THE GLOBAL POSITIONING SYSTEM:

THEORY AND OPERATION

By

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ABBREVIATIONS AND ACRONYMS

AZ	Azimuth
C/A	Course/Alignment
CRS	Course
DGPS	Differential Global Positioning System
DIS	Distance
DME	Distance Measuring Equipment
DOD	Department of Defense
FAA	Federal Aviation Administration
GDOP	Geometric Dilution of Precision
GEO	Geostationary Earth Orbit
GS	Ground Speed
GPS	Global Positioning System
HDG	Heading
HDOP	Height Dilution of Precision
ICBM	Intercontinental Ballistic Missile
IFR	Instrument Flight Rules
LAAS	Local Area Augmentation System
Lc	Link (Civilian)
Lm	Link (Military)

LOP	Line of Position
LORAN	Long Range Air Navigation
L1	Link 1
L2	Link 2
MAGVAR	Magnetic Variation
MCS	Master Control Station
Mhz	Megahertz (cycles per second)
MSL	Mean Sea Level
NAD 27	North American Datum 27
NAS	National Airspace System
NAVSTAR	Navigation System by Timing And Ranging
OBS	Omni Bearing Selector
P	"P" code (unclassified)
PDOP	Position Dilution of Precision
PPS	Precise Positioning Signal
PRN	Pseudorandom Noise
RADAR	Radio Detection And Ranging
RNG	Range
SA	Selective Availability
SPS	Selective Positioning Signal
TACAN	TACtical Air Navigation
TDOP	Time Dilusion of Precision
TRK	Track

TTFF	Time To First Fix
UHF	Ultra High Frequency
UTC	Coordinated Universal Time
VDOP	Velocity Dilution of Precision
VHF	Very High Frequency
VOR	VHF Omnirange
WAAS	Wide Area Augmentation System
WAC	World Area Chart
WGS-84	World Geodetic Survey 1984
XTE	Cross Track Error
Y	"Y" code (Classified)

CHAPTER I

INTRODUCTION

Ever since people first ventured out of caves to travel from one place to another, navigation has been important. As technology has increased so has the requirement for precise navigation. Today, with thousands of air vehicles such as balloons, commercial, private, corporate, or military aircraft, precise navigation is a requirement and a necessity. By using these systems today and merging them with newer technology, operations in related fields will be changed forever. The Global Positioning System (GPS) can contribute to the improvement in farming techniques, location of more natural resources, improvements of the ability to track vehicles, improvement of the navigation systems on highways, finding better and more efficient routes, and, thereby, saving gasoline and millions of otherwise wasted dollars. Industries will be able to more effectively operate and cut costs to the consumer. All that is required to move this program to newer heights is to educate the people on what GPS is and what it can do. The tendency in society is to do things faster, bigger, better, and without taxing the brain of the individual. A time will come, however, when technology may exceed the human capability to understand the advancement that science provides. The case in point is GPS. GPS is a huge advancement in technology developed by the United States government and taken over by, generally, American industry. The American aviation industry is leaping to embrace the capabilities available from GPS. The Federal Aviation Administration (FAA) has stated: "Satellite technology with GPS is so attractive we can't afford as a nation to pass it by" (Nix, 1998). An entire infrastructure of civilian business has been established to support a Department of Defense (DOD) requirement. Furthermore, American business has been able to increase the use of this system far beyond the original scope of operation. This system has been advertised to be so simple that anyone can use it. Herein lies the problem: the technology is simple to use, if you know what you are doing. The infrastructure, however, has failed to provide to the common user information on how the system works, what the theory is behind it, where the errors are and why they occur, and how to use the system. The GPS manufacturers do provide instructions on how to use a particular unit, but only the basics and none of the reasons why the system works. In recent days, some companies whose primary job is training have recognized the need to provide some training on the use of this equipment and have produced video tapes on the subject. Of course, these tapes are an additional expense and cover the basics, but not theory (ARINC Research Corporation, 1991).

Statement of the Problem

As GPS technology has increased and the threat of military conflict has decreased, the reliance of the public on this new technology has grown rapidly. Whereas the country enjoys the benefits of the "peace dividend," the capability of our navigation system has decreased. In an effort to cost-cut and downsize the expense of maintaining a national airway system, the federal government has planned to eliminate most of the current navigation aids by the year 2010 (United States. Department of Transportation and

Department of Defense, 1996). The U.S. Air Force has followed the general trend and did not produce any training courses on this new technology and, along with the U.S. Navy, plans to eliminate the last type of training that allows navigation from a strictly internal source, Celestial Navigation. The Navy and Air Force have decided that the sextant, used for celestial observations, has become obsolete because satellite-linked navigation (that is, the Global Positioning System) is more accurate (Maloney, 1998). Currently, navigator training in the U.S. Air Force does not provide information on the theory and operation of the GPS; it provides only an *Introduction to GPS* in a five page overview. The ability of navigators to understand the capabilities and limitations of a new navigation system is important and this information should be provided. The assumption that this new technology is simple to use could pose problems later.

Young navigator students used to joke about how “navigator judgment” was going to be “issued” after a certain point in training. Navigator judgment is the instinctive ability to tell if a position is in error or that something is not right with our navigation instruments. Obviously, judgment cannot be issued. It can be obtained only through years of experience. Navigators, however, are taught the theory and operation of all of the navigation instruments to establish a baseline between what is correct and incorrect. The ability of a navigator to determine the accuracy of the crew’s position will directly affect the outcome of the mission. Whether or not the crew is successful or killed may be, and usually is, directly related to the navigator knowing the precise location and the ability to interpret all of the available information.

An example of this is the story of the *Lady Be Good*, a B-24 “Liberator” bomber during World War II. The *Lady Be Good* took off from Soluch, Libya, on a bombing run to Naples, Italy, on April 4, 1943. During the return trip, the evidence indicates that the crew became lost in the dark and apparently used erroneous navigation aids for guidance. The Germans were continuously sending fake radio transmissions in order to confuse the allied air forces. It worked on the crew of the *Lady Be Good.* The aircraft was lost and the crew was never heard of again. This aircraft was finally found in 1959, 448 miles south of their intended base of landing in the Libyan desert (McClendon, 1987).

Aircrew members of today can suffer the same fate if they blindly trust their instruments. It is extremely important that navigators today use all of their knowledge and experience in a combat situation. This knowledge can save their lives and the lives of their crew, and return a valuable airplane to continue the battle.

GPS cannot be taken as an unerring navigation aid. It can be jammed or give false readings. As in all other courses that deal with navigational aids, a GPS course needs to be developed to explain the systems capabilities and limitations. Thus far, the U.S. Air Force has failed to provide such a course. Sometimes faster is not better, and bigger is not best. Education is the key to understanding and using technology.

Purpose of the Study

The purpose of this study is to document the theory, development, and training requirements of the United States Air Force with regard to the United States Global Positioning System.

Objectives of the Study

The objectives of this study are: (a) to document the theory and development of GPS, including differential GPS (DGPS); (b) to document the theory and development of the wide area augmentation system (WAAS) and the local area augmentation system (LAAS); and (c) to develop the training requirements necessary to educate the students on GPS theory and operation.

CHAPTER II

REVIEW OF LITERATURE

What is the Global Positioning System ?

The purpose of this study is to document the theory, development, and training requirements of the United States Air Force with regard to the United States Global Positioning System. To understand GPS, it is necessary to review the history and background in a comprehensive and nontechnical way. Two Global Navigational Satellite Systems (GNSS)exist. One, the Global Orbital Navigation Satellite System (GLONASS), is used and supported by Russia. The other is the Global Positioning System used and supported by the United States (Allen, Ashby, & Hodge, 1998). The remainder of this study will address the U.S. GPS because of the uncertainty of the political and economic conditions in Russia today.

The current radionavigation system in the United States consists of TACtical Air Navigation (TACAN), OMEGA, Long Range Air Navigation (LORAN), Very High Frequency Range (VOR), and Distance Measuring Equipment (DME). This radionavigation system is antiquated and expensive to operate and will be phased out of service as the new GPS system comes on-line (United States Department of Transportation and Department of Defense, 1996).

GPS was developed by the Department of Defense (DOD) to simplify accurate navigation. It uses satellites and computers to triangulate positions anywhere on earth. The implementation of GPS was conducted in three phases. Phase I, from 1973 to 1979 allowed companies to compete for design and development contracts of the three segments of GPS. In 1974, a contract was awarded to Rockwell International to develop 3 prototype satellites, later increased to 11. A contract was awarded in 1974 to General Dynamics for development of the control and user segments of NAVSTAR GPS. General Dynamic subsequently subcontracted development of the user segment equipment to Magnavox. The initial control station was located at Vandenberg AFB, California. The first satellite was launched in 1977, but malfunctioned after 7 to 8 months. The first four operational satellites were launched and in December 1978, three dimensional navigation capability using only satellites was available for the first time. Phase II started full scale development and system tests from 1980 through 1985. In 1980, contracts for development and design of the user segment equipment were awarded to Magnavox, Rockwell/Collins, Texas Instruments, and Teledyne. IBM was awarded the contract to build an initial control system as an interim system to fill the gap between the phase I control system and the final operational control system. At the same time, IBM was also awarded the contract to build the final operational control system which was to be located at Falcon AFS, Colorado. Phase III started in 1985 with the movement of the master control station from Vandenberg AFB, California, to Falcon AFB, Colorado. The entire system became operational for worldwide civilian use in April 1995 (Federal Aviation Administration Academy, 1998). The satellites weigh about 2000 pounds and, when deployed, are 17 feet wide. The satellites are expected to last an average of ten years with replacements being produced and launched into orbit on a continuous basis. GPS, also known as Navigation System by Timing And Ranging (NAVSTAR), is an all weather radionavigational system providing precise three-dimensional positioning, velocity, and time accuracy based on a common worldwide datum, easily converted to other datums on a continuous, real-time basis. The biggest advantage is that the GPS system will operate in any weather (Garmin Corporation, 1997).

The GPS system consists of 24 satellites, 21 operational and 3 spare, orbiting in six orbital planes around the earth at an altitude of approximately 10,900 nautical miles (20,200 km) (see Figure 1). Each plane contains four satellites that are equally spaced and provide precise data for navigational positioning, time, and velocity. These satellites, inclined 55 degrees to the equatorial plane, provide the best coverage at least expense (Hofmann-Wellenhor, 1994). This spacing provides for five to eight satellites to be visible from anywhere on Earth at any one time. The satellite coverage is 100% between 60 degrees North and 60 degrees South latitudes with lesser degree coverage at either the north or south poles (Dana, 1998).

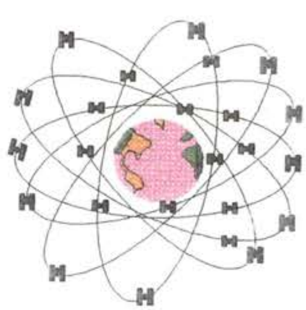

Figure 1. GPS Deployed Constellation

All satellites transmit the same information, but the information from each satellite is unique. The transmitter is very low powered, 50 watts or less. Each satellite transmits a pseudo-random noise code (PRN), time, almanac, and ephemeris data. Ephemeris data is a prediction of the position of the satellite in space. An ephemeris is a book of predicted sun and star locations with respect to time. It was used by early explorers and is still used today by some navigators to determine their location. The PRN is used to uniquely identify a particular satellite. All satellites have a PRN from 1-32 or an ID code. The extra numbers from 25-32 are used to identify spare satellites launched, but not in service until the ones they are to replace become unusable (Garmin, 1997). Each GPS receiver will display the PRN code for each satellite from which it is receiving data. GPS satellites transmit on two frequencies or links called Link 1 (L1) on 1575.42 Megahertz (MHz) or Link 2 (L2) on 1227.60 (MHz). These frequencies transmit a P(Y) code and, in addition, the L1 frequency also transmits a Coarse/Acquisition (C/A) code (Leick, 1997). The P(Y) code shows that the code can be used either in the clear or encrypted. The P code, which is available only to users authorized by the Department of Defense, is a seven day long code for each particular satellite. Repeated every seven days starting at Saturday/Sunday midnight, the code is transmitted at a bit rate of 10.23 MHz and is protected against unauthorized use because of this seven day cycle. This also serves to protect the P code from spoofing (intentional Jamming). The P code and the C/A code both use the modulation called PRN. The C/A code, which is available to all GPS users, is a 1023 Bit code that is transmitted at a 1.023 MHz rate; therefore it takes only 1 Millisecond (MS) to transmit the entire C/A code before it is repeated and provides accuracy within 20 to 30 meters. To the casual observer, this would seem like random noise; however, because the C/A code is repeated every 1 MS, the cycle can be determined. On the other hand, the P code, which is repeated every seven days, does appear to be truly random, and the user would have to have some prior knowledge about the cycle and where the cycle currently was in order to decode the Navigation (NAV) message that is superimposed on it. Superimposed on the C/A code and P code is the NAV message, which is not necessarily the same message on both codes. (Federal Aviation Administration Academy, 1998).

Two major services are provided by GPS, the Precise Positioning System (PPS), specifically designed for DOD and allied users, and the Standard Positioning System (SPS), designed for civilian use. SPS is the standard level of positioning and timing accuracy available free to all GPS users on a worldwide basis (Dana, 1998). In addition, the U.S. government has recently announced that additional GPS signals would be provided by 2005. The addition of a new frequency will improve navigation and position accuracy to 3-10 meters from 100 meters (Collins, 1998).

PPS is the most accurate positioning portion of GPS and is restricted to only authorized users designated by the United States and allied federal governments. PPS is in the encrypted mode to prevent unauthorized use. When the GPS signal is using the encrypted mode, the process is called Anti-spoofing (AS) (Beadles, 1995). Anti-spoofing is used to guard against fake transmissions of satellite data and requires a classified AS module in each receiver for use by military personnel with the cryptographic keys. The DOD has guaranteed access to L1 frequency for general civilian use (Dana, 1998). The

SPS will be the basis for the rest of this paper because of the classification of the PPS information.

The government will insure accuracy of the SPS, 95 % of the time, to an accuracy of 100 meters horizontally, 156 meters vertically, and time transfer accuracy to Universal Coordinated Time (UTC) within 340 nanoseconds (United States Naval Observatory, 1997). One of the reasons that the accuracy is not any better is that the government induces an error. This error is called Selective Availability (SA) and is basically a 30 meter error that varies with time. SA is a method of introducing errors into the GPS signal and degrading the accuracy of the system. SA is used to deny any enemy of the United States the advantage that this precision system can provide (that is exact targeting position) (A GPS Frequency and Time Standard, 1998). Currently, a major controversy exists between the civilian and government users of GPS on the introduction of these errors. The civilian users, specifically the commercial airline industry, want the government to stop introducing these errors so that precision navigation would be constantly available and will allow precision approaches to be certified by the FAA and used at all airports. L1 C/A PRN code is a dedicated frequency for civilian use. L2 is a dedicated military frequency. The combination of these two frequency P(Y) codes allows precision navigation to within a range less than 15 meters. This combination is what the military uses and what the civilian community wants. The government has compromised somewhat by allowing civilians to develop expensive GPS receivers that can receive and use the "carrier phase" signal of L2. This will allow commercial aviation to have more precise navigation. The additional ranging signal (not the navigation message) will be used by commercial aviation and will provide a more precise position as the signal passes through the ionosphere. Different frequencies from different satellites will travel to the GPS receivers at different rates canceling the effect of the ionospheric error and, thus, providing a more accurate position (Stanton, 1997). The government will allow the commercial industry to use this more accurate signal for only a limited period of time. In March 1996, the President signed a comprehensive national policy decision directive promising that the United States would stop degrading the GPS signal within the next decade (United States The White House, 1996).

Another controversy relates to how the government will provide precision approach and navigation ability to the commercial aviation industry while denying that capability to an enemy. The discussions center on whether or not to create a new frequency for commercial aviation called "Lc" and/or one for the military called "Lm" or to make them subsets of the current L1 and/or L2 (Anderson, 1997). This controversy has apparently been resolved by the Clinton Administration announcement on March 31, 1998, of the availability of new GPS frequencies by the year 2005 (New Navigation Signals, 1998).

Segments

The GPS has three major components of the system: space, control, and user sections. The space section is composed of the GPS satellites. These satellites send radio signals from space. This group or constellation of 21 operational satellites with 3 in-orbit spares are arranged in six orbital planes orbiting Earth once every 12 hours (Joint Program Office, 1997b). This permits a minimum of six to eleven satellites in view, at five degrees or more above the horizon, to the user, worldwide, at any point in time.

