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Report to the Chairman, Subcommittee on Transportation and Related Agencies, Committee on Appropriations, House of Representatives

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AIRSPACE SYSTEM

Emerging Technologies May Offer Alternatives to the Instrument Landing System

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The Honorable William Lehman
Chairman, Subcommittee on Transportation
and Related Agencies
Committee on Appropriations
House of Representatives

Dear Mr. Chairman:

Precision landing systems—which allow aircraft to land and depart under poor weather conditions—enhance airline safety and increase runway capacity. In the 1970s the Federal Aviation Administration (FAA), as part of an initiative sponsored by the International Civil Aviation Organization (ICAO), began to develop the microwave landing system (MLS) to replace the current instrument landing system (ILS). The ILS has now been in use for more than 50 years. The agency expects to complete the development of the MLS by the mid-1990s. The MLS will support advanced procedures, such as curved approaches, and meet other requirements that the current system cannot satisfy. Since the MLS decision was made, however, other alternatives for precision landing systems have emerged. FAA is currently supporting the development of (1) an ILS enhanced with a computer-based flight management system (FMS) on board the aircraft and (2) a satellite-based system.

To help your Committee in its budget decisions for the ILS and the alternatives now under development, you asked us to review these systems. Specifically, you requested that we (1) describe the capabilities and costs of these precision landing systems and (2) identify some of the potential consequences of FAA's approach to developing these systems.

Results in Brief

All three alternative systems under development can potentially provide greater precision landing capabilities than the ILS. For example, all three systems allow curved approaches to the airport, which enhance its capacity because more aircraft can approach an airport at the same time. However, the ILS/FMS combination is subject to problems that have affected the ILS at some airports, including frequency congestion and FM radio interference. Both the MLS and the satellite-based system are expected to overcome the ILS' problems, but full development and installation of these systems may take many years. Several major airlines view the ILS/FMS combination as a bridge to the MLS or the satellite-based system.

Thereafter, to meet the unique needs of each airport, one system, or a mix of systems, may ultimately provide the necessary precision landing services.

The costs of these systems will be substantial to FAA and users. FAA will, for example, incur costs to procure, install, and maintain ILS and MLS ground stations; develop enhancements to the satellite-based system; and procure new runway lights. Users will incur costs to procure and install equipment on board the aircraft (avionics). Users are already installing avionics for the ILS/FMS combination and the satellite-based system to support aircraft operations, including navigation. They would prefer to use this equipment for precision landings as well, rather than make an additional investment in MLS equipment.

We and aviation industry representatives are concerned that, although FAA is devoting substantial resources to develop the MLS, the agency is committing an insufficient level of resources to develop the ILS/FMS combination and the satellite-based system. For example, in fiscal year 1993, FAA's Satellite Navigation Plan called for $15.1 million to develop precision landing and other satellite applications; the agency submitted a budget request for less than $7 million.

Several consequences may follow if FAA does not provide a sufficient level of resources to develop all alternatives. First, the agency may not be able to provide users with the benefits of the ILS/FMS combination in the near term because new approach procedures will not be completed. Second, FAA may not be able to determine the feasibility of the satellite-based system for precision landings by the mid-1990s, when it intends to decide on full production of the MLS and must know if it has other options. Third, FAA may not be in the best position to determine the need for precision landing systems, on the basis of a runway-by-runway analysis of what system, or mix of systems, would provide the most benefits at the lowest cost to FAA and users.

Background

Ground-based precision landing systems (the ILS and MLS) are composed of (1) ground units located adjacent to airport runways[1] and (2) related equipment (avionics) installed on the aircraft. Satellite-based systems include (1) a satellite navigation system(s) with space and ground

[1]Because a ground-based system can provide precision landing service to only one end of a runway, two ground-based systems are needed to provide complete service for one runway. At certain airports, an MLS may be able to provide service to other runway ends if they are within the area covered by the MLS signal.

elements; (2) equipment required to enhance this satellite system(s); and (3) satellite navigation receivers on board the aircraft.[2]

In the 1970s the federal government, with the aviation community's support, decided to replace the ILS with the MLS as the primary precision landing system for civil and military purposes. In 1978 ICAO also selected the MLS as the international precision landing system. Under the ICAO agreement, FAA is required to install the MLS at all international runway ends equipped with an ILS by January 1, 1998. Currently, FAA estimates that 160 runway ends will qualify. The MLS will initially be collocated with the ILS, and FAA plans to operate these systems concurrently for a number of years before it starts decommissioning the ILS. FAA estimates that it will take about 10 years to reach this MLS/ILS parity and at least another 5 years before the ILS can be decommissioned. The MLS is currently listed as a major acquisition in FAA's Capital Investment Plan—the agency's program for modernizing the national airspace system.

The process for acquiring major systems such as the MLS is set forth in Office of Management and Budget (OMB) Circular A-109. This circular provides for decision-making by top-level agency management at four key decision points as major system acquisitions move from initial development into full production. At the first decision point, the agency should approve a mission need statement. The statement is based on a mission analysis, in which the agency analyzes its current and forecasted mission capabilities, technological opportunities, alternative approaches, overall priorities, and resources. At subsequent key decision points, OMB Circular A-109 directs the agency to revalidate the mission need statement, if necessary, after updating the mission analysis.

The ILS and Alternative Systems Have Different Capabilities and Costs

The three alternative systems under development can potentially provide greater precision landing capabilities than the ILS; however, their benefits and costs differ. For example, all three systems will provide the benefits of curved approaches, which the ILS cannot accommodate. In addition, components of the ILS/FMS and the satellite-based system will be used for other purposes. Costs to FAA and users for these three systems vary.[3]

[2]Because a satellite navigation system can provide coverage over a large area, one satellite-based precision landing system is expected to provide service for all of an airport's runways having approach lighting systems.

[3]All costs are in 1991 dollars unless otherwise noted.

The ILS

The ILS, a ground-based system, provides aircraft with a long, straight-in approach path to the runway and supports category I, II, and III approaches.[4] However, the technical and procedural limitations of the ILS constrain its ability to enhance runway capacity. For example, because the worldwide ILS frequency allocation is limited to 40 frequency channels, only a small number of ILSs can be installed in any one location. Also, some ILS channels experience FM radio frequency interference, which distorts the ILS approach path. In addition, the ILS signal, which provides the aircraft with the approach path for landing, can be distorted by natural and man-made obstacles, such as mountains and buildings around an airport, as well as snow on the ground. Finally, because the ILS signal provides a single approach path, usually fixed at an angle of 3 degrees, the ILS does not support advanced approach procedures, such as curved and steep approach paths, that can increase airport capacity by providing an increased number of direct flight paths to a runway. It was these limitations that led FAA and others to decide to replace the ILS with the MLS.

FAA and users have invested heavily in the ILS ground stations and the related avionics on board the aircraft. Moreover, FAA and users will have to continue investing in the ILS until the transition to an alternative system is completed. For example, between 1992 and 2000, FAA will have to replace aging ILS ground stations and install new ILS ground stations in those areas that have critical needs. During this period, FAA estimates that replacing old ILSs and installing new ones will cost $360.9 million. This estimate does not include the $63.1 million that FAA needs to install new approach and landing lights when it installs 24 new category II and III ILSs. Users may have to replace old ILS avionics or buy new equipment whose costs currently range from $3,600 for a general aviation aircraft to $107,500 for a commercial air carrier.[5]

The ILS/FMS Combination

The ILS/FMS combination is now being tested by FAA and airlines at a few airports. This system is being developed as an interim system and is expected to be operational in the near term. The ILS/FMS combination has the potential to support category I, II, and III approaches as well as advanced procedures such as curved approaches to a straight-in final

[4]The ILS is categorized by different minimum standards of height and visibility that an aircraft can safely descend to when using the system. Category I equipment allows aircraft to descend to a height of at least 200 feet above the ground when the runway visual range is at least 1,800 feet. Category II equipment allows aircraft to descend to a height of at least 100 feet when the runway visual range is at least 1,200 feet. Category III does not have a height minimum. Instead, it has three subcategories (a, b, and c) requiring runway visual range of at least 700 feet, 150 feet, and 0 feet, respectively.

[5]These costs are in 1992 dollars.

approach to the runway. In this system, the on-board FMS computes the curved approaches the aircraft is to fly and processes a wide range of other navigation and aircraft performance data. The ILS is used to fly the final approach. Although the ILS/FMS combination supports some advanced approach procedures, it is still constrained by all the ILS limitations. That is, it does not support other advanced approach procedures, such as those requiring steeper angles of descent, and can be subject to frequency congestion and FM radio interference.

