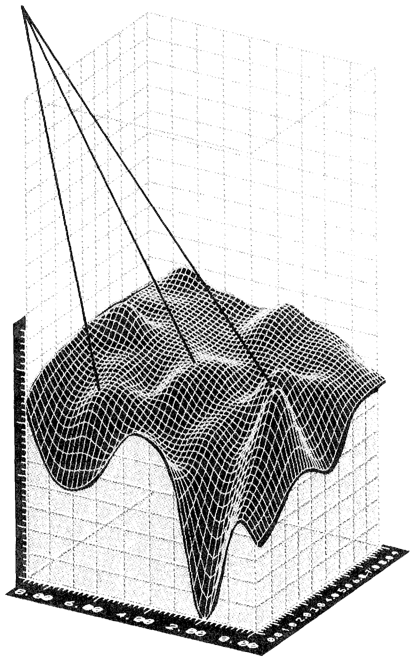

GPS in Civil Aviation

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"Innovation" is a regular column in GPS World *featuring discussions on recent advances in GPS technology and its applications as well as on the fundamentals of GPS positioning. This month we feature an article on present and future applications of GPS in civil aviation. The author is Keith McDonald, president of Sat Tech Systems, Inc., of Arlington, Virginia. McDonald was scientific director of the U.S. Department of Defense Navigation Satellite Program during the initial development stages of the GPS program and, more recently, director of the Federal Aviation Administration's Aeronautical Satellite Division and manager of its satellite technology and applications program.*

This column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Surveying Engineering at the University of New Brunswick. We welcome your comments and suggestions of topics for future columns.

The use of satellite systems for communications, navigation, and surveillance offers significant benefits for aviation safety, air traffic control, and aircraft operations. The development and testing of GPS over the past decade and the recent initial deployment of the GPS operational satellite constellation have significantly increased the attention given to the application of GPS in aviation.

This article focuses on a number of important and beneficial applications of GPS in aviation. It also provides a brief overview of the plans and activities of the Federal Aviation Administration (FAA) and other aviation organizations designed to bring GPS services into widespread use.

BACKGROUND

In 1969–70 the Department of Transportation (DoT) Air Traffic Control (ATC) Advisory Committee investigated the use of satellites as a key element in ATC and on board aircraft for communication, navigation, and surveillance. The committee's working groups analyzed the use of satellites for both over-ocean and continental applications. During this same period, an ad hoc group of the President's Science Advisory Committee considered the use of satellites for ATC surveillance of the continental United States and beyond.

Although satellite-based systems appeared feasible and the potential benefits significant, the ATC Advisory Committee did not believe the state of technology at the time would support this revolutionary approach. In an attempt to determine viable system configurations and to assess cost and potential benefits better, DoT and FAA pursued additional studies, including investigations by the Boeing and Autonetics companies as well as follow-on work over several years by the Mitre Corporation into space-based surveillance techniques.

In the early 1980s the Radio Technical Commission for Aeronautics (RTCA) initiated an investigation of the technology, benefits, and user needs for future communications, navigation, and surveillance systems for air traffic management and navigation, with special consideration given to space technology applications. (See RTCA Special Committee 155, *User Requirements for Future Communications, Navigation and Surveillance Systems Including Space Technology Applications*, RTCA Publication DO-193, September 1986.) RTCA Special Committee 155 (SC-155) met over a period of three years and addressed the actions needed to upgrade the ATC system to handle the requirements of the first decade of the 21st century. The committee concluded that satellite services were not only desirable, but in fact appeared to be the only viable method available for providing navigation and air traffic services to meet future aviation requirements on a worldwide basis.

Subsequently, the International Civil Aviation Organization (ICAO) established an international Future Air Navigation Systems (FANS) working group to address those issues. FANS currently is deliberating the use and future implications of a global navigation satellite system (GNSS) that incorporates such assets as GPS and the Soviet Union's Global Orbiting Navigation Satellite System (GLONASS).

In the early 1980s the author investigated the use of space-based techniques for cooperative independent surveillance (CIS) within FAA. This work was later expanded to include satellite-based surveillance development activities at the Jet Propulsion Laboratory of the California Institute of Technology and also addressed space-based CIS position determination and datalink techniques. These activities were extended in the mid-1980s using spread-spectrum modulation techniques similar to those used in GPS. (See J.W. Sennott and K.D. McDonald, *Performance of Selected Signalling Techniques for Independent Cooperative Surveillance*, IEEE Position, Location, and Navigation Symposium Conference Record, 1988.)