Each satellite is in a circular orbit at an altitude of 10,900 nautical miles and at an inclination of 55 degrees with respect to the equatorial plane. The satellite coverage will extend from an area between 60 degrees North to 60 degrees South latitudes. The placement of satellites allows GPS receivers to resolve the mathematical equation for latitude, longitude, and time with at least three satellites in view and height or altitude if a fourth satellite is present. Each satellite transmits a burst of data containing its position and time data. The SPS frequency (L1) contains a Coarse Acquisition (C/A) code and precision ranging navigation message. This message contains information about the satellite clock and ephemeris data, satellite health, and a UTC synchronization function. Every GPS receiver has an algorithm used to calculate and predict the location of a satellite with respect to time. It then validates the information being transmitted by comparing it to its own data information. When the data is validated, the GPS receiver "locks on" to the satellite and starts using the positioning data. Each satellite has its own unique identification number. The number is defined as a part of the signal each satellite sends (United States Naval Observatory, 1998)

The Operational Control Section (OCS) is made up of monitor stations, ground antennas, and a master control station. The five monitor stations are located at Hawaii, Kwajalein, Ascension Island, Diego Garcia, and Colorado Springs. Three ground antenna stations are located at Ascension Island, Diego Garcia, and Kwajalein. The master control station (MCS) is located at Falcon Air Force Base in Colorado. (see Figure 2)

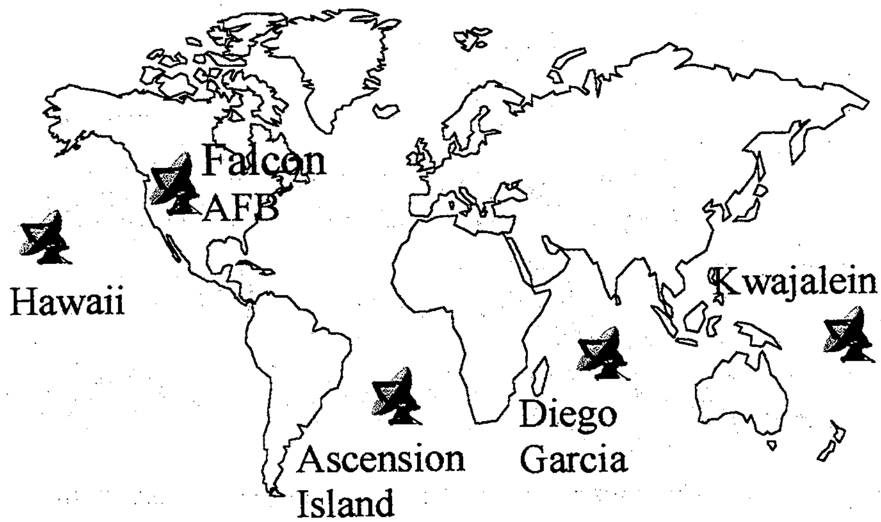

Figure 2. Location of the GPS Ground Stations

The monitor stations passively track all satellites in view using a GPS receiver and accumulate ranging data from the signal from each satellite. This data is used to compute a precise orbital data (ephemeris) and clock corrections for each satellite Errors in the ephemeris or satellite clock will cause an apparent error in the user's clock. The error range is very small, about five feet (Shank, Lavrakas, and Lavrakas, 1994). The information is collected and sent to the master control station at Falcon Air Force Base. The MCS determines the clock for each satellite and orbits, and updates the individual message from each satellite. The updated information is transmitted to each satellite from the ground antennas, which are also used to receive and transmit health and control information (The Aerospace Corporation, 1995b).

GPS receivers can be hand-held units or embedded units installed on airplanes, cars, trucks, or other vehicles. They receive the satellite transmissions, find, decode, and process the satellite signals. The GPS receiver tracks satellites using a carrier tracking loop and a code tracking loop. The GPS receiver will normally start with a general knowledge of its position, velocity, and time. In addition, it will use previously stored satellite almanac data. The position, velocity, and time can be input by the user or can come from an internal source. The previously stored almanac data will be the data from the last time the GPS receiver was in operation. All of this information does not have to exist for the GPS receiver to determine position; however, the more accurate this information is, the less the amount of time that is needed for the GPS receiver to calculate its position (Clarke, 1994). For the GPS receiver to use this data, it must first determine which satellites are "in view" or above the horizon. If it has received bad data, it must search the sky for any available satellite to track. Once it finds a satellite, it can then update its database and obtain an accurate position.

The user section consists of various configurations of antennas and receiver-processors to receive and compute navigational positions, velocities, and precise timing to the user (Dana, 1998). Two categories of users exist, the military user and the civilian user.

The military user is related to the DOD plan to embed all military systems, for example, planes, ships, and vehicles, with GPS. This would facilitate coordination between all military units across the services. This type of cooperation has been war tested during Desert Shield and Desert Storm.

The civilian use of GPS has accelerated much faster than the planners had expected. The original focus for the first few years was for navigation purposes. Today, GPS receivers are commonly used for all types of land and geodetic surveys, by sports people, and are starting to be used in the trucking industry for fleet management and control . In addition, GPS is used to support a variety of applications in many towns and cities. These include public works, police and fire departments and parks and recreation projects (Global Positioning Services Brochure, 1997).

How Does GPS Work?

Basically, the satellites have very accurate clocks that transmit signals at the speed of light along with a precise timing message. Ground units receive the transmission, but even at that speed some time delay occurs. The time delay is measured in nanoseconds and is explained later. The delay between transmission and reception is multiplied by the speed of light, allows receivers to calculate the distance to the satellite. To get precise information in three dimensions, the receiver must receive signals from a minimum of four satellites. Generally, GPS is similar to a TACAN with one important difference. TACAN is an active system, sending out a signal and receiving a signal in response. It then measures the time between transmission and receipt and determines the distance and azimuth. GPS is a passive system, meaning the satellite sends a signal and a receiver acquires the signal. No two-way transmission occurs as in TACAN. The receiver must know at what time the transmission was made and that information is encoded in the satellite transmission. The receiver compares its time of receipt to the time of transmission and computes the range. Time accuracy is critical for this operation to work (United States Department of the Air Force, 1983).

GPS time is referenced to the master clock at the U.S. Naval Observatory and is the most competent system for time transfer. Each satellite has four atomic clocks to ensure time accuracy. They use the precise oscillations of rubidium and cesium to maintain timekeeping accuracy to one billionth of a second (.000000001 second) (D'Antoni, 1996). Although these clocks are very accurate and may gain or lose one second every 20,000 years, the government intentionally disrupts the time by a fixed amount, changing the time. This is known as "clock dither," which will degrade position accuracy. This manipulation of the clocks along with SA is what degrades position accuracy by about 140 meters.

The basic theory behind satellite navigation is the measurement of distance between the satellite and the receiver unit (The Aerospace Corporation, 1995a). Ranging to one satellite provides one line of position (LOP). (see Figure 3)

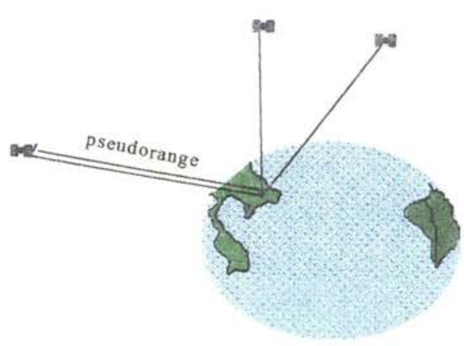

Figure 3. Satellite Ranging

The satellite is a platform for a radio transceiver. The equipment in the satellite sends a signal to receivers and allows them to measure the pseudorange to each satellite and the users can determine its spatial position from the message of the satellites (Payne, 1982). Obviously, the more satellites in view, the more accurate the position.

If you imagine the radiosphere of each satellite as a ball with the satellite at its center and you are located somewhere on the surface of the ball, you know your exact distance from the satellite. As an example, we will use 11,000 miles measured from the first satellite. (see Figure 4) Knowing we are 11,000 miles from a satellite narrows down our location.

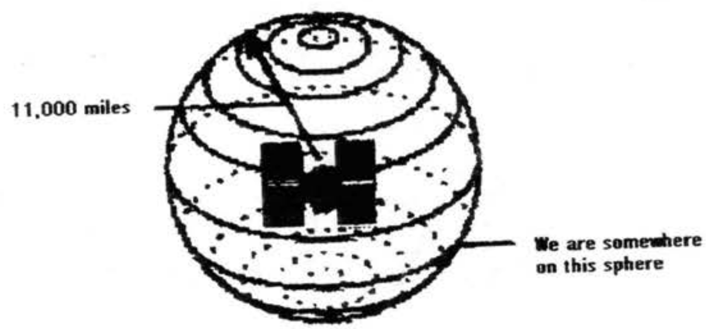

Figure 4. GPS Satellite Range

Receiving a second satellite message, and you know your exact distance from that satellite, then you know that you are somewhere where the two balls intersect. Since orbits are not exactly circular, we will say that the second satellite is 12,000 miles from our position. (see Figure 5)

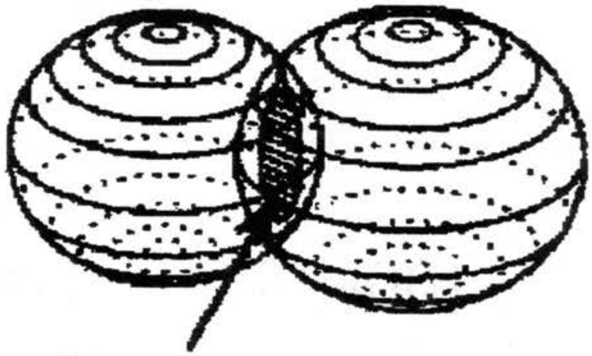

Figure 5. GPS Ranging from Second Satellite

If we do the same with a third satellite at 13,000 miles from our position, then we know that we are at only two possible locations. Usually, one of those two points is so far from our position, it is obvious as to which one we are at and the other can be eliminated (see Figure 6) (Triangulating from Satellites, 1998).

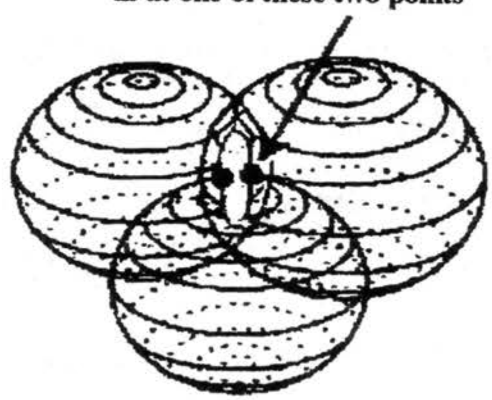

Figure 6. GPS Ranging from Third Satellite.

GPS receivers then use an algorithm to help us eliminate the improbable one. The ranging to four or more of these different satellites provide lines of position resulting in a position and altitude.

Satellite geometry is another important factor. If you are trying to obtain a position and all of the satellites in view are to the north and east, or they are in close proximity to each other, the geometry is poor. (see Figure 7)

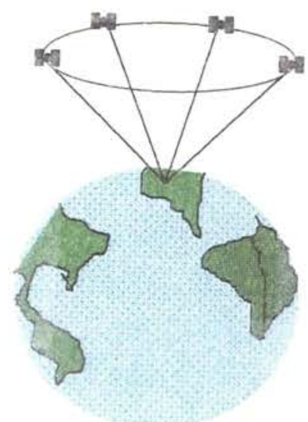

Figure 7. Poor Satellite Geometry

The ideal geometry would be three satellites 10 degrees above the horizon spaced at 120 degrees apart with a fourth satellite directly overhead at the user's zenith (see Figure 8) (United States Department of Defense Information and Analysis Center, 1996).

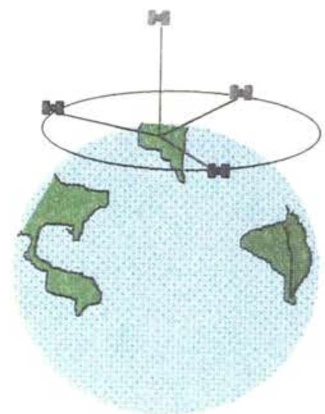

Figure 8. Good Satellite Geometry

Geometry will also play a role depending on your location and the surrounding area. For example, the ability to receive the GPS signal may be impaired by trees or buildings. The GPS signal is only a radio wave, and solid objects are some of the things that will block a signal. Most GPS receivers will provide a number associated with the receipt of a satellite signal. This number is called the Geometric Dilution of Precision (GDOP). In short, this measure of the geometry of a satellite has four types of "DOPs": position (PDOP), height (HDOP), velocity (VDOP), and time (TDOP) which are used to measure a receiver's accuracy. A general rule is the lower the GDOP number, the better (Merminod, Grant, & Rizos, 1990).

GPS Errors

As in all systems, some inherent errors exist. We have already briefly discussed the errors induced by the government called selective availability and clock dither. Another error, clock bias, happens when the receiver clock and the satellite clock are not synchronized. This error will show up when calculating the distance time travels between receiver and satellite clocks. Clock errors exist because not even these clocks are exactly the same and, therefore, may be off by a few nanoseconds when the navigation message is transmitted. The satellites use atomic clocks and most receivers use a quartz crystal clock which is much less accurate. Each nanosecond error will cause a position error of one foot. Even with this small error, however, GPS has become the principal supplier of accurate time (Allen, Ashby, &Hodge, 1998).

Errors of space control result from either the orbital position or clock that is in error. Errors of orbital position are problems with the ephemeris. The ephemeris data contains 17 pieces of information on the orbital dynamics, defining precisely the position of the satellite in its orbit. To establish a good position, the receiver must be able to fix a satellite position at a particular time. Unfortunately, even in the vacuum of space, factors affect the orbit of a satellite. The effects of solar winds and gravity play a role in determining the position of a satellite. It is difficult to determine the position of a satellite within a few meters while it is in orbit. To solve for this problem, the master control station predicts where the satellite is supposed to be at a specific time. This position is compared to actual position as reported by the monitor stations. This data is computed and a new orbit prediction is transmitted to all satellites, updating each individual database in the satellite. These corrections are continuously transmitted to all satellites and, in turn, to all users, minimizing these position errors (Wells, et al., 1987).

Atmospheric errors are found as the signal travels from the vacuum of space to Earth, passing through the atmosphere. To use ranging, however, it is assumed that the signal passes at the speed of light in a vacuum, but it runs into the ionosphere which induces errors to the calculations of the receiver. As the signal hits the ionosphere and the troposphere, it is bent much like light is bent in a prism and slows down, delaying arrival at the antenna of the receiver. (see Figure 9)

The troposphere is the lower region in the atmosphere and can be predicted and compensated for by the GPS receivers. Tropospheric delay makes altitude the least stable of position estimates. The amount of delay depends upon the density of the ions in the ionosphere. To compensate for this error, GPS satellites broadcast a model of a constant ionosphere. Although the ionosphere varies constantly, this compensates for about 75% of the atmospheric error (United States Department of Defense Information and Analysis Center, 1996).

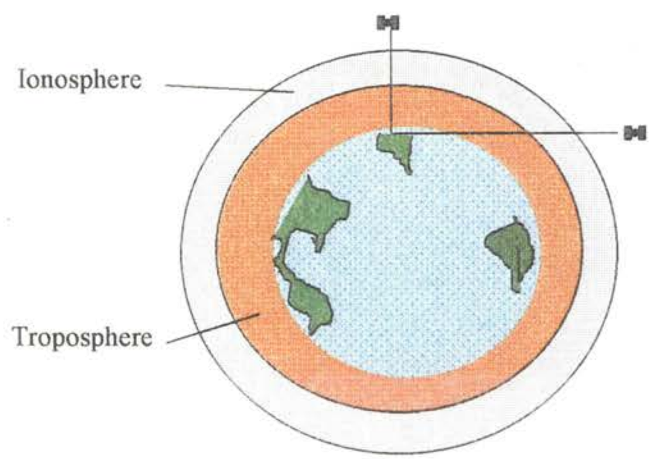

Figure 9. Atmospheric Interference

Satellites on the horizon, for example, would have to go through more ions than one directly overhead. The delay varies because of the time of day, the distance of the receiver from the equator, season of the year, and the 11-year solar cycle. All of these conditions are predictable and can be avoided with proper prior planning (Nordwall, 1997).

