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Introduction

The Federal Aviation Administration (FAA) has embarked on an aggressive program to make satellite-based navigation technology available for use throughout the National Airspace System (NAS). Satellite-based navigation services will provide significant economic and safety benefits to the entire aviation community. The FAA is working with the aviation industry to augment the Global Positioning System (GPS), developed by the Department of Defense (DOD), to provide navigation services adequate for all phases of flight. Together with improved computer-based decision aids for controllers, these services will improve the safety of flight operations, accommodate user-preferred flight profiles, and increase airport and airspace capacity to meet future air traffic demands.

The transition to satellite navigation will permit the use of a single type of navigation receiver onboard all aircraft rather than the current requirement for a number of unique receivers to support different phases of flight. New navigation, landing, and surveillance services will be possible that are not currently economically feasible. In addition, there will be significant reduction in the cost of equipage both to the aircraft operator and to the ground service provider. It will be possible to phase out both the ground equipment and the associated avionics for a large number of ground-based systems such as VHF omnidirectional range (VOR), distance measuring equipment (DME), instrument landing system (ILS), nondirectional beacon (NDB), Omega, Loran-C, and marker beacons.

This document provides an overview of the FAA's 15-year plan for transitioning to GPS-based services. The transition timelines presented in this document are consistent with the 1994 Federal Radionavigation Plan (FRP) and with International Civil Aviation Organization's (ICAO) commitments to preserving ILS's and transitioning to satellite-based navigation. The document reviews briefly the plan for implementing GPS-based navigation and landing guidance (covered more fully in *GPS Implementation Plan for Air Navigation and Landing* [1]) and discusses in greater detail the plan for transitioning to the use of these services and phasing out the existing ground-based systems. A subsequent effort will develop detailed decommissioning criteria and a site-by-site decommissioning schedule.

This transition plan is based on the expectation that augmented GPS will fully meet the re-quirements of a sole-means aircraft navigation and landing guidance system, thereby allowing the phaseout of existing ground-based systems. The planned transition includes an extended period of overlap, during which both augmented GPS and the existing systems will be available. This overlap period will

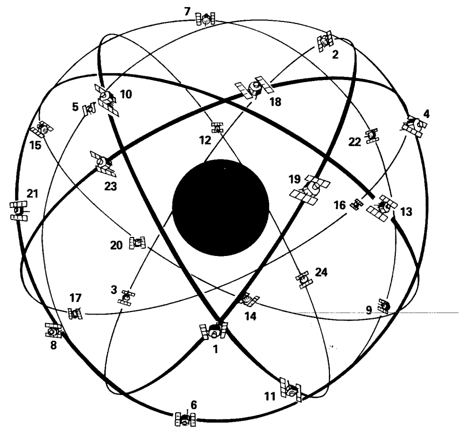

Figure 1-1
GPS Constellation

give both the FAA and aircraft operators the opportunity to become comfortable that augmented GPS meets the performance requirements before the existing sole-means systems are decommissioned. If aug-mented GPS fails to meet the performance requirements fully, the timetable for the phaseout of the existing systems will be modified as necessary to ensure continuity of navigation and landing guidance services.

1.1. GPS

GPS is a satellite-based system used for navigation, position determination, and time-transfer applications. The system consists of a 24-satellite constellation (Figure 1-1), plus associated ground-based monitoring and control facilities; it is operated and maintained by the DOD. The satellites radiate precisely timed signals coded so that a receiver on or near the surface of the earth can determine both the transmission time delay (or equivalently, distance) from the satellite to the receiver and the precise satellite position. By simultaneously receiving such signals from at least four satellites, the receiver can determine its position and time.

GPS provides two levels of service: a precise positioning service (PPS), available only to DOD and other authorized users, and a standard positioning service (SPS), available free of charge to civil users worldwide. SPS provides a lower level of position and time accuracy than PPS. Through a technique termed selective availability, the accuracy of SPS is controlled to protect U.S. national security interests. The DOD has committed to operating the system so that it provides a positioning accuracy of better than 100 meters horizontal (150 meters vertical) 95 percent of the time, and better than 300 meters horizontal (450 meters vertical) 99.99 percent of the time. Time accuracy is within 340 nanoseconds of Coordinated Universal Time (UTC).

The first of a series of research and development GPS satellites was launched in February 1978. In February 1989, the DOD launched the first of the operational GPS satellites. The GPS reached initial operational capability (IOC) on December 8, 1993, and full operational capability (FOC) on July 17, 1995; FOC means that the system fully meets its specified performance requirements.

To encourage both national and international civil use of GPS, the United States has committed to maintain the system for the foreseeable future and to provide a minimum of 6 years prior notice of any intent to discontinue the system. Replacement satellites (Block IIR) for the current constellation are in production, and the DOD is already initiating procurement of the Block IIF satellites as the follow-on to the Block IIR satellites. Together, the Block IIR and IIF satellites should provide for maintenance of the constellation to 2010 and beyond.

1.2. Benefits of GPS

The advent of satellite-based navigation will have a profound effect upon aviation. For the first time, aircraft will be able to determine their precise position anywhere in the world's airspace or on the surface. Using line-of-sight or long-range digital communications, aircraft will be able to communicate this satellite-derived position to nearby aircraft and to nearby or distant control centers. This will provide better situational awareness to pilots and will permit extending surveillance-based air traffic control to areas where it is not now technically or economically feasible, e.g., oceanic and remote airspace. Decommissioning some of the current en route radar-based surveillance systems may also be possible.

These capabilities will provide significant benefits to both aircraft operators and to the air traffic control systems which support their operations. Some of these benefits are:

- Precise 4-D (3 dimensions, plus time) navigation
- User-preferred flight paths
- Reduced separation standards for more efficient use of the airspace
- Precision approach capability at all runways
- Cost saving due to phasing out of ground-based systems (for example, VOR, DME, ILS, NDB, Omega, Loran-C)
- Lower avionics equipment cost (single type of avionics equipment supports all phases of flight)
- Reduced training costs, because ultimately pilots will only have to be trained to fly GPS-based procedures
- New procedures and navigation techniques

These benefits fall into two categories: those due to the greater operational efficiency which GPS permits, and those resulting from the phasing out of the current ground-based systems which GPS functionally replaces. Benefits in the first category accrue primarily to aircraft operators and are available as soon as GPS-based services are available. Benefits in the second group accrue primarily to the service provider (the FAA), but also to a lesser extent the aircraft operator; these benefits occur later, when equipage with GPS avionics has progressed to the point that the conventional systems can be decommissioned.

2

GPS Augmentation For Aviation

2.1. The Need for GPS Augmentation

GPS SPS, while suitable for many applications, including use as a supplemental means of aircraft navigation, fails to provide the accuracy, integrity, availability, and continuity of service which are currently required for service as a primary-means[1] or sole-means system in the NAS for aircraft navigation and landing guidance. The principal requirements for navigation and Category I landing guidance are summarized in Table 2-1 [2]. Requirements for Category II/III precision approach are specified in terms of required navigation performance (RNP) and are summarized in the Local Area Augmentation System Operational Requirements Document [3].

Table 2-1
Navigation and Category I Landing Guidance Performance Requirements

	En Route Through Non-Precision Approach	Precision Approach CAT I
Availability	0.99999	.999
Accuracy (95%)		
Horizontal	100 m	7.6 m
Vertical	not specified	7.6 m
Integrity		
Probability of HMI*	10^{-7}/hour	4×10^{-8}/approach
Time to Alarm	8 sec	5.2 sec
Continuity	$1-10^{-8}$/hour	.99995/approach

* Hazardously Misleading Information

[1] The ICAO definitions of supplemental, primary, and sole-means navigation systems appear in Appendix B.

Accuracy is the degree of conformance of an aircraft's measured position with its true position. Basic GPS meets the accuracy requirements for en route through nonprecision approach (NPA), but not for precision approach.

Integrity is the ability to provide timely warnings when part or all of the system is providing erroneous information and thus should not be used for navigation. Each GPS satellite broadcasts an integrity message to assure users that the signals being transmitted by the satellite are correct. However, one-half hour or more may elapse from the time that a fault occurs to the time that it is detected and the integrity message changed to reflect it. This is too long for aviation use. To ensure timely integrity information, current instrument flight rules (IFR)-certified aircraft GPS receivers use a technique termed receiver autonomous integrity monitoring (RAIM). This approach involves the use of redundant measurements to test the validity of the received signals. Four satellites in view are required to compute a GPS-derived position. With five satellites, if one fails, the receiver can determine that it is getting an inconsistent solution but cannot determine which has failed. If six or more satellites are in view, the receiver has enough information to determine which satellite has failed and use the remaining set in determining its position. While effective in providing integrity, RAIM reduces the availability, because now the system is available only when redundant satellites are in view in an acceptable geometry.[2] While this is generally the case when all 24 satellites are working, even then there are occasional "RAIM holes," i.e., regions where RAIM is not available for some period of time due to an insufficient number of satellites in view. If one or more satellites is out of service, for maintenance or due to a failure, periods of unavailability due to RAIM outages could become too numerous and too long to permit the use of GPS for aircraft navigation.

Availability is the probability that at any time the system will meet the accuracy and integrity requirements for a specific phase of flight.

Continuity is the probability that a service will continue to be available for a specified period of time, given that it is available at the beginning of the period (for example, that the system will continue to meet the requirements for approach guidance throughout an approach, given that it is available at the initiation of the approach). It is of concern primarily in the approach mode of flight.

To meet these requirements, the FAA has undertaken programs to develop two systems to augment GPS: the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS).

2.2. WAAS

WAAS is an augmentation of GPS which includes integrity broadcasts, differential corrections, and additional ranging signals. It is being developed to provide the accuracy, integrity, availability, and continuity required to support all phases of flight through Category I precision approach.