Much of the current activity by aviation organizations addresses the development of aviation standards and specifications for GPS, GPS/GLONASS, and related systems, including work by RTCA Special Committee 159 to establish minimum operational performance standards (MOPS) for GPS. This group has recently completed work on MOPS for supplemental use (with other navaids) and has initiated work on sole means MOPS for GPS. Likewise, the Airlines Electronics Engineering Committee (AEEC) satellite systems subgroup is working on standards for satellite-based air carrier (airline) avionics, including specification 741 for the Aeronautical Mobile Satellite Service, specification 743 for GPS avionics, and specification 743A for GPS/GLONASS avionics.

APPLICATIONS AND BENEFITS

The potential uses and benefits of GPS extend throughout aviation operations, including en route, terminal, approach, and landing phases, as well as runway incursion detection. GPS aviation applications affect the cockpit, the ATC system, and many ground-based services. Some of the immediate and

Immediate
Oceanic en route navigation
Domestic en route navigation
Terminal area navigation
Nonprecision approach guidance
Instrument landing guidance to near Category I
Altimetry
Runway incursion detection
Future
Precision landing guidance
Attitude and heading reference
Airport surface guidance

Figure 1. Aviation applications for GPS

future aviation applications of GPS and GPS/GLONASS services are shown in Figure 1.

Interest in GPS and its navigation capabilities arises in part from studies showing its potential for generating economic benefits for major airlines, commuter airlines, business aviation, and the general aviation community. These benefits include:

- Combination of GPS and satellite communications in automatic dependent surveillance should allow reductions in oceanic lateral and longitudinal separations required for aircraft to near domestic en route levels, with associated savings in fuel and flight time.
- Use of GPS for instrument approach and landing guidance may increase landing capacity at many airports and improve safety.
- Because GPS provides area navigation capabilities, it can provide more flexible use of airspace, allow greater use of random routings, and provide better service than the current domestic VOR/DME system.
- Differential GPS applications for runway/taxiway incursion detection and guidance may increase ground facility capacity and safety.

Several investigations have attempted to assess the benefits of specific GPS applications. A recent study of aviation traffic conditions and the benefits of selected aviation uses of GPS and communication satellites (Aeronautical Radio, Inc., with the National Business Aircraft Association, *The Need for the Global Positioning System within Business Aviation – Survey Report*, forthcoming) found the following:

- Major airlines could save about $280,000 per month per aircraft from improved Pacific/Alaska routings made possible by GPS and satellite communication.
- Major airlines could increase payloads by several thousand pounds through the use of GPS avionics providing improved instrument flight departures at LaGuardia and Washington National airports.
- Commuter airlines could increase revenues by as much as $90 million if flight cancellations were reduced by using landing guidance at small airports, made possible with GPS.
- Business aviation could cut losses from diversions/cancellations with improved airport approach capacity. The survey found that a group of 144 (35 percent of total) respondents indicated overall losses of about $1.4 million during the previous 60 days due to lack of airport approach capacity. GPS could significantly alleviate this problem.

GPS CIVIL LIMITATIONS

Several aviation organizations have recently encouraged FAA to develop an aggressive program to provide leadership in directing the implementation and use of beneficial space-based resources for civil aviation. Such a program needs to be consistent with a realistic assessment of the costs, benefits, and evolutionary complexities involved in introducing new systems. Moreover, FAA has limited control over civil GPS capabilities because the Global Positioning System is being deployed in its entirety by the Department of Defense (DoD) and has been designed with DoD applications in mind. Consequently, the civil community has access to only part of the system's capabilities.

Many questions arise relating to the role of GPS as a navigation system for civil aviation. How good is GPS for civil aviation use? How will the system be transitioned from its development phase into the operational arena? How can user requirements for GPS be satisfied while ensuring safety in the national airspace? How can this system best be used to satisfy the wide variety of domestic and international civil aviation applications? Similar issues, of course, can be stated for marine, land, and space applications. The aviation community is an important – but not the largest – user of GPS.