Multipath errors are caused by the satellite signal bouncing off some object, such as mountains or buildings, before going to the GPS antenna of the receiver. Like any other radio signals bouncing off objects, GPS signals will travel a longer distance to the antenna of the receiver and cause a slight range error in the process. This may cause a problem in mountainous or urban areas (Lachapelle, 1990). (see Figure 10)

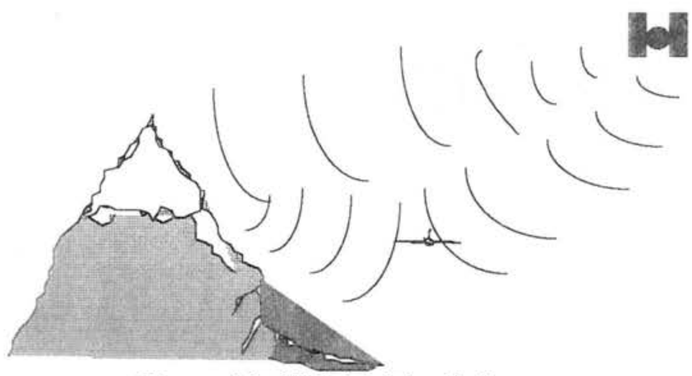

Figure 10. GPS Multipath Errors

Error sources can be classified into three groups: satellite related, propagation medium related, and receiver related. The satellite group consists of clock bias and orbital errors, the signal propagation is because of the atmosphere, and receiver errors are from antenna phase, clock bias, and multipath (Hofmann-Wellenhor, 1994).

In totaling up these errors, the amount of effect to a position is only about 14 meters. These errors may also cancel out each other, based upon the number of satellites that are in view. Normally, any civilian receiver can deliver accuracy of about 20 to 80 meters. It all depends on individual accuracy standards.

GPS Theory

Just as people had to learn to use maps and compasses, so now we must learn the new relationship between maps and GPS because they are not necessarily the same. Without understanding the new relationship, individuals will not comprehend the value of GPS and the precision it provides. For example, an individual was lost in the mountains of Colorado and had a hand-held GPS with him that was in perfect operating condition. The man, however, had no idea how to use it. He saw the numbers change, but did not know what they meant. He did not understand the relationship between where he was and where he wanted to go. If we are to use new technology, we need to understand this new relationship.

We have often used maps as a positioning and navigation aid to help us travel from one place to another. Because GPS is a source for positioning and navigation, we can merge the two together. This is done by observing the map legend and inputting the legend data into the GPS receiver. The legend contains information that we usually do not use, but is important when using GPS. This information is the horizontal datum, ellipsoid, vertical datum, the magnetic variation, and which geodetic survey reference the map is based on.

We have used a depiction of Earth called a globe as the true representation of our world. Everything on a globe is orientated to true north as opposed to magnetic north. A globe, however, has a very small scale and very little detail. Further, a globe may be relatively big and difficult to use. So, maps became popular and were used as the primary source for positioning and navigation.

Maps are a flat, two-dimensional representation of a three-dimensional Earth drawn to scale and, therefore, cannot show all dimensions of true direction, distances, areas, or shapes as seen from space. GPS receivers operate in a three-dimensional world to compute position and navigational information. Therefore, differences will always occur in distances, positions, and directions between maps and GPS positioning data. All of the natural and human features represented on a map are accomplished by symbols. Realistically, if every object (that is, every bridge, every tower, every power line, and so forth) were put on every map, it would be too cluttered to use easily. If map features are to be read and understood, they must be exaggerated in size, sometimes several times the actual size. Furthermore, the precise location cannot be judged because of the exaggerated size. Maps provide information on the locations of ground features such as cities, roads, train tracks, power lines, and so forth. They also show elevation of terrain and perhaps different types of vegetation in the United States (Department of Defense Information and Analysis Center, 1996). Thus, individuals who are planning trips can use maps to aid them in their planning.

As mentioned earlier, maps are a flat two-dimensional representation of a three-dimensional surface with four major components: an Ellipsoid to account for the shape of Earth, a Horizontal Datum to provide position data, a Vertical Datum to provide elevation data; and a Projection providing specific information on ground or air navigation. This is the information on a map legend that allows users to determine position and navigation information. Generally, very little attention was paid to the legend area, but with GPS, this area has become much more valuable.

Earth is not a true sphere. It bulges at the middle and is flatter at the poles (see Figure 11).

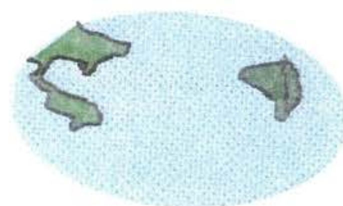

Figure 11. Earth Bulges at the Center

To compensate for this irregular shape, map makers use ellipsoid models that best represent a particular region of the world. Two types of ellipsoids exist: the regional and the world. The ellipsoid is a smooth surface shape of Earth to represent irregular shapes of topography, such as mountains, because it is based on a mathematical model. Regional ellipsoids are made by mapmakers of a particular region of Earth based on the values of the radius and the flattening ratio. These same values cannot be used for other regions of Earth (Kaplan, 1996).

World ellipsoids were developed when satellites gave us the capability to see Earth from space. This allowed mapmakers to develop a single system that could be used around the world. The world ellipsoid is based on the true center of Earth. The current world

world ellipsoid is provided by the World Geodetic System of 1984 (WGS-84) (Decker, 1986). GPS receivers can determine a three dimensional position based on this world ellipsoid.

Once the ellipsoid problem was corrected, the next step was to select the correct datum. A datum is a mathematical model of Earth used as a base reference to overlay a coordinate system on the surface of the Earth. Two types of datums are of concern: (a) horizontal datums covering Easting and Northing or Longitude and (b) Latitude and vertical datums covering elevations. Datums are not calculated by GPS receivers, but most will allow you to choose the datum you want to use (Langley, 1997).

Like ellipsoids, two types of horizontal datums exist: regional and world. The regional horizontal datum was selected for the region in which it was to be used and that best represented the surface of Earth in that region. The mapmaker will attempt to remove as much distortion as possible. The map is then connected to the ellipsoid by using some prominent feature in the region or using the center of the region. This location is surveyed as accurately as possible. This point then becomes the Initial Point or the Point of Origin. Once established, all other features are referenced to this point.

World horizontal datums were required when Intercontinental Ballistic Missiles (ICBMs) required a precise targeting location. Datums from one region are not accurate for another region. Until 1986, the North American horizontal datum was not based on the center of Earth, but rather on the North American datum of 1927 (NAD 27). This datum was based on an initial point at Meades ranch, Kansas. All maps for North America used this geographic point for the position reference system, and it is still used to define positions on U.S. Geological Survey topographic maps. In 1986, the National

Geodetic Survey completed a new survey for the horizontal datum and established the NAD 83 datum. Unlike the NAD 27 datum, based on Meades ranch in Kansas, NAD 83 is an Earth-centered datum. NAD 83 and WGS-84 are basically the same, differing by only a few meters. The point of origin for the world horizontal datum is the center of Earth. The current world datum is based on the World Geodetic System --1984 (WGS-84). So, the WGS-84 ellipsoid and the WGS-84 horizontal datum are used by GPS receivers to compute position. GPS users must always know what datum is used for their maps and which datums are being used by the GPS receivers. This information is contained in the map legend (U.S. Geological Survey, 1998). As discussed earlier, different regions of the world have different ellipsoids and horizontal datums. The U.S. government solved this problem by using the WGS-84 datum. WGS-84 is its own ellipsoid and horizontal datum referenced to the center of Earth. Because it is referenced to the center of Earth, it can interpret between all other regional datums and ellipsoid pairs worldwide. For this reason, the U.S. government has accepted WGS-84 as the U.S. standard datum, but others have not. For example, Russia (the former Soviet Union) uses a different datum plane for their GLONASS system called Soviet Geodetic System--1985 (SGS-85), a different frequency, and a different time source (Sheshayevich, 1991). The user must know what the map is based on and which map is being used.

After horizontal datums, the mapmaker must solve the problem of the vertical datum. The vertical datum is used as a reference to determine elevations. This will start just as the horizontal datum started, by determining an initial point.

Most maps use Mean Sea Level (MSL) to measure elevation. GPS receivers do not use MSL to measure height. Rather, they use the WGS-84 ellipsoid, but the ellipsoid is converted by the GPS receiver to MSL, for ease of user understanding. The beginnings of MSL was an attempt to establish a standardized way of measuring height. Countries bordering on the oceans had coastlines. The rise and fall of the tides were measured and a mean was established. This mean became the standard reference to zero elevation. Over the years, this became known as mean sea level (Hofmann-Wellenhor, 1994).

Just as one datum plane is not the same as another region, so MSL may be different from one country to the next. Specifically, those countries which did not have a coastline would have to accept the standards of another. This would solve an individual problem, but it does not solve everyone's problem. To create a worldwide reference for the vertical datum, a surface that was at mean sea level would extend around Earth underneath all continents. This surface, however, would be affected by differences in the density of Earth, a higher density under mountains, and a lower density in the middle of the ocean (see Figure 12).

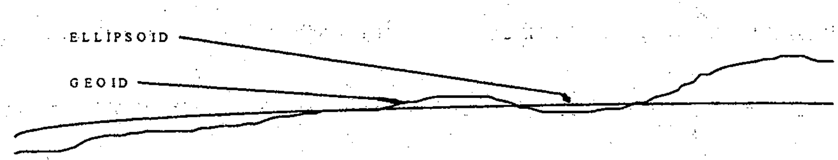

Figure 12. Mathematical Model and Geographic Model of the Surface of Earth

This surface is known as the "geoid." The geoid and MSL are about the same at any coastline. The geoid, like the WGS-84 datum, is referenced to the center of Earth, but unlike the smooth surfaces of an ellipsoid, it has an irregular surface because of the effects of the different rock densities within Earth. Ellipsoids and geoids are different and do not coincide in use. This difference is caused by the different measurements of gravity around the world and is used to create a geoid model based on tabular rather than mathematical data (Hofmann-Wellenhor, 1994). GPS receivers have a conversion program that references ellipsoid elevations to MSL around the world. The accuracy of the geoid has been refined over the years to the present accuracy of better than 4 meters for 93% of Earth.

Information about the vertical datum is usually contained in the legend of a map and is usually listed as MSL, although it may be listed as a national or local vertical datum. Again, caution is advised to know what information is being presented.

After the selection of the ellipsoid, horizontal, and vertical datums, the mapmaker selects the best map projection for his area of intended use. Three map classes exist: conical, spherical, and polar. Each map has projections that come in many types, and each type has a specific purpose (Richardus & Adler, 1972). The type of map projection is printed in the map margin area. Some types of GPS receivers have a capability to let the user define a grid area, but to do this the user must enter the type of projection to be used. Generally, maps used for aerial navigation come in two specific types: Transverse Mercator and Lambert Conformal. Both of these maps state that they are "reasonably accurate" for navigation because flat maps cannot exactly duplicate the surface of the spherical Earth (United States Department of the Air Force, 1983).

Whereas we function in a three-dimensional world, we use a two-dimensional map to represent the globe. GPS receivers work in a three-dimensional world.

Correlation between a two-dimensional flat map and data from a three-dimensional GPS receiver is difficult, even if we read both accurately and correctly.

In addition, maps made prior to using GPS were somewhat inaccurate. Several reasons exist for these inaccuracies. First, the primary tool was a sighting scope. The initial point was defined exactly with other reference points defined by visual line of sight calculations. Errors were accumulated as the process was continued. Second, deflection from vertical was determined by a plumb line, a piece of string with a weight at the end. The question becomes, "How can you be sure what is straight and what is not?" Third, the most familiar error is equipment error. It does not matter whether the hardware is a little off or that it may be set up a little off, there is still an error. This can cause changes in readings. The accumulation of these errors has made it clear that maps are not absolute truth (Langley, 1997). All maps have what is known as displacement error. This is exemplified when the mapmaker tries to show a road or a river. The actual size would be too small to actually use. Therefore, the size is exaggerated or displaced so it can be recognized. This displacement induces an error. The movement on the map may be only a few millimeters, but the actual position on Earth may differ by several hundred meters. GPS receivers will provide a better and more accurate position (United States Department of Defense Information and Analysis Center, 1996).

Maps are only symbols of reality and not meant to be used to go from map to a precise place in reality. Two worldwide coordinate systems are used: (a) Earth Centered, Earth Fixed, and (b) the Geodetic system. (see Figure 13)

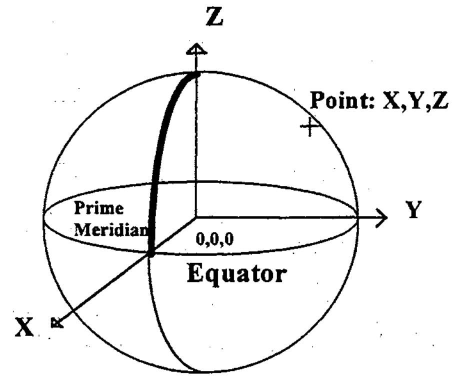

Figure 13. GPS Coordinate System

Earth Centered, Earth Fixed system defines a position in a three-dimensional plane called the X, Y, and Z coordinates and referenced from the center of Earth. The X-axis is defined as the intersection of the prime meridian and the equator. The Y-axis is defined as the intersection of longitude 90 degrees east of the prime meridian and the equator. The Z-axis points toward the north pole. GPS receivers use this system to obtain a precise position which is then converted to the coordinate or grid system selected by the user. To compute for a position, four satellites are required to provide the X, Y, and Z dimensions for position. A fourth is required for altitude computations.

The Geodetic system uses the traditional latitude, longitude, and elevation to define a three-dimensional position as referenced to the surface of Earth. The equator and the prime meridian are the two planes that are used to define the latitude and longitude. The geodetic latitude is the position north and south in a perpendicular angle to the equator. The geodetic longitude is the position east or west in a perpendicular angle to the prime meridian. The geodetic height is the distance above or below perpendicular to the ellipsoid.

Latitude ranges from 0 degrees at the equator to 90 degrees north and south. It defines the north and south hemispheres. Lines of latitude are parallel; therefore, the distance between them is constant. Longitude at the prime meridian is 0 degrees ranging to 180 degrees east and west. It is used to define the east and west hemispheres. Units of measure for latitude and longitude are broken down into degrees, minutes, and seconds. Sixty seconds equal 1 minute, and 1 minute of latitude equals 1 nautical mile, and 60 minutes equals 1 degree of latitude. Longitude is measured the same way, but only at the equator. As you move either north or south away from the equator, the lines of longitude start to converge and the distance between them gets smaller as you approach the respective pole (United States Department of the Air Force, 1983).

Another type of coordinate system is called the polar coordinate system, better known as "Bullseye." A bullseye is the center of origin. It can be fixed on the surface of Earth or it can be moving. It can be a landmark or just a set of coordinates to mark a center that is oriented toward magnetic north; basically, it is a compass. Each degree represents azimuth from the center of the compass or bullseye. A bullseye position is determined by an azimuth and range from the center. Imagine a point with concentric circles around it, such as a dart board. When you throw a dart into the board, you can determine its location as it relates to the center of the board. A bullseye type of position works on the same concept and is not meant to be a precise position, but it allows the operators to maintain some idea of where they are in relation to where they put the bullseye on the map.

Digitized database maps show positions that have been surveyed and the information has been put into a database. Information on these types of maps are much more accurate because the positioning is in three dimensions (United States Department of Defense Information and Analysis Center, 1996). This paper map is scanned and optically read, digitized, and stored. It can then be projected on a video screen. Information stored in this way is called raster information. A raster chart is an exact replica, an actual picture, of a paper chart. This means the information is stored in a bitmap format. This type of format stores pictures as a binary digits of "1's" and "0's" and requires a large memory capacity. Each line on a chart is converted into a "raster" picture element or "pixel." The pixels form images on a screen, but the computers cannot interpret what they mean. Images appears on a raster chart, but being able to determine height, length, age, and ownership comes from additional image processing called vectoring. This process is the actual graphic representation of a paper chart in a digital structure. (Canadian Hydrographic Service, 1997). Although raster charts are inexpensive compared to vector charts, each chart provides better technology for safer navigation. This capability is probably best known as a moving map display providing position, speed, track, geography of the terrain, obstacles, and different waypoints (Clarke, 1994).

Earth is surrounded by a magnetic field with magnetic north and south poles. These poles are not the same as the geographic poles. We use the geographic poles to navigate in a relationship to "true" north, and we use the magnetic poles to navigate in a relationship to "magnetic" north. The angular difference between the two is called variation. All commercial and military aviation maps display magnetic variation data in some form. The difference between true and magnetic and the relationship with GPS receivers must be known.

