Aviation Applications for User Segment

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Summary

The article describes aviation applications for user segment, their accuracy and certification of aviation GNSS. Paper describes classes of aviation augmentation systems like SBAS ABAS, GBAS and GRAS. Next part describes benefits to users for precision approach or oceanic flights and modernization of GNSS and next gen ATC management systems.

KEY WORDS
GNSS
RNAV
approach
aviation augmentation
GPS
backup navigation
modernization

INTRODUCTION

Aviation users represent a small fraction of the overall market for GNSS devices, but their demanding applications continue to advance the cutting edge of satellite navigation technology. Perhaps surprisingly, the primary concern in aviation applications of GNSS is not accuracy. Though accuracy is an important factor, the most critical characteristic for design and certification of aviation GNSS receivers is reliability. These systems must essentially never introduce a spurious signal that could compromise the safety of passengers or aircraft equipment. Specialized augmentation systems are thus required to ensure safety by monitoring GNSS for spurious signals and promptly alerting pilots in the case of an anomaly. This paper focuses on augmentation systems as the cornerstone of aviation applications of GNSS. The article discusses about the basic classes of augmentation systems and their applications and describes quantitative techniques used to analyze augmentation system performance.

CLASSES OF AVIATION AUGMENTATION SYSTEMS

Four classes of augmentation systems have been recognized by the international aviation community. These categories include: the aircraft-based augmentation system (ABAS), the SBAS, the GBAS, and a hybrid architecture known as the ground-based regional augmentation system (GRAS). The aircraft-based approach employs monitors built into user avionics and requires no external infrastructure (other than the GNSS satellites themselves). These monitors enable the construction of rigorous error bounds by detecting instances of hazardously misleading information (HMI), a term referring to any threatening GNSS anomaly.

By comparison to the aircraft-based approach, the other classes of augmentation systems all employ an infrastructure of terrestrial reference receivers. These receiver networks enhance the sensitivity of HMI monitoring. Additionally, these networks enable the broadcast of differential corrections that significantly improve user accuracy. All four classes of augmentation systems are illustrated in Figure 1.

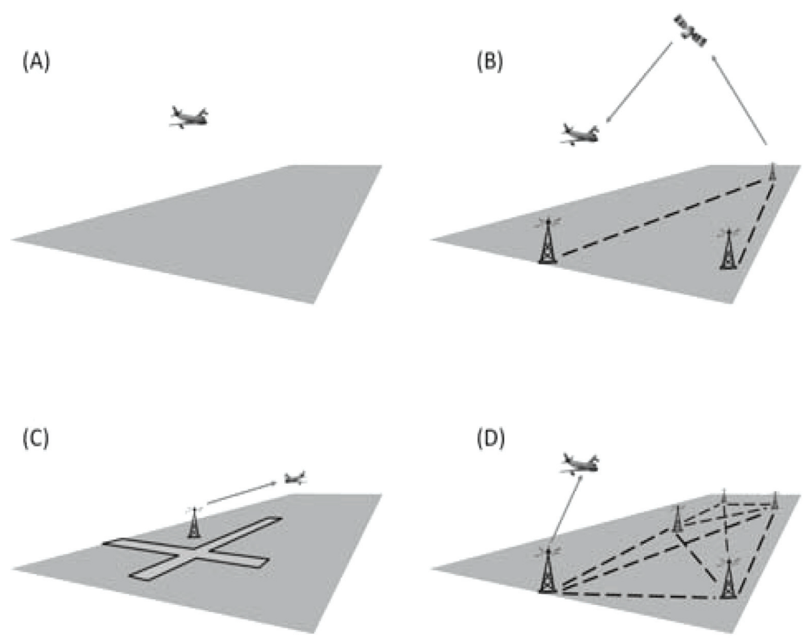

Figure 1. Four categories of augmentation systems: (a) ABAS, (b) SBAS, (c) GBAS, and (d) GRAS.

ABAS offers a distinct advantage in that it can be used nearly anywhere that GNSS satellites are in view. Although ABAS may incorporate non-GNSS sensors, an important subcategory of ABAS is GNSS-only RAIM. This approach implements monitoring using the least-squares residuals from the navigation solution. A large residual corresponds to a measurement that diverges from other measurements. By excluding divergent satellite measurements from the navigation solution, RAIM detects large HMI events and thereby can establish a tighter confidence bound on the navigation sensor error. To obtain nonzero residuals, RAIM requires at least one more measurement than conventional GNSS navigation (five satellites rather than four).