FAA will continue to incur the costs of procuring and maintaining the ILS ground stations, to develop ILS/FMS approach procedures,[6] and to certify related equipment on board the aircraft, including the FMS. Users will pay for this aircraft equipment; the cost is estimated to be between $500,000 and $775,000 for each FMS package, not including certification costs. The ILS/FMS combination may be used by most new commercial and business aircraft because they are already using the FMS for multiple navigational and operational purposes. Currently, about 20 percent of the aircraft of the major U.S. air carriers are equipped with the FMS; it is projected that approximately 50 percent of the new aircraft will be FMS-equipped by 1995. However, because of the high cost of the FMS, most general aviation users may not be able to afford the ILS/FMS combination.

The MLS

The MLS, also a ground-based system, will provide aircraft with multiple approach paths to a runway and is expected to support category I, II, and III approaches in the long-term. FAA expects to complete the development of the system by the mid-1990s. The MLS will not experience the frequency congestion and interference and other limitations that affect the ILS. Also, because the MLS signal provides wider coverage than the ILS signal, the MLS will permit aircraft to fly multiple approach paths, including curved ones, and will allow for steep approaches up to an angle of 15 degrees. Thus, aircraft will be able to land in areas where the ILS cannot be installed.

FAA plans to spend about $2.6 billion to develop, procure, and install 1,280 MLSs. The MLS project is the second most costly in FAA's Capital Investment Plan. The $2.6 billion estimate includes the cost of MLS ground stations—which range from $690,000 to $930,000 per system. Also, FAA will incur the cost to develop approach procedures and install new approach and runway lights. Because FAA has only 836 lighting systems installed and lights will be needed at all 1,250 MLS sites, the agency will have to procure

[6]Developing approach procedures includes determining the approach path that can be safely flown by aircraft down to the end of a runway.

414 new lighting systems. The total cost of these lighting systems ranges from $259 million to $1.1 billion, depending on the category of system needed. Costs for lighting are not included in the $2.6 billion MLS program or in the 1991 Capital Investment Plan. MLS costs that users will incur are principally for avionics. These costs vary, depending on the type of aircraft and category of system installed. For example, MLS avionics costs are estimated to range from $6,150 for a general aviation aircraft to $181,200 for a commercial air carrier.

The MLS may not be fully utilized because various airline and general aviation representatives told us that they do not plan to install MLS equipment on their aircraft. These representatives believe the investment in MLS equipment is not justified because the capabilities and benefits of the MLS may be provided by other alternative systems. The airlines are already installing components for these other systems to support aircraft operations during all phases of flight.

Satellite-Based System

FAA is doing research to develop a satellite-based system for precision landings as part of its effort to develop a variety of aviation applications of satellite technology. The agency expects to determine the feasibility of this system by the mid-1990s. The satellite-based system is expected to provide aircraft with multiple approach paths. Initially, it may support only category I approaches; however, it may support all types of approaches in the long term. This system will be based on the United States' satellite navigation system, the Global Positioning System (GPS). The GPS is a military system that needs to be enhanced for use in civil aviation. For example, because the GPS provides civil aviation with a position accuracy of only 100 meters and a precision landing system must provide position accuracies of a few feet, the accuracy of the GPS must be enhanced to support precision landings.

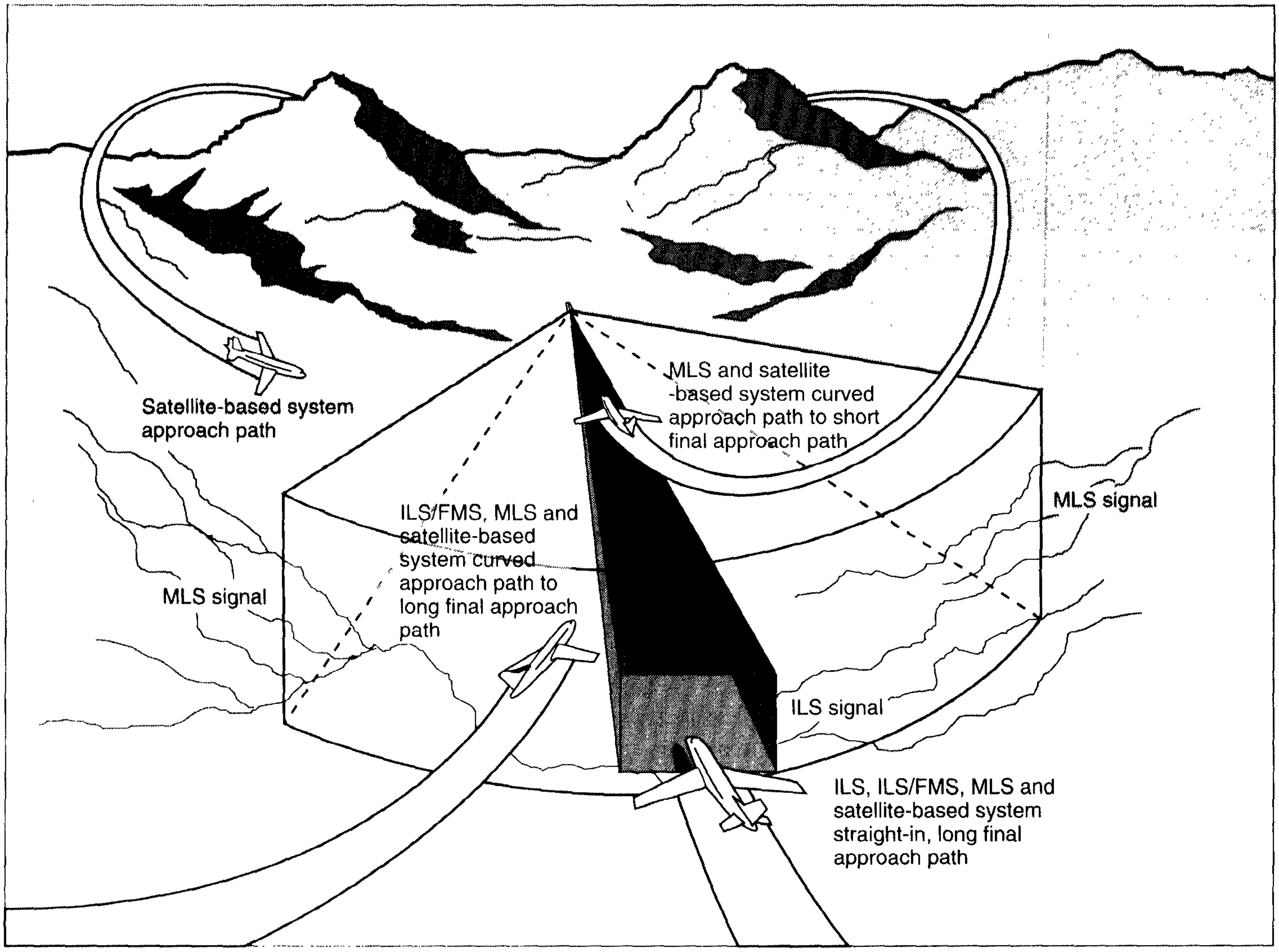
Enhancing the GPS to permit the satellite-based system to be used for precision landing is technically challenging. When the needed enhancements are completed, this system is not expected to have the ILS' limitations. For example, like the MLS, the satellite-based system will permit aircraft to fly multiple approach paths, including curved and steep approaches. Compared with the ILS and the MLS, which can provide service to only one end of a runway, the satellite-based system is expected to provide precision landing service not only to both ends of a single runway but also to all the runways within an airport. Similarly, the system may permit aircraft to navigate on the airport surface as well as in the air routes between airports, thereby eliminating the need to use separate navigation equipment during different phases of flight. Currently, although the GPS is not yet operational, civil aviation users are supporting and participating in the development of multiple GPS applications, including precision landings.

The costs of the satellite-based precision landing system, which have not been fully established, will be incurred by the Department of Defense (DOD), FAA, and users. DOD is incurring the development and implementation costs of the GPS, currently estimated at over $10 billion, as well as the operation and maintenance costs. FAA is expected to bear the costs of enhancing the GPS so that it can be used for civil aviation, including precision landings. These costs may be significant. For example, FAA estimates that accuracy enhancements will cost $315.8 million.[7] The costs of other enhancements have not been determined. Also, as with the other alternatives, FAA will incur costs to develop approach procedures, procure new approach and runway lights, and certify on-board avionics for precision approaches. Users will incur the costs of purchasing and installing these avionics. The avionics are estimated to cost between $3,500 for a general aviation aircraft and $92,047 for an air carrier; however, this equipment has not been approved for precision landing service. Certification costs are not included in this estimate. Many civil aviation users are installing, or plan to install, GPS-related technology in their aircraft. Because it supports navigation applications for all phases of flight, the GPS is expected to reduce the costs of equipping aircraft with navigation avionics and training pilots in the use of these avionics.

