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Current and Planned Use of the Navstar Global Positioning System by NASA

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ABSTRACT

NASA was quick to realize the potential that the Global Positioning System (GPS) had to offer for its many diverse vehicles, experiments and platforms. Soon after the first Block I GPS satellites were launched, NASA began to use the tremendous capabilities that they had to offer. Even with a partial GPS constellation in place, important results have been obtained about the shape, orientation and rotation of the earth and calibration of the ionosphere and troposphere. These calibrations enhance geophysical science and facilitate the navigation of interplanetary spacecraft.

Some very important results have been obtained in the continuing NASA program for aircraft terminal area operations. Currently, a large amount of activity is being concentrated on real time kinematic carrier phase tracking which has the potential to revolutionize aircraft navigation.

This year marks the launch of the first GPS receiver equipped earth-orbiting NASA spacecraft: The Extreme Ultraviolet Explorer and the Ocean Topography Experiment (TOPEX/Poseidon).

This paper will describe a cross section of GPS-based research at NASA.

INTRODUCTION

NASA has and is continuing to pursue an active, innovative GPS-based research program in three broad areas: aircraft, earth-orbiting satellites, and deep space navigation.

This year marks the launch of the first NASA earth-orbiting satellites to carry GPS receivers for precise positioning experiments: the Extreme Ultraviolet Explorer (EUVE) and the Ocean Topography Experiment (TOPEX/Poseidon).

Aeronautics applications include differential GPS to support fixed-wing and rotorcraft operations in phases of flight that require high accuracy of position such as terminal area operations. This activity includes GPS-aided inertial navigation systems supplemented by radar altimeter and barometric data.

With the GPS constellation in a fully operational state next year, GPS is expected to play an even more important role for NASA.

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GPS FOR NASA AIRCRAFT NAVIGATION EXPERIMENTS

The Navstar Global Positioning System has been used by NASA for aircraft terminal operation experiments for the past seven years. NASA centers involved with terminal area operations research include Langley Research Center, Hampton, Virginia, Ames Research Center, Moffett Field, California and Johnson Space Center, Houston, Texas.

At Langley a cooperative aircraft navigation research program between NASA, the Federal Aviation Administration, the Department of Defense and industry has resulted in development and flight test of an integrated navigation system. This system consists of a differential GPS receiver, an inertial navigation system (INS), a radar altimeter and barometer. A database has been created for comparing performance in automated landing phase operations with other navigation systems. This research has achieved the first automatic landing of a commercial transport aircraft (B-737) and has shown that the combination of the above systems can meet the shuttle-class vehicle autolanding navigation requirements of 40 feet (3 sigma) lateral and 8 feet (3 sigma) vertical.

The Johnson Space Center(JSC) has conducted an active test program in place to demonstrate GPS utility for the Space Shuttle using the Shuttle trainer aircraft. The next step will occur in late 1993 with a demonstration using an off-the-shelf, five channel Rockwell Collins 3M receiver on board the Shuttle. If this demonstration is successful, it will be a precursor of an implementation strategy that will replace the existing TACAN system with a triple redundant GPS system fully integrated into the Shuttle avionics system. This should meet the goal of a fully autonomous Shuttle during orbital and terminal area operations. However, for final approach and touchdown the existing precision microwave landing system, known as the Microwave Scanning Backup Landing System(MSBLS), will likely continue to be used well into the next century.

A joint program between NASA Ames Research Center, the Department of Transportation Federal Aviation Administration, and the NAVSTAR Joint Program Office was initiated in 1989. This program entitled "Terminal Area Operations with Differential GPS " developed and flight tested a Precision (P) Code differential GPS (DGPS) system and has evaluated the navigation performance to be expected with different levels of component integration through Kalman filtering.

McNally, et al conducted a flight test evaluation[1] of DGPS integrated with INS for terminal approach and landing operations, using a twin turbo-prop transport aircraft. Eight, sixteen and eighteen-state Kalman filter integrations of DGPS/INS were evaluated with final approach flight data. It was found that positioning accuracy was about the same for all levels of DGPS/INS integration. The system produced positioning accuracy (1 sigma) of on the order of one meter horizontally and three meters vertically. This is about a factor of three improvement over standalone P Code GPS accuracy.