As illustrated in Figure 2-1, WAAS comprises a network of wide-area reference stations which receive and monitor the GPS signals. Data from these reference stations are transmitted to master stations, where the validity of the signals from each satellite is assessed and wide-area corrections are computed. These validity (integrity) messages and wide-area corrections are transmitted to aircraft via geostationary communications satellites, which by serving as additional sources of GPS ranging signals thereby increase the number of satellites available to the system's users. The WAAS signal will be transmitted on the same frequency and with the same type of code-division multiplex modulation as the GPS SPS signal, so that the same receiver can acquire and process both the GPS and WAAS broadcasts.

[2] Altimeter aiding, i.e., the use of the aircraft's altitude as measured by its barometric altimeter, can substitute for one satellite in the integrity assessment.

The integrity message provided by WAAS, termed a ground-based integrity broadcast (GBIB), provides the user with a direct verification of the integrity of the signal from each satellite in view. The user does not require the extra satellites which are required for RAIM; in fact, since the WAAS satellite itself provides a ranging signal, generally only three GPS satellites will be required to compute position. With this reduced requirement for the number of satellites in view, GPS/WAAS will meet the availability and continuity requirements for all phases of flight.

The basic concept and operational feasibility of WAAS has been demonstrated, and a contract for the development of the operational system was signed in August 1995. The system is scheduled to reach its initial operational capability termed Initial WAAS (IWAAS) in early 1998. The IWAAS will provide dual coverage by geostationary satellites of the eastern and western parts of the continental United States, with an area in the center of the country having only single coverage (Figure 2-2).

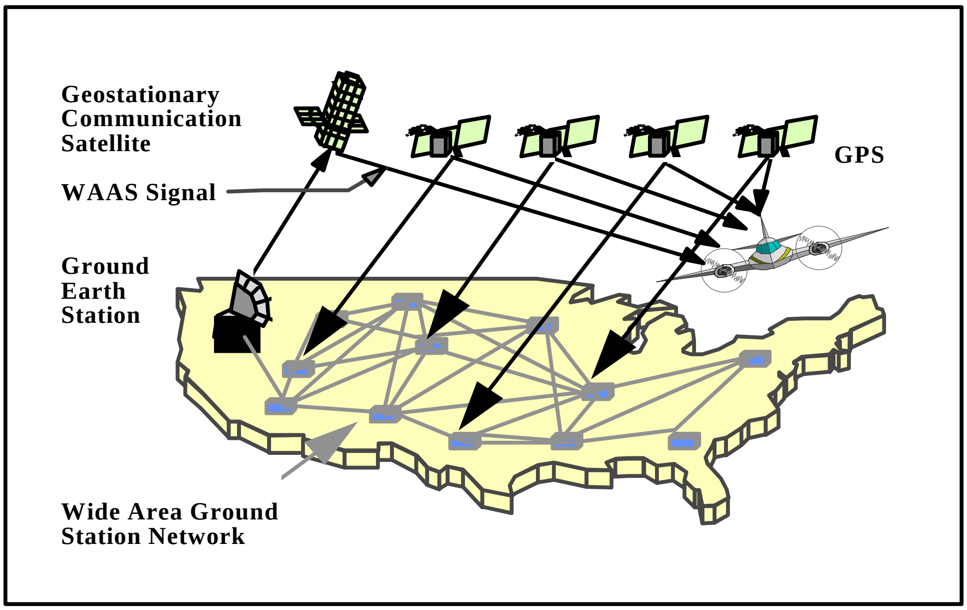

Figure 2-1
Wide Area Augmentation System

The wide-area correction signals transmitted by WAAS allow the aircraft's GPS/WAAS receiver to correct for the timing and ephemeris (satellite position) errors in the signals from each GPS or WAAS satellite and the signal delay due to the Earth's ionosphere. With these corrections, GPS/WAAS is expected to meet the accuracy requirements of Category I precision approach.

Although the IWAAS will have the capability for supporting navigation and Category I precision approach, it will not have the level of internal redundancy, and thus guaranteed availability in the event of failure of elements of the system, required of a sole-means system.

The WAAS contract contains several options for the expansion of the system of both the number of ground stations and the number of satellites. These options will be exercised in the years following IWAAS, with the goal that by 2001 WAAS will have achieved a sufficient level of robustness to enable it to serve as a sole-means system for air navigation and landing guidance.

In parallel with the development of WAAS, the avionics industry will be developing the requisite aircraft equipment. The basic WAAS minimum operational performance standard (MOPS), which includes the full specification of the navigation modes, was completed on January 16, 1996 [4]. Later in 1996, the WAAS MOPS will be updated to include definition of the precision approach modes. This will allow time for avionics to be developed by IWAAS.

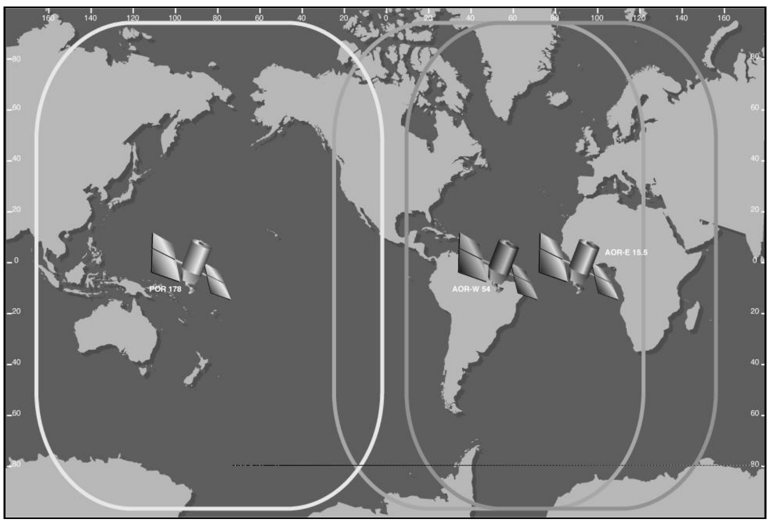

Figure 2-2
WAAS Coverage

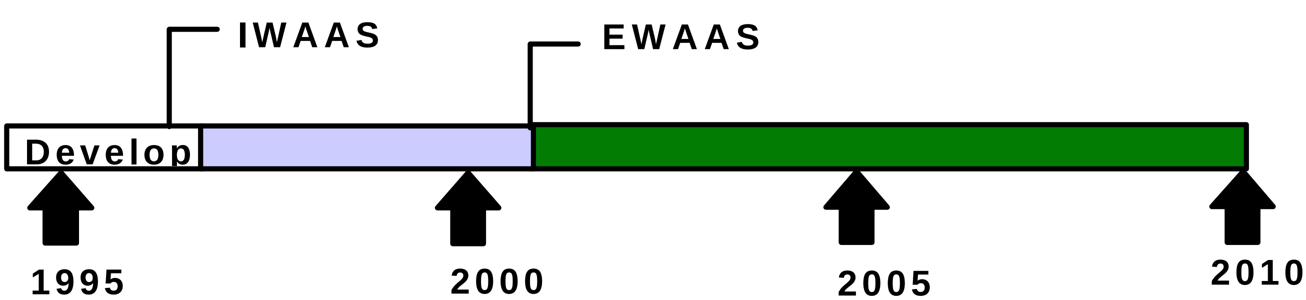

Figure 2-3
WAAS Implementation Schedule

As soon as they are available, GPS/WAAS avionics are expected to supplant technical standard order (TSO)-C129-based GPS avionics. The latter will continue to be useful for supplemental navigation and TSO-C129-based NPA's, but unless they are upgraded to meet the GPS/WAAS TSO they will not be useable for primary/sole-means navigation nor for GPS/WAAS nonprecision or precision approaches. The only foreseeable exception to the diminished value of TSO-C129 avionics will be for TSO-C129 equipment meeting the capabilities of FAA Notice 8110.60 and used for primary-means navigation in oceanic or remote areas.

2.3. LAAS

The accuracy provided by the WAAS will be adequate to support precision approaches to Category I minimums but not to Category II/III minimums. Meeting the more stringent requirements of Category II/III precision approaches will require a LAAS. As illustrated in Figure 2-4, under this concept the corrections to the GPS (and WAAS) signals are broadcast to aircraft within line of sight of a ground reference station. The range of this service will typically be 25-30 nautical miles (nm).

In addition to providing a Category II/III capability, LAAS may be used at some high-capacity airports to increase service availability beyond that ensured by WAAS alone. LAAS may also be needed to support Category I approaches at a small number of airports whose specific locations make it difficult to use GPS/WAAS because of inadequate visibility of WAAS satellites. LAAS can also provide terminal navigation, airport surface navigation, and guided missed approach and departure procedures.

The FAA is working with U.S. industry and universities to determine the technical feasibility of using satellite-based systems for Category II and III precision approaches. Several cooperative projects have already demonstrated the ability of both advanced code and kinematic carrier phase differential techniques to meet the accuracy requirements of Category III autoland approaches. Several satisfactory integrity techniques have also been demonstrated, but must be validated.

The work in this area is being closely coordi-nated with the development of local area differential GPS (LADGPS) systems for Special Category I (SCAT-I) precision approaches,

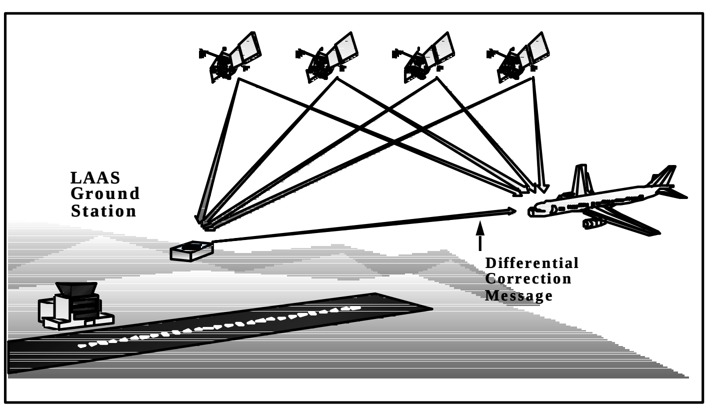

Figure 2-4
Local Area Augmentation System (LAAS)

which is being funded by private industry. The FAA will choose a LAAS architecture and develop LAAS and LAAS-compatible avionics standards by 1998. The method of acquiring LAAS is currently under review. The FAA may define the certification standards and let manufacturers develop the equipment and request its certification. The FAA is also conducting research on providing airport surface traffic surveillance and guidance based on LAAS-augmented GPS.