Figure 1 depicts aircraft using approach paths provided by the ILS and the alternative systems. As shown in the figure, the ILS and all its alternatives can provide aircraft with guidance to a straight-in final approach. However, alternative systems can also provide a variety of other approach paths, such as curved ones. Furthermore, the satellite-based system can also provide navigation guidance to an aircraft that has not yet entered an airport's final approach path.

[7]This cost is in 1992 dollars.

Figure 1: Multiple Approach Paths to a Runway Using the ILS and Alternative Precision Landing Systems



Consequences of FAA's Current Efforts to Develop Alternative Systems

FAA's current plan, based on a 1978 decision, is to procure 1,250 MLSs to replace 836 ILSs and to satisfy the need for additional precision landing systems. In its March 1992 MLS demonstration program report,[8] FAA projected that more runways would be candidates for precision landing systems than it had identified in 1978.[9] For example, the report projected that 1,877 runways would be candidates for these systems by the year 2010, including 497 runways that would be candidates for category II and III systems. However, the report did not identify which candidate runways would qualify for a precision landing system and which ones would require capabilities beyond category I.

Since FAA made its initial decision in the 1970s to develop the MLS, the other alternative precision landing systems have emerged and FAA has recently started to support their development. For example, FAA has been working with the aviation industry to develop these alternatives and has formed a team to develop a framework for selecting the best long-term system architecture and implementation strategy for precision approach and landing service in the national airspace. However, aviation industry representatives are concerned that FAA may not be committing sufficient resources to develop these alternative systems. For example, in recent testimony before the Congress, the Air Transport Association stated that FAA needs 30 additional staff over the next 3 years to develop approach procedures for the ILS/FMS combination, the MLS, and the satellite-based system. Also, airline and aviation interest groups have noted that FAA's planned funding for satellite navigation was inadequate. For fiscal year 1993, FAA's congressional budget request was $6.8 million to develop satellite navigation applications. When testifying before your Subcommittee in April, we stated that this request for funding was insufficient to support the development of satellite navigation applications, including precision landings.[10] In fiscal year 1993, FAA needs $15.1 million to pursue the objectives highlighted in its 1992-97 Satellite Navigation Plan; however, the agency submitted a budget request for less than 50 percent of the plan's budget requirement.

[8] Microwave Landing System Demonstration Program: Project Summaries and MLS User Financial Analysis, Mar. 1992.

[9] FAA uses a two-step process to determine which runways will get category I, II, or III precision landing systems. First, FAA identifies which runways are candidates for a precision landing system on the basis of factors such as the size of the runways and the annual number of instrument approaches to the runways. Second, on the basis of a cost-benefit analysis or other considerations, such as congressional direction, FAA identifies which candidate runways actually qualify for precision landing systems. In the past, this process has been used to choose which runways will receive an ILS.

[10] Congress, House, Subcommittee on the Department of Transportation and Related Agencies, Committee on Appropriations, Hearings on the Department of Transportation and Related Agencies Appropriations for 1993, 102nd Cong., 2nd Sess., 6 April, 1992.

If FAA commits insufficient resources to the development of all alternatives, the consequences could be significant. First, the agency may be unable to provide users with the benefits of the ILS/FMS combination in the near term because new approach procedures will not be completed. Second, FAA may not know whether the satellite-based system is feasible by the mid-1990s, when the agency intends to decide on full production of the MLS and will need to know if it has other options.

In accordance with OMB Circular A-109, FAA drafted a mission need statement in 1990 to justify the MLS acquisition. This statement compared the MLS with alternative systems and concluded that the satellite-based system could not meet the operational requirements needed for a precision landing system. The statement could not, of course, be conclusive on the feasibility of the satellite-based system because FAA was just initiating research on satellite navigation technology. Also, the statement did not identify, runway-by-runway, how many precision landing systems were needed and what category of system would provide the most benefits at the lowest cost to FAA and users. In addition, because the statement assumed that all ILSs would be replaced by MLSs, it did not determine whether the replacement of each ILS with a higher capability system was actually justified. To its credit, the Department of Transportation has directed FAA to update or to prepare a new mission need statement before entering into full production of the MLS.

Conclusions

Although FAA's development of the MLS is a prudent step, FAA's decision to replace the ILS with the MLS is premature because the capabilities and benefits of the MLS may be provided by emerging alternative systems. Some airlines are already installing components for these other systems to support aircraft operations during all phases of flight.

A commitment of resources to developing all three alternatives would put FAA in the best position to make future decisions on precision landing systems, which require major investments by FAA and users. Resources are needed to develop approach procedures for the ILS/FMS combination, the MLS, and the satellite-based system; continue support for the MLS; and fully fund the development of the satellite-based system.

Furthermore, because of the emerging technologies, it makes sense for FAA to prepare a new mission need statement for precision landing systems in general, not for MLS alone. FAA could use this statement to determine—on a runway-by-runway basis—how many precision landing systems are needed at each airport. Such an assessment would help ensure that the type and category of system(s) chosen would provide the most benefits at the lowest cost to FAA and users.

Recommendations

To determine which alternative precision landing systems will best meet the requirements for precision landings, we recommend that the Secretary of Transportation direct the Administrator of FAA to

- provide full budgetary support for the development of all alternative systems so that by the mid-1990s decisionmakers will have a meaningful basis for comparing the systems' capabilities, benefits, and costs; and
- prepare a mission need statement for precision landing systems in general that is based on a runway-by-runway determination of which system, or mix of systems, provides the most benefits at the lowest cost to both FAA and the system's users. This general mission need statement should be ready when FAA selects the precision landing system that will replace the ILS.

Agency Comments

As requested, we did not obtain written agency comments on this report from the Department of Transportation and FAA. We did, however, discuss our findings with officials from the Office of the Secretary and FAA's offices of Air Traffic, Systems Engineering and Development, NAS Development, Aviation Policy and Plans, and Government and Industry Affairs. They provided us with some revised funding and contract information, as well as with other factual information, which we have incorporated into our report.

However, FAA officials believed that we did not fully acknowledge their recent efforts to evaluate the feasibility of implementing a satellite-based system for use as a precision landing system. In response to these comments, we more clearly identified FAA's current efforts.

Scope and Methodology

We conducted our work between October 1991 and September 1992 in accordance with generally accepted government auditing standards. We obtained information on the need for precision landing systems from FAA program officials and aviation interest groups. We obtained information on the systems' capabilities from FAA's ILS, MLS, and satellite program offices; the Department of Defense; NASA Ames; RTCA, Inc., a private, nonprofit corporation that addresses requirements and technical concepts for aviation; aviation interest groups; U.S. airlines; and FAA consultants employed during the MLS demonstration program. Regarding the systems' costs, we obtained information from FAA's ILS, MLS, and satellite program offices; the Department of Defense; aviation interest groups; U.S. airlines; and manufacturers of systems' ground equipment and avionics. Some of this information was gathered in interviews with representatives from the organizations previously mentioned. We obtained other information by reviewing documentation on key technical requirements, studies on the different systems, and funding information on the ILS, the ILS/FMS combination, the MLS, and the satellite-based system (including FAA budget requests), and the funds appropriated, allocated, and obligated for these systems. In addition, we reviewed ILS and MLS procurement contracts.

We are providing copies of this report to interested congressional committees; the Secretary of Transportation; and the Administrator, FAA. We will also make copies available to others upon request.

This work was performed under the direction of Kenneth M. Mead, Director, Transportation Issues, who may be reached at (202) 275-1000 if you or your staff have any questions. Major contributors to this report are listed in appendix III.