Different GPS receivers will use either true heading or magnetic heading, and some can do both for analysis. True heading refers to traveling in relation to the geographic poles and magnetic heading refers to traveling in relation to the magnetic poles. The location of these poles are not the same and the angular difference between the two is measured as magnetic variation and is different depending on the user location around the world. Individuals using a GPS need to know which type of navigation the receiver uses, because in some parts of the United States the variation between magnetic and true could be as much as 28 degrees. To navigate relative to magnetic north, most GPS receivers have a computer model called magnetic variation (MAGVAR) (United States Department of Defense Information and Analysis Center, 1996). This model computes the magnetic variation at the GPS location and applies it to the true heading to get the magnetic heading. As time goes by, the variation at any one place will change in one or two degree increments. The MAGVAR computer model will be updated every five years; the current model was started in 1995. Individuals using GPS receivers on the ground need to remember that the model of magnetic variation accounts only for the variation of the magnetic field of Earth and not for local ore deposits or any other type of localized magnetic fluctuation. This could vary from location to location. To use the model effectively, individuals must select magnetic mode or enter the values from the map legend. Magnetic variation is not expressed in terms of plus or minus, but in degrees east or west of a line of no variation called the agonic line and runs between the magnetic poles. If the magnetic variation lines are marked on the user chart, they are connected by lines showing the constant variation on lines called isogonic lines. Depending on the location of magnetic north, variation is either added or subtracted in order to get a magnetic heading. If the variation is east, then the variation is subtracted from true north to obtain a magnetic heading and for west variation, the variation is added to true north (United States Department of Defense Information and Analysis Center, 1996).

Failure to understand the concepts of GPS theory could lead to confusion and a lack of confidence in using a very precise navigation system. Operators of GPS receivers must understand the types of maps they are using, which datum plane they are using, and how to use a particular type of GPS receiver to effectively and safely navigate around Earth (United States Department of Defense Information and Analysis Center, 1996).

Differential GPS

Differential GPS (DGPS) is exactly what its name says it is, a different type of GPS signal transmitter. This transmitter was developed to refine and provide better accuracy for the SPS used in the civilian sector. The following is a description of how DGPS works. A station is surveyed at a precise location. It receives positioning data from normal GPS receivers from all satellites in view, compares the positioning data with the fixed location information, and determines the difference. (see Figure 14)

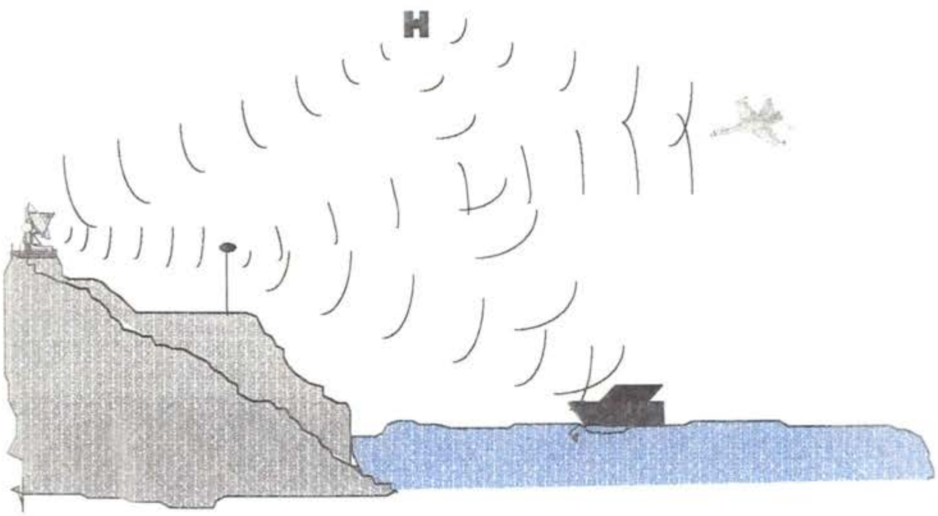

Figure 14. Differential GPS

This difference is the combination of all errors from those satellites in view. The station then transmits the error corrections on a Ultra High Frequency (UHF) of 283.5-325.0 Kilohertz (kHz), much like a normal radio beacon, from its location to anyone who can pick them up, usually a couple hundred miles. With the right equipment, you can connect a GPS receiver to a DGPS receiver and have all corrections go directly into your GPS receiver. The final position displayed will be the corrected one, usually within 10 meters or less. Using DGPS is the only way individuals using SPS can eliminate the errors induced by the government through SA. The U.S. Coast Guard is already using this type of system to aid maritime navigation close to shore and at other inland locations. At the time of this writing, DGPS stations run by the Coast Guard cover almost all of the eastern United States (Garmin, 1997). The Federal Aviation Administration (FAA) is also conducting experiments on using this type of system for air navigation and precision approaches. Single DGPS installation allows for the creation of multiple approaches at multiple airports, usually within 15 miles depending on the terrain (Goyer, 1998). People are authorized to use this system free of charge, but need to purchase the DGPS receiver.

Use of GPS

Several applications for GPS are already in use in the United States, and many more loom on the horizon. It is used in surveying, camping, hiking, tracking vehicles, banking, maritime navigation, and air navigation. The concentration will be only on the air navigation portion, although some of the information may be generic in nature and apply to other uses of the GPS system. All GPS units should have the minimum capability to compute and fix the user's present position; provide ground track and groundspeed; provide distance to the next point; create and use waypoints, alarms approaching a point, and some sort of database of intersections, airports, and radio aids.

Most GPS units can be set up based on the individuals who are going to use them. It depends on whether they want miles or kilometers, meters or feet, and so forth. Second, make sure to check to insure that the correct datum and ellipsoid information is being used. Third, check the equipment and make sure it is operating properly and all of the correct components are present (antenna, batteries, cables, and so forth). The last of the initial steps is to turn on the unit and get the initial Time-to-First-Fix (TTFF). TTFF is the time it takes for the receiver unit to power-up, look for satellites in view, and determine a position. If this is the first time the receiver has been turned on, or if a long time has elapsed since the last use, the TTFF could take anywhere from 10 to 15 minutes to initialize to the user's position. If the user knows the current present position, however, the unit will "lock-on" to a satellite much faster. Once the unit has acquired a satellite, it will download time, the position of the satellite, and almanac data, and update its database. It is now ready to use (United States Department of Defense Information and Analysis Center, 1997).

All GPS receivers provide several pieces of information useful to the pilot, including:

1. Ground speed (GS) - relative speed of a vehicle traveling across the surface of Earth.

*NOTE: Different GPS receivers will have different threshold/limits to measure ground speed. Check the instructions to ascertain if this unit will track ground speed.

2. Azimuth (AZ) - an angle measured from North on a horizontal plane around the aircraft.
3. Course (CRS) - the flightplanned path of travel measured as an azimuth.
4. Range (RNG) - distance measured between two points, usually in nautical miles.
5. Cross Track Error (XTE) - the perpendicular distance left or right of course.
6. Track (TRK) - the actual path the aircraft takes across the ground measured as an azimuth.
7. Heading (HDG) - the magnetic course to follow to get to the next point or destination.

8. Distance (DIS) - the actual range from present position to next point or destination (Clements, 1997).

Positions are generally loaded by using latitude and longitude, although most units with a database allow positions to be defined as intersections, airports, radionavigation facilities, and user defined points along with latitude and longitude (Adventure GPS, 1997).

GPS is used for flying in two ways. First, the “bullseye” method. If the unit is going to be used by a general aviation flier who plans to stay within a couple hundred miles of the local airport, the bullseye method is probably the easiest use of GPS. The airport of departure is the bullseye point. By using this method, the pilot will always know how to get back to the airport of departure by using the azimuth and range displayed on the unit. In addition, this is a useful tool in helping the pilot maintain a situational awareness of where the aircraft is in relation to the departure airport. This is a very simple, nontechnical use of the GPS system (Clarke, 1994).

The second use involves commercial, business, and private pilots going cross country. This is accomplished by inputting a group of waypoints into the receiver. A waypoint is a defined location, such as an airport, intersection of roads, paths, and intersection of airways. A group of waypoints makes up a route. Generally, a route is planned to follow a published airway or to avoid certain areas, such as military operating areas, special use airspace, or mountains. Each waypoint is entered in the order that the flight is intended to take. After all of the waypoints have been entered, the pilots will have all the data for each leg of the flight. Track, ground speed, TO and FROM points, heading, distances, enroute time, and position can all be made available at a push of a button.

Different methods of navigation are possible with GPS. One way is to insert the flightplan and fly it. This will direct the aircraft from one waypoint to another in the order entered. As long as the aircraft stays on-course, the cross track error will be zero or when deviations occur from the planned course, the FAA Air Route Traffic Control Center alters the aircraft course; or if a deviation is required because of weather, this is where GPS then makes traveling and navigating a lot easier. GPS receivers always show the present position, the heading to the next point, and how far off course the aircraft has drifted. The pilot can then elect to return to the course or fly directly to the next point. Having GPS helps maintain the situational awareness. As the aircraft approaches the selected waypoint, the GPS provides the pilot with visual or aural indication that the aircraft is nearing the point. The GPS system automatically switches to the next point or the user may select to switch it over manually. In either case, both provide distance and heading information to the next destination. As the aircraft arrives at the destination airport, some GPS databases contain the published approach plates for specific airports. These databases are updated every 28 days. The GPS published approaches define the approach waypoints up to the missed approach point by latitude and longitude. Several GPS receivers can provide distance, horizontal, and vertical data to assist with approaches; however, no FAA approved precision approaches exist (Collins, 1998).

Safety is a concern when using GPS. Most GPS receivers contain a database which allows the pilot to select NEAREST AIRPORT or NEAREST FACILITY. This can be extremely useful during cross country flights when bad weather suddenly appears.

Hand-held GPS receivers present a couple of problems. First, because they are portable, they are not fixed or secured. During times of turbulence or abrupt turns, the GPS receiver may fall to the floor and require the pilot or passenger to look away from outside the cockpit to inside, possibly causing the pilot to suffer spatial disorientation or leave the receiver on the floor and risk the receiver possibly jamming some of the flight controls. In addition, they are fairly fragile pieces of equipment, and damage could occur. Generally, portable GPS receivers have antennas attached to the unit. GPS signals can be interrupted by the side of the aircraft or by the wings of the aircraft during turns. GPS reception from within the aircraft can be extremely difficult.

Embedded GPS receivers can be independent or may be connected with some other navigation sensor, such as LORAN or VOR. These systems work the same way as the hand-held GPS receivers except they do not flop around the cockpit, the antennas are generally attached to the exterior of the aircraft, and they can provide more precise information when tied to another sensor. The drawback, however, is that these other sensors are being phased out of service over the next two decades (United States Department of Transportation and Department of Defense, 1996). Finally, do not depend on GPS as the sole source instrument for Visual Flight Rules (VFR) or Instrument Flight Rules (IFR) navigation; maintain situational awareness; and know where your aircraft is and where it is going.

Probably the most common type of GPS receiver is one with a moving map display. This type of system is very useful for the user to maintain a situational awareness of the area around them. These receivers, with the correct software and hardware, can be hand-held units, embedded systems, or can be used in conjunction with laptop computers (Clarke, 1994).

The hand-held GPS and those embedded system receivers having a moving map display present an electronic map with the aircraft in the center of the screen. The display will usually provide navigation information on the side of the display, and different ranges of view can be selected. This type of display will also show the position of other airports, radionavigation facilities, and airspace boundaries. The problem with these types of receivers, other than those already mentioned, is that the display is rather small. Also, embedded systems rely on the aircraft power to work.

Laptop computers provide an operator with a much more flexible and powerful system. Software on the laptop can display several types of charts, including sectional and World Area Charts (WAC). These charts allow the operator to fix their present position, and also to see where the towns, roads, and other information are located. Laptops having the correct software and connected to a GPS receiver can then receive the GPS data and convert it so it displays on the screen. Depending on the software package, these laptops are capable of displaying aircraft instruments and performing flightplanning functions along with the normal moving map display. Another added benefit to laptops is that they can run on aircraft power or on battery power, if required. Some companies produce laptop holders for the individual flying alone (Clark, 1994). The use of moving map displays is very useful in showing our location relative to map landmarks and have the additional capability of showing the correct direction and how to get there in an easily readable format.

Future with GPS

One of the main uses for GPS is to provide information and guidance data for aircraft to fly approaches to selected airports. Although several different types of GPS receivers exist, the set up for use is basically the same. To use GPS for approaches, the steps are:

1. The desired destination airport must be in the active flight plan or be the current "Direct To" waypoint.
2. Select the desired airport.
3. Select the page listing the types of approaches available for that airport.
4. Select the type of approach to be flown.
5. Select the desired starting place for the approach.
6. Set the range to "Auto."
7. Select Omni Bearing Selector (OBS) for radar vectors or holding pattern and Leg Mode when intercepting the final approach course.
8. Look for Approach Leg (APR-LEG) and Approach Active (APR-ACTV) displayed on unit. Fly the airplane so as to keep the needle centered (Clements, 1997).

Safety is still the key word. Be sure to read the approach chart carefully and thoroughly, and practice a lot with the GPS unit in visual conditions before flying in weather (Clements, 1997).

Currently, GPS receivers are approved by the FAA for nonprecision approaches only. They are working on a precision capability. The FAA is in the process of testing and implementing the Wide Area Augmentation System (WAAS). The FAA will build and maintain its own system of about 35 ground and master stations. The ground stations will receive the GPS satellite information and send the data to the master stations for processing. This processing will determine integrity, differential corrections, and ionospheric information from each GPS satellite and develop Geostationary Earth Orbit (GEO) satellite navigation parameters. This combination of processed data will be uplinked to the GEO satellites which will be able to downlink this data on the GPS L1 frequency. This will allow the same receiver to be used to receive both GPS and WAAS signals (United States Department of Transportation and Department of Defense, 1996). The initial operational date for WAAS is in early 1999 with a goal of 2001 to achieve a level of sole-source navigational capability (United States Department of the Air Force, Feb.1998). As soon as GPS/WAAS avionics are available, they will take the place of technical standard order (TSO)-C129-based GPS avionics. The manufacturers of aviation products submits requests for TSOs to the FAA. A TSO is issued by the FAA Administrator and is a minimum performance standard for specified equipment used on civil aircraft. Therefore, TSO-C129 GPS avionics (currently being used) will not be usable for primary or sole-source navigation capability, nor can they be used for GPS/WAAS nonprecision or precision approaches unless they are upgraded to meet the new avionics standard (United States Federal Aviation Administration, 1997). The accuracy of this information will be 100 meters 95% of the time throughout the National Airway System (NAS), and for Category I approaches, horizontal and vertical are guaranteed at 7.6 meters 95% of the time. (NOTE: Category I approaches refer to the type of landing of an aircraft using an Instrument Landing System (ILS) and determine the minimum altitude allowed for that particular approach.) The benefits of the WAAS system will be:

- Aircraft will be able to fly more direct routes, saving time and money.
- Current, expensive, older radionavigation aids will be eliminated.
- National Airway System will be less congested, allowing more aircraft into the system and reducing airplane and passenger delays.
- Onboard navigation equipment will be reduced. (United States Department of Transportation and Department of Defense, 1996).

The Local Area Augmentation System (LAAS) is a plan to start where WAAS stops. It calls for a DGPS system to be set up at major airports with a range of about 25-30 nautical miles and providing line-of-sight navigational guidance so a pilot will be able to fly Category II or III approaches. Category II and III approaches lower aircraft minimums for landing and increase proficiency requirements for the pilots (United States Department of Transportation, Federal Aviation Administration, 1997).

LAAS will also provide approach and departure guidance, terminal navigation, and airport surface navigation. The FAA will choose the LAAS architecture and development by 1998 (United States Department of Transportation and Department of Defense, 1996). The FAA has decided to have the users of the LAAS system pay for its use. The users will fund the development of the LAAS through a system of 143 installations to be operational by 2006 (United States Department of the Air Force, Jun. 1998).

In summary, GPS is a great leap forward in terms of navigation and locating a precise position on Earth. Indeed, it is the most accurate aid currently available. The key word, however, is aid. It is a tool to assist the individual and should not be relied upon to be precisely accurate 100% of the time. This system has drawbacks as does any other similar system. Individuals who require precise positioning should always maintain a situational awareness of their location to ensure that the information received from GPS is reasonable and accurate. Using GPS will be of greater benefit to the user as an aid as opposed to a sole source positioning unit until the system is 100% accurate, 100% of the time.

CHAPTER III

METHODOLOGY

The purpose of this study is to document the theory, development, and training needs relative to the United States Global Positioning System for the United States Air Force.

The Headquarters of Air Education and Training Command (AETC) was contacted and asked for all training materials dealing with GPS. AETC advised that the Air Force did not currently have any training program on GPS theory and operation. The only information being used was an *Introduction to GPS* lesson developed for a one hour block of instruction during navigation school, which is not used in pilot training at all. Because the Air Force does not have a program developed on GPS, a need exists to develop one for the Air Force to use in the training of military pilots and navigators (Major Jones, personal communication, May 1997).

The author has developed other navigation lessons over a 25-year Air Force career. The format developed was an introduction, past history, present status, future enhancements, and a conclusion. The following outline was used to develop this training program.