3

Introduction of GPS-Based Services

3.1. Early Operational Use

Even with its limitations, unaugmented GPS is already being used productively to enhance aircraft operations. A number of the significant events relating to this early use are listed in Table 3-1, illustrating the rapid pace at which GPS is being introduced into operational service.

Table 3-1
Significant Events Supporting Early Operational Use of GPS

{PRIVATE**}**Feb 1991	GPS approved as an input to multisensor navigation systems
Dec 1992	TSO-C129 issued for GPS receivers
Jun 1993	GPS approved for supplemental use for en route through NPA
Jun 1993	NPA overlay program initiated
Aug 1993	RTCA published minimum aviation system performance standard (MASPS for SCAT-I differential GPS system
Dec 1993	First private GPS NPA in operation
Feb 1994	The Administrator announced GPS to be operational and an integral part of the U.S. air traffic control system
Feb 1994	Initiated approval of supplementary GPS receivers for oceanic, domestic en route, terminal, and NPA's
May 1994	First GPS route established
Jun 1994	First GPS helicopter approach approved
Aug 1994	First stand-alone GPS NPA published
Aug 1994	Published FAA Order 8400.11 for the approval of SCAT-I systems
Sep 1994	Letter from the Administrator to ICAO reiterating U.S. offer of GPS SPS
Dec 1994	Approval of GPS as a primary means of navigation in oceanic airspace
Sep 1995	Use of future air navigation system (FANS)-1 in Pacific

Domestic Navigation and Nonprecision Approach

Following issuance of TSO-C129 for GPS receivers, GPS was approved in June 1993 for use as a supplemental system for navigation and NPA. Its status as a supplemental system means that a primary- or sole-means system must be onboard and operational in case GPS is not useable. However, it allows the aircraft to realize some of the operational benefits of GPS, e.g., direct, off-airways navigation.

The overlay initiative, which permits the use of GPS to fly most existing NPA procedures, has been of particular significance in achieving early operational benefits from GPS. The convenience of GPS for executing the thousands of existing VOR- and NDB-based NPA's was made immediately available to suitably equipped aircraft.

In addition to the "overlay" NPA's, the FAA is moving aggressively to produce and publish GPS-based NPA's for runways for which approaches do not previously exist, as well as improved approaches (lower minimums) for runways with existing NPA's. The FAA de-veloped more than 500 such approaches in 1995 (of which more than 100 have since been published) and plans to develop an additional 500 in 1996. Both nonprecision and precision approaches produced after 1996 will be designed for GPS/WAAS avionics and will not be useable by unmodified TSO-C129 GPS avionics. Both overlay and stand-alone approaches designed for TSO-C129 avionics will continue to be supported until at least 2005.

The increased navigational accuracy which GPS provides, and the ability to define routes in three dimensions, will lead to much more efficient use of the airspace. Climbing and descending terminal arrival and departure routes can be precisely defined and flown, improving the efficiency of terminal area traffic flow and better allowing the avoidance of noise-sensitive areas. Separation standards may be reduced. Realizing full advantage of these capabilities will require improved, data-link-based air-ground communi-cations and advanced automation-based control-ler aids, such as automated en route air traffic control (AERA) and center TRACON automa-tion system (CTAS). Airspace efficiencies will thus be paced by the availability of the new hardware and software required for these systems. The goal is to provide the aircraft operator with increasing flexibility, evolving through easily changeable user-preferred routing with optimized climb and descent profiles to a nearly free-flight environment. In true free-flight, the operator will be able to choose and vary his/her route at will, subject only to the constraints of conflict with other aircraft and restricted airspace.

As an early initiative in providing more efficient routing for aircraft, the FAA is gradually reducing the altitude above which direct routing will be routinely approved for suitably equipped (i.e., area navigation capable) aircraft; the goal is to reduce this altitude to flight level 290 (29,000 feet). Flight management system (FMS)-equipped aircraft with scanning-DME area navigation (RNAV) capability can already take advantage of these direct routes; however, many older aircraft are not so equipped. A GPS navigator is a cost-effective means to achieve the RNAV capability, much lower in cost than equipping with FMS/scanning-DME.

FAA Order 7100.10, "Air Traffic Implementa-tion Plan For The Use Of The Global Position-ing System," sets forth a number of specific steps the FAA is considering to provide benefits to the airspace user. Among these are:

En route

- Restructure existing airway system to accommodate direct routings.
- Use GPS capabilities to reduce separation standards in the domestic en route environment.
- Develop a flexible offset route capability and procedures that will relieve saturation on high-density routes.
- Restructure special-use airspace to accommodate a GPS-based en route system
- Establish an altitude stratum in domestic airspace designated for GPS-equipped aircraft.

Terminal

- Establish a GPS-based terminal route structure.
- Use GPS capabilities to reduce terminal separation standards.
- Use GPS to identify, track, and control aircraft and vehicles on an airport surface to an accuracy of 1 to 3 meters.

While some operational benefits can be realized as soon as a single aircraft equips with GPS, many of the more significant benefits depend on a high degree of equipage and/or providing segregated airspace for GPS-equipped aircraft. The FAA will implement these services in a way which encourages equipage by maximizing benefits for the equipped user, while minimizing the operational penalty to the unequipped user.

Oceanic Navigation

GPS provides the basis for a revolution in oceanic operations. Currently, aircraft are restricted to minimum lateral/longitudinal separations of 60/120 nm because of the limited accuracy of the available means of oceanic navigation—Omega and dead-reckoning based on inertial navigation systems—and the poor pilot-controller communications. With GPS, precision navigation will be available to aircraft out of range of land-based systems. Automatic dependent surveillance (ADS), based on reporting of GPS-derived position by satellite or high frequency data link, will provide the oceanic controller with a radar-like display of aircraft position. Over time, oceanic operations will evolve to resemble those over land, with much reduced separations and the flexibility associated with operating in a surveillance-based air traffic control (ATC) environment.

The first step in this direction was the approval in December 1994 of the use of GPS as a primary means of navigation for oceanic operations; this capability was first used operationally in July 1995. Also 1995 saw the initial operational use in the Pacific of the FANS-1 "package," which includes GPS-augmented navigation and satellite data-link reporting of position and will result in reduced separations and more flexible flight paths.

The reduction of lateral/longitudinal separations to 50/50 nm in the South Pacific is scheduled for 1997, and further reductions to 30/30 nm are scheduled for 1999. Although initial implementation of these separation standards is scheduled for the South Pacific, the reduction of separation standards in other regions is also expected for aircraft equipped with FANS-1 capabilities.

Foreign Use

Many countries with less developed navigation infrastructures than the United States and Western Europe have moved rapidly to make GPS an integral part of their air navigation systems. A prime (but not the only) example is Fiji, which, with U.S. assistance, now bases its internal aircraft operations entirely on GPS.

Experiments, Demonstrations, and Private Use

In addition to the operational use described above, there have been numerous experimental demonstrations of GPS capabilities, especially of the use of differential GPS for precision approach guidance. Further, several specific operators have been authorized to use GPS guidance for commercial operations; these include NPA's by medical helicopters and NPA and departure guidance at Aspen, Colorado, by Continental Airlines. Several locations and operators are currently seeking approval for the use of industry-developed LADGPS systems for Special Category-I (SCAT-I) precision approach.[1]

3.2. Introduction of WAAS

As soon as IWAAS is achieved, WAAS will increase the availability of navigation and NPA's throughout its coverage volume. The combination of additional ranging signals and ground integrity broadcast will allow GPS/WAAS to be used as the primary radionavigation system.

In parallel with the operational use of WAAS for navigation, intensive testing will be carried out to verify that the accuracy of the WAAS-provided differential corrections is adequate for precision approach. It is currently expected that within 3 to 6 months after IWAAS, the use of WAAS will be approved for precision approach. Initially, minimums may be somewhat higher than normal ILS minimums while both the FAA and aircraft operators gain additional experience in its use.

The use of WAAS for precision approach requires not only the availability of the signal, but also the production and flight testing of WAAS-based approach procedures. Producing these procedures requires the acquisition of new, high-precision data bases of the approach waypoints. Production of procedures will be initiated in 1997, with the goal that by the year 2000 procedures will be available for at least all runways currently equipped with ILS.

In parallel with the development and certification of GPS/WAAS-based Category I approaches where ILS approaches currently exist, approaches will be developed and certified for runways and heliports which do not currently have precision approaches.[2] The technical capability will exist to provide a precision approach to essentially all qualifying runways and heliports. The development of procedures will become the pacing item in meeting the demand for new approaches, and the current FAA resources and systems available for building such procedures may become quickly overwhelmed with the demand.

To satisfy these new requirements in a timely fashion, and to take full advantage of the accuracy and other capabilities obtainable with satellite-based systems, instrument approach procedure development time must be reduced to keep pace and to be responsive to the demand. That places a high priority on the new instrument approach procedures automation upgrade currently underway. The upgrade offers significant potential for developing faster terminal instrument approach procedures; the program will be aggressively pursued to achieve full operational utility from GPS/WAAS in a timely manner, while maintaining the highest level of safety.