The limitations of the GPS signal available to the civil aviation community have evoked several principal concerns:

- *Integrity* deals with the provision of timely notice to users about changes in the status of system health and acceptability for navigation. Currently GPS cannot provide warnings to pilots about system failures or degraded accuracy within the 10 seconds considered desirable during landing approaches or the 30 seconds while flying en route.
- *Availability/coverage* describes when and where GPS signals are adequate for user determination of position to a specified accuracy. Additional GPS satellites are required to provide continuous availability for three-dimensional navigation worldwide. Even with the planned GPS constellation fully deployed, coverage will degrade over large areas at times.
- *Accuracy* describes the degree of freedom from error of the position and velocity determinations. Civil GPS service meets current requirements for most phases of flight, from en route to nonprecision approach. Precision guidance with GPS currently is not feasible for all approach and landing conditions, but the matter is under study. Code differential techniques may support the least demanding requirements for precision approach guidance.
- *Institutional commitment* denotes the service providers' level of assurance that GPS capabilities will be available to civil aviation. Although DoD has made no long-term commitment to the civil community, it has stated that GPS will be *its* primary system for navigation well into the next century. A substantial investment of public funds ($7–10 billion) has been made to ensure this.

AVIATION COMMUNITY ACTIVITY

The limitations and concerns relating to GPS have led to the formation of a number of committees and working groups to address and resolve aviation issues. Players include RTCA, AEEC, the National Business Aircraft Association, the Air Transport Association, the Airline Owners and Pilots Association, and the Airline Pilots Association. These groups have maintained a strong organized involvement with GPS issues for many years and have been very effective.

Because issues of flight safety are involved, the U.S. government – through FAA – plays a significant role in determining the conditions under which GPS or other navaids can be carried and used on board aircraft. FAA regulates the introduction and use of aircraft electronics (avionics) and, therefore, is responsible for developing definitive plans, activities, standards, and procedures to implement GPS applications to benefit civil aviation. Within FAA, the activities and resources of many groups – including those responsible for aviation standards, regulation, certification, air traffic control, national airspace system (NAS) development, and airway facilities – have been coordinated to provide expertise. Several international civil aviation organizations also are involved because GPS has global implications.

A basic issue is whether the aviation community, including FAA, can develop standards and procedures for GPS in a timely way so as to transition from today's air traffic system navigation needs to those of the 21st century. The underlying motivations for these standards and procedures center on performance, safety, and cost–benefit. For FAA and the aviation industry to address client interests, they must consider three major categories:

- Certification, MOPS, technical standard orders (TSOs), advisory circulars, and similar items that influence equipment manufacture, sale, and operation and draw the attention of manufacturers of avionics equipment.
- Operating standards, terminal en route procedures (TERPs), flight inspection, cockpit procedures, and avionics operation, which most concern the "stick and rudder" people, or aircraft operators.
- The air traffic control system, which is the element that allows a large number of aircraft to operate in the same airspace. An outstanding crew and excellent avionics are of limited value if the aircraft can't take advantage of ATC and its capability to transport people and goods from point to point. ATC must have procedures, equipment, and regulations that accommodate the new technology and can handle advanced aircraft.

Figure 2 illustrates the interrelationship between these categories and some of the ways in which FAA's satellite program, under manager Joe Dorfler, is involved. FAA is also developing the basis for a national policy on GPS that focuses on civil aviation concerns.

A brief listing of the GPS activities and FAA programs supporting the development and testing of techniques, standards, and procedures is shown in Figure 3. In the avionics area, activities include the development of MOPS for GPS and the establishment of a GPS testbed at the FAA Technical Center. The test facility will include a simulation laboratory that can determine if GPS avionics meet established criteria for certification.

The Technical Center is designing a database to support the documentation needed for certification and other requirements, such as airworthiness, for the operational acceptance of GPS equipment. The center is also involved in the development and testing of a ground integrity channel (GIC) to ensure system integrity by broadcasting GPS satellite-status data to aviation users via Inmarsat and possibly other geostationary satellites. That technique overlays the GPS coverage with integrity signals from small transponders on the satellites.

In addition to broadcasting integrity data, the satellites may provide differential correction and ranging information at the civil GPS frequency to suitably equipped users, providing a wide-area differential capability at the 2–5-meter accuracy level. This system is already implemented commercially in several parts of the world by service providers using Inmarsat. The FAA Technical Center also will investigate the potential for meter and submeter accuracy levels with local differential operation.