GPS: Theory and Operation

I. Introduction

   A. Concept of satellite positioning

II. Background

   A. Composition of the Global Positioning System

   B. Principles of operation

      1. Satellite frequencies

      2. How does GPS work?

      3. Positioning

      4. Geometry

      5. GPS errors

III. GPS theory

   A. Two dimension vs. three dimension

   B. Horizontal vs. vertical datums

   C. Earth-Centered, Fixed Coordinate system

   D. Magnetic variation

   E. Differential GPS

IV. GPS operation

   A. Initial setup

   B. Information available

   C. GPS uses

V. Future uses of GPS

A. Approaches

B. WAAS and LAAS

VI. Conclusion

The introduction is used to provide the audience with an overview of the materials being presented. The background, GPS theory, GPS operations, and future uses of GPS comprise the body of the lesson. The body is used to provide new instructional material sequenced to ensure the maximum transfer of knowledge. It will provide the detail necessary to support the efforts of assigned instructional personnel.

The conclusion will provide a summary of the materials presented in the introduction and body of the lesson (United States Department of Defense, 1990).

CHAPTER IV

FINDINGS

If education is the key to the use and understanding of technology, then educators must provide the education that American businesses do not provide. The education system is required, by definition, to provide users of new and innovative technology with the educational base from which to understand their new capability. Individuals must not only know how to use the system, but must also be aware of the theory behind the system, why it works, how it works, and in what circumstances the system may not work, in order to take the maximum benefit from it.

Several individuals have asked, "What is so important about knowing the theory and background of GPS?" The following rationale is an attempt to explain the importance of GPS theory and operation.

The U.S. Air Force, when teaching about any aviation system, has always included information about theory and concept of operation. People who use most complex systems, such as airplanes, computers, or cars, have a general understanding of how and why the systems work and what errors may be inherent in the system.

Regarding radionavigation aids, such as TACAN, slant range errors and possible 40 degree "lock-on" errors are inherent in this system. RADAR can have a slant range error, a "no show" area, and a variety of intensities depending on the density of the target.

These are inherent errors of this system. Finally, celestial navigation has induced errors based on level or nonlevel flight, changes of airspeed, and the changing of the positions of the stars and planets (United States. Department of the Air Force, 1983). These are but a few examples.

The Global Positioning System has been promoted as a new user-friendly navigational system that anybody can use, anytime, anywhere. GPS, however, is not a carefree and absolutely correct radionavigation aid, it has errors.

GPS users must understand and realize that errors occur. Failing to use the system properly and not realizing that errors could occur might hamper the user's safety in finding or returning to a checkpoint or navigation point. Further, for individuals who plan to develop areas or facilities that will use GPS such as airports or harbors/docking facilities, GPS theory will be a requirement. Along with being more knowledgeable about the system they are using, users will have a better overall understanding of the limitations of the GPS system.

Finally, understanding the system might let the user determine whether or not the system needs maintenance, in which case the system should not be trusted. Some type of error represents only a momentary occurrence, such as sun spots or solar flares that can affect radionavigation equipment. What is important in learning and understanding the GPS system? The importance is the proper use and understanding of new technology.

Major Rick Jones, Chief of U.S. Air Force Navigator Training at Headquarters Air Education and Training Command (HQ AETC) relates, "The U.S. Air Force does not have any other training program other than the one hour block training on *Introduction to GPS*" (Major Rick Jones, personal communication, May 1997). In September 1997, Congress mandated that all military aircraft will have GPS. Although the Air Force is in the process of developing a theory and operations course on GPS, this one hour of training will barely scratch the surface of GPS.

The Air Force block training consists of the following information:

1. A brief introduction to GPS.
2. Military and civilian applications of this system.
3. A general system description of GPS.
4. A brief explanation of the theory of operation.
5. A discussion of the errors inherent in GPS.
6. A discussion of the system's security and survivability.

All of this information is provided in a one hour block lesson and does not provide any information on GPS capabilities or limitations. Based on the author's experience of over 25 years in the Air Force training business and the review of literature, the GPS: Theory and Operation course was developed. (See the Appendix for the GPS course on theory and operation.)

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The purpose of this study is to document the theory, development, and training requirements as related to the United States Global Positioning System for the United States Air Force.

This study has explained in a simple format the inner workings of the Global Positioning System. The discussions have centered on GPS, basic understanding of DGPS, WAAS, and LAAS and a better understanding of the overall system and how it works. The research has revealed that the Air Force does not have any training program to provide GPS theory or operations. It has been directed by Congress that all military aircraft will have use of GPS by the year 2000. This will force the Air Force to develop and implement a training program for GPS before that time. It is conceivable that a quick and poorly made training package could be developed to offset the speed of new developing technology. Only the passage of time will determine if this is true. However, aviators should be aware that GPS is still a relatively new navigational aid and should be used only as an aid and not as a sole source totally reliable capability.

The technology is changing so rapidly as to outdate this information in a very short amount of time. The increase of technology should not change the basic concept of how and why the GPS system works. Technology will probably solve the problem of providing precise positioning capability to allow anyone to navigate anywhere in the world and even to allow Category II and III precision approaches at most major airports. The DOD and FAA will be able to work together to provide precise navigation to the civilian sector while providing security to our military forces. The cost is still to be determined, in money or lives. Only time will tell.

This study revealed the Global Positioning System has errors. Some of these are inherent and some can be induced by the system or the user. The following are recommendations on how to correct or minimize these errors.

1. Aviation education should provide a course on GPS to provide the basic information to the users, as in the appendix to this study. Users need to be aware of not only the inherent errors, but also of the errors that they may induce by carelessly inputting the wrong data or having problems with either the receiver hardware or software. The course could provide information for the student to know when things are in error.

2. In addition to a course, users should have available to them a GPS laboratory to provide a "hands on" approach to GPS usage. This lab could provide simulations of known GPS problems and allow the user to become familiar with what an error looks like on a receiver. This would also provide the student with an opportunity to learn about situational awareness, determine if the system is wrong, and how to correct it. The lab could also be used to reinforce the concept that GPS should never be relied on as a sole means of navigation.

3. To make use of the current computer technology and to provide the information to a broader audience, there should be an Internet web site established to collect data on GPS errors that users could read and /or participate. These lessons learned from across the user spectrum could provide invaluable information on errors, corrections of errors, and in what situation these errors occurred. This information could be in a Lessons Learned format so that it could be shared by anyone wanting or needing this type of information. This would lessen the chance of making the same errors as someone else. This bulletin board could provide a means for users to stay current on different GPS issues, such as, how to read and understand Notices to Airmen (NOTAMS), WAAS, LAAS, NAS, and to stay abreast on new GPS changes.

Aviation education has played and will play an increasing role in the evolution of GPS and other new and innovative technologies. We must always keep an open mind, so we can see and avoid the pitfalls that new technology brings to us and never blindly accept the "cure all" approach as GPS has been presented. After all these years in development, GPS is still only a radio.

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APPENDIX

GPS: THEORY AND OPERATION

COURSE

Purpose:

The purpose of this course is to provide information about GPS in a simple, understandable way, and to develop a basic nontechnical training course on GPS theory and operation.

Objectives:

To comprehend:

1. The history of GPS
2. The description of the GPS constellation.
3. What the satellites transmit.
4. The satellite frequencies.
5. The different segments comprising the GPS program.
6. Ranging, Positioning, and Geometry of GPS.
7. The inherent errors of GPS.
8. Maps, Earth surfaces, and coordinate systems.
9. Differential GPS and how it works.
10. What GPS provides to the user.

This type of detailed discussion will provide better understanding of GPS and provide the operator with knowledge and confidence to use the overall system, while making the user aware of GPS capabilities and limitations. It also provides some insight into the future of this system, how GPS will integrate into the NAS, and what is needed to conduct precision approaches.

The following GPS course is provided in the Instructional Systems Design (ISD) format. In addition, each lesson has attached suggested extracted data to assist the instructor with lesson development.

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: INTRODUCTION

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this course is to provide information about GPS in a simple, understandable way, and to give a basic nontechnical training course on GPS theory and operation.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-1 thru GPS-9

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-1		
	A. OVERVIEW	
GPS-2		
	1. This lesson will cover the introduction to GPS Satellite Navigation. 2. The purpose of this lesson is to introduce the student to the Global positioning System (GPS). B. MOTIVATION 1. The information presented in this lesson will provide the student with the history of this system and provide some of the reasons for GPS. 2. This lesson provides the start for a firm foundation in understanding GPS. C. OBJECTIVES	
GPS-3		
	Given and in accordance with (IAW) the information provided by the instructor, the student will be able to:	

1. List two reasons for the need of GPS navigation.

2. Describe the GPS constellation and it's components.

3. Explain the GPS area of coverage.

4. List the components of the GPS system.

5. Name the location of the five ground stations and their functions.

II. BODY

A. SATELLITE NAVIGATION HISTORY

1. In discussing GPS, it might be helpful to understand the reasons why GPS became necessary.

a. To replace the aging radionavigation system.

b. To reduce the cost of maintaining the various types of radionavigation aids.

GPS-4

2. GPS Evolution

a. Phase I was to allow companies to compete for design and development contracts of the three segments of NAVSTAR GPS.

b. Phase II started full scale development and system test from 1980 through 1985.

c. Phase III started in 1985 with the movement of the master control station from Vandenberg AFB, California. to Falcon AFB, Colorado.

GPS-5

B. NAVSTAR SYSTEM

1. 24 Satellite Constellation

a. 21 operational

b. 3 spare

2. Satellite coverage between 60 degrees North and 60 degrees South is 100%

3. The system has three major components.

GPS-6

a. Space - The space section is composed of the GPS satellites.

GPS-7

b. Operations Control - The Operational Control Section (OCS) is made up of monitor stations, ground antennas, and a master control station.

c. User - The User section consists of the various configurations of antennas and receiver-processors.

III. SUMMARY

GPS-8

A. LESSON REVIEW

1. Satellite Navigation History

2. NAVSTAR System and it's components.

B. OBJECTIVES

Given and IAW the information provided by the instructor, the student will be able to:

1. List two reasons for the need of GPS navigation.

2. Describe the GPS constellation and it's components.

3. Explain the GPS area of coverage.

4. List the components of the GPS system.

5. Name the location of the five ground stations and their functions.

C. PREVIEW

The next lesson will discuss the principles of operation.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 1

- INTRODUCTION

The GPS satellite system is an all weather radionavigation positioning aid capable of providing a precise position within centimeters, with the right equipment. The Federal Radionavigational Plan, revised 1996, will eliminate most aviation navigational aids by the year 2005. This has a twofold purpose: (a) To replace the aging radionavigation system providing more accurate positioning and (b) To reduce the cost of maintaining the various types of radionavigation aids in use today.

GPS was developed by the Department of Defense (DOD) to simplify accurate navigation. It uses satellites and computers to triangulate positions anywhere on earth. The implementation of GPS was conducted in three phases. Phase I was from 1973 to 1979. The first year of Phase I was to allow companies to compete for design and development contracts of the three segments of NAVSTAR GPS. In 1974, a contract was awarded to Rockwell International to develop 3 prototype satellites which were later increased to 11. A contract was awarded, in 1974, to General Dynamics for development of the control and user segments of NAVSTAR

GPS. General Dynamic subsequently subcontracted development of the user segment equipment to Magnavox. The initial control station was located at Vandenberg AFB, California. The first satellite was launched in 1977, but malfunctioned after 7 to 8 months. The first four satellites were launched in December 1978, providing three dimensional navigation capability using only satellites for the first time. Phase II started full scale development and system test from 1980 through 1985. In 1980, contracts for development and design of the user segment equipment was awarded to Magnavox, Rockwell/Collins, Texas Instruments, and Teledyne; and IBM was awarded the contract to build an initial control system as an interim system to fill the gap between the Phase I control system and the final operational control system. At the same time, IBM was also awarded the contract to build the final operational control system which was to be located at FALCON AFS, Colorado. Phase III started in 1985 with the movement of the master control station from Vandenberg AFB, California. to Falcon AFB, Colorado. and the entire system became operational for worldwide civilian use in April 1995.

The NAVSTAR system consists of 24 satellites, 21 operational and 3 spare, orbiting in six orbital planes around the earth at an altitude of approximately 10,900 nautical miles. Each plane contains four satellites spaced at 60 degree intervals providing precise navigational positioning, time and velocity data. This spacing provides for five to eight satellites to be visible from anywhere on earth at any one time. The satellite coverage is 100% between 60 degrees North and 60 degrees South with lesser degree coverage at either pole.

The GPS has three major components of the system: space, control, and user sections. The space section is composed of the GPS satellites. These satellites send radio signals from space. This group or constellation of 21 operational satellites with 3 in-orbit spares arranged in six orbital planes orbits the earth once every 12 hours.

Each plane contains four satellites spaced at 60 degree intervals providing precise navigation positioning, time, and velocity data.

Ground stations

The Operational Control Section (OCS) is made up of monitor stations, ground antennas, and a master control station. The five monitor stations are located at Hawaii, Kwajalein, Ascension Island, Diego Garcia, and Colorado Springs. Three ground antenna stations are located at

Ascension Island, Diego Garcia, and Kwajalein. The master control station (MCS) is located at Falcon Air Force Base in Colorado.

The monitor stations passively track all satellites in view using a GPS receiver and accumulate ranging data from the signal from each satellite. This data is used to compute a precise orbital data (ephemeris) and satellite's clock corrections. Errors in the ephemeris or satellite clock will cause an apparent error in the user's clock. The error range is very small, about five feet. The information is collected and sent to the master control station at Falcon Air Force Base. The MCS determines the clock for each satellite and orbits, and updates the individual message from each satellite. The updated information is transmitted to each satellite from the ground antennas, which are also used to receive and transmit health and control information

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: GPS: THEORY AND OPERATION

LESSON TITLE: PRINCIPLES OF OPERATION

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to provide the student with the basic information concerning the placement of satellites, the validation of their position, and the data transmitted.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-10 thru GPS-18

HANDOUTS:

OTHER PERTINENT INFORMATION

	I. INTRODUCTION	NOTES
GPS-10		
GPS-2	A. REVIEW 1. In the previous lesson the discussion centered on the introduction to GPS history. 2. This lesson will address the principles of operation of GPS satellites. B. OVERVIEW	
GPS-11		
	The purpose of this lesson is to provide the student with the basic information concerning the placement of satellites, the validation of their position, and the data transmitted. C. MOTIVATION 1. The information in this lesson will continue to build the foundation of explaining GPS. It discusses the satellite transmissions and what is contained in the message.	

2. It is important for students to understand the inner workings of the system to assist them in evaluating a GPS position.

D. OBJECTIVES

GPS-12

Given and IAW the information provided by the instructor, the student will be able to:

1. Comprehend the placement of GPS satellites.

2. Describe how the satellites validate their position.

3. Describe what information is transmitted by the satellites.

4. Describe the use of time, almanac, and ephemeris data.

II. BODY

A. SATELLITE POSITION

1. The placement of satellites allows GPS receivers to solve for latitude, longitude, and time with at least three satellites in view and height or altitude if a fourth satellite is present.

2. Every GPS receiver has an algorithm used to calculate and predict a satellite's location with respect to time.

B. SATELLITE TRANSMISSIONS

GPS-13

1. Pseudo-Random Noise (PRN).
The PRN is used to uniquely identify a particular satellite. All satellites have their own PRN from 1 - 32 or their own ID code

GPS-14

2. Time.
The satellites have very accurate clocks that transmit signals at the speed of light along with a precise timing message

GPS-15

3. Almanac.
The Almanac is an estimated position of the satellite constellation based on a six-month projection.

GPS-16

4. Ephemeris.

a. Ephemeris data is transmitted in every navigation message providing precise satellite orbital information and clock corrections for that specific satellite.

b. Ephemeris data is updated about every two hours from a ground station and assists GPS receivers in determining a position.

III. SUMMARY

GPS-17

A. LESSON REVIEW

1. Satellite placement

2. Satellite Transmissions

B. OBJECTIVES

GPS-18

Given and IAW the information provided by the instructor, the student will be able to:

1. Comprehend the placement of GPS satellites.

2. Describe how the satellites validate their position.

3. Describe what information is transmitted by the satellites.

C. PREVIEW

The next lesson will discuss satellite frequencies.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

The placement of satellites allows GPS receivers to solve for latitude, longitude, and time with at least three satellites in view and height or altitude if a fourth satellite is present. Each satellite transmits a burst of data containing its position and time data. This message contains information about the satellite clock and ephemeris data, satellite health, and a UTC synchronization function. Every GPS receiver has an algorithm used to calculate and predict a satellite's location with respect to time. It then validates the information being transmitted by comparing it to its own data information. When the data is validated the GPS receiver "locks on" to the satellite and starts using the positioning data. Each satellite has its own unique identification number. The number is defined as a part of the signal each satellite sends.