Sincerely yours,

J. Dexter Peach
Assistant Comptroller General

Contents

Abbreviations

ATA	Air Transport Association
DME	distance measuring equipment
DME/P	precision distance measuring equipment
DOD	Department of Defense
FAA	Federal Aviation Administration
FMS	flight management system
GAO	General Accounting Office
GLONASS	Global Orbiting Navigation Satellite System
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
ILS	instrument landing system
ILS/FMS	instrument landing system enhanced with on-board flight management system
IRS	inertial reference system
IRU	inertial reference unit
MLS	microwave landing system
OMB	Office of Management and Budget
PPS	precise positioning service
SPS	standard positioning service
VHF	very high frequency
VOR	very high frequency omni range

Capabilities of the ILS and Alternative Precision Landing Systems

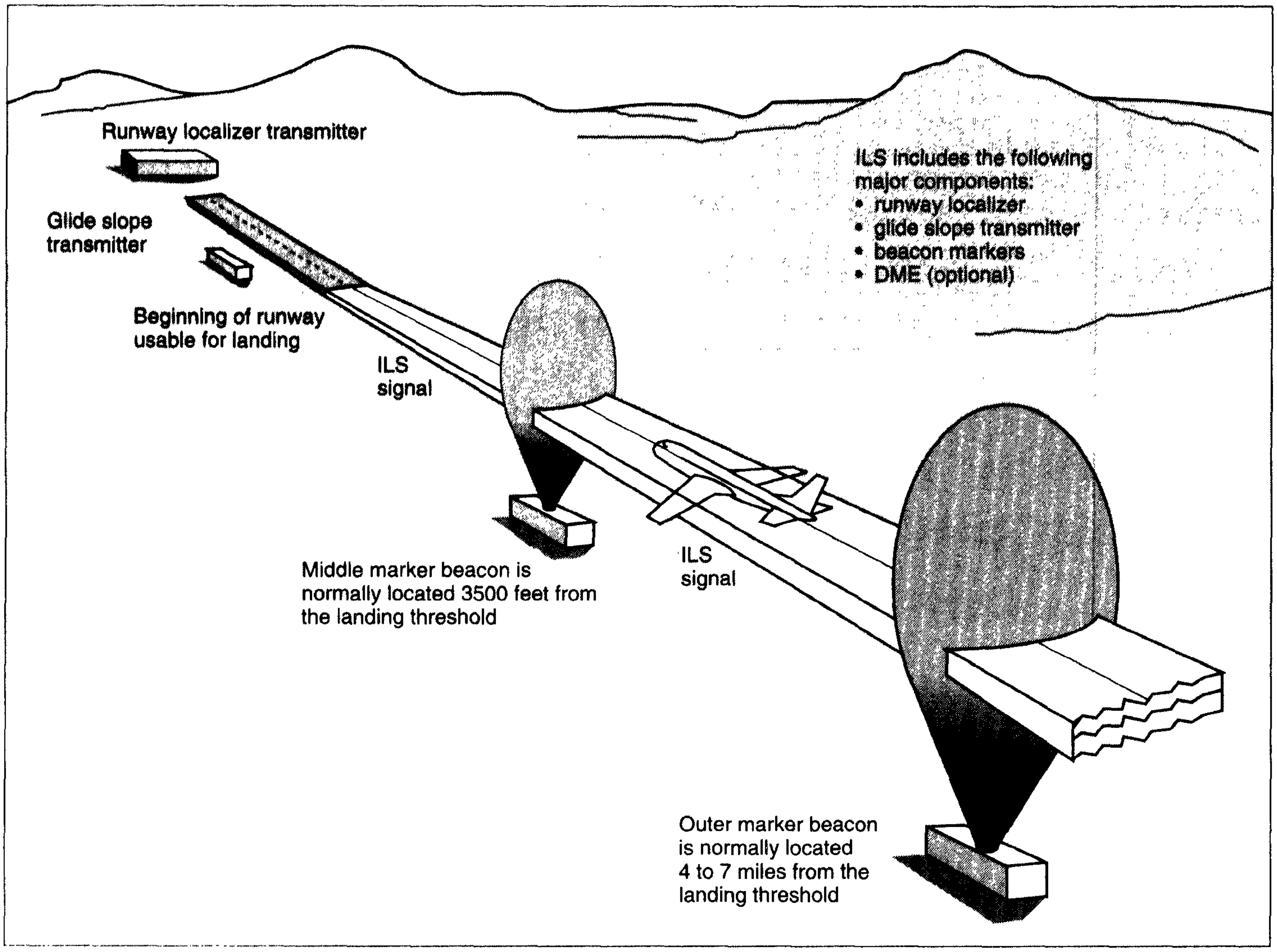
This appendix describes the capabilities of the precision landing system currently in place in the nation's airports, the instrument landing system (ILS), and those of three systems under development. These systems include (1) the microwave landing system (MLS), which was chosen by both the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO) to replace the current system; (2) the ILS enhanced with a flight management system (FMS) on board the aircraft; and (3) the satellite-based system. All three of these systems may satisfy the requirements for future precision landing systems.

Capabilities of the ILS

The ILS is a mature technology, adopted by FAA in 1941 and by ICAO in 1949. The ILS provides aircraft with a single, straight path for precision approaches and landings at a runway. It also supports departures.

An ILS consists of three basic ground components: (1) a localizer, which generates a signal indicating a course down the runway centerline (horizontal guidance); (2) a glide slope transmitter, which generates a signal, usually at an angle of 3 degrees, for descent to the runway (vertical guidance); and (3) two or three marker beacons, each of which marks a position on the approach path to the runway. An aircraft can use distance measuring equipment (DME) instead of one or more marker beacons to measure distance to the runway anywhere along the approach path. Figure I.1 shows the layout of the ILS' ground components and an aircraft following a straight course and angle of descent to the runway.

Figure I.1: Layout of ILS Ground Components



As of March 1992, FAA had 836 ILSs at 551 airports. Most of these systems are category Is. Seventy-six of these ILSs are category II or III; of these 76 ILSs, 7 are category IIIa and 23 are category IIIb. Category I systems allow aircraft to descend to a height of at least 200 feet above the ground when the runway visual range is at least 1,800 feet. Category II and III systems allow an aircraft to descend when weather conditions are below category I minimums. Category II equipment allows aircraft to descend to a height of at least 100 feet when the runway visual range is at least 1,200 feet.

Category III equipment does not have a height minimum, but it has three subcategories (a, b, and c) requiring runway visual ranges of at least 700 feet, 150 feet, and 0 feet, respectively.

The ILS Is Limited in Its Ability to Enhance System Capacity

Initially, the ILS increased the safety and capacity of the national airspace system by providing aircraft with an angle of descent as well as lower minimum height and visibility levels for landing. In the 1970s, however, ICAO identified 38 operational requirements that would satisfy future precision landing needs; the ILS is not capable of meeting all these requirements. The requirements cover a wide range of characteristics that would increase capacity. The requirements are categorized into four main areas that include

- precise position information to enable guidance for advanced operations,
- wide-area coverage to facilitate efficient transition between phases of flight,
- capability to provide service at all required locations, and
- ability to operate unaffected by weather.

The 38 operational requirements have been adopted by FAA to describe its future precision landing needs. According to FAA and ICAO, the ILS can fully satisfy 12 of these requirements and partially satisfy an additional 11 but cannot satisfy the remaining 15 requirements. For example:

- ILS does not support advanced approach procedures, such as curved approach paths, computed centerline approaches, and multiple/variable descent paths.
- The system provides limited area coverage by supporting a single, straight-in path down to the runway. This single path can create conflicts among aircraft flying in areas where several airports are located.
- The system cannot be used in all locations because of siting, channel capacity, and signal interference problems. For example, the ILS cannot be installed in some locations because of obstacles or lack of enough land to permit the long flight path required. Also, the ILS is limited to 40 frequency channels,[1] which restricts the number of ILSs that can be allocated frequencies within a given geographical area. In addition, the ILS frequency suffers from interference from high-powered FM radio transmitters that operate on adjacent frequencies.

[1] Although there are 40 frequency channels, 2 are used for testing. The remaining 38 channels can be assigned to ILSs.

- The ILS is sensitive to signal interference caused by reflecting objects near a runway, including ground traffic and structures. Large protected areas must therefore be used so that the ILS ground equipment can be operated without problems.
- The ILS' operations are affected by snow on the ground, which causes signal diffraction.

These limitations impede air traffic control operations in several ways. For example, because aircraft using the ILS must fly a single, straight path in heavy traffic, these aircraft have to form a long queue to land, resulting in approach and departure delays. Furthermore, since the ILS provides little flexibility in approaches and departures, it cannot help reduce aircraft noise by allowing aircraft to use multiple takeoff and landing paths to reduce noise in any one area.

Capabilities of Alternative Systems Under Development

We examined the capabilities of three alternatives to the ILS. They are the ILS combined with an on-board flight management system (FMS), the MLS, and the satellite-based system.

Capabilities of the ILS Combined With an FMS

Currently, FAA and the aviation industry are working to enhance the ILS by combining it with the FMS. The ILS/FMS combination allows aircraft to fly curved approaches—using the FMS guidance—to the long, straight final approach supported by the ILS.

Development of the FMS began in the late 1970s. The FMS is an advanced aircraft computer system that automates and simplifies increasingly complex flight tasks that crews are expected to perform. The system configuration includes dual flight management computers, map displays, and external redundant sensors, such as multiple inertial reference units (IRU) used for navigation.

Initially the FMS, using various navigation sensors, was envisioned as supporting en route navigation. However, the FMS is now used to process a wide range of navigation data in the terminal environment. The FMS compares an aircraft's current position with the intended flight path. To do so, the FMS processes data from various navigation sensors, including the inertial reference system (IRS), very high frequency omni range (VOR), and distance measuring equipment (DME). These data are used to compute the aircraft's position and velocity for guidance. Currently, about 20 percent of the aircraft of the major U.S. air carriers are equipped with an FMS; it is projected that approximately 50 percent of the new aircraft will be so equipped by 1995.