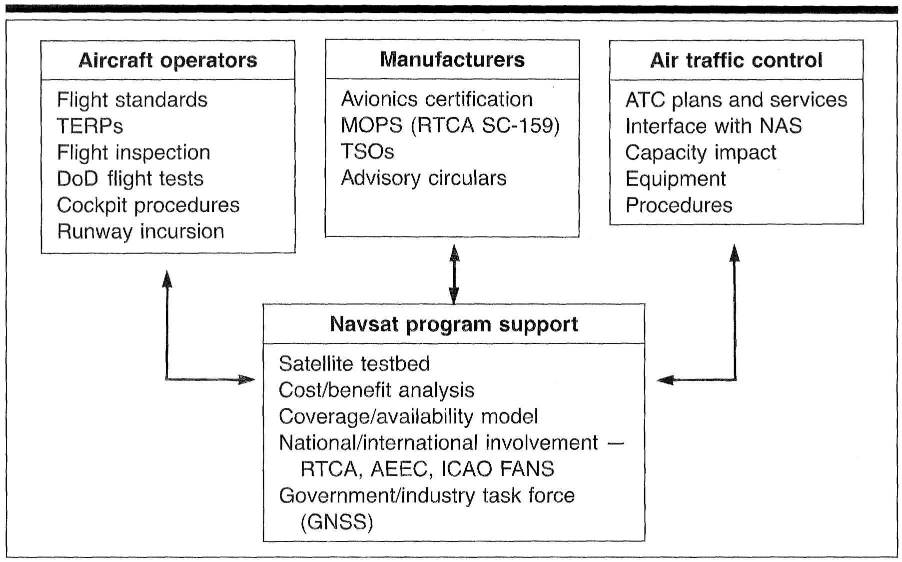

Figure 2. FAA involvement with aviation organizations' GPS-related activities

FAA, DoD, and the National Aeronautics and Space Administration (NASA) have established a cooperative program for obtaining GPS code and experimental carrier-phase measurements in support of precision landing guidance. Work is progressing at the NASA Ames flight test center in California.

GPS AND GLONASS

MIT's Lincoln Laboratory is investigating the feasibility and performance characteristics of and standards required for combining GPS with the Soviet GLONASS system. Lincoln Laboratory is gathering operational performance data on GLONASS and is analyzing methods for obtaining receiver autonomous integrity monitoring (RAIM) from GPS and GLONASS. Although the RAIM approach is an alternative to the use of a GIC, both may be required for some time.

Internationally, both the U.S. government and private industry are involved in cooperative programs with the Soviet Union. Governmental agencies have been most interested and active in examining the capabilities, requirements, and standards for a combined GPS/GLONASS receiver. Those efforts were encouraged by the Soviet Union's release of information on GLONASS operation at the ICAO FANS meeting in May 1988. A number of technical coordination meetings have been held in both the United States and the Soviet Union since the initial meeting in November 1989.

FAA Technical Center satellite testbed
- GPS integrity broadcast (GIC)
- Local differential GPS
- Wide-area differential GPS
- Inmarsat geostationary overlay

MIT Lincoln Laboratory
- GPS/GLONASS capabilities, standards, and RAIM

NASA Ames
- Differential code, carrier-phase measurements

National/international activities
- DoD/DoT/FAA: National GPS policy
- RTCA: Minimum operational performance standards
- AEEC: Airline avionics specifications
- ICAO: FANS (GNSS)
- Mitre: Coverage/availability model, RAIM
- Others: DoT (RAIM), Ohio University, contractors

Figure 3. GPS investigations

About a year ago, the Soviet Union gave FAA an Interface Control Document (ICD) on GLONASS providing more detailed information than that provided at the ICAO FANS meeting. A comprehensive six-phase plan of activities was developed in Moscow during October 1990, and an exchange of GPS and GLONASS receivers took place in April 1991.

Two principal areas have raised technical concerns about the attempt to build a combined GPS/GLONASS receiver: time reference and coordinate reference systems. GPS uses Universal Time Coordinated (UTC) without leap seconds, and GLONASS employs either Moscow Time or UTC (SU). Their coordinate reference systems also differ. GPS uses the World Geodetic Coordinate System 1984 while GLONASS operates in terms of the Soviet Geocentric Coordinate System 1985. Recently, as a result of coordination activities, the Soviet Union modified its time standard information in its ICD. (See Innovation, *GPS World*, November/December 1990 and "GLONASS and GPS: Prospects for a Partnership," *GPS World*, April 1991, for more detailed comparisons of GPS and GLONASS.)

