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US Satellite Navigation Program Status

Carl McCullough

(*Federal Aviation Administration*)

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This paper provides an update of the development and implementation of the United States of America Federal Aviation Administration (FAA) Wide Area Augmentation System (WAAS) and Local Area Augmentation Systems (LAAS). It also addresses FAA efforts to implement these satellite navigation technologies into the US National Airspace System (NAS), as well as interoperability efforts concerning Satellite Based Augmentation Systems (SBAS) between the FAA and other worldwide Civil Aviation Authorities.

1. INTRODUCTION. GPS is here to stay for use in civil aviation navigation worldwide. The Global Positioning System (GPS) has proven its value, first in providing new military capabilities, and more recently for such diverse interests as hiking, farming, emergency services and virtually all modes of transportation. There are many pilots today who rely more on unaugmented GPS than on conventional navigation and landing systems. Golfers use it, truckers use it and, of course, sailors use it, but the system in place today falls short of the high standards required for all phases of civil flight. That is why the US Federal Aviation Administration is assuming world leadership in developing augmentation systems to increase the accuracy,

integrity and continuity of satellite navigation service. Our systems, with which many are familiar, are called the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS).

2. WIDE AREA AUGMENTATION SYSTEM (WAAS). The Wide Area Augmentation System (WAAS) (Figure 1) will use a network of newly installed ground stations (WAAS Reference Stations or WRSs) (Figures 2, 3) and two existing

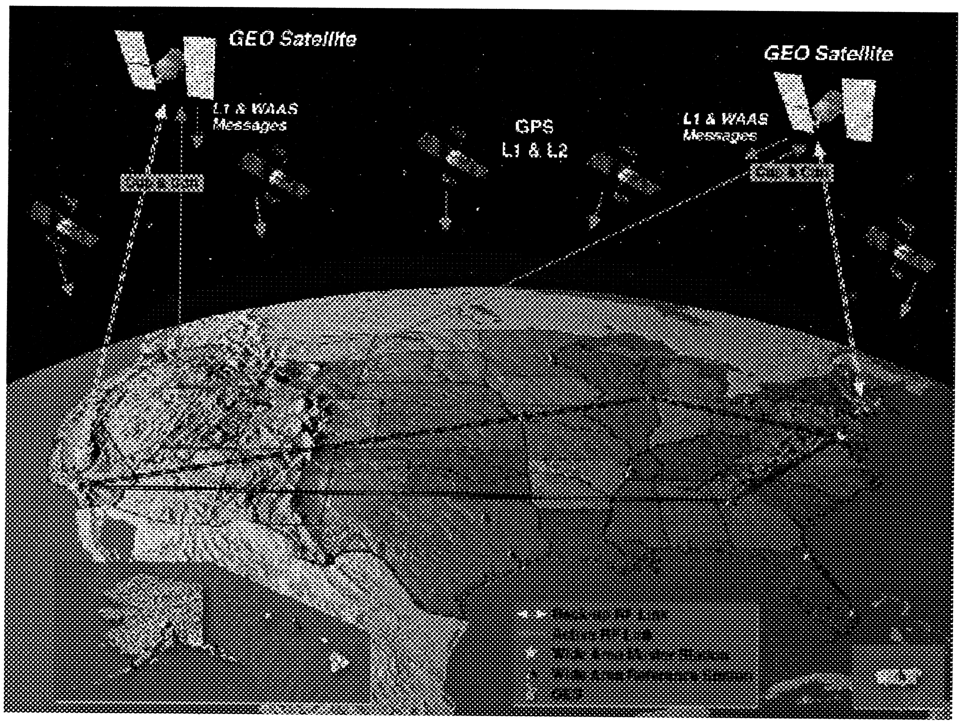

Figure 1. Graphic representation of WAAS architecture.

Inmarsat III geostationary communication satellites (GEOs) to establish certifiable service in the oceanic, en route, non-precision, and even precision approach domains. The entire complement of 25 reference stations, two master stations, three geostationary communication satellite uplink facilities, two Inmarsat III geostationary communications satellites, and an expansive, diverse terrestrial communications network linking each reference station to multiple master stations has already been fully installed.