Investigations are continuing at Ames Research Center on kinematic carrier phase tracking of GPS signal. The Ames DGPS system will be upgraded with continuous carrier tracking Coarse Acquisition (C/A) Code receivers. Flight tests will be conducted using the NASA King Air and a UH-60 helicopter.

The 20 centimeter wavelength of the GPS carrier offers the potential for subdecimeter accuracy in real-time, given that problems of ambiguity resolution and multipath can be solved. Relative positioning accuracy of a centimeter has been demonstrated by modern surveying receivers and in several aircraft flight test experiments using post processing. However, these techniques do not lend themselves to real-time solutions. The challenge is to develop a method to resolve carrier phase ambiguities on a moving platform. Hatch [2] describes the ambiguity search problem and discusses some efficient methods to perform the search.

A number of researchers are working on the problem and, if successful, will revolutionize aircraft navigation.

GPS FOR EARTH-ORBITING SPACE MISSIONS

Navigation of earth-orbiting space missions can be grouped into two classes:

(1) Real-time, e.g., space borne scientific missions that require real time solutions in the 18-100 meter range. This list includes the Extreme Ultraviolet Explorer, the Space Shuttle (candidate), the Space Station Freedom (candidate), and the Earth Observing System platform(candidate);

(2), Post processed precise orbit determination (non real time), e.g., missions that require sub decimeter accuracy using post processed differential techniques. Examples of this class are Aristoteles (candidate), an ESA mission that will provide precise gravity measurement of the earth and the Ocean Topography Experiment (TOPEX/Poseidon).

TOPEX/Poseidon, an element of the World Climate Research program, is a cooperative space program between the United States and France that will provide the measurement capability needed to determine circulation patterns of the global oceans and study their influence on world climate. The spacecraft measures the ocean topology to an accuracy of a decimeter. The satellite is in a near circular orbit at 1336 km (830 miles) altitude with an inclination of 66 degrees. A very accurate altimeter is used to determine the sea surface height above the geoid. Altitude error is a major error source for this mission.

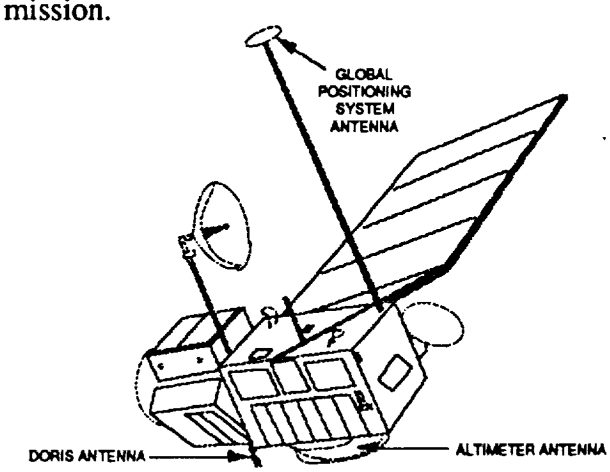

FIGURE 1 TOPEX/Poseidon

Normally, several independent means are used concurrently for spacecraft navigation. There are three in the case of TOPEX/Poseidon(Figure 1). First, twelve ground-based laser tracking stations range on corner reflectors on the satellite to yield orbital accuracy of several centimeters. A second system, the French-built Doppler Orbitography & Radiopositioning by Satellite (DORIS) system determines the satellite velocity precisely by measuring the Doppler shifts of two very stable microwave frequencies that are transmitted by a network of fiducial ground-based beacons. The third system uses an on-board Motorola Monarch GPS receiver in conjunction with six Osborne Rogue GPS receivers located at precisely located ground stations spaced roughly evenly around the world (Figure 2). The data collected is transmitted to a central processor located at JPL, Pasadena, California.