According to airline representatives, their airlines are developing FMS applications for landing and departures. For example, United Airlines has been testing precision approaches supported by ILS/FMS at Chicago's O'Hare Airport; Northwest Airlines has been testing them at the Minneapolis/St. Paul International Airport; and American Airlines has been testing them at New York's John F. Kennedy Airport. American Airlines has also developed and implemented departure procedures supported by FMS at the Eagle County, Colorado, Airport.

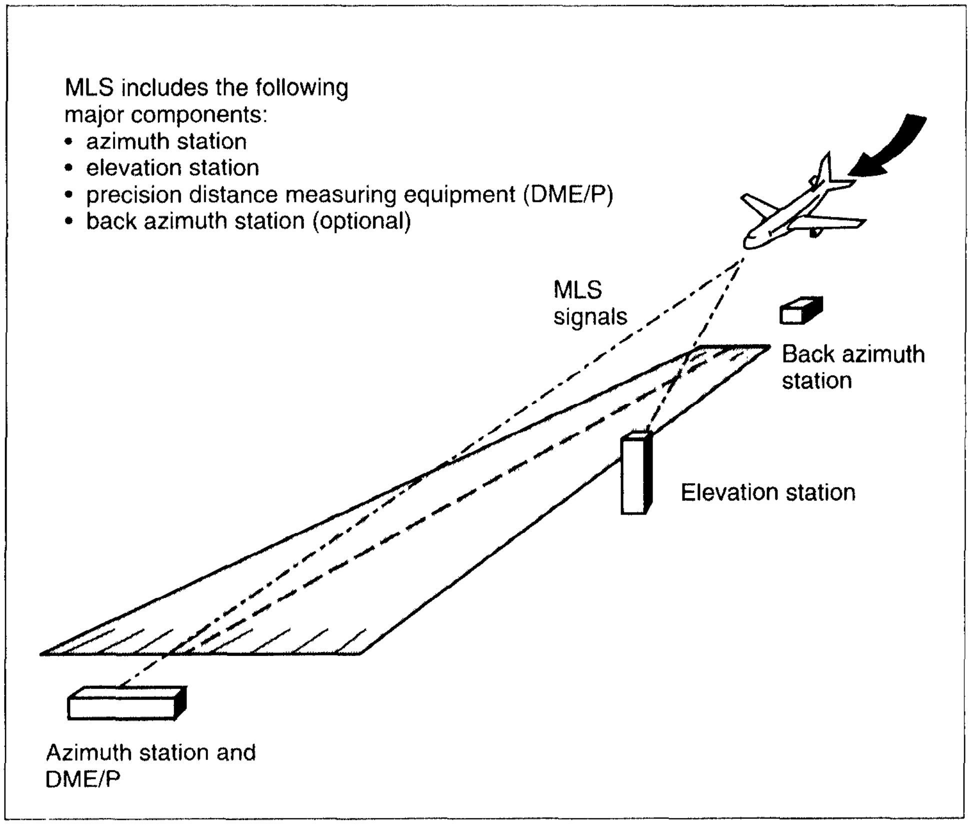
The ILS/FMS combination is attractive to the airlines because the ILS is already in place and FMS technology, as noted earlier, is increasingly being installed on commercial aircraft. Also, the FMS can provide benefits, such as capacity enhancements and time savings, that result from curved approaches. In the future, the FMS could use navigation information provided by the Global Positioning System (GPS) to compute highly precise curved approaches.

Although the ILS/FMS combination has the potential to provide benefits to the airlines in the short term, these benefits are limited for two reasons. First, the ILS/FMS combination will still be affected by some of the ILS' limitations, such as frequency congestion, FM interference, and operations impaired by weather. Second, the system will provide benefits to a limited number of users, mostly commercial and business users. Most general aviation users will not benefit from the enhanced system because of the cost of the FMS. (App. II provides information on the costs of the ILS/FMS combination.)

Capabilities of MLS

An MLS consists of three standard ground components: an azimuth station, an elevation station, and precision distance measuring equipment (DME/P). (See fig. I.2.) The azimuth station sends a signal that provides horizontal guidance of up to ±60 degrees and guides the approaching aircraft down to the runway centerline. The elevation station, analogous to the ILS' glide slope transmitter, transmits a signal that provides an angle of descent (vertical guidance) to the runway of up to 15 degrees. The DME/P broadcasts a signal that provides the aircraft with accurate distance to the runway. It is these MLS components that allow aircraft to fly multiple precision approach paths, including both straight and curved ones. Also, an MLS can have an optional component, a back azimuth station, that sends a signal to provide horizontal guidance for departures and missed approaches. According to an FAA representative, the agency is not planning to use this station in the national airspace system.

Figure I.2: Layout of MLS Ground Components



MLS is expected to support category I, II, and III precision approaches and landings. It will also support departures. Compared with the ILS, the MLS will provide improved performance because it meets the full range of operational requirements, as defined by ICAO, for precision landing systems. For example, the MLS will offer air traffic control a variety of approach procedures by providing aircraft with vertical and horizontal guidance information over a wider and higher area. The MLS will permit aircraft to fly multiple approach paths, including both straight-line and curved approaches. Multiple paths will reduce delays and the amount of noise related to air traffic over any one area. Also, the MLS will allow steep glide path approaches to airports located in populated areas and mountainous terrain. In addition, the MLS will make it possible to execute precision landings on runways where the ILS cannot be installed because of its limitations. Moreover, the MLS will not be affected by frequency congestion or FM interference problems, or by environmental conditions, such as weather.

Although the MLS is not expected to have any of the ILS' limitations, benefits of the MLS may be limited because the system may not be fully used by the aviation community. According to FAA, TW Express, Continental Express, Horizon Air, Mark Air, Era Aviation, Reeve Aleutian Airways, and Pen Air are currently using or planning to use FAA's Category I MLSs. However, few of the major and regional airlines and general aviation associations we have spoken to are planning to switch to the MLS, for two reasons. First, many airline and general aviation representatives believe that by the time the development of the MLS is completed, the satellite-based system will be able to provide at least category I precision landing services. Second, some of these representatives are concerned about the high cost of MLS avionics, the on-board equipment needed to use the system. (These costs are detailed in app. II.) If a large percentage of the airline and general aviation aircraft continue to use the ILS when the MLS is available, the reductions in airport delays and the benefit of the availability of curved approaches will be minimized.

FAA awarded two first article category II/III MLS development contracts in June 1992. Each contract supports the development and testing of six MLSs, with an option for six additional systems. Delivery of these first systems is expected in 1996.

Capabilities of the Satellite-Based Precision Landing System

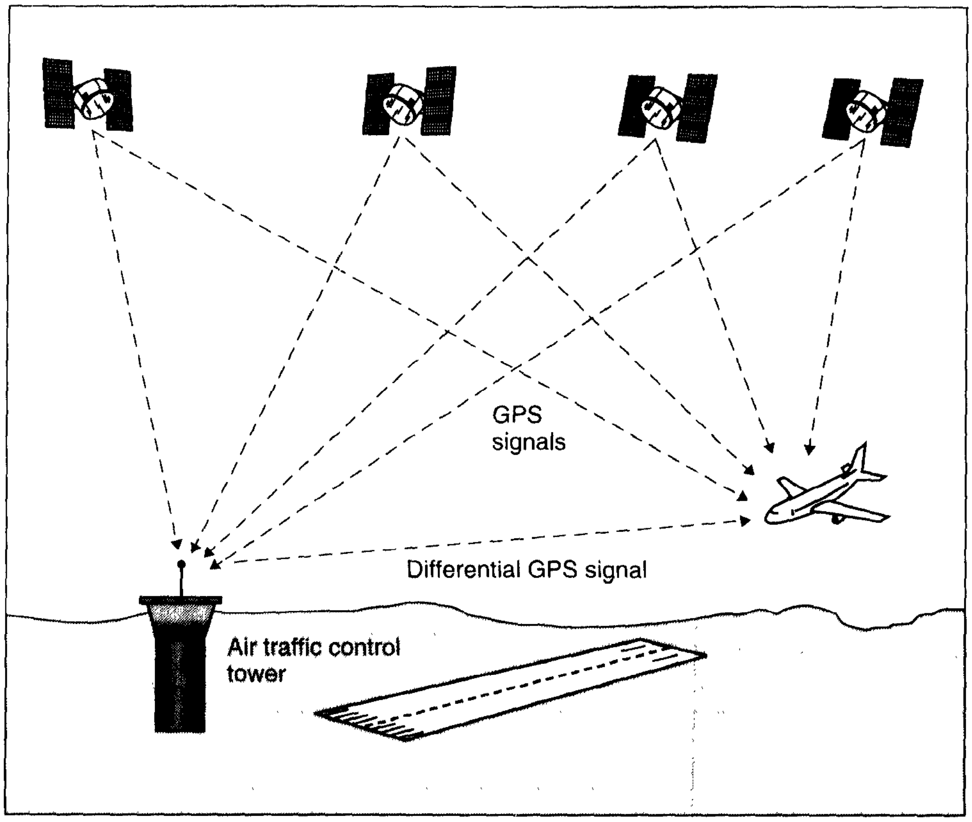
Currently, FAA is working together with the Department of Defense (DOD) and the airlines to develop the satellite-based navigation system that can be used for various military and civil aviation purposes, including precision landings. This system will initially be based on the GPS, a satellite-based radio navigation system designed to provide multiple aviation, maritime, and surface users with continuous and highly precise navigation and time information anywhere on earth and in any weather condition. The Air Force, Army, Navy, Marine Corps, and Defense Mapping Agency combined their technological resources to develop GPS beginning in 1973. DOD is currently implementing the system, which is expected to be operational in 1993. The GPS satellite constellation will consist of 24 satellites (21 operational satellites and 3 spares) in six orbital planes.