SBAS monitors for HMI using a network of terrestrial receivers distributed over vast distances, with coverage areas typically on the scale of large countries or continents. Alert messages, error bounds, and differential corrections are broadcast to users in this coverage area via a space-based communications link, most typically via a satellite positioned in GEO. In the United States, the Federal Aviation Administration (FAA) introduced the world's first SBAS when it declared WAAS operational in 2003. Around the world, other governments are coordinating new SBAS implementations, such as Japan's Multifunctional-Transport SBAS (MSAS), which is in operation since year 2007. The European Geostationary Navigation Overlay Service - (EGNOS), (in operation since 2009) and India's GPS and GEO Augmented Navigation System (GAGAN) – since year 2010. SBAS offers a distinct advantage over ABAS in that it provides differential corrections that estimate and mitigate major GNSS error sources, including ionosphere, troposphere, and clock errors. As GEOs broadcast over standard GNSS frequencies, conventional antennas can receive SBAS transmissions. In fact, each GEO provides users with an additional ranging measurement that effectively transforms the GEO into another GNSS satellite (although ranging measurements from today's GEO satellites are not as accurate as measurements from GPS satellites).

GBAS monitors for HMI using a small network of receivers distributed over short baselines, on the order of hundreds of meters. These systems, such as the FAA's LAAS and the U.S. military's Joint Precision Approach and Landing System (JPALS), are intended to support high-precision aviation applications over a compact service volume (less than 60 km in radius). In GBAS, alerts and differential corrections are broadcast from a terrestrial VHF transmitter. Although the GBAS message reaches fewer users than would an SBAS message, GBAS users benefit from their proximity to the reference antenna. At short ranges, differential corrections are significantly more effective in removing spatially correlated ionosphere and troposphere errors, resulting in higher accuracy. Also, the simpler broadcast structure of GBAS (direct VHF communication rather than "bent-pipe" communication via a satellite) results in shorter communication latency. Alert times are thus shorter for GBAS than SBAS, an important factor in achieving the tight time-to-alert requirements for precision applications such as low-visibility landing. [1,2]

GRAS is a hybrid that exploits widely distributed networks of terrestrial receivers, like SBAS, but communicates differential corrections to users via ground-based VHF transmitters, like GBAS. The GRAS concept has been developed in large part to enable an SBAS-like capability for Australia and the South Pacific, where political, technical, and economic factors have made GEO access difficult and where access is readily available to a pre-existing VHF transmission network. GRAS is intended to support nonprecision and precision approach operations while interfacing with GBAS to support automated landing. [3][4]