The way WAAS works is relatively simple. Signals from GPS satellites are received by the ground reference stations, which are located at precisely surveyed locations. Since each reference station is precisely surveyed, and their positions (longitude/latitude/altitude) known to a high level of accuracy, any errors in the GPS navigation signals being received in the respective geographic regions can be determined. Each reference station then relays this region-specific data to a WAAS master station (WMS), where the correction information for the entire WAAS coverage area is computed. A corresponding WAAS correction message is then prepared by the master station and uplinked to one of the two initial Inmarsat III

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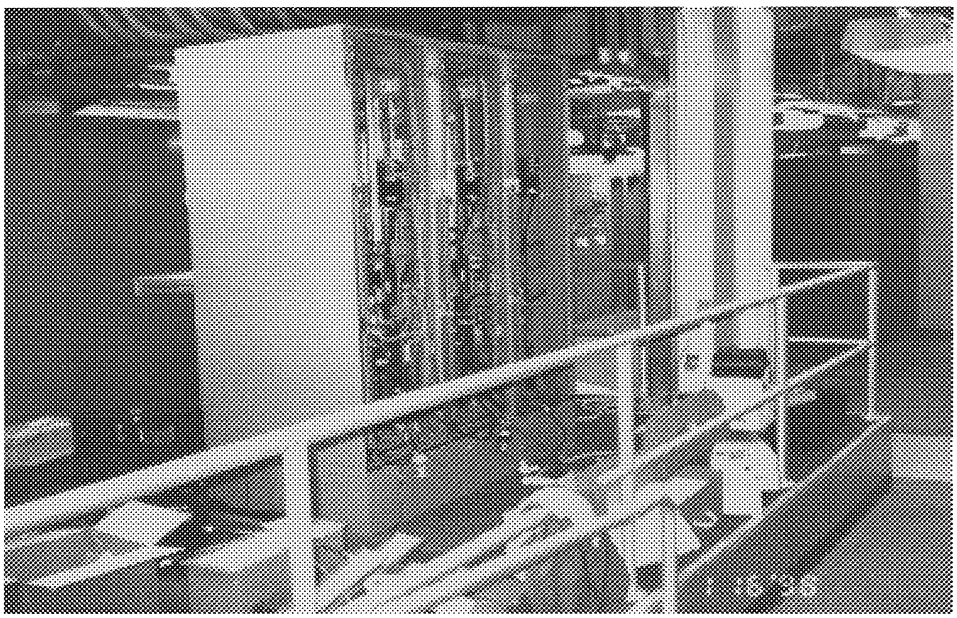

Figure 2. WAAS Reference Station equipment rack.

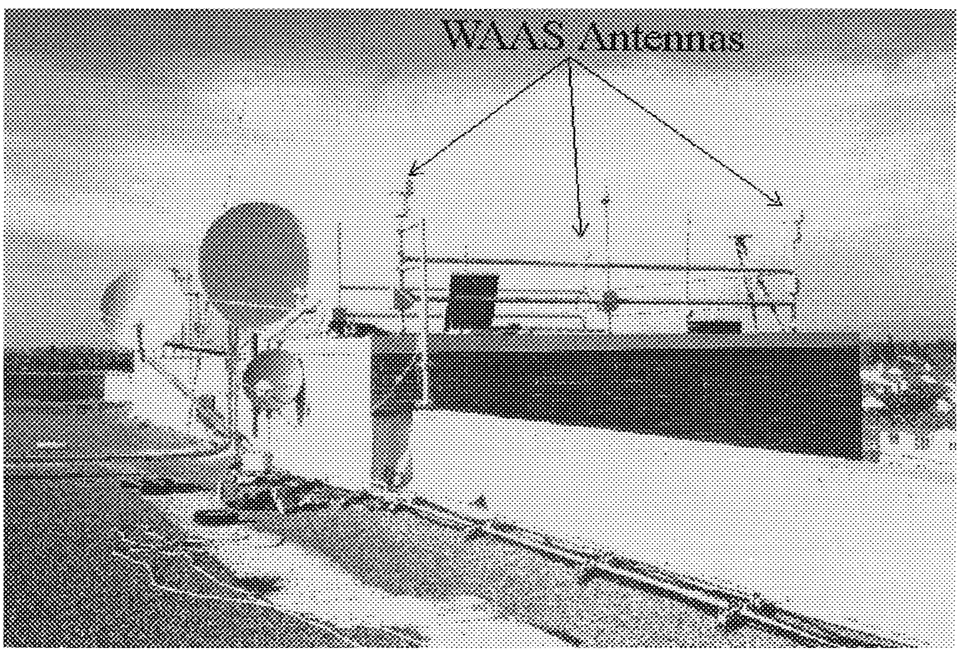

Figure 3. WAAS Reference Station antenna layout.

geostationary communications satellites, which broadcast the message on the same frequency as GPS (L1, 1575·42 MHz) to GPS/WAAS receivers on board aircraft (or other modes of transportation) located within the WAAS broadcast area. This entire process is required to take no longer than approximately six seconds.