The GPS will offer two levels of services to calculate position: (1) the precise positioning service (PPS) and (2) the standard positioning service (SPS). PPS allows military and other authorized users to calculate highly accurate three-dimensional position (latitude, longitude, and altitude) to about 16 meters.[2] SPS can also allow users to calculate highly accurate position. However, for national security reasons, SPS is being degraded by DOD so that civil users will only be able to calculate position with an accuracy of about 100 meters. When SPS is not being degraded, it has shown accuracies of between 21 and 53 meters.

The GPS has three components: in space, at control facilities, and with the user. The space component includes the satellite navigation constellation located approximately 11,000 miles above the earth. The satellites are located so that, with high likelihood, the signals from four or more of them will be received simultaneously anywhere on earth, in any weather condition. The control component consists of a master control station, five monitoring stations, and three ground antennas located throughout the world. The monitor stations, using the GPS receivers, track all the GPS satellites. The ground antennas are used to communicate with the satellites for operations. The user component consists of the GPS receivers that, by processing the GPS signals, allow users on land, at sea, or in the air to determine their three-dimensional position (latitude, longitude, and altitude), their velocity, and the time of day. Figure I.3 shows an aircraft making a precision approach using the GPS signals.

[2]Accuracy refers to the degree of agreement between measured and true position. An accuracy to about 16 meters means that a measured position differs by at least 16 meters from the true position.

Figure I.3: Layout of the Satellite-Based System for Civil Aviation



Note: The differential signal provides the aircraft with data to correct the position calculated using the GPS satellites.

Like the other alternatives, the satellite-based system is expected to support precision approaches, landings, and departures. Initially, it may provide category I service; however, FAA is also evaluating the feasibility of providing category II and III service. The satellite-based system is also expected to support navigation on airport surfaces and in the air routes between airports. With enhancements, this system may also satisfy the operational requirements defined by ICAO for future precision landing needs. For example, the system is expected to provide multiple approach paths, including both straight-line and curved approach paths. Like the MLS, the satellite-based system may allow steep approach paths to airports located in populated areas and mountainous terrain and may make it possible to execute precision landings to runways where the ILS cannot be installed. The advantage of the satellite-based system over the other alternatives is that it is expected to provide service to more runways within an airport, because the GPS that supports it will provide wider coverage. Specifically, the system may provide service to all runways equipped with lighting systems within an airport, as well as to both ends of these runways.

The satellite-based system currently has potential limitations because it will need enhancements to satisfy the requirements for a precision landing system. For example, a precision landing system is required to provide accuracies of a few meters, give warnings about the integrity of the system's signals within seconds of detecting a problem, and be available almost all of the time.[3] To ensure that the GPS satisfies these requirements so that it can support precision landings and other civil aviation applications, ground, on-board, and space enhancements are being developed to support the system.[4] These enhancements will be technically challenging and require significant resources.

Currently, FAA is evaluating two differential techniques to enhance the accuracy of the GPS. The first technique for enhancing accuracy, code phase tracking, is expected to provide GPS accuracies of a few meters, which will satisfy category I accuracy requirements. Under code phase tracking, the accuracy of the GPS satellite signals is monitored by ground stations to determine the difference between the calculated position and the position of the ground station. This differential information is then sent to the aircraft, where it is used to calculate the aircraft's position. The differential information is sent by the ground stations to the aircraft through data communications equipment, such as VHF radio, Mode-S, or communications satellites. VHF radio and Mode-S will provide correction information to all aircraft operating within the small area covered by these

[3]In addition to accuracy requirements, a precision landing system must satisfy integrity and availability requirements. Integrity refers to the ability of a navigation system to provide timely warning when position error exceeds a specified limit. ILS currently provides integrity warnings of between 2 and 10 seconds; MLS provides them within a second. It has been recommended that a GPS-based system satisfy similar integrity requirements. Availability refers to the probability of obtaining a specified level of service at an arbitrary time and location in the service area. Because the unavailability of GPS would affect large geographical areas and a large number of aircraft, it has been recommended that GPS be unavailable for less than 1 second per day.

[4]An RTCA, Inc. task force, sponsored by FAA, recently examined satellite navigation applications for civil aviation, including precision landings. This task force attempted, among other things, to define schedules for the development and implementation of these applications. On October 14, 1992, the task force released its report, which concluded that the global navigation satellite system is a here-and-now capability that will provide major operational benefits to all users of the air transportation system. The task force also strongly recommended implementation of an early initial operational capability and follow-on efforts to quickly resolve longer-term institutional and equipment development issues.

systems. By comparison, a communications satellite will provide differential information to aircraft operating over the wide area covered by the satellite. The second technique for enhancing accuracy of the GPS signal, carrier phase tracking, is expected to provide accuracies of under 1 meter, which will satisfy category II and III requirements. Under carrier phase tracking, the accuracy of the GPS satellite signals is monitored not only on the ground but also in the aircraft. The differential information produced in both places is then used in the aircraft to calculate its position.

FAA is also currently testing two techniques to enhance the integrity of the GPS. In the first technique, ground stations monitor the health of the GPS satellites to provide warnings within seconds of detecting a satellite malfunction. Warning messages are then sent by the ground stations to the on-board GPS receivers through data communications equipment. In the second technique, aircraft monitor the health of the GPS satellites to provide, within seconds of detecting a satellite malfunction, warning messages to the GPS receivers. It is expected that these two techniques will be used simultaneously to enhance integrity.

To enhance the availability of the GPS, FAA is considering such options as using communications satellites equipped with navigation packages to transmit GPS-like radio signals, adding satellites to the GPS, and using ground-based transmitters—so-called pseudolites—to transmit GPS-like radio signals. Because Russia, which was part of the former Soviet Union, is also implementing a satellite navigation system—the Global Orbiting Navigation Satellite System (GLONASS)—FAA is also considering using GLONASS to enhance the GPS. In 1991, the-then Soviet Union announced that, once GLONASS becomes operational, the world aviation community will be able to use the system free of charge for 15 years. This system is expected to become operational by the mid-1990s.

Initially, the GPS will be used by civil aviation to complement other navigation systems on board the aircraft, that is, as a supplementary navigation system. Only when the GPS satisfies the accuracy, integrity, and availability requirements will it be used by itself, as a sole means of navigation. FAA expects that the enhanced GPS will be available to start supporting the special category I precision landing service by the mid-1990s. This service will permit certain aircraft to land using category I minimum standards of height and visibility at selected airports. Eventually, the enhanced GPS is expected to support all categories of precision landing services in all the adequately equipped runways anywhere in the world.

Using satellite technology for precision landings is an entirely new concept in terms of standards and approach procedures. Because most of the standards and approach procedures in use are for ground-based systems, approach procedures that use the capabilities of the satellite-based system will have to be developed. It is expected that the precise navigation and time information provided by the GPS will make it possible to reduce standards that now govern separation among aircraft and between aircraft and ground obstacles. Efforts are already under way to develop standards and procedures for precision landings and other phases of flight.

For example, standards and approach procedures are being tested as part of flight tests now being conducted to assess the extent to which the GPS can be used for precision approaches, landings, and departures. Specifically, Northwest Airlines and Honeywell, in cooperation with FAA, are conducting a five-phase test program on the use of satellites for precision landings at FAA's Technical Center in Atlantic City. To date, the first two phases of the program have been completed. The first phase of testing evaluated the GPS navigation information without attempting to enhance it. The test was conducted when DOD was not intentionally degrading the accuracy of the GPS satellite signals. The recently published results of the test indicate that the GPS, by itself, could support near-category-I-precision approach procedures. The second phase tested the accuracy of the GPS enhanced with a differential ground-based technique, when the system was intentionally degraded. The results of this test will be published during 1992. According to industry representatives, because this enhancement makes possible accuracies of a few meters, this test will probably show that category I accuracies are achievable.