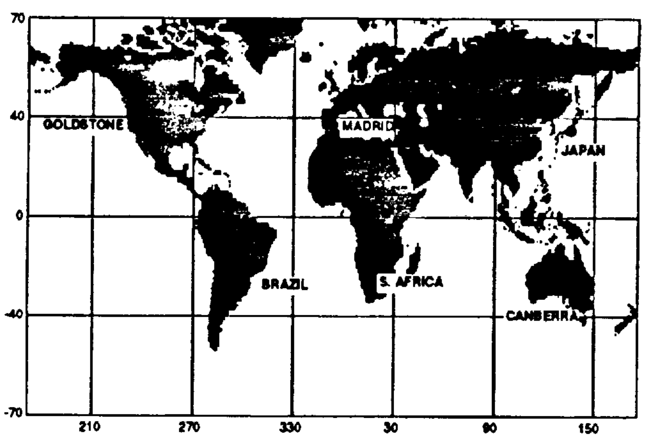

FIGURE 2 GPS GROUND NETWORK

TOPEX/Poseidon orbital accuracies about of 7-10 centimeters are anticipated from the GPS system. There is one problem that could prevent obtaining this accuracy. The Department of Defense has imposed a form of denial of accuracy for civil (non-cryptographic) users of GPS such as TOPEX/Poseidon. This denial of accuracy mode is known as "Anti-spoofing". Anti-spoofing encrypts the P code and, since the L2 frequency is obtained by de-spreading the P code, this encryption essentially prevents the dual frequency operation essential for ionospheric calibration. Davis, et al [3] describes the effects of denial of accuracy. He estimates that the ionospheric error alone would be several meters for low earth orbiters and less than a meter for high earth orbiters. This is an unacceptable error for the TOPEX/Poseidon mission. Therefore, NASA has made a formal request[4] to the Department of Defense that anti-spoofing be turned off for certain periods from launch until July 1, 1993 for the TOPEX/Poseidon mission. It is hoped that models of the upper ionosphere can be made from data taken during these periods to enable satisfactory operation with anti-spoofing on. Data is now being acquired and processed. Results should be published soon.

The Extreme Ultraviolet Explorer, launched May 28, 1992 in a 550 km near circular orbit, 28.5 degrees inclination, is conducting a survey of the celestial sphere in the extreme ultraviolet spectrum (wavelengths of between 100 and 1000 angstrom units). This mission has begun a series of GPS demonstrations using a Motorola receiver configured for Standard Positioning Service (SPS) and dual antennas. This receiver can track L1, C/A or P code simultaneously from twelve GPS satellites using parallel channels.

The EUVE satellite presented a significant challenge in the design of the receiver and

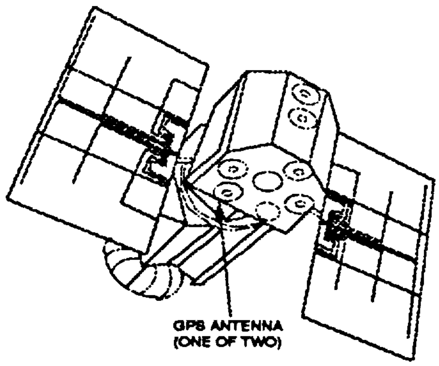

FIGURE 3 EUVE SATELLITE

serves to illustrate some of the difficulties that face designers of space borne GPS systems. First, the antenna could not be zenith mounted due to the spacecraft configuration. Two body-mounted antennas experienced severe blockages from the solar panels and payload structure (Figure 3). Each antenna is blocked from view of any GPS satellite many times during an orbit. To complicate matters further, the spin-stabilized spacecraft rotates three times per orbit. A receiver with a simultaneous dual antenna system provided the only solution to this problem (Figure 4). The initial performance of this system has exceeded all expectations and has demonstrated P-code first fix times of less than sixty seconds. Autonomous operation has been demonstrated successfully with the unattended receiver operating weeks after a single uplink of GPS and EUVE almanac data. The EUVE receiver, besides being the first space borne GPS receiver to fly on a NASA mission, was also the first to track eleven GPS satellites simultaneously. There were seventeen satellites in the GPS constellation at the time.