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We have plans to provide an augmented signal-in-space this year that will be used to support system level stability tests, as well as communication links and user equipment testing. It is envisioned that this signal-in-space will progressively allow the FAA to perform more advanced flight tests of both non-precision and precision approaches at many key airports throughout the US National Airspace System (NAS).

Our objectives with satellite navigation take at least two different forms. First, the acquisition and fielding team, represented by the FAA's GPS Product Team, is committed to delivering satellite augmentation systems, specifically WAAS and LAAS, that are *capable of supporting all phases of flight without relying on other navigation equipment*. Our contract with Raytheon Systems Corporation for WAAS development is driven by a system specification that spells out accuracy, integrity and availability performance levels that will make this goal possible.

On a broader scale, however, the FAA, in conjunction with other organizations, continues to assess the technical, operational, and institutional risks of that objective, in light of ever changing conditions around us. Those conditions include, among other things, the budget climate (at home and abroad), technical performance of the operational system, international cooperation, vulnerability to interference and jamming, and, of course, user acceptance. Many of these factors are interrelated. User acceptance, for example, is dependent upon satisfactory technical performance, which in turn is dependent on coping successfully with interference. It follows that support from the US Congress for further investments is reliant on a strong user endorsement of our initially fielded system. Answers to some of these questions will be known in the coming months; others may take longer. The US Government and its industry partners have undertaken a number of initiatives aimed at identifying and mitigating risk.

First and foremost among these initiatives is a study that was conducted by the Johns Hopkins University Applied Physics Laboratory and released on 29 January, 1999. This specific study, which focused on concerns about the ability of GPS to meet all of aviation's stringent safety and reliability standards, concluded that 'GPS with appropriate WAAS and LAAS configurations can satisfy the required navigation performance as the only navigation system installed in aircraft and the only navigation service provided by the FAA'. To support this conclusion, the study assesses the risk to the raw and augmented GPS signal from intentional interference, or jamming, and unintentional interference, such as heightened solar activity and interference from certain commercial TV and VHF broadcast signals. Essentially, the study states that a combination of procedural and technical measures to mitigate the effects of both types of interference are achievable and should be implemented as part of the future augmented GPS system to ensure acceptable performance. The report also identifies the need for closer cooperation with the US Department of Defense (DOD) in investigating more efficient combinations of DOD and the Department of Transportation systems, including the possibility of additional GPS satellites.

We are continuously working to identify and mitigate sources of interference. Along this line, we actively participate in the FAA Satellite Operational Implementation Team (SOIT), which developed a White Paper on the current status of Interference Reporting and Investigation in November 1998. This report identified ways to improve the timing and efficiency of reporting of GPS interference within the NAS. It also recommended improvements such as a national database for GPS anomalies, development of an airborne interference locating system, upgraded ground-based locating systems, and improved coordination with the Federal Communications Commission (FCC), Federal Bureau of Investigations (FBI), and NAV CANADA. We are currently assessing the recently released Johns Hopkins GPS Risk Assessment Study and will consider each of the findings and recommendations.

Additionally, the Vice President of the United States recently announced a new × 400 million initiative to modernize the Global Positioning System, including the addition of two new civilian signals on future satellites. The second civil signal will be located at 1227·60 MHz along with the current military signal, and will be available for general use in non-safety critical applications. This signal would be implemented beginning with the first GPS Block IIF satellite, which is currently scheduled for launch in early 2003. However, the third civil signal, that will meet the requirements for critical safety-of-life applications in civil aviation, will be located at 1176·45 MHz, and will be implemented beginning on the seventh Block IIF satellite which is scheduled to launch in 2005. That means that at the current satellite replenishment rate, all 24 GPS satellites would be broadcasting two civil signals by 2010.