Industry activities concerning GPS/GLONASS have primarily involved a cooperative venture between Northwest Airlines and Honeywell to flight test GLONASS and GPS/GLONASS receivers on Northwest aircraft, and Honeywell's development of a hybrid receiver. Currently, both GPS and GLONASS receivers are being tested on Northwest 747 cargo aircraft. Honeywell plans to have its hybrid receiver completed by the end of the year. Ashtech, an affiliate of SAGEM, also has an agreement with GLAVKOSMOS and others in the Soviet Union to build a GPS/GLONASS receiver, with a production model scheduled for completion by December.

Table 1. Projected user demand dates for augmented GPS services

	Phase of flight						
GPS and augmentations	**Oceanic**	**Offshore**	**En route (NAS)**	**Terminal**	**NPA[1] (VOR)**	**NPA[1] (Loran)**	**Near Cat I**
GPS multisensor system (multisensor integrity)	1991	1991	1991	TBD	TBD	N/A	N/A
GPS supplemental (coarse RAIM integrity)	1993	1993	1993	TBD	TBD	N/A	N/A
GPS with Loran (RAIM integrity)	N/A	1993	1993	1993	1993	N/A	N/A
GPS with local DGPS (accuracy)	N/A	1993	NNR	1993	1993	1993	1993
GPS with wide-area integrity[2]	1996	1996	1996	1996	1996	1996	1996
GPS with wide-area DGPS (accuracy)	NNR	1993	NNR	NNR	NNR	1993	1993
GPS with Inmarsat ranging (availability/coverage)[3]	1996	1996	1996	1996	1996	1996	1996

[1]Nonprecision approach.
[2]GPS/GLONASS with RAIM potentially available in 1995.
[3]Includes Inmarsat and other geostationary satellites. Inmarsat 3 satellites with ranging transponders are planned for deployment by 1995.
N/A = Not applicable.
NNR = No need or requirement.
TBD = To be determined.

IMPLEMENTATION CONCERNS

As we look into the future, GPS clearly will become more and more accessible to aviation users. Innovation will provide new aviation applications, and use of the service will increase significantly. So, when will aviation users generate substantial demand for these augmented GPS services? Table 1 projects user demand dates that appear reasonable from the author's viewpoint. Actual operational dates are difficult to estimate but hopefully will not lag behind demand by more than a year or two. However, meeting desired operational dates depends upon FAA and the aviation community providing resources and high-level support to resolve GPS concerns and issues in a timely manner.

The prospects for use of GPS for most phases of flight from en route to nonprecision approach appears very promising and should occur within about two years of the operational deployment of the full constellation. Initial implementations of GPS will be augmented with other capabilities, such as other navaids (including inertial systems, GLONASS, and Loran), differential systems, and integrity assurance techniques. A period of operational validation is anticipated before GPS is fully accepted as a sole means navigation aid.

Although many would recommend a very rapid introduction of GPS into all phases of aviation, regulatory authorities are clearly taking a deliberate and considered approach. In view of the considerable safety implications of GPS, this appears to be the prudent course.

GPS will be implemented in aviation initially as part of a multisensor system. Using various aids, including the onboard altimeter, GPS receiver clock, and air data or inertial sensors, GPS may provide a fully capable RAIM system. As differential capabilities become available, these enhancements will provide substantial improvements in accuracy and may be sufficient to provide integrity on a local or a wide-area basis. Until then, we will continue to see avionics combining GPS with Loran-C, GLONASS, or other sensors.

The incorporation of GPS into civil aviation is solidly established in both DoD and the civil community, with more than 50 manufacturers of GPS equipment and GPS standards for aviation use well under way.

Areas such as civil system implementation cost, user and provider liability, and related institutional issues still need to be addressed. Also, a substantial amount of research and development is needed to ensure the full potential of GPS for civil aviation use.

It is an exciting time for the GPS community. Many applications for the system are well defined, others are progressing rapidly, and still other fascinating applications are developing on the leading edge of the technology. Much of this work likely will result in profound and pervasive changes in navigation, landing guidance, runway incursion, and other services that may be essential to the growth, operation, economics, and safety of future aviation.

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