UHF communications. Originally built to fill the gap preceding the FLTSAT launches, they still provide SATCOM service for DOD. Will be replaced by UHF Follow-on. (UFO utilizes Gapfiller frequencies.)
Gateway	A ground station that acts as a relay between satellites in a system or a link between the satellite and entry into the terrestrial communications network.
Geostationary Orbit	A special type of geosynchronous orbit which is nearly circular, has an inclination of approximately zero degrees, and a period of one day. A satellite in geostationary orbit appears to remain fixed in the sky above

	the equator when observed from the earth's surface. A typical geostationary orbit has, at an altitude of approximately 22,300 miles over the equator, an orbital period of 24 hours thus coinciding with the rotation period of the Earth.
Geosynchronous orbit (GEO)	Any orbit with an orbital period of one day. A satellite in a geosynchronous orbit does not necessarily appear to be stationary in the sky to an observer on the surface of the Earth. A geosynchronous satellite in an inclined, circular orbit will sweep out a ground trace in the shape of a figure eight.
Ground track (trace)	The intersection of the Earth's surface with lines projected from the satellite to the Earth's center as the satellite moves in its orbit.
High Data Rate	Rates of 2,048 Mbps and higher.
Inclination	The angle between the plane of the orbit of a satellite and a reference plane. For a satellite in Earth orbit, inclination is the angle between the orbital plane and the equatorial plane as the satellite crosses the equator northward. Inclination values may be any angle between zero and 180 degrees.
Infrared radiation	Electromagnetic radiation with wavelengths between about 0.7 to 1000 micrometers. Infrared waves are not visible to the human eye. Longer infrared waves are called thermal infrared waves.
Ionization	The process by which a neutral atom, or a cluster of such atoms, becomes an *ion.* This may occur, for instance, by absorbtion of light ("photoionization") or by a collision with a fast particle ("impact ionization").
Ionosphere	A region covering the highest layers in the Earth's atmosphere, containing an appreciable population of *ions* and free *electrons.* The ions are created by sunlight ranging from the ultra-violet to x-rays.
Launch window	The period of time during which a satellite can be launched directly in to a specific orbital plane from a specific launch site.
Look angle	The angle between perpendicular and the direction an antenna or sensor is pointed.
Low Data Rate	Rates between 75bps and 2.4Kbps.

Magnetopause	The boundary of the magnetosphere, separating plasma attached to Earth from the one flowing with the solar wind.
Magnetic storm	A large-scale disturbance of the *magnetosphere,* usually initiated by the arrival of an *interplanetary shock,* originating on the Sun.
Major Axis	The distance form apogee to perigee measured through both foci. The longest diameter of an ellipse.
Medium Data Rate	Rates greater than 2.4 Kbps up to and including 2,048 Mbps.
Microsatellite	A satellite weighing between 10 – 100 kg.
Minisatellite	A satellite weighing between 100 – 500 kg.
Molniya orbit	A highly inclined (typically about 63.4 degrees), highly elliptical orbit with a 12-hour period.
Multispectral imagery	Imagery collected by a single sensor in multiple regions (bands) of the electromagnetic spectrum.
Nadir	The point on the Earth's surface directly below the satellite.
Nanosatellite	A satellite weighing between 1 – 10 kg.
Narrowband	Encompasses data rates less than 64 kbps.
National systems	A term used generically to refer to any asset used by the intelligence collection organizations of the U.S., especially space-based systems.
Negation	Measures to deceive, disrupt, deny, degrade or destroy an adversary's space systems and services
Orbital Period	The length of time (usually measured in minutes) for a satellite to complete one revolution.
Panchromatic	Black and white imagery that spans an area of the electromagnetic spectrum, typically the visual region.
Particle	In general, a charged component of an atom, that is, an ion or electron.
Particle beam	Stream of subatomic particles that are accelerated to high fractions of the speed of light and formed into non-divergent beams.
Passive sensor	One type of remote sensing instrument, a passive sensor picks up radiation reflected or emitted by the Earth. ETM+ is a passive remote sensing system