The current WAAS schedule provides for a navigation signal that will begin broadcasting in Fall 1999. This signal will be broadcast from two Inmarsat III geostationary satellites already on contract (Atlantic Ocean Region – West and Pacific Ocean Region) and will be capable of supporting non-safety applications, such as an aid to visual flight rule (VFR) flight. WAAS Phase I commissioning, scheduled for the Fall of 2000, will support instrument flight rule (IFR) flight. When Phase I becomes operational, WAAS will provide pilots with en-route navigation at 99·9% availability throughout the entire WAAS service area (basically the US NAS). It will also provide vertical guidance for precision approaches to runways over a limited portion of the continental US.

It is expected that these various studies and analyses, combined with our first real dose of operational experience, will provide the basis for an additional investment decision sometime in the first half of FY 2001. Simply stated, that means the earliest opportunity for completion of a new space segment (i.e., additional geostationary satellites and associated communications links) is estimated to be in FY 2004 or 2005. Meanwhile, we will continue with our planned expansion of the ground segment, in order to improve significantly both coverage and availability in the following years.

3. LOCAL AREA AUGMENTATION SYSTEM (LAAS). The Local Area Augmentation System (LAAS) is an augmentation to the GPS signal that will complement the WAAS in the US National Airspace System to provide full satellite-based precision approach and landing capability (Figure 4). In practical terms, this means that LAAS will meet the more stringent Category III a and III b precision approach requirements that exist at select locations throughout the US, as well as provide a Category I precision approach capability at locations where WAAS is unable to meet existing navigation and landing requirements (such as availability). For example, LAAS will provide Category I service to airports with extremely high availability requirements (i.e., Chicago O'Hare International Airport). The LAAS ground station will be able to support Category I, II, III a, and III b operations depending on its configuration. This will be accomplished through a modular deployment of augmentations designed to meet the specific requirements of an

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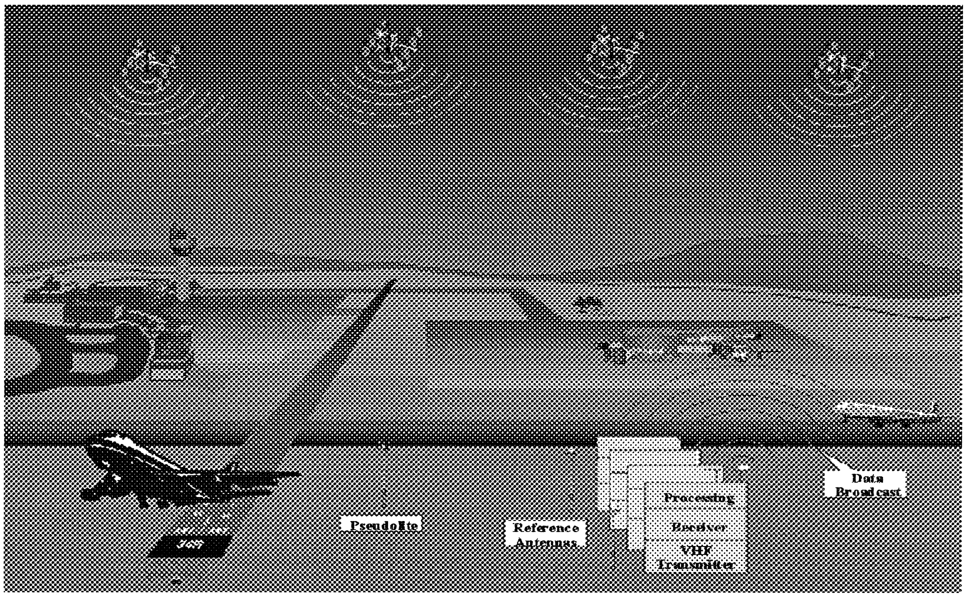

Figure 4. Graphic representation of LAAS architecture.

individual airport. These different configurations result from the need for increased frequency of satellite range measurements and redundancy for locations with higher availability requirements. The LAAS architecture may also consist of Airport Pseudolites (APL) that act and function just like GPS satellites, although they are a component of the ground segment. The purpose of the APL is to enhance the availability of LAAS service by providing an additional ranging source that originates from the local airport.