Each satellite transmits a pseudo-random noise code (PRN), time, almanac, and ephemeris data.

Ephemeris data is a prediction of the satellite's position in space. An ephemeris is a book of predicted sun and star locations with respect to time. It was used by early explorers and is still used today by some navigators to determine their location.

The PRN is used to uniquely identify a particular satellite. All satellites have their own PRN from 1 - 32 or their own ID code. The extra numbers from 25 - 32 are used to identify other extra satellites launched but will not be put into service until the ones they are to replace become unusable.

Each GPS receiver will display the PRN code for each satellite it is receiving data from.

- Time

Basically, the satellites have very accurate clocks that transmit signals at the speed of light along with a precise timing message. Ground units receive the transmission, but even at that speed some time delay occurs. This delay between transmission and reception, multiplied by the speed of light, allows receivers to calculate the distance to the satellite. The satellite encodes the time of transmission in its broadcast.

The receiver compares the time of transmission with the time of reception and computes the range to the satellite.

GPS time is referenced to the master clock at the U.S. Naval Observatory and is the most competent system for time transfer. Each satellite has four atomic clocks to ensure time accuracy. They use the precise oscillations of rubidium and cesium to maintain accurate timekeeping. These clocks are accurate to one billionth of a second (.000000001 second) (D'Antoni, 1996). Although these clocks are very accurate and may gain or lose one second every 20,000 years, the government intentionally disrupts the time by a fixed amount, changing the time. This is known as "clock dither," which will degrade position accuracy. This manipulation of the clocks along with SA is what degrades position accuracy by about 140 meters.

Time accuracy at the satellite and the receiver are critical to a good position solution.

- Almanac

The Almanac is an estimated position of the satellite constellation based on a six-month projection.

The Almanac tells the receiver where the satellite is at turn on.

Almanac data is updated once daily from a ground control station, then passed to GPS receivers in the navigation message.

Once one satellite is found, the rest of the constellation can be located.

- Ephemeris Data

Ephemeris data is transmitted in every navigation message providing precise satellite orbital information and clock corrections for that specific satellite.

Ephemeris data is updated about every two hours from a ground station and assists GPS receivers in determining a position.

END OF LESSON 2

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: GPS: THEORY AND OPERATION

LESSON TITLE: SATELLITE FREQUENCIES

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to describe the two satellite frequencies and how they are used.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-19 thru GPS-26

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-19		
	A. REVIEW 1. In the previous lesson the discussion centered on the message transmitted by GPS satellites. 2. This lesson will discuss in detail the current satellite frequencies and their limitations. B. OVERVIEW	
GPS-20		
	The purpose of this lesson is to describe the two satellite frequencies and how they are used. C. MOTIVATION 1. The information in this lesson will provide the student knowledge of the services, standards, and limitations of satellite transmissions.. 2. Students should be made aware from the beginning that GPS does have limits and the accuracy of this system.	

D. OBJECTIVES

GPS-21

Given and IAW the information provided by the instructor, the student will be able to:

1. Name the two satellite frequencies.

2. Briefly describe Precision positioning System (PPS) and the Standard positioning System (SPS).

3. Describe the accuracy standards and limitations of these frequencies.

4. Describe the Course/Alignment, P, and Y codes.

II. BODY

GPS-22

A. TWO SATELLITE FREQUENCIES

1. LINK 1 - transmits on 1575.42 MHz and has a Coarse/Acquisition Code (C/A) and a Precision Code (P).

2. LINK 2 - transmits on 1277.60 MHz and a precision Code (P).

B. GPS SERVICES

GPS-23

1. The Standard Positioning System (SPS), designed for civilian use. SPS is the standard level of positioning and timing accuracy available to all GPS users on a free worldwide basis.

2. The Precise Positioning System (PPS) is the most accurate positioning portion of GPS and is restricted to only authorized users designated by the U.S. and allied federal governments.

C. DEFINING TWO FREQUENCIES

GPS-24

1. Link 1 (L1) transmits on 1575.42 (MHz). - This frequency is for civilian use. The L1 frequency also transmits a Coarse/Acquisition (C/A) code. The C/A code which is available to all GPS users, is a 1023 Bit code that is transmitted at a 1.023 MHz rate; therefore it only takes 1 MSEC to transmit the entire C/A code before it is repeated and provides accuracy within 20 to 30 meters.

2. Link 2 (L2) transmits on 1227.60 (MHz). - This frequency is currently only used by authorized Department of Defense (DOD) users and is encrypted.

3. Both of these frequencies transmit a P(Y) code. The P(Y) code shows that the code can be used either in the clear or encrypted. The P code is only available to users authorized by the Department of Defense. The P code, which is repeated every seven days, does appear to be truly random.

	III. SUMMARY
GPS-25	
	A. LESSON REVIEW 1. Two satellite frequencies 2. GPS services 3. Defining two frequencies B. OBJECTIVES
GPS-26	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Name the two satellite frequencies. 2. Briefly describe Precision positioning System (PPS) and the Standard positioning System (SPS). 3. Describe the accuracy standards and limitations of these frequencies.

	4. Describe the Course/Alignment, P, and Y codes. C. PREVIEW The next lesson will discuss part I of how GPS works.		

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

All satellites have a PRN from 1-32 or an ID code. The extra numbers from 25-32 are used to identify spare satellites launched but not in service until the ones they are to replace become unusable. Each GPS receiver will display the PRN code for each satellite from which it is receiving data. GPS satellites transmit on two frequencies or links called Link 1 (L1) on 1575.42 (MHz) or Link 2 (L2) on 1227.60 (MHz). These frequencies transmit a P(Y) code and, in addition, the L1 frequency also transmits a Coarse/Acquisition (C/A) code. The P(Y) code shows that the code can be used either in the clear or encrypted. The P code, which is available only to users authorized by the Department of Defense, is a seven day long code for each particular satellite. It is repeated every seven days starting at Saturday/Sunday midnight. It is transmitted at a bit rate of 10.23 MHz and is protected against unauthorized use because of this seven day cycle. This also serves to protect the P code from spoofing (intentional jamming). The P code as well as the C/A code both use a type of modulation called Pseudo-Random Noise (PRN). The C/A code ,which is available to all GPS users, is a 1023 Bit code that is transmitted at a 1.023 MHz rate; therefore it takes only 1 MSEC to transmit the entire C/A code before it is repeated and provides accuracy within 20 to 30 meters. To the casual observer, this would seem like random noise, however, since the C/A code is repeated every 1 MS the cycle can be determined. On the other hand, the P code, which is repeated every seven days, does appear to be truly random and the user would have to have some prior knowledge about the cycle and where the cycle currently was in order to decode the NAV message that is superimposed on it. Superimposed on the C/A code and P code is the NAV message, which is not necessarily the same message on both codes. The NAV message that is superimposed on the C/A code has been intentionally degraded.

END OF LESSON 3

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **<u>GPS: THEORY AND OPERATION</u>**

LESSON TITLE: **<u>HOW DOES GPS WORK (PART I)</u>**

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) **<u>1.5 HRS.</u>**

LESSON OVERVIEW:

The purpose of this lesson is to describe the basic workings of satellite navigation.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-26 thru GPS-35

HANDOUTS:

OTHER PERTINENT INFORMATION

NOTES

I. INTRODUCTION

GPS-27

A. REVIEW

1. In the previous lesson a detailed discussion on the current satellite frequencies and their limitations was conducted.

2. In this lesson, part I of how the GPS satellite system works.

B. OVERVIEW

GPS-28

The purpose of this lesson is to describe the basic workings of satellite navigation.

C. MOTIVATION

1. The information in this lesson will provide the student knowledge of the satellite clock system, how distance is measured, and how a position is derived.

2. This lesson, along with the one that follows, provide the student with valuable knowledge that will assist them with obtaining a correct position.

D. OBJECTIVES

GPS-29

Given and IAW the information provided by the instructor, the student will be able to:

1. Describe the satellite clock system relates to positioning.

2. Describe how distance is measured.

3. Describe how a position is derived.

	II. BODY
GPS-30	
	A. RANGING 1. The time delay between transmission and reception, multiplied by the speed of light, allows receivers to calculate the distance to the satellite. 2. The basic theory behind satellite navigation is the measurement of distance between the satellite and the receiver unit. B. POSITIONING
GPS-31	
	1. If you imagine the radiosphere of each satellite as a ball with the satellite at its center and you are located somewhere on the surface of the ball, you know your exact distance from the satellite.
GPS-32	
	2. Receiving a second satellite signal and you know your exact distance from that satellite, then you know that you are in an area somewhere where the two ranges intersect.
GPS-33	

3. If we do the same with a third satellite then we know that we are at only two possible locations.

	III. SUMMARY
GPS-34	
	A. LESSON REVIEW 1. Ranging 2. Positioning B. OBJECTIVES
GPS-35	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe the satellite clock system relates to positioning. 2. Describe how distance is measured. 3. Describe how a position is derived.

C. PREVIEW

1. During the next class period, the students will provide one of the three required papers on GPS, Wide Area Augmentation System (WAAS), or local Area Augmentation System (LAAS).

2. Following the next class, part II of how GPS works will be given.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 4 - PART I

How does GPS work?

Basically, the satellites have very accurate clocks that transmit signals at the speed of light, along with a precise timing message. Ground units receive the transmission but even at that speed there is some time delay. This time delay between transmission and reception, multiplied by the speed of light, allows receivers to calculate the distance to the satellite. In order to get precise information in three dimensions, the receiver must receive signals from a minimum of four satellites. The basic theory behind satellite navigation is the measurement of distance between the satellite and the receiver unit.

- Positioning

If you imagine the radiosphere of each satellite as a ball with the satellite at its center and you are located somewhere on the surface of the ball, you know your exact distance from the satellite. As an example, we will use 11,000 miles measured from the first satellite. Knowing we are 11,000 miles from a satellite narrows down our location. We know we are not on Mars.

When receiving a second satellite signal and you know your exact distance from that second satellite, then you know that you are in an area somewhere where the two ranges intersect. Since orbits are not exactly circular, we will say that the second satellite is 12,000 miles from our position.

If we do the same with a third satellite at 13,000 miles from our position, then we know that we are at only two possible locations. Usually, one of those two points is so far from our position, it is obvious as to which one we are at, and the other can be eliminated.

END OF LESSON 4

PART I

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: **PRESENTATIONS I**

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) **1.5 HRS.**

LESSON OVERVIEW:

The purpose of this lesson is to allow the student to present the first of three briefings covering either GPS, Wide Area Augmentation System (WAAS), or Local Area Augmentation System (LAAS).

•

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-36 thru GPS-40

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-36		
	A. REVIEW 1. In the previous lesson, the first of two parts on how GPS works was conducted. 2. In this lesson, the students will present their first of three papers on GPS, WAAS, or LAAS. B. OVERVIEW	
GPS-37		
	The purpose of this lesson is to involve the students to accomplish some research and present the information to the class. C. MOTIVATION The information in this lesson will provide the class with the most current information on one of these subjects.	

D. OBJECTIVES

GPS-38

Given and IAW the information provided by students, at the end of this lesson, the class will:

1. Be more aware of the different navigation systems, either current or proposed.

2. Discuss the presentation for content and delivery.

	II. BODY	
GPS-39		
	STUDENT BRIEFINGS	

III. SUMMARY

A. LESSON REVIEW

Student briefings

B. OBJECTIVES

GPS-40

Given and IAW the information provided by students, at the end of this lesson, the class will:

1. Be more aware of the different navigation systems, either current or proposed.

2. Discuss the presentation for content and delivery.

C. PREVIEW

2. The next class will be part II of how GPS works.

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: **HOW DOES GPS WORK (PART II)**

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to provide the student with the background on satellite geometry, resolution of position, and what information is provided by GPS satellites.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-40 thru GPS-47

HANDOUTS:

OTHER PERTINENT INFORMATION

NOTES

I. INTRODUCTION

GPS-40

A. REVIEW

1. In the previous class, students presented one of a three presentation requirement on GPS, WAAS, or LAAS.

2. In this lesson, part II of how the GPS satellite system works, will be discussed.

B. OVERVIEW

GPS-41

The purpose of this lesson is to provide the student with the background on satellite geometry, resolution of position, and what information is provided by GPS satellites.

C. MOTIVATION

1. Students must understand that the position of GPS satellites can have an influence on the resulting position and on the information GPS is providing.

2. This lesson, along with the information from part I, provide the student with valuable knowledge that will assist them with obtaining a correct position.

GPS-42

D. OBJECTIVES

Given and IAW the information provided by the instructor, the student will be able to:

1. Describe satellite geometry (good and bad).

2. Describe the Geometric Dilution of Precision (GDOP).

3. Describe what GPS provides in its transmission message.

	II. BODY
GPS-42	
	A. SATELLITE GEOMETRY
GPS-43	
	1. Poor geometry - Satellites are in close proximity to each other, the geometry is poor.
GPS-44	
	2. Good geometry - The ideal geometry would be three satellites 10 degrees above the horizon spaced at 120 degrees apart with a fourth satellite directly overhead at the user's zenith B. GEOMETRIC DILUTION OF PRECISION (GDOP) 1. It is a measure of the geometry of a satellite 2. There are four types of "DOPs": position (PDOP), height (HDOP), velocity (VDOP), and time (TDOP).

B. GPS PROVIDES

GPS-45

All GPS units should be able to provide the four basic functions of position coordinates, speed, time, and elevation.

	III. SUMMARY
GPS-46	
	A. LESSON REVIEW 1. Satellite Geometry 2. Geometric Dilution of Precision 3. GPS provides B. OBJECTIVES
GPS-47	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe satellite geometry (good and bad). 2. Describe the Geometric Dilution of Precision (GDOP). 3. Describe what GPS provides in its transmission message.

C. PREVIEW

The next lesson will cover some of the inherent errors within GPS.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 6 - How does GPS work? PART II

GEOMETRY

POOR GEOMETRY

Satellite geometry is another important factor. If you are trying to obtain a position and all of the satellites in view are to the north and east of you, or they are in close proximity to each other, the geometry is poor.

GOOD GEOMETRY

The ideal geometry would be three satellites 10 degrees above the horizon spaced at 120 degrees apart with a fourth satellite directly overhead at the user's zenith. Geometry will also play a role depending on your location and the surrounding area. For example, your ability to receive the GPS signal may be impaired by trees or buildings. The GPS signal is still only a radio wave, and solid objects are one of the things that will block a signal. Most GPS receivers will provide a number associated with the receipt of a satellite signal. This number is called the Geometric Dilution of Precision (GDOP). In short, it is a measure of the geometry of a satellite and there are four types of "DOPs": position (PDOP), height (HDOP), velocity (VDOP), and time (TDOP). These are used to measure a receiver's accuracy. A general rule is the lower the GDOP number, the better.

GPS PROVIDES

All GPS units should have the minimum capability to compute and fix your present position; provide ground track and groundspeed; provide distance to the next point; create and use waypoints, alarms approaching a point, and some sort of database of intersections, airports, and radio aids.

END OF LESSON 6

PART II

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: GPS: THEORY AND OPERATION

LESSON TITLE: GPS ERRORS

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to aquatint the students with the inherent errors associated with GPS.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-47 thru GPS-56

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-47		
	A. REVIEW 1. In the last class, the discussion centered around the geometry required by satellites to obtain a good position and the information provided by GPS satellites.. 2. In this lesson, he discussion will be on the inherent errors within the GPS satellite system. B. OVERVIEW	
GPS-48		
	The purpose of this lesson is to provide the student with the information on the errors associated with using satellite navigation provided by GPS satellites. C. MOTIVATION 1. Anyone using satellite navigation should be aware of the errors inherent within the system. 2. This information is important in determining the accuracy of any position and/or if the information could be flawed.	

	D. OBJECTIVES
GPS-49	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe and define clock bias errors. 2. Explain and define space control errors. 3. Describe and define atmospheric errors. 4. Describe and define Multipath errors.

	II. BODY
GPS-50	
	A. GPS ERRORS 1. Clock Errors 2. Space Control Errors 3. Atmospheric Errors 4. Multipath Errors B. CLOCK ERRORS
GPS-51	
	1. Clock bias error happens when the receiver clock and the satellite clock are not synchronized. 2. Clock errors exist because not even these clocks are exactly the same and, therefore, may be off by a few nanoseconds when the navigation message is transmitted.

C. SPACE CONTROL ERROR

GPS-52

1. Space control errors are due to either the orbital position or the clock that are in error.

2. Several factors play a role in effecting satellites, such as, solar winds, gravity, and they are in moving orbits as opposed to stationary orbits.