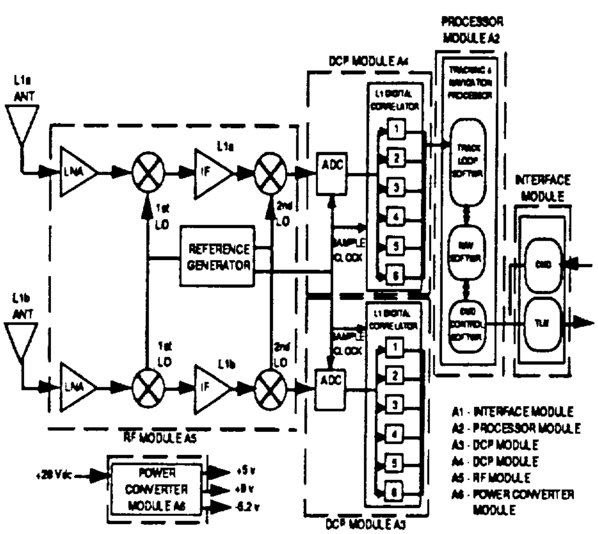

FIGURE 4 MOTOROLA EXPLORER RECEIVER

The goal of this demonstration is to provide precise navigation in a dynamic environment with a position error (3D) of less than 100 meters. This conservative goal was chosen because the free electron content of the upper region of the ionosphere is not known. Since the receiver operates on a single frequency, ionospheric correction factors cannot be obtained.

Perhaps one of the more exacting applications of GPS under consideration is the multinational Earth Observing Satellite (EOS) which will monitor global changes. EOS is scheduled to be launched in 1999. GPS will provide the navigational reference for an instrument known as the GPS Geoscience Instrument that will measure the amplitude and phase changes of up to 18 GPS satellite signals simultaneously as they occult the earth. Data supplied from these measurements will yield stratospheric and tropospheric temperature profiles and ionospheric total electron content mapping at zenith (from a zenith oriented antenna). In addition, GPS will provide non-real-time orbit determination of the platform to about 3 centimeters. GPS is being investigated for orbit determination of geosynchronous Tracking and Data Relay Satellites. These are satellites that communicate with earth orbiting satellites and relay the data captured to ground stations in New Mexico for distribution to customers. Orbit determination of geosynchronous and highly elliptical satellites presents special problems. The conventional approach of placing a GPS receiver on one of these satellites is hindered considerably since GPS signals can only be received from satellites far away on the other side of the earth. These signals would have to pass through the atmosphere (Figure 5). Further, the number of GPS satellites that can illuminate a TDRS simultaneously is limited (usually less than four at any given time).

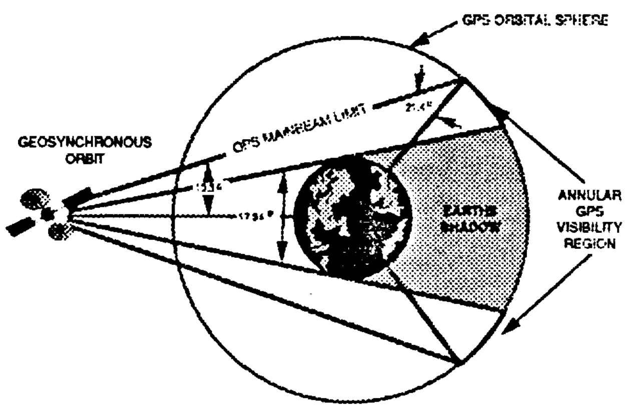

FIGURE 5 GPS VISIBILITY FROM GEOSYNCHRONOUS ORBIT

DEEP SPACE NAVIGATION

The Voyager spacecraft encounter with the planet Neptune took place some three billion miles from the earth. Angular tracking accuracy of about 30 to 50 nanoradians were required to guide the spacecraft to the desired trajectory.