The final LAAS architecture is currently being addressed in conjunction with the approval of Ground Based Augmentation System (GBAS) Standards and Recommended Practices (SARPS) being developed by the International Civil Aviation Organization (ICAO). The results of this activity will describe LAAS ground system functions to the maximum extent possible, remaining consistent with FAA operational requirements. It is expected that the Category I LAAS ground system specification and associated Minimum Operating Performance Standards (MOPS) will be complete by Summer 1999. Both of these documents will allow for eventual inclusion and accommodation of Category II and III requirements. A Category III ground system specification and associated MOPS should be completed the following year.

The GPS Product Team is pursuing an innovative approach to LAAS operational prototype production, fielding, test and evaluation, and approval for public use. Budget constraints can dictate the manner in which systems are developed, procured, and fielded. In some cases, the traditional approach to doing business is not possible; that is, the FAA cannot contract with industry directly for these activities. To overcome this difficult working environment, we are forming cost-sharing partnerships with industry 'teams' interested in developing, producing, installing, and testing the LAAS ground station and associated avionics. At the beginning of April 1999, the FAA established cost-sharing partnership(s) with two industry 'teams' led by the Raytheon Systems Company and Honeywell to develop LAAS ground equipment and avionics. Each of these teams consist of a vendor who is engaged in Local Area Differential GPS development under RTCA DO-217, an avionics vendor who has produced GPS user equipment under Technical Standard Order (TSO) C129 or C129a, a user or manufacturer of Federal Aviation Regulations (FAR) Part 23, 25, 27 or 29 transport category aircraft, and a suitable airport for installation, test, and evaluation to authorization for public use.

Many of the questions that we field on LAAS relate to the schedule and expected time frame for operational LAAS Category I through III capability in the US. Initially, these Government Industry Partnerships (GIPs) will produce Category I equipment for test and evaluation. Subsequently, the FAA will review the status of work completed and re-negotiate the partnerships, as necessary, to continue work on Category III LAAS development. We truly hope to have at least one installed and authorized public-use Category I LAAS by 2001, and a public-use Category III LAAS by late 2002. If these stages prove successful, it is our intent to purchase up to 143 LAAS installations (Category I and III) for use in the US NAS. This procurement will satisfy all Category II and III precision approach requirements and supplement WAAS-based precision approach service where needed. Full LAAS deployment is planned to be complete by 2006.

4. OPERATIONAL IMPLEMENTATION. No matter how successful we are at developing a state-of-the-art, accurate, and safe satellite navigation system, it is relatively worthless unless we also execute parallel plans to implement these systems into the NAS. Since these are new technologies that have never before been used operationally, one can see that this is not an easy task. The operational implementation of satellite navigation technologies into the existing NAS architecture presents unique challenges that have never before been addressed, and probably represents the most significant change the aviation community will have faced in over 50 years. The FAA's GPS Product Team (Figure 5) has adopted an innovative

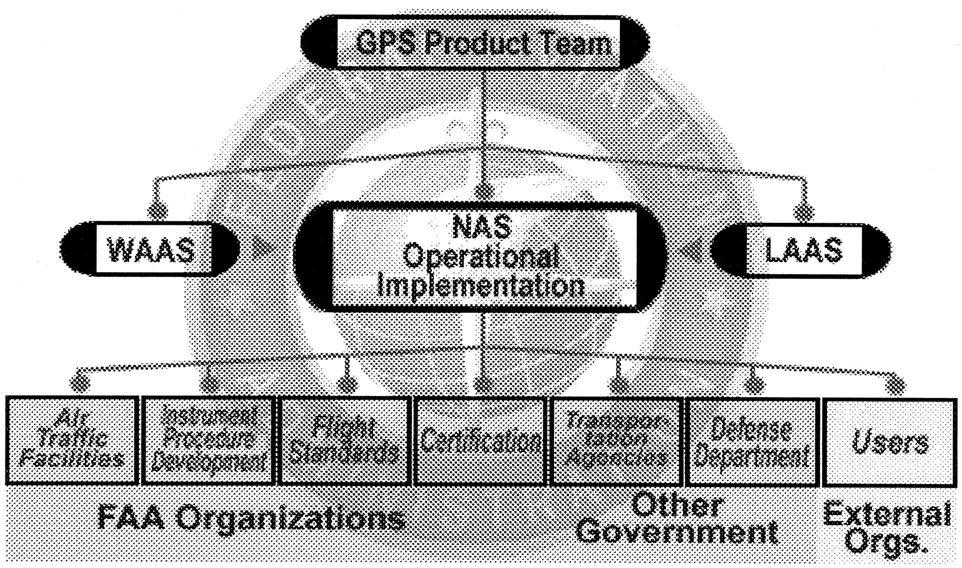

Figure 5. The FAA GPS Product Team.