Payload	That portion of the load on the satellite for which a customer is willing to pay. Also, in general terms, the satellite to be delivered by the rocket.
Perigee	The point in a satellite's orbit where it is closest to Earth and its velocity is highest.
Period	The length of time it takes for the satellite to complete one orbit.
Perturbations	External forces that will cause a satellite to deviate from its normal orbital path.
Phased Array Radar	Any of a class of radars that, instead of using a rotating dish antenna to scan, uses electronically steered beams. The typical coverage of this fixed radar is 120 degrees per face or side; a phased array radar with three faces can provide coverage in all directions.
Picosatellite	A satellite weighing less than 1 kg.
Pixel	Picture element, the smallest element of a digital image.
Platform	A launched object, provides initial stabilization and orientation for payload or upper stage.
Polar orbit	An orbit with its plane aligned parallel with the polar axis of the Earth. Landsat has a polar orbit and flies 438 miles (705 kilometers) above the Earth.
Prevention	Measures to preclude an adversary's hostile use of third party or U.S. space systems and services
Radar	Radio detection and ranging.
Radiation belt	The region of high-energy particles trapped in the Earth's magnetic field.
Radiometer	A device that detects and measures electromagnetic radiation.
Radiometric resolution	The ability of a sensor to detect levels of reflectance.
Regenerative Channel	On a regenerative channel, the satellite receiver converts the data signal (from the ground or airborne terminal) back into its original "ones" and "zeros." The satellite then uses those "ones" and "zeros" to retransmit the data toward the Earth to the receiving terminal.
Resolution	A unit of granularity in imagery.
Retrograde orbit	Any orbit with an inclination greater than 90 degrees.
Satellite	An object in space that is in orbit around another more massive object.

Scintillation	Random fluctuations in a transmitted signal's amplitude, phase or frequency.
Sensors	Electronic equipment used to find things. Sensors can be either active or passive.
Slot	That longitudinal position in the geosynchronous orbit into which a communications satellite is "parked."
Space control	The ability to assure access to space, freedom of operations within the space medium, and an ability to deny others the use of space, if required.
Space segment	That portion of a space system (see below) that is located in space, i.e., the satellite.
Space surveillance	The network of dedicated, collateral or network contributing space surveillance sensors.
Space system	An organization made up of equipment, some of which is in space, and people whose purpose is to perform specific technical tasks with the equipment. Space systems are almost universally made up of three principle subsystems, or segments; the space segment (satellite), the user segment (equipment and persons used to exploit the satellite's products), and the control segment (equipment and persons dedicated to maintaining the satellite).
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.
Space weather	The popular name for energy-releasing phenomena in the magnetosphere, associated with *magnetic storms, substorms* and *shocks.*
Spectral resolution	The ability of a sensor to detect information in discrete regions of the electromagnetic spectrum.
Spot beam	A focused antenna pattern sent to a limited geographical area.
Spread spectrum	A technique used to overcome deliberate communications interference in which the modulated information is transmitted in a bandwidth considerably greater than the frequency content of the original information.

Solar wind	Hot solar *plasma* spreading from the Sun's *corona* in all directions, at a typical speed of 300-700 km/sec. It is caused by the great heat of the *corona.*
Space	The universe outside of the Earth's atmosphere. There is no universal definition of where space begins. For army purposes, it is practical to define space as being the universe beyond the minimum altitude of a satellite in a circular orbit, about 89 miles.
Spoof	To cause a receiver to display, report, or cause to be carried out erroneous information or actions.
Sunspot cycle (or solar cycle)	An irregular cycle, averaging about 11 years in length, during which the number of sunspots (and of their associated outbursts) rises and then drops again.
Sun-synchronous orbit	An orbit in which a satellite is always in the same position with respect to the rotating Earth at the same time of day. The satellite travels around the Earth in the same direction, at an altitude of approximately 438 miles (705 kilometers).
Telemetry	Electronic remote monitoring of a launch vehicle's or satellite's functions. The purpose of telemetry is to provide ground control personnel with information as to the "health" and activity of a satellite.
Temporal resolution	The space of time between collection of successive images.
Thermal infrared	Electromagnetic radiation with wavelengths between 3 and 25 micrometers.
Transfer Orbit	A highly elliptical orbit which is used as an intermediate stage for placing satellites into their final orbit.
Uplink	The Earth-to-space telecommunications pathway.
User Segment	That portion of the space system that is ground-based and provides useful products. This may consist of receivers, processors, and special support personnel at a fixed site, or a simple portable radio that provides satellite access.
Visible radiation	The electromagnetic radiation that humans can see as colors. The visible spectrum is made up of wavelengths between 0.4 to 0.7 micrometers. Red is the longest and violet is the shortest.

Wavelength	Wavelength is literally the length of one complete cycle (wave) of an electromagnetic signal. In radio signal terms, for example this can be determined by dividing the speed of light in meters per second (about 300,000,000) by the frequency, measured in hertz (also known as cycles per second). The result will be wavelength in meters.
Wideband	Encompasses data rates greater than 64 kbps.