[3] A number of aircraft operators are interested in achieving Category I GPS operations before the availability of WAAS. To satisfy this need, the FAA has cooperated with RTCA in the development of minimum aviation system performance standard (MASPS) for SCAT-I systems. Systems built to these MASPS would be procured and installed by the operator, and their use would usually be limited to that operator's aircraft. Thus, SCAT-I approaches may not be used by the general public, but can continue to be used by the private operators even after WAAS and LAAS are deployed. It is not anticipated that SCAT-I receivers would be compatible with WAAS/LAAS.

[2] WAAS-based precision approaches can be implemented quickly, and at relatively low cost, as long as full approach lighting systems are not required. Deploying the approach without a standard approach lighting system will mean that an additional 1/4 nm visibility (3/4 nm visibility) will be required to execute the approach. The FAA will develop new establishment criteria for precision approaches with and without approach lighting systems. Airports with runways which do not meet the establishment criteria for a federally provided approach lighting system will have the option of acquiring and installing such a system using airport funds in order to obtain the lower approach minimums. Unless purchased with Airport Improvement Program (AIP) or Passenger Facility Charge (PFC) funds, maintenance would be the responsibility of the airport. If the approach lighting system is purchased with AIP or PFC funds, the FAA will only assume maintenance responsibility if (1) the system is designed to an FAA specification, or (2) the system is certified to Part 171 of the Federal Aviation Regulations and is or can be 100 percent supportable by the FAA Logistics Center.

4

Transition to GPS/WAAS-Based Navigation and Landing Guidance

Today, aircraft navigation and landing guidance functions are provided by a multiplicity of systems including VOR/DME,TACAN, Omega, Loran-C, NDB, ILS, and INS. In the United States alone, the ground-based infrastructure for navigation and for precision approach guidance each represent a billion-dollar-level investment. In addition, the navigation-related avionics investments in each of the three principal user communities—air carrier, general aviation, and military—themselves represent billion-dollar-level investments. To transition from this massive in-place infrastructure, which enjoys great user confidence based upon decades of operational experience, to a totally new system represents a substantial undertaking—one which will require a major investment of resources by both the service provider and the aircraft operator. The required investment by each of the three elements of the user community will be on the order of a billion dollars, excluding the costs of aircraft downtime and the retraining of air crews and maintenance personnel.

Before such a transition can take place, three essential prerequisites must be met:

Operational Benefit - The aircraft operator must perceive sufficient operational benefit to motivate the investment in the new technology.

System Performance - Through analyses, flight tests, and operational experience, aircraft operators must be convinced that the new system meets their requirements for accuracy, integrity, and reliability. This can only be finally proven through extensive operational experience.

Transition Period - The aircraft operators must have time to recoup their investment in conventional avionics. While many avionics systems have been used for 15 to 20 years or more, a transition period of approximately 10 years appears to be a reasonable compromise between the FAA's desire for a rapid transition and the aircraft operator's desire to use current equipment as long as possible.

The transition will be a three-phase process. In the first phase, the new system will be available on a supplemental basis. This phase allows the users to gain confidence through operational experience and to begin to realize substantial operational benefits, while the conventional systems are still fully operational. During this period even new aircraft must still be equipped with avionics for the ground-based systems.

In the second phase, the new system will be certified as primary/sole-means for navigation and/or landing guidance. During this phase both the old and new are primary/sole-means systems; aircraft can operate with either or both. During this period new aircraft could be equipped only with GPS/WAAS, and existing aircraft would be gradually re-equipped with GPS/WAAS. The user would no longer be required to be equipped with avionics for the ground-based systems.

Finally, in the third phase of the transition, the conventional systems will be decommissioned. At this point, users must be equipped with GPS/WAAS in order to operate their aircraft using electronic navigation.

As pointed out above, a 10-year dual-primary/ sole-means period (phase 2) is felt to be a reasonable compromise between the aircraft operators' desire to realize maximum economic benefit from their investment in existing avionics and the service providers' need to decommission existing systems to save sustainment costs.

4.1. Transition Considerations

Before the current sole-means systems can be decommissioned, two principal events must occur. First, aircraft must be equipped with GPS/WAAS; and second, both the ground system operators and the aircraft operators must be convinced that GPS/WAAS-based operation meets required standards of safety and reliability. The latter issue will be addressed through a combination of extensive analyses, flight tests, and operational experience.

A number of issues need to be considered in assessing the overall ability of the system to meet aviation's needs.

Reliability

GPS/WAAS must have, and demonstrate, the overall level of reliability needed to support civil aviation operations. This involves not only reliability in day-to-day operations but also a demonstrated level of redundancy to cope with failures in elements of the system (for example, satellites). In addition, a credible plan must be in place for system sustainment, especially satellite replenishment.

Electromagnetic Interference

Radio-frequency interference (RFI) is a matter of concern in any radionavigation system. While all systems which depend on radio transmission are susceptible to both accidental and intentional interference, GPS/WAAS is especially vulnerable because of the very low level of signal power received from the satellites.

Interference to GPS/WAAS is being evaluated by a number of agencies, including the RTCA Special Committee 159. Analyses, field measurements, and operational experience to date give confidence that all naturally occurring (i.e., non-intentional) RFI can be adequately suppressed at the source. Continuing analytical and experimental investigations and operational experience will validate this conclusion well before GPS/WAAS is designated as a sole-means system.

A prerequisite for making GPS/WAAS a sole-means system will be to develop the ability to detect, locate, and suppress any interference rapidly, intentional or non-intentional, which may occur. Procedures will also need to be in place to maintain separation safely and recover aircraft which are affected by such interference during the time between when the interference occurs and when it can be suppressed. This is not a new situation; procedures are in place today to deal with the temporary loss of a major system element such as a regional radar or control facility.

Accuracy

Some naturally occurring phenomena, especially ionospheric disturbances, are known to affect GPS/WAAS accuracy. There is some continuing concern related to the magnitude of this effect on the accuracy of the WAAS during the peaks of the 11-year sunspot cycle. Experience of GPS users during the most recent peak period of 1989/90 gives confidence that these effects are manageable. However, data during the upcoming peak period around 2001 will be important to finalizing the system parameters, especially the number of WAAS reference stations needed to maintain the requisite system accuracy during ionospheric disturbances, and the number of local area systems required to maintain the very high level of availability required at high capacity airports.

Operation During National Emergencies

Concern has been expressed that during a national emergency the DOD might use its control of GPS to deny the signal to civil users or to degrade GPS to the point where it could no longer support civil aviation. All U.S. navigation facilities, and in fact all electronic emitters, are subject to control at the direction of the National Command Authority (i.e., the President). Ever since World War II a plan, termed SCATANA (Security Control of Air Traffic and Navigation Aids), has existed to exercise such control if needed. However, the United States is committed to making GPS available for both national and worldwide civil applications, and only in a dire national emergency (for example, a direct attack on the United States) would it deny the availability of GPS along with any other navigation systems which could assist an attacker.

Operation during GPS Signal Disruption

The FAA's plan is that GPS/WAAS/LAAS will become the sole-means radionavigation and landing guidance system; this, by definition, means that no back-up radionavigation system will be required. During an extended transition period, the current navigation and landing guidance systems, especially the VOR/DME and ILS, will provide a backup while the aviation community becomes convinced, through extensive operational experience, that GPS/WAAS provides the level of availability and integrity required of a sole-means system. Only when this has been accomplished will the current ground-based systems be decommissioned.

As discussed above, after VOR/DME and ILS are decommissioned, there will need to be procedures for coping with a possible temporary interruption of GPS/WAAS, for example due to the occurrence of unintentional or intentional inter-ference. A principal option under consideration is for ATC to maintain separation of the affected aircraft using surveillance which is independent of GPS/WAAS (e.g. primary and/or secondary radar), vectoring the aircraft to visual conditions or to a region unaffected by the interference.

4.2. Projected User Equipage with GPS/WAAS Avionics

Achieving widespread user equipage with GPS/WAAS avionics is critical to the transition to GPS/WAAS-based navigation and landing guidance. Only when essentially all aircraft are equipped can extensive decommissioning of current ground-based systems take place.

It is expected that for most aircraft, equipage with GPS/WAAS avionics will occur in two steps, the first motivated by the operational benefits of GPS/WAAS and the second by the reduced maintenance and training costs of being GPS/WAAS-only equipped and by the expected phaseout of ground-based navigation and landing guidance aids.

Almost all aircraft used regularly for IFR operations are equipped with redundant avionics,[3] both to provide a backup in the event of a failure of one of the units and for the convenience of being able to tune to two VOR/DME's at one time. However, essentially all of the operational benefits

[3] Redundant avionics are required for Part 121 (air carrier) and Part 135 (regional) operators, and optional for Part 91 (general aviation) operators.

of GPS/WAAS can be achieved with a single GPS/WAAS receiver. It is expected, therefore, that most aircraft being retrofitted with GPS/WAAS will initially be equipped with a single unit, with the conventional avionics left in place as a backup both to possible failure of the on-board GPS/WAAS unit as well as to the possible unavailability of the GPS/WAAS signal. (GPS/TSO-C129 avionics may also be retained in a backup role.) In many cases, such equipage will take place—and provide benefits—even before GPS/WAAS is certified as a sole-means system. The second step in the process, equipage with dual GPS/WAAS avionics, will most likely occur only after GPS/WAAS is certified as sole-means, aircraft operators are fully convinced of its ability to serve as a sole-means system, and the time for decommissioning of the ground-based systems is imminent.

The aircraft operator achieves several benefits from this approach. First, the added cost of dual equipage is deferred for a considerable period, perhaps 5 to 10 years. Second, by deferring the acquisition of the second unit the operator has the advantage of additional years of design maturity, likely providing additional features and/or lower cost based on the years of experience with the construction and use of the early units.

Until essentially all operators are dual-equipped, there will be continued dependence on the conventional ground systems as back-up. This has been a major factor in determining the time-scale for system decommissioning.