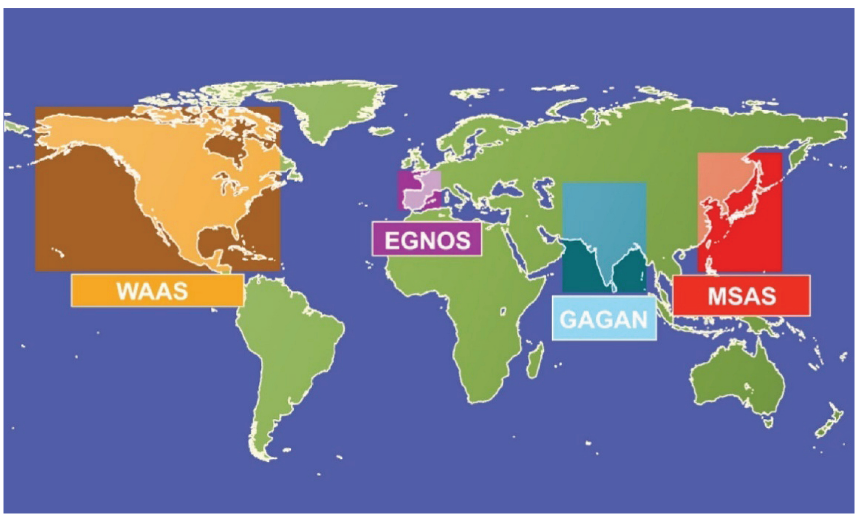

Figure 2. SBAS coverage

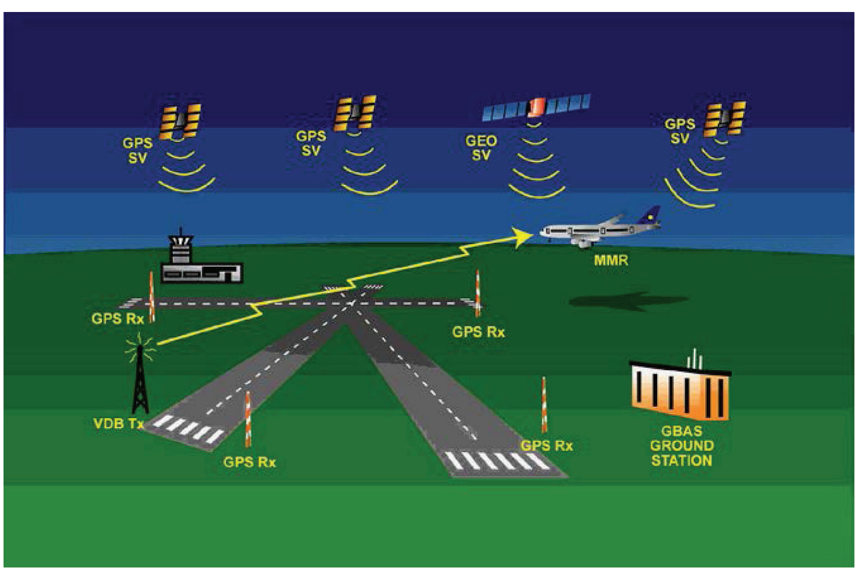

Figure 3. GBAS components

BENEFITS OF GPS AND AUGMENTATIONS TO AVIATION USERS

Prior to the advent of NAVSTAR GPS, aircraft navigation relied primarily on inertial sensors and a network of ground-based radio transmitters. As soon as the FAA declared the GPS constellation operational in 1994, civil aviation was quick to adopt GNSS technologies. Satellite navigation signals offer a significant benefit for aviators in that they are available globally and enable a uniform quality of navigation throughout all phases of flight. Accordingly, more flexible route planning and higher-capacity operations (with tighter separation minima) are possible. GNSS signals also reduce user operating costs and permit the decommissioning of underutilized ground-based navigation aids. [6][7]

OCEANIC FLIGHT

Satellite navigation has been particularly beneficial in supporting transoceanic flights. Historically, the lack of terrestrial navigation aids and radar installations has significantly hindered navigation and surveillance functions for flights over water. As a consequence, aircraft spacing has depended primarily on procedures (including predefined flight paths) rather than on sensing. Separation minima have been correspondingly large, historically 60 nm in the lateral and longitudinal directions.

Because satellite navigation does not require ground-based facilities, GNSS technologies are particularly well-suited for oceanic navigation. As a consequence, civil aviation authorities have certified GPS as a "primary-means" system for navigation over the ocean (as well as for flights in other remote areas). Separation minima have already decreased from 60 nm to 50 nm for properly equipped aircraft in certain oceanic regions. Civil aviation authorities expect an eventual reduction of oceanic separation minima to 30 nm worldwide. Safety guarantees are not possible, however, without signal monitoring provided by ABAS. [8]

OVERLAND FLIGHTS, ENROUTE, TERMINAL, AND NONPRECISION APPROACH

Overland flights benefit from a pre-existing, ground-based communication, navigation and surveillance (CNS) infrastructure. Ground-based beacons have defined the international standard for en route navigation under instrument meteorological conditions for over half a century. Examples of beacon systems include tactical air navigation (TACAN), VOR, distance measurement equipment (DME), and combined VOR and TACAN (VORTAC). [8]

GNSS technology provides significant new capabilities to improve operational efficiency beyond what has been possible with ground-based navigation beacons, alone. For instance, GNSS navigation provides higher accuracy than ground-based beacons, on the order of tens of meters rather than hundreds. More significantly, GPS supports area navigation (RNAV), allowing for flexible flight paths that are not necessarily constrained to lie along routes between navigation aids. The FAA has certified GPS for supplemental navigation in many phases of flight (en route, terminal and nonprecision approach) and will likely certify GPS for primary means navigation in the future. Safety guarantees are not possible without ABAS or SBAS, however. ABAS is already widely used by commercial aircraft equipped with multimode receivers (MMRs), and SBAS (in the form of WAAS) is now used by private pilots as an affordable alternative to general aviation.

PRECISION APPROACH AND LANDING

Most approaches and landings occur under visual flight rules (VFR). Accurate and robust navigation technologies are nonetheless absolutely critical to enable safe landings under low-visibility conditions [instrument flight rules (IFR)]. ILS remains the predominant technology used to support aircraft landing under instrument conditions. ILS installations operate by creating a pair of signals, called the glide slope and localizer that together allow an aircraft to determine its vertical and lateral deviations from a reference trajectory leading downward toward the runway.