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approach to acquisition management by creating a NAS Implementation Team to meet these challenges head-on. The results of our overall NAS implementation effort is ultimately to fulfill Initial Operating Capability (IOC) requirements at the earliest possible date and provide NAS users with increased safety, capacity, and efficiency benefits.

This implementation team works in parallel with the actual system design and development activities. Their mission is to ensure that the requisite infrastructure, policies, and procedures of the NAS are prepared, revised, updated, in place, and capable of supporting the utilization of new satellite navigation systems. Our concept of preparing the operational infrastructure necessary to support these new technologies in conjunction with system development will allow the aviation community to realize maximum benefits in the shortest amount of time.

One of our focus areas is the design of MOPS for both WAAS and LAAS receivers. This is accomplished through our support of the RTCA industry forum, development of prototype user equipment, and creation of TSO documentation required by avionics manufacturers for FAA certification of commercial receivers. Likewise, we are responsible for the development of operational guidance material such as the terminal instrument procedures (TERPS) criteria. These criteria define aviation system performance, operational approvals for pilots, as well as guidance and training documentation for system users and FAA safety inspectors alike (Figure 6).

We also monitor the surveying of airports, design and publication of satellite

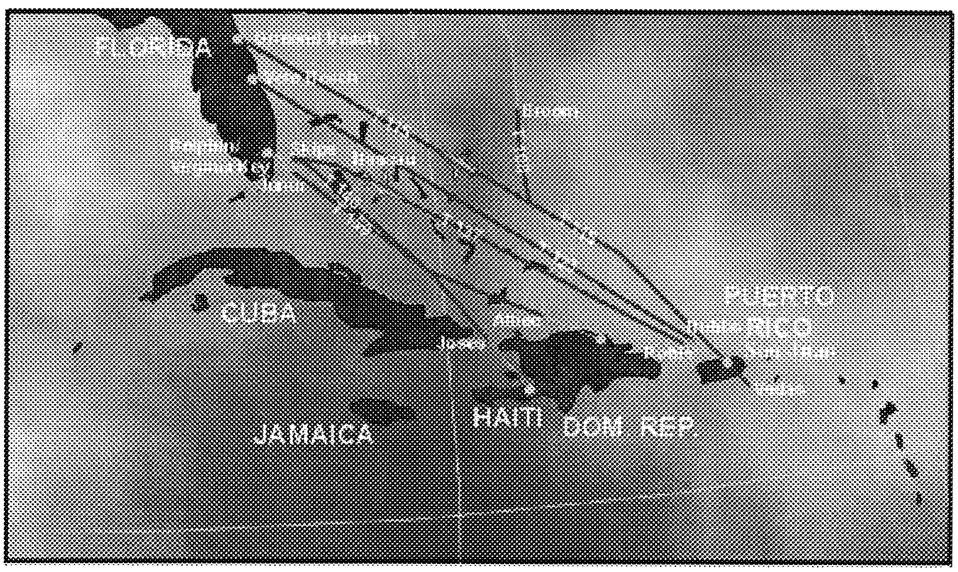

Figure 6. Map of new GPS-based air navigation routes in the Caribbean.

navigation instrument flight procedures, creation of new satellite navigation charting specifications, and the conduct of flight inspections. As a final responsibility, this team co-ordinates the development and provision of air traffic control (ATC) training, implementation of user-preferred direct routeing, designing of airspace revisions, and initiation of regional air traffic projects to increase aviation user benefits. Along this line, ATC simulations have shown that substantial savings in flight time and fuel can be achieved through the redesign of air routes using satellite navigation technology.