Several factors will pace the rate of equipage with GPS/WAAS avionics during both phases of equipage. Principal among these is the aircraft operators' perception of the tradeoff between operational benefit and cost. The rate of equipage itself has a significant effect on cost, especially for operators of scheduled services. The cost of having an aircraft out of service can be a major part of the equipage cost; one airline has estimated a typical cost of $35,000 per day for an aircraft out of service. Thus there is a strong desire to perform the installation of any new avionics at a time when the aircraft is already out of service for major scheduled maintenance actions. For an airline fleet this itself can spread equipage over a 4- to 6-year period.

Similar factors affecting the equipage rate for private and corporate aircraft include the production rate of avionics and the installation rate which the avionics service industry can support. Both manufacturing and service industries are sized to meet a relatively steady demand. They cannot economically expand to meet a one-time peak load, for example to equip the general aviation fleet with GPS/WAAS avionics in a 1- to 2- year period, and then revert to the size needed to support a reduced steady-state load. Thus, even if there were a demand for rapid equipage of the large general aviation fleet with GPS/WAAS avionics, it would take a number of years to satisfy that demand.

The operational benefits of GPS/WAAS, especially increased routing flexibility and many more precision approaches, will motivate most operators of aircraft used extensively for IFR operations to equip with GPS/WAAS in the 5- to 6-year period following the availability of services. Thus, with expected GPS/WAAS implementation schedules, most aircraft will be at least single-GPS/WAAS-equipped by 2005. At that point, the current sole-means ground systems—VOR, DME, and ILS—will become backup systems for these operators. Since most aircraft will be navigating using GPS/WAAS, substantial reductions can then be made in the number of VOR/DME and ILS ground facilities.

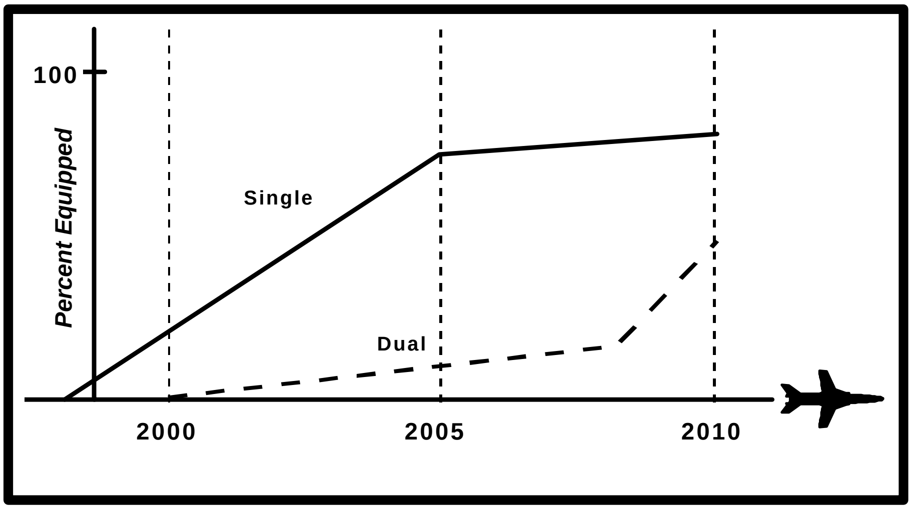

Figure 4-1
Projected Equipage with GPS/WAAS Avionics

Although a sufficient number of ground facilities will be maintained to allow users to complete their flight without GPS/WAAS avionics, there may be some loss in flexibility and efficiency. For example, for aircraft not equipped with a GPS/WAAS receiver, the reduction in the number of VOR/DME facilities may lead to less-direct routing, and the reduction in the number of ILS facilities will mean that ILS-based precision approach may not always be available or may be restricted to a single runway at airports now having multiple ILS approaches.

As operators gain increasing confidence in GPS/WAAS, and as GPS/WAAS avionics with new features and reduced cost become available, equipage with dual GPS/WAAS avionics will increase. By the end of the transition period—nominally 2010—all operators who require essentially 100 percent avionics reliability will be dual-GPS/WAAS-equipped. (Just as today many operators who fly IFR only occasionally are not dual avionics equipped, the same can be expected to be the case when GPS/WAAS is sole-means.) This projected equipage strategy is illustrated in Figure 4-1; as indicated above, dual-equipage never reaches 100 percent, reflecting that some operators who do not use their aircraft for extensive IFR operations will choose not to equip with redundant avionics.

4.3. Phaseout of Current Systems

The following sections outline the current plans for phasing out each of the existing ground-based navigation and landing guidance systems. The dates indicated are consistent with the 1994 FRP [5] and are based on the current schedules for when GPS-based capabilities will provide a level of service equivalent to the system being phased out. Thus, for example, the phaseout of the current sole-means systems—VOR/DME,TACAN and ILS—would be delayed if WAAS were delayed; however, the phaseout of Omega and Loran-C would not be affected by a delay in the introduction of WAAS, as basic GPS already provides an equivalent level of service.

4.3.1 Navigation System Phaseout

The NAS currently provides several systems to support en route and terminal area navigation, including NPA. These include VOR with associated DME, TACAN, NDB, Omega, Loran-C, and GPS. Omega and Loran-C are operated and maintained by the U.S. Coast Guard. Omega is used by a limited number of aircraft for oceanic and domestic en route navigation. Loran-C is widely used by general aviation for en route and terminal area navigation.

The current inventory of the FAA-operated systems is shown in Table 4-1.

Table 4-1
FAA-Operated Ground-Based NAVAIDS[4]

NAVAID TYPE	INVENTORY
VORTAC	640
VOR/DME	256
VOR	36
NDB	725

VOR, DME, and TACAN

VOR is the principal aircraft navigation system in the United States and, to a large extent, the rest of the world. It is the basis of the current low- and high- altitude aviation route (airways) structure; airways usually consist of direct lines connecting the VOR's.

The VOR system (i.e., the combination of transmitting station and aircraft receiver) typically has an accuracy of a few degrees, resulting in cross-track errors on the order of a mile at 20 miles from the station. This is the principal factor defining both the width of airways and how close adjacent independent airways can be spaced.

VOR navigation normally consists of flying these airways. Because of the location of the VOR's, this often leads to indirect, inefficient flight paths between an aircraft's origin and destination.

Of the 932 FAA-operated VOR stations in the United States, all but 36 have an associated DME to allow an aircraft to determine its distance as well as bearing from the station and thus define its two-dimensional position in space. By using a combination of two or more VOR's and/or DME's to determine position, specially equipped aircraft can navigate off airways. This is referred to as area navigation (RNAV) and allows more direct routing. Most new air carrier and similarly equipped aircraft have a flight management system (FMS) which uses multiple DME's to determine position; with this equipment, RNAV with a precision of 0.3 nm or better is possible.

VOR/DME-based navigation is used for almost all aircraft navigation in the United States, including en route, terminal area, and non-precision approach. Exceptions are direct high-altitude navigation flown using Omega or on-board INS's and a few remaining low-frequency airways in Alaska and other parts of the world defined as lines connecting low-frequency beacons.

In addition to forming the basic en route navigation network, in recent years many VOR's have been added to assist in organizing arrivals and departures at major terminal areas. This has been necessary because without the special avionics which allow RNAV capability, aircraft using VOR navigation must fly on radials to or from a VOR station. Thus, wherever a route is desired, one or more VOR's must be installed to define it. This is one of the principal limitations of VOR navigation.

Most VOR sites are part of the airways structure; i.e., they are a navigation fix for one or more airways. Many of these also provide NPA guidance to nearby airports. In addition, there are a small number of VOR's whose function is solely as an NPA aid.

TACAN is functionally similar to VOR/DME. Both use the same ranging component (DME), but the TACAN azimuth component operates in a different radio-frequency band than VOR. TACAN is widely used by DOD aircraft; in fact, most fighters and bombers are not VOR-equipped and depend on TACAN for airway navigation and NPA. The FAA-operated VORTAC's combine VOR, DME, and TACAN in a single facility.

[4] In addition, there are approximately 100 non-FAA VOR facilities, and 1,000 non-FAA NDB's.

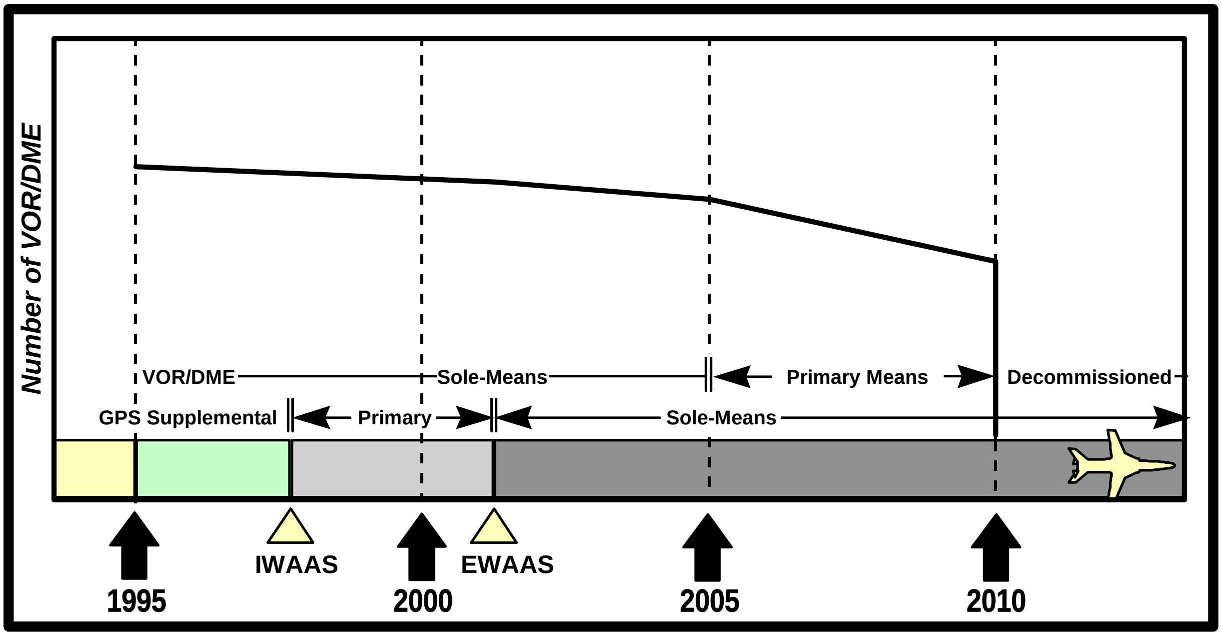

Figure 4-2
Phaseout of VOR/DME

Phaseout of VOR and DME

Maintaining the current VOR/DME system is expensive. To provide the current level of service, the equipment costs are estimated at $139 million over the next 10 years, and the operations and maintenance costs are estimated at $80 million per year. Thus, there is considerable financial incentive to reduce the number and ultimately phase out VOR/DME.