ILS technology has proven its reliability over decades of operation, but it is also somewhat expensive to deploy and maintain. Since it allows only for straight-in approaches and not for curved approaches, ILS technology also restricts the development of new procedures that could enhance terminal area traffic flow in the future. An enhanced technology known as the Microwave Landing System (MLS) was once perceived to be the successor to ILS, but it was largely abandoned when more cost-effective GNSS-based solutions were proposed.

After years of research, GNSS-based landing solutions have begun to emerge. WAAS has already been certified to support some ILS-like operations, designated as localizer performance with vertical guidance (LPV) approaches. For these approaches, the pilot must descend below clouds or fog and establish visual contact with the runway by a decision altitude of 250 ft. WAAS capabilities will be extended in the near future to enable a new type of operation called LPV-200, which is similar in nature to a category-I landing operation in that it enables a decision altitude of 200 ft. Automated landing capabilities will be provided by GBAS (by LAAS, for example). Although international deployment of LAAS would provide an enormous benefit to commercial aviation, certification of LAAS was not possible prior to 2008, in large part due to concerns about system reliability during severe ionosphere storms. LAAS certification for category-I landing is expect 2009. Continued research and development will be necessary to extend LAAS capabilities to handle category-II and category-III operations. The desired end state for LAAS is an enhanced Category-IIIc system that will fully support automated landing and rollout under zero-visibility conditions. [1]

GNSS MODERNIZATION

It is likely that GNSS will radically evolve up to year 2020, as modernized satellites and new satellite constellations arrive in orbit. An immediate impact for aviation will be the improved accuracy possible with new signal structures (such as BOC modulation) and the ability to mitigate ionosphere delays using multiple frequencies. In the longer term, it will be enormously beneficial to employ ranging signals from heterogeneous constellations to augment geometric diversity.

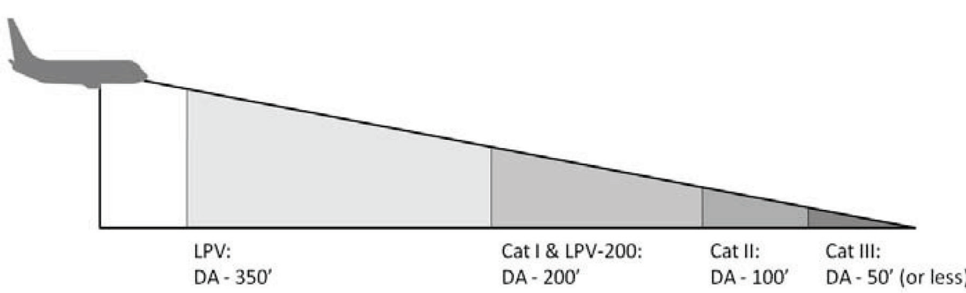

Figure 4. ILS-like approaches are enabled by GNSS augmentation systems

Figure 5. VOR – VHF omnidirectional range with distance measuring equipment

Multiple constellations will provide a more even distribution of satellites across the sky, yielding more accurate and more robust navigation solutions that significantly increase the percentage of time that aviation augmentations (and especially ABAS) are available. Merging ranging signals from multiple constellations is not a trivial proposition. However, given the significant potential benefits of multiconstellation navigation, it is anticipated that this hurdle will be overcome.

As new constellations are launched, GPS will remain a critical component of the overall GNSS infrastructure. A modernized GPS constellation will offer a range of new features. For aviation users, the most important of these has been the introduction, beginning with block IIF satellites, of an additional civil signal called L5C. Together the L1 and L5 civil signals can be combined for ionosphere-free navigation, alleviating the largest error source and the most threatening anomaly for GNSS navigation. The "magic" of the L1 and L5 frequencies is that, unlike the L2 frequency, they lie in an internationally regulated region of the electromagnetic spectrum designated for aeronautical radio navigation services (ARNS). The ARNS designation is critical to ensuring availability of signals worldwide, as radar and mobile services may interfere with the L2 frequency in some regions. If all goes well, four GNSS constellations will soon offer worldwide service: GPS, operated by the United States; GLONASS, operated by Russia; Galileo, operated by Europe; and Compass/Beidou, operated by China. The Russian government is attempting a major revitalization of the GLONASS constellation following a gradual decline in its size through the late 1990s and early years of the current century. [4][9]