Also, as part of this program, a satellite-based system supported by the GPS and enhanced by a differential ground station will be tested by Northwest Airlines, Honeywell, and FAA at the Minneapolis/St. Paul International Airport. In addition, Honeywell is developing on-board enhancements to the GPS receiver to provide differential information to correct errors in the computed aircraft position. The information provided by this on-board enhancement will incorporate the information generated by ground-based differential equipment. The use of such enhancements has the potential to achieve accuracies that would satisfy category III standards.

Costs of the ILS and Alternative Precision Landing Systems May Differ

Ground-based systems such as the ILS and the MLS are directly comparable in terms of costs because both of these systems are used only to provide approach, landing, and departure services. This appendix will identify the costs of a new ILS and MLS, the costs to replace an ILS, and the status of each system, including information on recently awarded contracts. Since the MLS that FAA intends to implement is under development, its current cost estimates may change.

The costs of the ILS and the MLS cannot be easily compared with those of the ILS/FMS combination and the satellite-based system because components of the latter systems are used for more than just precision approaches, landings, and departures. However, this appendix will identify some of the costs of the ILS/FMS combination and the satellite-based system. Like costs for the MLS, the current costs for ILS/FMS combination and the satellite-based system may change because both systems are under development.

ILS Costs

FAA plans to fund the maintenance, replacement, and addition of new ILSs. FAA's Capital Investment Plan estimates this will cost $360.9 million between 1992 and 2000.

Costs to Maintain the ILS

Many of the ILSs now in use were installed in the late 1960s and the 1970s. Maintenance and support of these systems has become a problem because of their age. For example, the category II and III ILSs are experiencing severe logistics support problems because parts are no longer available from the manufacturer. These problems have led to rising maintenance and support costs and, as a consequence, these systems will continue to be replaced until the transition to an alternative system is completed.

Costs to Replace ILSs

FAA currently operates 836 full ILSs at 551 airports. FAA plans to replace, totally or partially, 220 category I ILSs and replace most of its category II and III ILSs by 2000. FAA also plans to install new ILSs at locations that have a critical safety need for a precision landing system.

Since October 1989, FAA has awarded five contracts to procure ILSs. Between October 1989 and May 1991, the Wilcox Corporation was awarded three contracts at a total cost of $12 million to produce 79 category I ILSs. In September 1991, the Wilcox Corporation was awarded a $31.4 million contract to produce 53 category II and III ILSs to replace some of these already in use. FAA also has the option of procuring additional category II and III systems (up to 47 more) with future fiscal year dollars. If this option is exercised, FAA will have to procure new approach and landing lights for at least 24 of these systems at a cost of $63.1 million. Most recently, in September 1992, the Wilcox Corporation was awarded a $9 million contract to produce 34 category I ILSs. FAA will install 29 of these systems and DOD will install the remaining systems.

In 1993, FAA plans to award a competitive contract for 280 category I ILSs. This contract will permit FAA to replace 27 category I ILSs already in use, replace components of an additional 153 category I ILSs to extend their service life, and add 100 new systems at a rate of 20 new ILSs per year.

Table II.1 shows the median costs to replace an ILS. These costs are highest for category III ILSs. Also, the costs to replace an ILS are less than the costs to install a new ILS because some of the installation costs are not incurred again when an ILS is replaced.

Table II.1: Median Costs to Replace an ILS, by Category

ILS	Category I	Category II	Category III
Hardware	$180,000	$259,000	$293,000
Installation	348,000	406,000	511,000
Total	**$528,000**	**$665,000**	**$804,000**

Note: Total excludes spare parts, maintenance, and other costs.

Source: Landing Systems Program Office, FAA.

In addition to these costs, FAA will incur costs of at least $28,000 per year for spare parts and maintenance, and a one-time charge of $206,000 in transition maintenance and other costs (site preparation, freight, and initial testing costs) when it replaces an old category I ILS. These costs increase with category II and III ILSs. To replace a category III ILS, FAA will incur costs of at least $51,000 per year for spare parts and maintenance, and a one-time charge of $316,000 in other costs.

Cost of a New ILS

The cost to procure a new ILS is higher than the cost to replace an ILS because of the additional costs for site preparation and installation. Category III systems are the most expensive. Table II.2 shows FAA's median cost for a new ILS.

Table II.2: Median Costs to Procure a New ILS, by Category

ILS	Category I	Category II	Category III
Hardware	$180,000	$259,000	$293,000
Installation	432,000	519,000	598,000
Total	**$612,000**	**$778,000**	**$891,000**

Note: Total excludes spare parts, maintenance, and other costs.

Source: Landing Systems Program Office, FAA.

In addition to these costs, FAA will incur costs of at least $28,000 per year for spare parts and maintenance, and a one-time charge of $206,000 in transition maintenance and other costs for a category I ILS. These costs increase for category II and III ILSs. A new category III ILS will cost at least $51,000 per year for spare parts and maintenance, plus a one-time charge of $316,000 for maintenance and other costs.

To provide precision landing services, an airport needs not only an ILS but also an approach and landing lighting system. The type of lighting system needed depends on the category of the ILS. Table II.3 shows that the median costs for a category II and III lighting systems are over four times the cost of a category I lighting system.

Table II.3: Median Costs of Approach and Landing Lighting Systems, by Type

Components of lighting systems	Category I lighting system	Category II and III lighting system
Hardware	$211,000	$1,037,000
Installation	304,000	1,198,000
Maintenance	21,000	40,000
Spare parts	3,000	26,000
Other costs	87,000	327,000
Total	**$626,000**	**$2,628,000**

Source: Landing Systems Program Office, FAA.

User Costs for the ILS

ILS users pay both procurement and maintenance costs for the avionics associated with ILSs. Table II.4 shows the current costs for ILS avionics, with and without DME, by various aircraft types.

Table II.4: User Costs per Aircraft for ILS Avionics

Avionics by aircraft type	Current costs without DME[a]	Current Costs with DME
Boeing, category III	$69,500	$107,500
Douglas, category III	49,000	88,000
General aviation executive, category III	66,500	95,500
Rotorcraft category II	Unknown	Unknown
Twin/turbo prop commuter, category I/II	49,000	87,000
General aviation recreational, category I	3,600	Not applicable

Notes: All costs are in 1992 dollars. The ILS costs included in this table are for receivers, flight directors, antennas, installation of hardware, and labor to install the equipment.

[a]According to FAA, the distance measuring equipment (DME) is an optional component of the ILS system. In some systems, the DME replaces one or more marker beacons.

Source: Landing Systems and MLS Program Offices, FAA.

Some users will have to upgrade or replace their ILS receivers beginning in 1998 because of a new requirement in ICAO's Annex 10. This requirement stipulates that aircraft using the ILS on international runways must upgrade their receivers by 1998 to meet a new FM immunity criterion. The requirement also states that beginning in 1995, all new ILS receivers installed in aircraft for use on international runways must meet the new criterion. The upgraded receiver is expected to reduce the FM interference that ILS receivers currently experience. The cost for receivers that meet the FM immunity standards ranges between $15,000 and $16,000.

Costs of the ILS/FMS Combination

Costs for the ILS/FMS combination will be incurred by both FAA and users. FAA will also incur costs to develop ILS/FMS approach procedures and certify the ILS/FMS combination for use as a precision landing system.

Costs to FAA

If airlines are to use the ILS/FMS combination for advanced approach procedures, such as curved approaches, FAA must continue to maintain, replace, and upgrade the ILS. Furthermore, FAA must develop these approach procedures. Once these procedures are developed, FAA must certify the ILS/FMS avionics to be used for curved approaches. These requirements involve a commitment of FAA staff. According to the Air Transport Association (ATA), this commitment may require more staff than FAA currently has working on procedural development and certification, and FAA's 1993 budget request does not ask for staff for this purpose. As a result, ATA has recently asked the Congress to provide 30 additional staff members over 3 years. The development of approach procedures for the ILS/FMS combination will provide experience for developing advanced approach procedures in other programs, such as the MLS and the satellite-based system.

Costs to Users

Users will also incur costs to develop and certify the ILS/FMS combination for advanced approach procedures. For example, American and Northwest Airlines are currently paying to develop and test these approach procedures in various airports throughout the United States. These test results will be used by FAA to develop standards and approach procedures for the ILS/FMS combination and eventually to certify this system for curved approaches.