However, until GPS/WAAS is approved as a primary means of navigation in the NAS (estimated to occur by 1998/99), all aircraft which wish to operate under IFR will have to be equipped with the avionics for VOR navigation. This in general requires at least two VOR receivers and frequently one or more associated DME's. The aircraft operator will want to be able to use this equipment for a reasonable service life before being forced to re-equip.

As soon as GPS/WAAS avionics are available, operators are anticipated to begin equipping with it to achieve the associated operational benefits and convenience. Because of its accuracy and flexibility, GPS/WAAS will be the navigation aid of choice. An operator who equips or re-equips an aircraft during this period is likely to equip with one GPS/WAAS system in addition to retaining one or two conventional VOR system(s). The latter will allow completing a flight in the event of a temporary unavailability of GPS/WAAS, albeit with less convenience. But to do this, the VOR ground environment must still be in place. The conventional system is now relegated to the role of backup. Even when GPS/WAAS becomes certified as sole-means, decommissioning of the VOR ground environment would require the aircraft to have dual GPS/WAAS equipage to maintain avionics redundancy.

The basic phaseout strategy will be to gain, as quickly as possible, the cost savings from reducing the number of VOR facilities while at the same time minimizing adverse financial impact on aircraft operators. A transition period of approximately 10 years during which both VOR and GPS/WAAS can be used as a sole means of navigation is viewed as a reasonable compromise between the FAA's desire to minimize its cost for maintaining and replacing VOR and the aircraft operators' desire to get maximum utilization from their investment in conventional avionics.

For the first 5 years of this 10-year period, the VOR/DME system will be maintained at its full capability. In the second 5 years, VOR/DME facilities will be selectively phased out in such a way that aircraft operators will still be able to complete their flight using VOR-based navigation, but with some efficiency penalty. This will incentivize the frequent operator to equip with GPS/WAAS, while minimizing the financial penalty to the occasional system user. For example, the removal of selected VOR's in terminal or en route environments would mean that the VOR-only-equipped aircraft would need to follow more circuitous routes than the GPS/WAAS RNAV-equipped aircraft, but the former would still be able to get from origin to destination.

Some VOR's which are still in relatively good condition when decommissioned could be used to replace critical stations which have reached the end of their service life and are no longer maintainable.

At the end of the transition period (nominally 2010), remaining VOR/DME facilities will be rapidly phased out. Since it is expected that there will be few or no new installations of VOR/DME avionics following the time when GPS/WAAS is declared sole-means, all such avionics will by that time have had a service life of at least 10 years.

Throughout the decommissioning period, the FAA will work closely with aircraft and airport operators to minimize financial impact. The impact on individual operators will be balanced against the financial cost to the system as a whole, recognizing that the aviation system is ultimately paid for primarily by its users.

Phaseout of TACAN

The TACAN equipment at the FAA-operated VORTAC's (especially the rotating antenna) is expensive to operate and maintain. The FAA is working with the DOD to decommission the TACAN azimuth component of as many VORTAC's as possible while still supporting the DOD's operational requirements. The remaining VORTAC's will be operated until 2005, by which time all DOD aircraft are expected to be GPS-equipped.

Nondirectional Beacons

NDB's serve two principal functions in the NAS: first, as a stand-alone NPA aid at small airports; and second, as a compass locator, generally collocated with the outer marker of an ILS to assist pilots in getting on the ILS course in a non-radar environment. Currently there are 232 NDB's in the first category and 493 in the second. Almost all of the approximately 1,000 non-FAA NDB's are in the first category, i.e., they are stand-alone facilities to support NPA's.

In addition to these uses of NDB's, a few are used in Alaska to define low frequency airways. Because of this heavy reliance on NDB's in Alaska, a separate transition plan will be developed for Alaskan airspace which considers its unique operating environment.

To make use of an NDB for en route navigation or NPA guidance requires an automatic direction finder (ADF) in the aircraft.

NDB's are a relatively low-cost navigation aid. The typical cost for an FAA-installed NDB used as an approach aid at a small airport is $100,000. In many cases, NDB's have been purchased and installed by a community and then turned over to the FAA for maintenance. The annual sustainment cost of the existing system is estimated to be approximately $9 million.

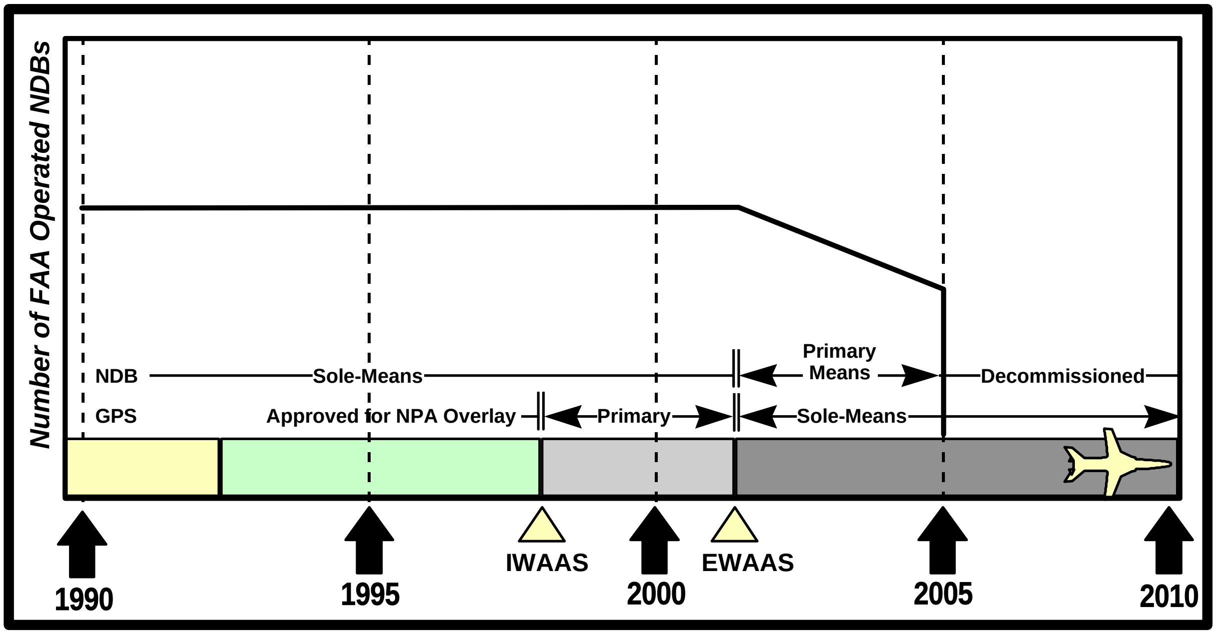

Figure 4-3
Phaseout of NDB's

Phaseout of NDB's

As a result of the overlay program, GPS today can substitute for an NDB in carrying out an NPA. Thus, the overlapping transition period between GPS and NDB can be considered to have begun in February 1994.

The phaseout strategy for NDB's will be to maintain the current level of capability through the year 2005, decommissioning prior to that date only redundant facilities where essentially equivalent capability is provided by VOR. After the year 2005, the remaining stand-alone NDB's will be rapidly phased out. However, in each case, through consultation with the user community, aircraft operator desires for continued NDB service will be weighed against the cost of continuing to provide that service. There may be cases where operation and maintenance of an NDB will be taken over by an individual operator or community desiring to delay its phaseout.

NDB's required as the compass locator for ILS approaches where no equivalent ground-based means for transition to the ILS course exists, will be maintained until the underlying ILS is itself phased out, as discussed below.

Omega

Omega is a long-range navigation system operating in the very-low-frequency band. Eight transmitting stations radiate signals between 10.2 and 13.6 kHz. A receiver determines its position based on the phase differences between the various received signals.

The Omega stations are located in Norway, Liberia, North Dakota, Hawaii, La Reunion Island, Argentina, Australia, and Japan. The U.S. Coast Guard operates the two U.S.-based stations.

Omega provides two-dimensional position accuracy of 2 to 4 nm with an availability of 99 percent and is approved for long-range navigation and as an RNAV system. Omega may be used as a sole-means system (i.e., the only installed long-range navigation system) for class II navigation (commonly referred to as operation in oceanic and remote airspace). It may also be used as a supplemental system for RNAV in U.S. domestic airspace.
Omega is used for navigation by approximately 1,400 air carrier aircraft (600 U.S. and 800 foreign) and for the tracking of radiosonde balloons by international weather services.

Phaseout of Omega

The United States plans to discontinue support for Omega at the end of 1997 [5]. Australia is also planning to terminate operations at its Omega station on September 30, 1997. Since GPS can now substitute for the long-range RNAV function of Omega, there are no plans to continue operating the Omega system after that date.

Loran-C

Loran-C is a navigation system installed, operated, and maintained by the U.S. Coast Guard. Loran-C was first installed primarily to serve maritime users in coastal and harbor areas (as well as military operations), but in recent years it has gained widespread use by general aviation aircraft. To serve the needs of general aviation, Loran-C coverage has been extended so that it now covers the entire United States except for Hawaii and parts of Alaska.