5. STANDARDIZED WORLDWIDE NAVIGATION. The commitment of our international partners in satellite-based augmentation technology will be instrumental in the success of US and worldwide Satellite Based Augmentation Systems (SBASs) (Figure 7). Through our support to the ICAO regional satellite

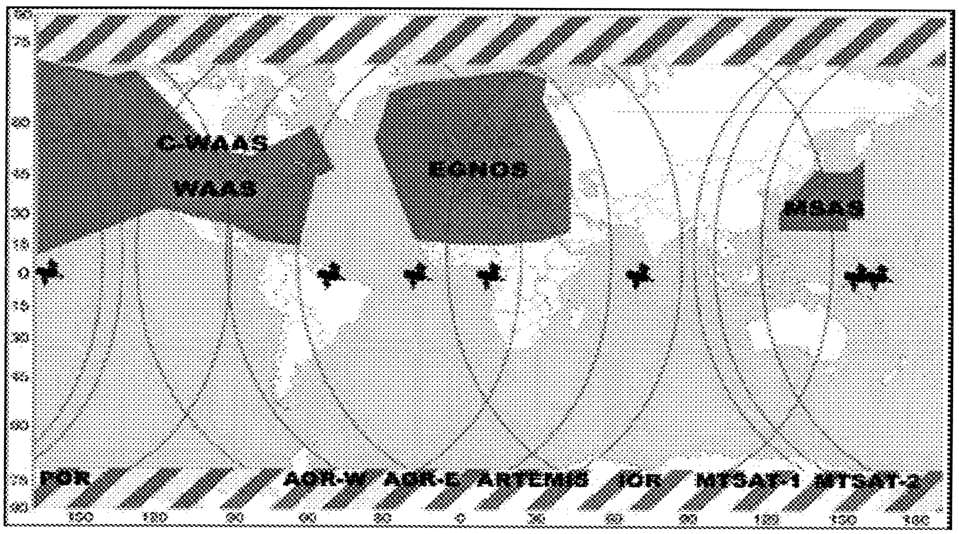

Figure 7. Map showing expected service areas of major worldwide SBAS.

navigation implementation efforts, it has become increasingly apparent that all SBAS developers must look not only at the development of their respective systems, but at SBAS systems as a whole. The FAA, along with Japan (MTSAT Satellite Augmentation System, or MSAS), European Community (European Geostationary Navigation Overlay System, or EGNOS), and Canada (Canadian WAAS, or CWAAS) have recognized that, while our systems are independent from one another, there are many issues that need to be addressed collectively. These issues need to be successfully addressed in order to maximize the utility, effectiveness, efficiency, and safety of these SBAS systems both individually and as a single entity.

One activity that has been, and will continue to be, a vital forum to address these issues is the SBAS Technical Interoperability Working Group (IWG), which was initiated in August 1997. This working group began as a collaboration of key technical representatives from the US, Europe, Japan, and Canada, and has grown in scope and importance over the past two years. The primary focus of the IWG is to address the safety-critical interoperability issues that a user would encounter while transitioning from one SBAS area of coverage to another. This advanced cooperation between SBAS developers should help lower individual implementation costs, while increasing levels of service for all users.

Recently, the IWG has been discussing the standardization of service levels provided within each SBAS, and has been investigating ways to forecast the levels of service that users can expect in zones between SBAS coverage areas. The IWG has also begun to voice its opinions as a united group in adjacent areas of interest. A few of these areas include Global Navigation Satellite System (GNSS) frequency protection, ionosphere effects on navigation signals, and coordination with ICAO on the development and approval of SBAS standards and recommended practices, or SARPS. All work is designed to create a truly seamless GNSS; one that is both cost-effective for the developers and efficient for the users.

6. CONCLUSION. The FAA is, and will continue to work at a variety of levels within the US Government and the international community to bring to fruition ICAO's vision of a seamless worldwide air navigation system based on satellite navigation technology. Already, the maturity of these navigation technologies, and the revolutionary benefits that they offer the aviation community, have prompted several nations to begin developing plans for advanced GPS and WAAS implementation. Some of these same nations, along with others around the globe, have also expressed interest and are developing implementation plans for LAAS systems.

The Johns Hopkins study confirmed what we in the GPS Product Team have been working towards all along; that GPS, augmented with WAAS and LAAS, can satisfy the required navigation performance as the only navigation system installed in aircraft and the only navigation service provided by the FAA. These revolutionary technologies have the ability to provide aircrew in the cockpit with continuous, highly accurate three-dimensional position information for all phases of flight, reduce training-related accidents by providing a consistent navigation capability that does not change regardless of location, replace major portions of current ground-based navigation infrastructures, and simplify the avionics suite. Remarkably, all these same benefits are attainable and can be realized on a worldwide basis. In order to make this a reality, the FAA will continue regional and international cooperation to ensure the furtherance of this seamless, satellite-based global air navigation system.

KEY WORDS

1. Air. 2. GNSS. 3. Augmentation. 4. Navaids