D. ATMOSPHERIC ERRORS

GPS-53

1. Atmospheric errors are found as the signal travels from the vacuum of space to Earth, passing through the atmosphere.

2. As the signal hits the ionosphere and the troposphere, it is bent much like light is bent in a prism and slows down, delaying arrival at the receiver's antenna.

E. MULTIPATH ERRORS

GPS-54

Multipath errors are caused by the satellite signal bouncing off some object, such as a mountain or building, before going to the GPS receiver antenna.

	III. SUMMARY
GPS-55	
	A. LESSON REVIEW 1. Clock errors 2. Space control errors 3. Atmospheric errors 4. Multipath errors B. OBJECTIVES
GPS-56	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe and define clock bias errors. 2. Explain and define space control errors.

3. Describe and define atmospheric errors.

4. Describe and define Multipath errors.

C. PREVIEW

The next lesson will cover GPS map theory.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 7 - GPS ERRORS

There are four main errors associated with GPS.

CLOCK ERRORS

Clock bias error happens when the receiver clock and the satellite clock are not synchronized. This error will show up when calculating the distance time travels between receiver and satellite clocks. Clock errors exist because not even these clocks are exactly the same and, therefore, may be off by a few nanoseconds when the navigation message is transmitted. The satellites use atomic clocks, and most receivers use a quartz crystal clock which is much less accurate. Each nanosecond error will cause a position error of one foot.

Satellites and receivers create their own pseudorandom noise sequence or pseudo code.

The receiver compares the information it receives from the satellite. The difference between the two is the clock error. Since the satellite uses atomic clocks (very accurate) and receiver units use a less accurate clock (usually a quartz crystal) there is an error.

At the receiving end, this error is called clock bias error and at the satellite, satellite clock error. This error will usually be the same for all satellites in view. Receivers have a built-in algorithm to compare four or more satellites' clock errors and compensate for them.

SPACE CONTROL ERRORS

Space control errors are due to either the orbital position or the clock that are in error. Orbital position errors are problems with the ephemeris. The ephemeris data contains 17 pieces of information on the orbital dynamics defining precisely the satellite's position in its orbit. In order to obtain an accurate position, we must know where the satellite is. However, because of the complexities of solar winds and gravity, satellites may not be where we think they are. This is further hampered because the satellites are orbiting and not stationary.

The master control station predicts the satellites' locations. Monitor stations obtain the actual position and these two positions are compared.

The master control station computes the corrections which are sent to all monitor stations for transmission to the satellites.

The satellites include this correction in their satellite navigation message.

ATMOSPHERIC ERRORS

Atmospheric errors are found as the signal travels from the vacuum of space to Earth, passing through the atmosphere. However, to use ranging, it is assumed that the signal passes at the speed of light in a vacuum but it runs into the ionosphere which induces errors to the receiver's calculations. As the signal hits the ionosphere and the troposphere, it is bent much like light is bent in a prism and slows down, delaying arrival at the receiver's antenna. The amount of delay depends upon the density of the ions.

The Troposphere is lower in the atmosphere and can cause delays in reception.

Most satellites used for a navigation position have a lower elevation. Tropospheric delay can be predicted by GPS receivers and compensated for, especially if the receiver's altitude is known. Tropospheric delay influences altitude the most in position measurement.

MULTIPATH ERRORS

Multipath errors are caused by the satellite signal bouncing off some object, such as a mountain or building, before going to the GPS receiver antenna. Like any other radio signals bouncing off objects, GPS signals will travel a longer distance to the receiver antenna and cause a slight range error in the process. This may cause a problem in mountainous or urban areas.

END OF LESSON 7

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: GPS: THEORY AND OPERATION

LESSON TITLE: GPS MAP THEORY

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to provide information to the student on the basic theory of GPS navigation.

INSTRUCTOR REFERENCES:

GPS: THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-57 thru GPS-63

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-57		
	A. REVIEW 1. In the last lesson, the discussion was on the inherent errors within the satellite navigation system. 2. In this lesson, the discussion will be on the basic theory that governs satellite navigation and use. B. OVERVIEW	
GPS-58		
	1. Since GPS is a source for positioning and navigation, then we must be able to merge the two. The information necessary for this merger is the horizontal datum, ellipsoid, vertical datum, the magnetic variation, and which geodetic survey the map is based on. This is required to provide precise positioning and navigation. 2. The purpose of this lesson is to provide the student with some of the basic information on the theory associated with the use of satellites. C. MOTIVATION 1. Anyone using satellite navigation should be aware of the basic theory that governs its use.	

2. This information is important to review the basic theory of this system to ensure understanding.

D. OBJECTIVES

GPS-59

Given and IAW the information provided by the instructor, the student will be able to:

1. Discuss the description and perception of Earth.

2. Describe two-dimensional versus three-dimensional maps.

3. Describe horizontal versus vertical datums.

4. Describe ellipsoids and geoids..

II. BODY

GPS-60

A. EARTH

1. Man has used a depiction of Earth called a globe as the true representation of our world.

2. Earth is not a true sphere. It bulges at the middle and is flatter at the poles.

B. MAP SURFACES

1. Maps are a flat two-dimensional representation of a three-dimensional Earth.

2. GPS receivers operate in a three-dimensional world.

3. Ellipsoid - is a smooth surface shape of Earth based on a mathematical model.

4. Datum - is a mathematical model of Earth used as a base reference to overlay a coordinate system on Earth's surface.

	5. Geoid - has an irregular surface because of the effects of the different rock densities within Earth.
GPS-61	
	6. Ellipsoids and geoids are different and do not coincide in use.

	III. SUMMARY
GPS-62	
	A. LESSON REVIEW 1. Earth 2. Map surfaces B. OBJECTIVES
GPS-63	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Discuss the description and perception of Earth. 2. Describe two-dimensional versus three-dimensional maps. 3. Describe horizontal versus vertical datums.

4. Describe ellipsoids and geoids..

C. PREVIEW

The next lesson will cover the coordinate system.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 8 - GPS THEORY

We have often used maps as a positioning and navigation aid helping us to travel from one place to another. Since GPS is a source for positioning and navigation, then we must be able to merge the two. The information necessary for this merger is the horizontal datum, ellipsoid, vertical datum, the magnetic variation, and which geodetic survey the map is based on. This is required to provide precise positioning and navigation.

EARTH

We have used a depiction of Earth called a globe as the true representation of our world. Everything on a globe is oriented to true as opposed to magnetic. However, a globe has a very small scale and very little detail. Further, a globe is relatively big and bulky and has a hard time fitting into your pocket. So, maps became popular and were used as the primary source for positioning and navigation. Maps are a flat two-dimensional representation of a three-dimensional surface with four major components: an Ellipsoid to account for the shape of Earth, a Horizontal Datum to provide position data, a Vertical Datum to provide elevation data, and a Projection providing specific information on ground or air navigation. This is the information on a map legend that allows users to determine position and navigation information. Generally, very little attention was paid to the legend area, but with GPS, this area has become much more valuable.

Earth is not a true sphere. It bulges at the middle and is flatter at the poles. In order to try to compensate for these irregular shapes, mapmakers use ellipsoid models that best represent their region of the world.

Maps are a flat two-dimensional representation of a three-dimensional Earth drawn to scale and, therefore, cannot show all dimensions of true direction, distances, areas, or shapes as seen from space. GPS receivers operate in a three-dimensional world to compute position and navigational information. Therefore, there will always be differences in distances, positions, and directions between maps and GPS positioning data.

MAP SURFACES

Horizontal vs. vertical datums

The ellipsoid is a smooth surface shape of Earth to represent irregular shapes of topography, such as mountains, because it is based on a mathematical model. Regional ellipsoids are made by mapmakers of a particular region of

Earth based on the values of the radius and the flattening ratio. These same values cannot be used for other regions of Earth.

Once the ellipsoid problem was corrected, the next step was to select the correct datum. A datum is a mathematical model of Earth used as a base reference to overlay a coordinate system on Earth's surface. Two types of datums are of concern, (a) horizontal datums covering Easting and Northing or Longitude and (b) Latitude and vertical datums covering elevations. Datums are not calculated by GPS receivers, but most will allow you to choose the datum you want to use. It is important to pick the correct datum for your use.

To create a worldwide reference for the vertical datum, a surface that was at mean sea level would extend around Earth underneath all continents. This surface, however, would be affected by differences in the density of Earth, a higher density under mountains, and a lower density in the middle of the ocean. This surface is known as the "geoid." The geoid and MSL are about the same at any coastline. The geoid, like the WGS-84 datum, is referenced to the center of Earth, but unlike the smooth surfaces of an ellipsoid, it has an irregular surface because of the effects of the different rock densities within Earth. Ellipsoids and geoids are different and do not coincide in use. This difference is caused by the different measurements of gravity around the world and is used to create a geoid model based on tabular rather than mathematical data. GPS receivers have a conversion program that references ellipsoid elevations to MSL around the world. The accuracy of the geoid has been refined over the years to the present accuracy of better than 4 meters for 93% of Earth.

Information about the vertical datum is usually contained in the legend of a map and is usually listed as MSL, although it may be listed as a national or local vertical datum. Again, caution is advised to know what information is being presented.

END OF LESSON 8

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: **COORDINATED SYSTEM**

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to provide information to the student on coordinate systems used with GPS and traditional navigation.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-64thru GPS-70

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-64		
	A. REVIEW 1. In the last lesson, the basic theory of GPS navigation was discussed. 2. In this lesson, the student will be provide information on the coordinate system used by GPS and how it is derived. B. OVERVIEW	
GPS-64		
	This lesson will acquaint the student with the coordinate system used for tradition and GPS navigation. 2. The purpose of this lesson is to provide the student with some of the basic information on the coordinate system associated with the use of satellites. C. MOTIVATION 1. Anyone using satellite navigation should be aware of the coordinate system that is used to provide positional information. 2. This information is important for the student to understand the forces that may and do effect GPS.	

	D. OBJECTIVES	
GPS-66		
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe and define Earth Centered, Fixed Coordinate system. 2. Describe and define the geodetic system. 3. Describe magnetic variation.	

	II. BODY
GPS-67	
	A. COORDINATE SYSTEMS 1. Earth Centered, Earth Fixed 2. Geodetic system B. EARTH CENTERED, EARTH FIXED
GPS-68	
	Earth Centered, Earth Fixed system is used to define a position in a three- dimensional plane called the X, Y, and Z coordinates and referenced from the center of Earth. C. GEODETIC The Geodetic system uses the traditional latitude, longitude, and height to define a three dimensional position as referenced to the surface of Earth. D. MAGNETIC VARIATION

1. Earth is surrounded by a magnetic field with magnetic north and south poles.

2. There are geographic North and South poles and magnetic North and South poles. The angular difference between these two is called variation.

III. SUMMARY

GPS-69

A. LESSON REVIEW

1. Earth Centered, Earth Fixed coordinates
2. Geodetic coordinates
3. Magnetic variation

B. OBJECTIVES

GPS-70

Given and IAW the information provided by the instructor, the student will be able to:

1. Describe and define Earth Centered, Fixed Coordinate system.

2. Describe and define the geodetic system.

3. Describe magnetic variation.

C. PREVIEW

The next class will be the second of three presentations provided by students on GPS, WAAS, or LAAS.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 9 - COORDINATES

EARTH CENTERED - FIXED COORDINATES

Maps are only symbols of reality and not meant to be used to go from map to a precise place in reality. Two worldwide coordinate systems are used: (a) Earth Centered, Earth Fixed, and (b) the Geodetic system. Earth Centered, Earth Fixed system is used to define a position in a three-dimensional plane called the X, Y, and Z coordinates and referenced from the center of Earth. The X-axis is defined as the intersection of the prime meridian and the equator. The Y-axis is defined as the intersection of longitude 90 degrees east of the prime meridian and the equator. The Z-axis points toward the north pole. GPS receivers use this in obtaining a precise position which is then converted to a coordinate or grid system selected by the user. In order to compute for a position, four satellites are required to provide the X, Y, and Z dimensions for Position and Time. A fourth is required for Altitude computations.

The Geodetic system uses the traditional latitude, longitude, and height to define a three dimensional position as referenced to the surface of Earth. The equator and the prime meridian are the two planes that are used to define the latitude and longitude. The geodetic latitude is the position north and south in a perpendicular angle to the equator. The geodetic longitude is the position east or west in a perpendicular angle to the prime meridian. The geodetic height is the distance above or below perpendicular to the ellipsoid.

Latitude at the equator is 0 degrees ranging to 90 degrees north and south. It is used to define the north and south hemispheres. These lines of latitude are parallel; therefore, the distance between them is constant. Longitude at the prime meridian is 0 degrees ranging to 180 degrees east and west. It is used to define the east and west hemispheres. Latitude's and longitude's units of measure are broken down into degrees, minutes, and seconds. Sixty seconds equal 1 minute, and 1 minute of latitude equals 1 nautical mile, and 60 minutes equals 1 degree of latitude. Longitude is measured the same way, but only at the equator. As you move either north or south away from the equator, the lines of longitude start to converge and the distance between them gets smaller.

Another type of coordinate system is called the polar coordinate system, better known as "Bullseye." A bullseye is the center of origin. It can be fixed on Earth's surface or it can be moving. It can be a landmark or just a set of coordinates to mark a center that is oriented toward magnetic north; basically, it is a compass. Each degree represents azimuth from the center of the compass or bullseye. A bullseye position is determined by an azimuth and range from the center. Imagine a point with concentric circles around it, such as a dart board. When you throw a dart into the board, you can determine its location as it relates to the center of the board. A bullseye type of position works on the same concept and is not meant to be a precise position, but it allows the operators to maintain some idea of where they are in relation to where they put the bullseye on their map.

Earth is surrounded by a magnetic field with magnetic north and south poles. These poles are not the same as the geographic poles. We use the geographic poles to navigate in a relationship to "true" north, and we use the magnetic poles to navigate in a relationship to "magnetic" north. The angular difference between the two is called variation. All commercial and military aviation maps display magnetic variation data in some form. It is important, therefore, to understand the difference between true and magnetic and the relationship with GPS receivers.

END OF LESSON 9

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: **PRESENTATIONS II**

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to allow the student to present the first of three briefings covering either GPS, Wide Area Augmentation System (WAAS), or Local Area Augmentation System (LAAS).

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INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-71 thru GPS-75

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-71		
	A. REVIEW 1. In the previous lesson, the first of two parts on how GPS works was conducted. 2. In this lesson, the students will present their first of three papers on GPS, WAAS, or LAAS. B. OVERVIEW	
GPS-72		
	The purpose of this lesson is to involve the students to accomplish some research and present the information to the class. C. MOTIVATION The information in this lesson will provide the class with the most current information on one of these subjects.	

D. OBJECTIVES

GPS-73

Given and IAW the information provided by students, at the end of this lesson, the class will:

1. Be more aware of the different navigation systems, either current or proposed.

2. Discuss the presentation for content and delivery.

II. BODY

GPS-74

STUDENT BRIEFINGS

	III. SUMMARY A. LESSON REVIEW Student briefings B. OBJECTIVES
GPS-75	
	Given and IAW the information provided by students, at the end of this lesson, the class will: 1. Be more aware of the different navigation systems, either current or proposed. 2. Discuss the presentation for content and delivery. C. PREVIEW The next class will cover Differential GPS (DGPS).

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: DIFFERENTIAL GPS (DGPS)

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to familiarize the student with differential GPS and its uses.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-76 thru GPS-82

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-76		
	A. REVIEW 1. In last class, students presented the second of three discussions of GPS, WAAS, or LAAS. 2. In this lesson, the instructor will provide some of the basic information on differential GPS. B. OVERVIEW	
GPS-77		
	1. Differential GPS is a new navigation capability being used by the United States Coast Guard to improve inland waters and harbor areas navigation capability. 2. The purpose of this lesson is to provide the student with some of the basic information on DGPS and to introduce some other possible uses for this system C. MOTIVATION 1. The use of differential GPS is relatively new as compared with GPS. 2. This information is important for the student to understand the newer aspects of navigating with DGPS.	

D. OBJECTIVES

GPS-77

Given and IAW the information provided by the instructor, the student will be able to:

1. Describe the purpose of DGPS

2. Explain how DGPS works.

3. Describe current and future uses of DGPS.

II. BODY

GPS-78

A. PURPOSES OF DGPS

1. Refine and improve accuracy for coastal and harbor navigation..

2. To improve airport navigation as part of the National Airways System (NAS).

B. HOW DGPS WORKS

GPS-79

1. Station has a precise position

2. Station receives normal GPS positioning information.

3. Formulates the difference between the two and transmits corrections.

GPS-80

C. CURRENT AND FUTURE USES.

1. Currently, the U.S. Coast Guard has set up several DGPS stations around the United States at major harbors to provide accurate shipping navigation capability to all types of shipping.