Loran-C is a low-frequency navigation system in which the receiver determines its position by measuring the time-of-arrival differences from signals received from several (three or more) ground stations. It provides substantially greater accuracy than VOR/DME, typically 0.3 miles within its primary coverage area. Because its coverage is not limited to line-of-sight transmission, it provides better coverage than VOR for low-altitude general aviation and helicopter operations. Since users can determine their position anywhere within the coverage area, Loran-C is inherently an RNAV system.

Loran-C is widely used by general aviation aircraft for its convenience and accuracy; however, it has never been a primary- or sole-means navigation system in the NAS. With IFR-certified avionics (most general aviation Loran-C avionics are not IFR-certified), it is approved for supplemental IFR navigation but not for NPA.

Phaseout of Loran-C

The annual operating cost of Loran-C is approximately $18 million. In addition, since much of the ground station equipment is nearing the end of its useful life, operation beyond the year 2000 would require extensive refurbish-ment, estimated to cost more than $100 million in capital investment over a 10-year period.

GPS can already provide the aircraft operator with all of the functions of Loran-C (plus, with appropriately certified equipment, NPA capability). As indicated above, most of the approximately 130,000 Loran-C receivers estimated to be in use in general aviation are VFR-only units, functionally equivalent to the low-cost non-TSO GPS receivers (hand-held or panel-mounted). Ever since GPS avionics have been available at comparable cost and greater capability, there has been little or no new equipage with Loran-C. The United States intends to discontinue Loran-C service in the year 2000 [5]. This will give aircraft operators generally 10 or more years to amortize their investment in Loran-C avionics before they are no longer functional (most of the Loran receivers in service were installed before 1990).

Global Positioning System

As described earlier, GPS is experiencing increasing use in the NAS as a supplemental navigation system, using avionics certified under TSO-C129, *Airborne Supplemental Navigation Equipment Using the Global Positioning System*. TSO-C129 defines several classes of GPS avionics which provide different levels of service, from en route navigation through NPA. When certain additional approval criteria are met (as defined in Notice 8110.60, *GPS as a Primary Means of Navigation for Oceanic/Remote Operations*, dated 12/04/95), GPS can be certified for use as a primary navigation system in oceanic airspace.

Phaseout of GPS Avionics

GPS avionics which only meet the requirements of TSO-C129 can never be approved for general use as a sole-means system in the NAS and cannot provide precision approach guidance. Therefore it is intended that the use of these avionics, and the associated NPA’s, will be phased out, to be replaced by GPS/WAAS avionics and approaches. (It is expected that it will be possible to upgrade some, but probably not all, TSO-C129 avionics to meet GPS/WAAS requirements.) Non-upgraded TSO-C129 avionics will continue to be useful indefinitely as a backup to GPS/WAAS avionics for en route and terminal navigation, and for NPA until the TSO-C129-based approaches are decommissioned. It is currently planned to maintain these approaches at least through 2005. After 2005, GPS overlay approaches will be canceled when the associated ground-based navaid (VOR or NDB) is decommissioned; a GPS/WAAS NPA will be provided in its place. (If the associated ground-based navaid for an overlay approach is decommissioned before 2005, a stand-alone GPS/TSO-C129 approach will be provided for that airport.) Also after 2005, stand-alone GPS/TSO-C129 approaches will gradually be decommissioned; in all cases, a substitute GPS/WAAS approach will have been commissioned prior to decommissioning the TSO-C129 approach. TSO-C129 approaches, overlay and stand-alone, will be decommissioned by 2010.

Inertial Navigation System

The Inertial Navigation Systems are self-contained navigation systems which use onboard gyros and accelerometers to measure precisely the changes in aircraft speed and direction. At the beginning of each flight the pilot initializes the INS with the aircraft's exact location. Based on its continuous measurement of the aircraft's speed and direction, the INS continuously computes the aircraft's position. The positional accuracy of an INS degrades with time at the rates from approximately 0.25 to 2.0 nm per hour. As in the case of Omega, INS is approved as a sole-means navigation system for oceanic operation and as a supplemental means for domestic en route navigation.

With the introduction of GPS, the role of INS shifts from navigation to flight control. Since this relaxes the requirements for very low drift, it will allow the use of lower-cost Inertial Reference Systems (IRS). Several aircraft operators have indicated their intent to replace existing INS with GPS because of the high maintenance cost of older inertial systems.

4.3.2 Precision Approach and Landing System Phaseout

A precision approach and landing system is one which provides a landing aircraft with electronic vertical as well as horizontal guidance. ILS is the current worldwide standard for precision approach and landing. ILS provides lateral guidance by a fixed "localizer" beam transmitted at a VHF frequency (in the band 108-112 MHz) and vertical guidance by a fixed "glideslope" beam transmitted at a UHF frequency (in the band 328.6-335.4 MHz).

Because of operational and technical limitations of ILS (especially frequency congestion, interference from adjacent broadcast services, and siting difficulties), a microwave landing system (MLS) was developed in the 1970's as a replacement for ILS. MLS was designated by ICAO to be the new world standard for precision landing, beginning in 1998. However, because of the reluctance of both service providers and aircraft operators to equip with MLS (because of its high cost), and the advent of satellite-based guidance technology, the United States recom-mended at the ICAO Communications/Opera-tions Divisional meeting in the spring of 1995 that the mandatory transition to MLS by 1998 be repealed and that ILS be retained as an alternate until satellite-based precision landing technology could be fully evaluated. This recommendation was adopted and will lead to the continuation of ILS for several years, with the gradual introduction of GPS/WAAS-based precision approach as it becomes available. In the meantime, the United States has canceled its program to develop MLS systems.

There are three categories of ILS, differing in their associated landing minimums, expressed as decision height and visibility (or runway visual range (RVR)) requirements. Decision height is the height above a runway to which a pilot can descend by electronic guidance, after which the pilot must be able to complete the approach and land visually. Visibility or RVR is a measure of the current "seeing" conditions, determined either by visual observation by a tower controller (visibility) or by measurement with electronic instrumentation beside the runway RVR.

The current inventory of ILS and MLS systems within the United States is shown in Table 4-2. Although the United States has canceled its MLS development program, there are currently 26 Category I MLS systems under contract. The current plan is to deploy these systems to provide an interim capability to meet special needs at selected airports, pending the availability of GPS/WAAS.

While costs vary somewhat from site to site, the typical cost to procure and install a Category I ILS system at an airport is $0.8 million and Category II/III ILS is $1.1 million. These costs are for the ILS electronics, associated monitoring systems, and RVR's as required. In addition, approach lighting systems are required, which themselves cost (including installation) on the order of $0.4 million for a Category I approach and $0.9 million for a Category II/III approach. Note that in the case of Category I ILS, an approach lighting system is required only to achieve the full capability of the Category I ILS (200 foot decision height, 1/2 mile visibility). Without an approach lighting system the standard visibility minimums are raised from 1/2 mile visibility to 3/4 mile visibility.

Table 4-2
FAA-Operated Precision Approach Systems

NAVAID TYPE	INVENTORY
ILS (CAT I)	871[5]
MLS (CAT I)	29[6]
ILS (CAT II/III)	80

The operation and maintenance costs for the currently installed ILS systems total approximately $80 million per year.

Phaseout of Category I ILS

Up to the time (estimated to be the year 2001) that WAAS is certified as a sole-means approach aid and approaches exist for essentially all airports which have Category I ILS, aircraft needing precision approach capability will have to be equipped with ILS receivers. That time will then be the starting point for an approximately 10-year dual-sole-means transition period. As in the case of VOR/DME, essentially all Category I ILS's will remain in service until 2005. After that date it will be assumed that most IFR aircraft are at least single-GPS/WAAS equipped, and Category I ILS's will begin to be decommissioned; enough will be retained, however, to serve as a backup in case of failure of the single GPS/WAAS avionics unit. In 2010, the remaining Category I ILS's will be rapidly phased out. This transition strategy is depicted in Figure 4-4.

[5] Plus about 200 non-Federal systems.
[6] Includes planned installations.

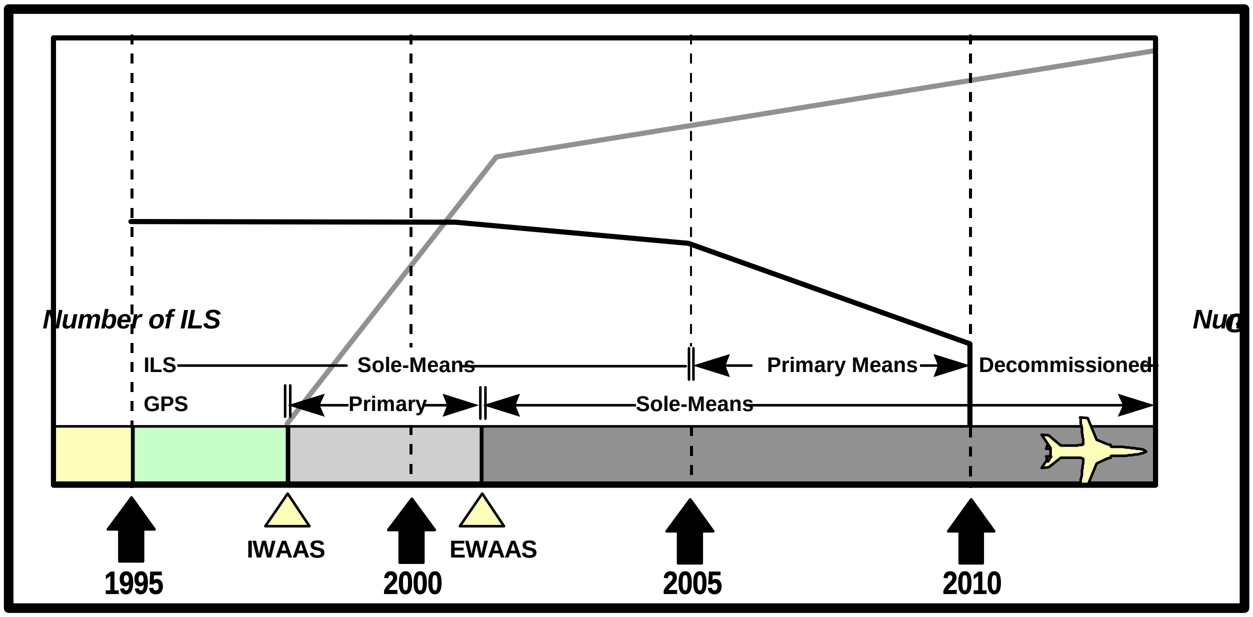

Figure 4-4
Phaseout of Category I ILS

In the years prior to 2001, Category I ILS will be installed at newly qualifying runways only if there is clear indication that the benefits to be realized by 2005 exceed the costs. It is not expected that there would be any deployment of new Category I ILS systems once GPS/WAAS is available to support Category I approaches. During the dual-sole-means transition period, ILS's may be decommissioned where redundant: for example, if there are multiple ILS's at an airport, or where there is an indication of so little use that it is not cost-effective to maintain. As in the case of VOR, the strategy will be to minimize sustainment costs consistent with continuing to provide the capability for the aircraft operators to complete their flights.