How can the earth orbiting GPS spacecraft facilitate navigation of deep space probes? GPS, with dual frequency operation, can dramatically reduce errors caused by ionospheric and tropospheric delays, reduce relativistic and mechanical clock errors, improve knowledge of ground station location, and polar motion of the earth.

The total electron count of the ionosphere along the signal path, a major error source, can be determined at least three times better with GPS than the Faraday rotation techniques previously used. Further, navigation of planetary spacecraft involves a detailed knowledge of earth orientation and rotation. Although Very Long Baseline Interferometry (VLBI) is necessary for precise time and polar motion determination, GPS can augment these data without the extensive utilization of the Deep Space Network's 70 Meter diameter antennas and the extensive processing time required for VLBI.

Hydrogen masers have been used on the Deep Space Network for many years. These time references typically provide stability factors of 1 part in 10 to the fifteenth power over 3000 seconds. Since VLBI requires two Deep Space Network Stations, separated by intercontinental distances, working together synchronously, it is essential that the time offset be accurately known. Before GPS was available, these offsets were determined by "travelling clocks". These were portable hydrogen masers that often traveled first class and plugged into the aircraft power systems on the long commercial air trips between Goldstone, California, Madrid, Spain and Canberra, Australia. GPS receivers at the DSN sites can now monitor the clock offsets continuously with no transport of instruments.

In order to provide the angular precision required for navigation of planetary missions, the precise determination of earth rotation is very important.[5] For example, for the Magellan mission to Venus, earth rotation errors must be known to 30 centimeters. Future missions will require an order of magnitude improvement in this error source. GPS has also been used to estimate the Earth's geocenter. Using nine GPS satellites in two orbital planes, R.P. Malla and S.C. Wu[6] obtained estimated geocenter position with accuracy of better than 35 centimeters.

An excellent paper by Lichten and Border of JPL[7] describes planetary navigation errors and methods to reduce them.

SUMMARY

NASA was among the first users of GPS and maintains an active comprehensive program to improve the navigation capabilities of aircraft, earth orbiting spacecraft and planetary probes. GPS has enabled NASA to accomplish many navigation functions in a better, more cost effective manner for many years. The future holds great promise for expanded use of GPS by NASA. For example, a new program is under consideration that would use GPS signals to obtain time-varying pressure measurements on a global scale using occultation techniques perfected by researchers for planetary encounters[8]. Such research could revolutionize weather prediction.

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REFERENCES

1 B.David McNally, et al, "Flight Evaluation of Differential GPS Aided Navigation Systems", Paper presented at the AGARD Guidance and Control Panel Specialist Meeting, Ottowa, Canada, May 14, 1992.

2 Hatch, R., "Instantaneous Ambiguity Resolution", Proceedings of the KIS Symposium, Banff, Canada, September, 1960.

3 E.S. Davis, W.G. Melbourne, T.P. Yunck," Applications to Space-based Remote Sensing: Coping with Denial of Accuracy", JPL Document, Jet Propulsion Laboratory, Pasadena, California

4 Interagency Agreement between the Department of Defense and the National Areronautics and Space Administration for Access and Use of the Global Positioning System Precise Positioning Service, Washington, D.C. November, 1990.

5 A.P. Freeman, "Determination of Earth Orientation Using the Global Positioning System", JPL TDA Progress Report 42-99, Jet Propulsion Laboratory, Pasadena, California, November 15, 1989

6 R.P. Malla and S.C. Wu, "The First Geocenter Estimation Results Using GPS Measurements", JPL TDA Progress Report 42-102, Jet Propulsion Laboratory, Pasadena, California, April-June, 1990.

7 S.M. Lichten and J.S. Border, "A Demonstration of High Precision GPS Orbit Determination for Geodedic Applications", JPL TDA Progress Report, Jet Propulsion Laboratory, Pasadena, California, July-September, 1987.

8 G. Leonard Tyler, et al, "The Microwave Opacity of Saturn's Rings at Wavelengths of 3.6 and 13 cm from Voyager 1 Radio Occultation", Center for Astronomy, Stanford University, Stanford, California, November 15, 1982

AUTHOR BIOGRAPHY

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