New GLONASS satellites will introduce new signals and will likely transition away from frequency domain multiple access (FDMA) in favor of code division multiple access (CDMA). Europe's Galileo will introduce entirely new satellite navigation constellation, with three signals lying in ARNS bands (designated E1, E5a, and E5b). In addition to an open navigation service, Galileo will also provide specialized data, including a new safety of life service. China will deploy a mixture of medium Earth orbit (MEO) and GEO satellites to evolve its current satellite navigation capability into a worldwide service called Compass/Beidou. Compass/Beidou signals are expected to be interoperable with Galileo, but few details about the proposed constellation have been released. As new constellations emerge, new augmentation systems will be needed. In the next decade, SBAS will be updated to provide widespread LPV-200 service and to support multiple frequencies. [9] With an eye toward the more-distant future, the FAA has commissioned the GNSS Evolutionary Architecture Study (GEAS) to consider new options for providing LPV-200 service worldwide. This panel has identified three possible options: including (1) a GNSS integrity channel (GIC) that integrates existing worldwide SBAS capabilities, (2) an approach called absolute RAIM that extends the conventional ABAS model, and (3) a hybrid approach called relative RAIM that blends conventional SBAS and ABAS methods. Preliminary analysis indicates that these options present different cost and availability trade-offs. The GIC approach appears to provide high availability using a relatively expensive infrastructure of reference stations and GEO satellites. Absolute RAIM requires minimal infrastructure but appears to deliver reduced availability.

The hybrid relative RAIM approach appears to fall between these two extremes in terms of both cost and availability.

NEXT-GENERATION AIR TRAFFIC MANAGEMENT SYSTEM (NEXTGEN)

An international effort is under way to transform the practice of air traffic management to double or triple airspace capacity by 2025. In the United States, this effort is known as the "NextGen" program. GNSS navigation will be an important component of the NextGen CNS infrastructure. In particular, capacity will be increased through the use of four-dimensional trajectories that designate a precisely timed path for each aircraft, from departure gate to arrival gate. If robustness issues can be resolved, the use of four-dimensional trajectories will enable optimized scheduling, especially for the highly congested terminal-area airspace and for surface operations. GNSS will also play an important role in terrain-awareness warning systems.

New communication technologies, notably the automatic dependent surveillance-broadcast (ADS-B) service, will allow nearby aircraft to communicate their positions to each other as well as to air traffic controllers. Together, ADS-B and GNSS will be vital to enabling aircraft to detect and resolve conflicts, effectively decentralizing air traffic control responsibilities and allowing air traffic managers to handle increased traffic levels by focusing less on individual aircraft and more on the flow of groups of aircraft. Automated conflict resolution will also be particularly critical in enabling and certifying the new generation of UAVs, allowing them to enter the airspace alongside conventional manned aircraft. [3][5]

BACKUP NAVIGATION CAPABILITIES FOR AVIATION

At one time, the GNSS was widely perceived as a cost-effective replacement for a patchwork of existing ground-based navigation aids, from ILS to TACAN, VOR, and DME beacons. A complete reliance on GNSS navigation, however, would introduce a significant vulnerability to RFI. Military GNSS users have long understood the need to protect GNSS signals against hostile jamming. The vulnerability of civil GNSS applications to interference, intentional or unintentional, was first highlighted by a Volpe Center study in 2001. Instances of unintentional RFI have since been observed in the Monterey Bay, where faulty houseboat television receivers jammed GPS for several months in 2001, and in regions of San Diego, where a Navy training exercise briefly jammed GPS in 2007. [6]

To maintain the availability of radio navigation in the case of a GNSS outage (due to RFI or due to other factors, such as scintillation during a major ionosphere storm), ground-based navigation aids must be employed. One possibility is that e-Loran will serve as a backup system for GNSS navigation for a wide range of applications. Another possibility is that a slimmed-down network of navigation beacons will be maintained. In either case, it is hoped that some cost savings can be achieved by deactivating underutilized navigation aids.

CONCLUSION

As the development of aviation augmentation systems like WAAS and LAAS continues, the needs of aviation users and the nature of GNSS continues to evolve. New satellite systems are being introduced worldwide. These satellites will provide a many of new signals that will enhance aircraft navigation but that will also motivate the development of new augmentations. In the meantime, the aviation community is exploring radically new approaches to air traffic management (ATM) that will double or triple the capacity of the worldwide airspace. An emphasis on ubiquitous and accurate positioning within this new ATM architecture will lead to an increased reliance on GNSS navigation. For this reason, and because of enhanced security concerns in the new millennium, backup navigation systems will be absolutely essential to ensure graceful degradation of navigation performance should GNSS services be interrupted.

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