Phaseout of Category I MLS

The Category I MLS systems will be phased out on a schedule similar to that of the Category I ILS: decommissioning beginning in 2005, with all systems decommissioned by 2010.

Phaseout of Category II/III ILS

The date when GPS-based Category II/III approaches will become available for public use is less certain. Extensive testing has demonstrat-ed the ability of LAAS to meet Category II/III accuracy requirements. Analyses and field tests are currently in progress to demonstrate that the integrity requirements can also be achieved. Following this, several years will be required to select among the available techniques and develop and certify an operational system.

Until certified GPS-based systems are available, the FAA plans to meet Category II/III requirements with ILS. This will entail sustaining the existing Category II/III systems and providing new systems to meet the requirements for upgrading the capability of a system (Category I to Category II or Category II to Category III), and for new establishments. Upgrades and new system establishments will be done only if cost-benefit analyses indicate that they are cost beneficial, given the expected availability of GPS-based Category II/III approaches by 2005 and the projected 2010 ILS decommissioning date.

5

Summary

GPS, augmented by WAAS and LAAS, offers substantial benefits both to aircraft operators and to the FAA. For the aircraft operators, the benefits include increased operational efficiency and safety and reduced equipage, maintenance, and training costs associated with having a single system for navigation and landing guidance rather than the multiplicity of systems required today to perform those functions. For the FAA, the primary benefits come from eliminating the sustainment costs of the existing ground-based navigation and landing guidance systems, which today total approximately $200 million per year just for operations and maintenance (O&M) compared to a projected O&M cost of about $80 million per year for WAAS/LAAS. Realizing these benefits requires that the WAAS and LAAS be developed and fielded, that aircraft be equipped with GPS avionics, and that the ground-based systems be decommissioned.

This document has described the FAA's plan to accomplish this transition. The plan represents a balance, or compromise, between the aircraft operators' desire to get maximum return on investment in avionics for the existing ground-based systems, and the FAA's desire to decommission the ground equipment for these systems as rapidly as possible to minimize sustainment costs. For the primary navigation and landing guidance systems, the plan has been designed around a 10-year transition period from the time that a service is available from GPS until the corresponding ground-based system is decommissioned. For the first half of this transition period, the ground-based system is maintained at full functionality; during the second half, functionality is reduced commensurate with the reduced number of users, but sufficient functionality is retained to permit continued operation by aircraft which are not yet equipped with GPS.

REFERENCES

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3. *Operational Requirements Document: Local Area Augmentation System (LAAS)*, Federal Aviation Administration, February 28, 1995.

4. *Minimum Operational Performance Standard for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, RTCA Document No. DO-229, January 16, 1996.

5. *1994 Federal Radionavigation Plan*, Document Number DOT-VNTSC-RSPA-95-1/DOD-4650.5, National Technical Information Service, Springfield, VA 22161.

Appendix A

Acronyms

ADF	Automatic Direction Finder
ADS	Automatic Dependent Surveillance
AERA	Automated En Route Air Traffic Control
ATC	Air Traffic Control
CAT	Category
CTAS	Center TRACON Automation System
DME	Distance Measuring Equipment
DOD	Department of Defense
EMC	Electromagnetic Compatibility
EWAAS	End-State WAAS
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FMS	Flight Management System
FOC	Full Operational Capability
FRP	Federal Radionavigation Plan
GBIB	Ground-Based Integrity Broadcast
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HMI	Hazardously Misleading Information
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
INS	Inertial Navigation System
IOC	Initial Operational Capability
IRS	Inertial Reference Systems

IWAAS	Initial WAAS
LAAS	Local Area Augmentation System
LADGPS	Local Area Differential Global Positioning System
MASPS	Minimum Aviation System Performance Standard
MLS	Microwave Landing System
MOPS	Minimum Operational Performance Standard
NAS	National Airspace System
Navaid	Navigation Aid
NDB	Nondirectional Beacon
nm	Nautical Mile
NPA	Nonprecision Approach
PPS	Precise Positioning Service
RAIM	Receiver Autonomous Integrity Monitoring
RFI	Radio Frequency Interference
RNAV	Area Navigation (Radio)
RNP	Required Navigation Performance
RVR	Runway Visual Range
SCAT-I	Special Category I
SCATANA	Security Control of Air Traffic and Navigation Aids
SPS	Standard Positioning System
TACAN	Tactical Air Navigation
TRACON	Terminal Radar Control
TSO	Technical Standard Order
U.S.	United States
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional Range
VORTAC	Collocated VOR and TACAN
WAAS	Wide Area Augmentation System

Appendix B

Definitions

Area Navigation (RNAV) - A method of navigation that permits aircraft operations on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability.

Autoland Approach - A precision instrument approach to touchdown and, in some cases, through the landing rollout. An autoland approach is performed by the aircraft autopilot which is receiving position information and/or steering commands from onboard navigation equipment.

Category I (CAT I) precision approach - A precision approach procedure which provides for approach to a height above touchdown of not less than 200 feet and with runway visual range of not less than 2,400 feet (with touchdown zone and centerline lighting 1,800 feet Category A,B,C; 2,000 feet Category D).

Category II (CAT II) precision approach - A precision approach procedure which provides for approach to a height above touchdown of not less than 100 feet and with runway visual range of not less than 1,200 feet.

Category III (CAT III) precision approach - A precision approach procedure which provides for approach without a decision height minimum and:

IIIA - with runway visual range of not less than 700 feet.
IIIB - with runway visual range of not less than 150 feet
IIIC - without runway visual range minimum

Differential - A technique used to improve radionavigation system accuracy by determining positioning error at a known location and subsequently transmitting the determined error, or corrective factors, to users of the same radionavigation system, operating in the same area.

End-State WAAS (EWAAS) - Final stage of WAAS which is capable of supporting navigation and Category I precision approach with internal redundancy and guaranteed availability in the event of failure of elements in the system.

En Route - A phase of navigation covering operations between a point of departure and termination of a mission. For airborne missions the en route phase of navigation has two subcategories, en route domestic and en route oceanic.

Full Operational Capability (FOC) - For GPS, this is defined as the capability that occurred when 24 GPS satellites (Block II/IIA) were operating in their assigned orbits and were tested for military functionality and met military requirements.

Initial Operational Capability (IOC) - For GPS, this is defined as the capability that occurred when 24 GPS satellites (Block I/II/III) were operating in their assigned orbits and were available for navigation use.

Initial WAAS (IWAAS) - Initial stage of WAAS which is capable of supporting navigation and category I precision approach but lacks internal redundancy and guaranteed availability in the event of failure of elements in the system.

Minimum Aviation System Performance Standard (MASPS) - A set of standards that specify characteristics that should be used to designers, installers, manufacturers, service providers, and users for systems intended for operational use within the United States National Airspace System

Minimum Operational Performance Standard (MOPS) - A set of standards that define minimum performance, functions, and features for Area Navigation (RNAV), and optionally Vertical Navigation (VNAV) equipment to be certified in order to serve in the NAS.

Nonprecision Approach (NPA) - A standard instrument approach procedure in which no electronic glide slope is provided.

Precision Approach - A standard instrument approach procedure in which a course and glideslope/ glidepath are provided.

Primary Means of Navigation - A navigation system approved for a given operation or phase of flight that must meet accuracy and integrity requirements, but need not meet full availability and continuity-of-service requirements. Procedural restrictions apply to the given phase of flight since there is no requirement to have a sole-means system onboard to support the primary system.

Pseudorange - The distance between a user and a ground-based and/or space-based signal source plus an unknown user clock offset distance.

Required Navigation Performance (RNP) - A statement of the navigation performance accuracy necessary for operation within a defined airspace, including the operating parameters of the navigation systems used within that airspace.

RTCA, Inc. - An association of aeronautical organizations of the United States from both Government and industry that seeks sound technical solutions to problems involving the application of electronics and telecommunications to aeronautical operations.

Sole Means of Navigation - An approved navigation system for a given operation or phase of flight that must allow the aircraft to meet, for that operation or phase of flight, all four navigation system performance requirements: accuracy, integrity, availability, and continuity of service.

Supplemental Means of Navigation - An approved navigation system that can be used in controlled airspace of the NAS in conjunction with a sole means of navigation.

Terminal - A phase of navigation covering operations required to initiate or terminate a planned mission or function at appropriate facilities. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

Technical Standard Order (TSO) - A set of standards that avionics must meet in order to be identified with the applicable TSO marking.