2. The FAA is experimenting with DGPS for use in the NAS to provide precision approach capability to all types of aircraft.

3. In addition, the military is looking at DGPS for precision weapon guidance and civilians are looking at DGPS in transportation, and recreation

	III. SUMMARY
GPS-81	
	A. LESSON REVIEW 1. Purposes of DGPS 2. How does DGPS work 3. Current and future uses of DGPS B. OBJECTIVES
GPS-82	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe the purpose of DGPS. 2. Explain how DGPS works. 3. Describe current and future uses of DGPS.

C. PREVIEW

The next lesson will discuss the setup and use of GPS.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 11 - DIFFERENTIAL GPS

DGPS is exactly what its name says it is, a different type of GPS signal transmitter. This transmitter was developed to refine and provide better accuracy for the SPS used in the civilian sector.

DGPS works like this. A station is located at a surveyed, precise location. It receives positioning data from normal GPS receivers from all satellites in view, compares the positioning data with the fixed location information, and determines the difference. This difference is the combination of all errors from those satellites in view.

The station then transmits the error corrections on a UHF frequency of 283.5-325.0 kHz, much like a normal radio beacon, from its location to anyone who can pick them up, usually a couple hundred miles.

With the right equipment, you can connect a GPS receiver to a DGPS receiver, and have these corrections go into your GPS receiver and the position displayed will be the corrected one, usually within 10 meters or less. The Federal Aviation Agency (FAA) is also conducting experiments on using this type of system for air navigation and precision approaches. Single DGPS installation allows for the creation of multiple approaches at multiple airports, usually within 15 miles depending on the terrain (Goyer, 1998) People are authorized to use this system free of charge, but need to purchase the DGPS receiver.

DISCUSS CURRENT/FUTURE USES OF GPS

Military - Weapons -precision guidance

Rescue - downed aircrew members

Civilian - Transportation

Trucking, airlines, cars etc.

Recreation

Hiking, fishing etc.

END OF LESSON 11

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: GPS: THEORY AND OPERATION

LESSON TITLE: GPS - SETUP AND USES

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to familiarize the student with differential GPS and its uses.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-83 thru GPS-89

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-83		
	A. REVIEW 1. The last class discussed differential GPS, how it worked, and the current and future uses.. 2. In this lesson, the instructor will provide some of the basic information concerning the initial setup and uses for GPS for flying. B. OVERVIEW	
GPS-84		
	The information presented during this lesson will describe how the initial setup of GPS should be conducted and some uses during flight. C. MOTIVATION Knowledge of the setup procedures and uses during flight can assist the users in using this navigation system. 2. This information is important for the student to understand what is happening during the setup procedure.	

D. OBJECTIVES

GPS-85

Given and IAW the information provided by the instructor, the student will be able to:

1. List four step setup process.

2. List and describe the two ways to use GPS for flying.

	II. BODY
GPS-86	
	A. GPS SETUP 1. Most GPS units can be set up based on the individuals who are going to use them. 2. Make sure you check to insure you are using the correct datum and ellipsoid information. 3. Check your equipment and make sure it is operating properly and you have all of the correct components. 4. Turn on the unit and get your Time-to-First-Fix (TTFF). B. GPS USES
GPS-87	
	1. The "bullseye" method. 2. Inputting a group of waypoints into your receiver.

	III. SUMMARY
GPS-88	
	A. LESSON REVIEW 1. GPS setup. 2. GPS uses B. OBJECTIVES
GPS-89	
	Given and IAW the information provided by the instructor, the student will be able to: 1. List four step setup process. 2. List and describe the two ways to use GPS for flying.

C. PREVIEW

The next lesson will discuss the Wide Area Augmentation System (WAAS).

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 12 - GPS SETUP

First of all, most GPS units can be set up based on the individuals who are going to use them. It depends on whether they want miles or kilometers, meters or feet, and so forth. Second, make sure you check to insure you are using the correct datum and ellipsoid information. Third, check your equipment and make sure it is operating properly and you have all of the correct components (that is, antenna, batteries, cables, and so forth). The last of the initial steps is to turn on the unit and get your Time-to-First-Fix (TTFF). If this is the first time your receiver has been turned on, or if a long time has elapsed since the last use, the TTFF could take anywhere from 10 to 15 minutes to initialize to your position. If you know your position, however, your unit will "lock-on" to a satellite much faster. Once your unit has acquired a satellite, it will download time, the position of the satellite, and almanac data, and update its database. It is now ready to use.

GPS USES

There are two ways to use GPS for flying. First, there is the "bullseye" method. If you are a general aviation flier and you are going to fly and stay within a couple hundred miles of your local airport, the bullseye method is probably the easiest use of GPS. The airport of departure is the bullseye point.

By using this method, the pilots will always know how to get back to their airports of departure by azimuth and range, displayed on the unit. In addition, this is a useful tool in helping the pilots maintain a situational awareness of where they are in relation to the departure airport. This is a very simple, non-technical use of the GPS system. The second type of flying is used by commercial, business, and private pilots going cross country. This is accomplished by inputting a group of waypoints into your receiver. A waypoint is a defined location, such as an airport, intersection, and so forth. A group of these waypoints makes up a route. Generally, a route is planned to follow a published airway or to avoid certain areas, such as military operating areas, special use airspace, or mountains. Each waypoint is entered in the order that the flight is intended to take. After all of the waypoints have been entered, the pilots will have all the data at their fingertips for each leg of the flight. Track, ground speed, TO and FROM points, heading, distances, enroute time, and position can all be made available at a push of a button.

END OF LESSON 12

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: WIDE AREA AUGMENTATION SYSTEM (WAAS)

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) 1.5 HRS.

LESSON OVERVIEW:

The purpose of this lesson is to provide the student with some background on WAAS and potential problems.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-90 thru GPS-97

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-90		
	A. REVIEW 1. The last class discussed the initial setup and use of GPS. 2. In this lesson, the instructor will provide some of the basic information concerning the Wide Area Augmentation System (WAAS). B. OVERVIEW	
GPS-91		
	1. The information presented during this lesson will briefly describe the background of WAAS and potential problems. C. MOTIVATION 1. The information provided will enhance the students knowledge of the GPS navigation system and its integration into the National Airways System (NAS). 2. This information is important for the student to understand the background, and potential uses for WAAS.	

D. OBJECTIVES

GPS-92

Given and IAW the information provided by the instructor, the student will be able to:

1. Describe how WAAS is setup.

2. Describe the process of how WAAS will work.

3. List some of the benefits expected from WAAS.

4. Discuss potential problems with WAAS.

	II. BODY
GPS-93	
	A. WAAS 1. Ground stations 2. Geostationary satellites B. WAAS PROCESS 1. Process data from each GPS satellite. 2. Relay accurate positional data to users. C. EXPECTED BENEFITS FROM WAAS
GPS-94	
	1. Direct routing 2. Eliminate older and more costly systems. 3. Reduced congestion of air traffic.

4. Less complicated equipment required on aircraft.

D. POTENTIAL PROBLEMS

GPS-95

1. New flight instruments required for sole-source navigation.

2. Systems delays

	III. SUMMARY
GPS-96	
	A. LESSON REVIEW 1. WAAS 2. WAAS process 3. Expected benefits 4. Potential problems B. OBJECTIVES
GPS-97	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Describe how WAAS is setup. 2. Describe the process of how WAAS will work.

3. List some of the benefits expected from WAAS.

4. Discuss potential problems with WAAS.

C. PREVIEW

The next lesson will discuss the Local Area Augmentation System (LAAS).

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 13 - WAAS

Currently, GPS receivers are approved by the FAA for non-precision approaches only. They are working on a precision capability. The FAA is in the process of testing and implementing the Wide Area Augmentation System (WAAS). The FAA will build and maintain its own system of about 35 ground and master stations. The ground stations will receive the GPS satellite information and send the data to the master stations for processing. This processing will determine integrity, differential corrections, ionospheric information from each GPS satellite and develop Geostationary Earth Orbit (GEO) satellite navigation parameters. This combination of processed data will be uplinked to the GEO satellites which will be able to downlink this data on the GPS L1 frequency. This will allow the same receiver to be used to receive both GPS and WAAS signals. The initial operational date for WAAS is in early 1999 with a goal of 2001 to achieve a level of sole-source navigational capability. As soon as GPS/WAAS avionics are available, they will take the place of technical standard order (TSO)-C129-based GPS avionics. Therefore, TSO-C129 GPS avionics (currently being used) will not be usable for primary or sole-source navigation capability nor can they be used for GPS/WAAS nonprecision or precision approaches unless they are upgraded to meet the new avionics standard. The accuracy of this information will be 100 meters 95% of the time throughout the National Airway System (NAS), and for Category I approaches, horizontal and vertical are guaranteed at 7.6 meters 95% of the time. (NOTE: Category I approaches refers to the type of landing of an aircraft using an Instrument Landing System (ILS) and determines the minimum altitude allowed for that particular approach.) The benefits of the WAAS system will be:

- Aircraft will be able to fly more direct routes, saving time and money.
- Current, expensive, older radionavigation aids will be eliminated.
- National Airway System will be less congested allowing more aircraft into the system and reducing airplane and passenger delays.
- Onboard navigation equipment will be reduced.

END OF LESSON 13

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: **LOCALAREA AUGMENTATION SYSTEM (LAAS)**

DATE PREPARED/REVISED: **8/25/98**

CLASS DURATION (in hours) **1.5 HRS.**

LESSON OVERVIEW:

The purpose of this lesson is to provide the student with some background on LAAS and potential problems.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-98 thru GPS-104

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-98		
	A. REVIEW 1. The last class discussed WAAS and the purpose and potential problems in this new system. 2. In this lesson, the instructor will provide some of the basic information concerning the Local Area Augmentation System (LAAS). B. OVERVIEW	
GPS-99		
	The information presented during this lesson will briefly describe the background of LAAS and potential problems. C. MOTIVATION 1. The information provided will enhance the students knowledge of the GPS navigation system and its integration into the National Airways System (NAS). 2. This information is important for the student to understand the background, and potential uses for LAAS.	

	D. OBJECTIVES
GPS-100	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Briefly describe LAAS and its purpose. 2. Describe how LAAS is to be set up and used. 3. Discuss potential problems.

	II. BODY
GPS-101	
	A. LAAS 1. Purpose - to start where WAAS stops. 2. Location - major airports with a range of about 25-30 nautical miles and providing line-of-sight navigational guidance. B. LAAS USE 1. Providing line-of-sight navigational guidance so a pilot will be able to fly Category II or III approaches. 2. Relay accurate positional data to users. C. EXPECTED BENEFITS FROM WAAS
GPS-102	
	1. Direct routing 2. Eliminate older and more costly systems.

	3. Reduced congestion of air traffic.
	D. POTENTIAL PROBLEMS
GPS-103	
	1. New flight instruments required.
	2. Systems delays

	III. SUMMARY
GPS-103	
	A. LESSON REVIEW 1. LAAS 2. LAAS use 3. Expected benefits 4. Potential problems B. OBJECTIVES
GPS-104	
	Given and IAW the information provided by the instructor, the student will be able to: 1. Briefly describe LAAS and its purpose. 2. Describe how LAAS is to be set up and used.

3. Discuss potential problems.

C. PREVIEW

In the next class, the students will present the last of three presentations on GPS, WAAS, or LAAS.

SUGGESTED EXTRACTED DATA FOR LESSON DEVELOPMENT

LESSON 14 - LAAS

The Local Area Augmentation System (LAAS) is a plan to start where WAAS stops. It calls for a DGPS system to be set up at major airports with a range of about 25-30 nautical miles and providing line-of-sight navigational guidance so a pilot will be able to fly Category II or III approaches. Category II and III approaches lower aircraft minimums for landing and increase proficiency requirements for the pilots.

LAAS will also provide approach and departure guidance, terminal navigation, and airport surface navigation. The FAA will choose the LAAS architecture and development by 1998. The FAA has decided to have the users of the LAAS system pay for its use. The users will fund the development of the LAAS through a system of 143 installations to be operational by 2006.

END OF LESSON 14

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: <u>GPS: THEORY AND OPERATION</u>

LESSON TITLE: <u>PRESENTATIONS III</u>

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) <u>1.5 HRS.</u>

LESSON OVERVIEW:

The purpose of this lesson is to allow the student to present the first of three briefings covering either GPS, Wide Area Augmentation System (WAAS), or Local Area Augmentation System (LAAS).

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

GPS-105 thru GPS-109

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-105		
	A. REVIEW 1. In the previous lesson, the LAAS was discussed. 2. In this lesson, the students will present their last of three papers on GPS, WAAS, or LAAS. B. OVERVIEW	
GPS-106		
	The purpose of this lesson is to involve the students to accomplish some research and present the information to the class. C. MOTIVATION The information in this lesson will provide the class with the most current information on one of these subjects.	

	D. OBJECTIVES
GPS-107	
	Given and IAW the information provided by students, at the end of this lesson, the class will: 1. Be more aware of the different navigation systems, either current or proposed. 2. Discuss the presentation for content and delivery.

II. BODY

GPS-108

STUDENT BRIEFINGS

III. SUMMARY

A. LESSON REVIEW

Student briefings

B. OBJECTIVES

GPS-109

Given and IAW the information provided by students, at the end of this lesson, the class will:

1. Be more aware of the different navigation systems, either current or proposed.

2. Discuss the presentation for content and delivery.

C. PREVIEW

The next class will be the final exam.

LESSON PLAN COVER SHEET

COURSE NO. AND NAME: **GPS: THEORY AND OPERATION**

LESSON TITLE: **FINAL EXAM**

DATE PREPARED/REVISED: 8/25/98

CLASS DURATION (in hours) **1.5 HRS.**

LESSON OVERVIEW:

The purpose of this class is for the student to demonstrate an understanding of the GPS, WAAS, and LAAS navigational systems.

INSTRUCTOR REFERENCES:

GPS:THEORY AND OPERATION textbook.

VISUAL NUMBERS AND COMMENTS:

HANDOUTS:

OTHER PERTINENT INFORMATION

		NOTES
	I. INTRODUCTION	
GPS-110		
	A. REVIEW 1. In the previous lessons, GPS, WAAS, and LAAS navigational systems were discussed. 2. In this class, the students will demonstrate an understanding of these systems C. MOTIVATION The information in this course has the class with the most current information on all of these subjects. D. OBJECTIVES	
GPS-111		
	Given and IAW the information provided by students and the instructor, at the end of this class, the students will: Pass the prepared examination.	

VITA

Lester P. Tucker

Candidate for the Degree of

Doctor of Education

Thesis: THE GLOBAL POSITIONING SYSTEM: THEORY AND OPERATION

Major Field: Applied Educational Studies

Biographical:

Personal Data: Born in Lynchburg, Virginia, on October 9, 1947, the son of Victor and Virginia Tucker.

Education: Graduated from Greenbriar Military School, Lewisburg, West Virginia in June 1967; received Bachelor of Arts in History from Elon College, Elon College, North Carolina; completed the requirements for the Master of Business Administration from Central Michigan University, while assigned to Seymour-Johnson Air Force Base, Goldsboro, North Carolina in June 1981. Completed Squadron Officers School in September 1974, Air Command and Staff College in May 1982, and Air War College in June 1987; graduated from U.S. Air Force Certified Flight Instructor School in June 1979 and the Air Intelligence School in October 1983; completed requirements for the Doctor of Education degree from Oklahoma State University, Stillwater, Oklahoma in December, 1998.

Experience: Lieutenant Colonel Lester P. Tucker (USAF, Retired) was commissioned in 1972. After completion of Undergraduate Navigator Training in October 1973, he was assigned to the 384th Air Refueling Squadron serving in KC-135 StratoTankers. In 1978, Colonel Tucker was transferred to Kadena Air Base, Japan. In 1980, he was a participant in the ill-fated Hostage Rescue from Iran. After returning from Japan, he was assigned to Headquarters Tactical Air Command as an Air Intelligence Officer. In 1988, Colonel Tucker was assigned to the 552nd Air Control Wing, Tinker Air Force Base, Oklahoma. During Desert Shield and Desert Storm, Colonel Tucker served as Chief of

Combat Operations in Riyadh, Saudi Arabia. In March 1992, he was selected as Operations officer for the 966th Flying Training Squadron, the largest flying training squadron in the U.S. Air Force. Colonel Tucker retired from the Air Force in March 1998 and is currently Commander of Edmond North High School's Junior Reserve Officer Training Corps, Edmond, Oklahoma.

Professional Memberships: Retired Officer Association, Air Force Association.