In addition, the airlines will incur the cost of installing the FMS in each aircraft. Currently, the FMS package costs between $500,000 and $775,000 per aircraft, depending on the number of redundant features. This package includes dual inertial reference units (IRU), dual flight management computers, map displays, and other redundant features. Because the on-board FMS will be used for multiple navigational and operational purposes, its costs cannot be apportioned to its various uses. As noted earlier, about 20 percent of the aircraft of major U.S. air carriers are already equipped with the FMS and are using it for a variety of navigation purposes. Most new commercial aircraft are being manufactured with the FMS installed, and about 50 percent of these aircraft will have an FMS by the mid-1990s. The costs may decline as more FMSs are developed and installed.

Because of the high cost of the FMS, the benefits of the ILS/FMS combination will be limited mostly to commercial and business aircraft. Thus, most general aviation aircraft will not benefit from this enhanced system.

MLS Costs

Since the early 1970s, FAA has been working toward developing the MLS. The costs of the MLS include the program costs to develop a new system, the costs of installing a new MLS, and user costs.

Program Costs

FAA has estimated that the MLS program will cost the agency $2.6 billion by 2008.[1] This includes the cost to develop and implement category I, II, and III systems, as well as costs for site preparation, program support, and the

[1]Currently, the MLS program is the second most costly project in FAA's Capital Investment Plan.

demonstration project. Through fiscal year 1992, $255 million had been appropriated for this program.

In 1984, a multiyear, $79 million procurement contract was awarded to the Hazeltine Corporation to develop 178 category I MLSs. The first of these systems was scheduled to be delivered in 1986. FAA experienced serious problems with this procurement because Hazeltine encountered engineering, software, and production difficulties. In the spring of 1988, Hazeltine delivered two category I systems to FAA. In 1989, FAA terminated the contract because Hazeltine would not deliver the rest of the systems. The two Hazeltine systems are currently being used only for testing at FAA's Technical Center in Atlantic City.

Because of the development problems and delays, the entire MLS program was restructured and the schedules were modified. Also, a Conference report on the 1990 Department of Transportation Appropriation Act directed FAA to evaluate the benefits of the MLS before proceeding with a full production contract for the system.[2] In response to this direction by the Conference report and similar recommendations we made in a report issued in May 1988,[3] FAA began a nine-project demonstration program in 1989 to evaluate the economic and operational benefits of the MLS. A report to the Congress containing the results of the demonstration program was issued in March 1992. The report stated that the MLS would provide economic and operational benefits. As a result, FAA plans to proceed with its original objective to replace all ILSs with MLSs.

In April 1990, FAA procured two additional category I MLSs at a cost of $3 million from the Wilcox Corporation.[4] These systems were used in the demonstration program. They are currently operational at John F. Kennedy Airport in New York and Midway Airport in Chicago.

In June 1991, FAA signed a procurement contract with the Bendix Corporation (a division of Allied-Signal Aerospace) for 26 category I MLSs, at a cost of $16.9 million. These systems will be delivered beginning in November 1992. These systems will be used for testing, to develop

[2]Conference Report H.R. 101-315 on the Department of Transportation and Related Agencies Appropriations Act for the fiscal year ending Sept. 30, 1990.

[3]Microwave Landing Systems: Additional Systems Should Not Be Procured Unless Benefits Proven (GAO/RCED-88-118, May 16, 1988).

[4]The Wilcox and Bendix category I MLSs are nonfederal systems. They meet the Federal Aviation Regulations (FAR) Part 171 requirements but do not meet the National Airspace System (NAS)-1000 specifications.

approach procedures, and for operational purposes. FAA does not plan to procure any more category I MLSs.

Instead, FAA plans to procure 1,250 category II and III MLSs, at an estimated cost of $1.5 billion, and use them to provide category I, II, and III service. FAA had planned to award two full-development, limited-production contracts in August 1991 to procure at least six of these MLSs per contract. However, the awarding of the contracts was delayed by 10 months. In June 1992, FAA awarded contracts to the Wilcox Corporation and Raytheon at a total cost of $148 million. Each contract is for developing six category II and III MLSs and all options, including the development of six additional systems. This development will take approximately 46 months.[5]

By the end of this development period, FAA plans to award full-scale production contracts for the remaining 1,226 category II and III MLSs to the contractors that are developing the MLS. By 2000, FAA plans to procure 464 II and III systems, including the first-article MLSs. The remaining 786 systems will be procured after 1999.

Costs of a New MLS

Like the ILS, the MLS includes costs for hardware, installation, maintenance, spare parts, and approach and landing lights; these costs vary, depending on the category of the system. As shown in table II.5, the median cost is the highest for category III systems. These costs are estimates and may change.

Table II.5: Median Costs to Procure a New MLS, by Category

MLS	Category I	Category II	Category III
Hardware	$440,000	$560,000	$680,000
Installation	250,000	250,000	250,000
Total	**$690,000**	**$810,000**	**$930,000**

Note: Total excludes spare parts, maintenance, and other costs.

Source: MLS Program Office, FAA.

In addition to these costs, FAA will incur median costs of $16,083 per year for maintenance and a one-time transition charge of $66,537 when FAA changes over from the ILS to the MLS. These costs are estimated for a category I MLS and may increase when a category II or III MLS is installed.

[5]Bendix has filed a protest over FAA's contract award to the Wilcox Corporation and Raytheon for the development and design of first-article category II and III MLSs. A decision is expected to be rendered by Dec. 1992.

Other costs will be incurred for spare parts, training, site preparation, and other activities; however, information on these costs is not available. If FAA decides to support missed approaches and departures with a back azimuth, hardware costs may increase.

Like the ILS, the MLS must be supported by an approach and landing lighting system. The lights used by the MLS depend on the category of service provided. The lighting costs are the same for the ILS, the MLS, and the satellite-based system (see table II.3). Currently, FAA has 836 runways operating with approach and landing lights (760 runways with category I lighting systems and 76 runways with category II and III lighting systems). Because FAA plans to procure 1,250 MLSs, it will have to procure 414 new lighting systems to support the MLS. These systems are estimated to cost between $259 million and $1.1 billion, depending on the category of lighting systems procured. Also, FAA may incur up to $1.5 billion in lighting costs because it projects that 1,877 runways will be candidates for category I, II, and III precision landing systems by 2010. Thus, given the current number of lighting systems that are supporting the ILS, FAA will have to install an additional 620 category I and 421 category II and III lighting systems so that runways can be used to provide precision landing services. As noted earlier, category I lighting systems have a median total cost of $626,000. Category II and III lighting systems have a median total cost of $2.6 million. The lighting cost is not included in FAA's MLS program or the 1991 Capital Investment Plan.

User Costs for the MLS

FAA's plan to replace the ILS with the MLS has caused concern among users because of the high level of investment required to procure the system. Although FAA will bear the costs of acquiring, installing, and maintaining the MLS ground systems, users will have to bear the costs of procuring new MLS avionics. According to FAA's demonstration program report, costs to the user include avionics hardware, procurement, installation, certification, and maintenance. Hardware costs are combined with procurement and installation costs in the demonstration program report and are projected by the type of aircraft as well as by the category of precision landing needed. Table II.6 shows estimated current and future costs of MLS avionics for a variety of aircraft. MLS avionics costs are expected to decline as the demand for them increases, which is reflected in the future costs shown in table II.6.

Table II.6: User Costs per Aircraft for MLS Avionics

Avionics by aircraft type	Current costs	Future costs
Boeing, category III	$181,200	$84,000
Douglas, category III	130,500	63,300
General aviation executive, category III	178,900	82,500
Rotorcraft, category II	122,600	57,800
Twin/turbo prop commuter, category I/II	124,900	84,000
General aviation recreational, category I	6,150	6,150

Note: MLS costs included in this table are for receivers, central display units, antennas, precise distance measuring equipment, installation of hardware, and labor to install the equipment.

Source: MLS Program Office, FAA.

Calculating costs for users on the basis of projected MLS avionics costs of Douglas and Boeing aircraft, it would cost users between $252 million and $336 million to equip the entire U.S. fleet of about 4,000 commercial aircraft. The costs for MLS avionics may be higher because some airlines have expressed interest in dual or triple MLS/ILS or MLS/GPS receivers.

FAA projects that avionics maintenance costs for each MLS component will be similar to those for the ILS. Average repair costs were estimated at $1,250 for the receiver, $1,250 for the control display unit, $300 for the antenna, and $1,300 for the antenna with a preamplifier.

Users would also need to pay for the certification of MLS avionics. Certification costs are a one-time cost. The demonstration project report estimated that the cost of certifying all types of commercial air carriers with category III MLS avionics would be between $18.0 million and $26.2 million for the entire U.S. fleet. Similarly, the cost of certifying all types of commuter air carriers with category II MLS avionics is expected to be between $5.0 million and $16.3 million. For general aviation aircraft, depending on the certification process chosen and the size of the aircraft, costs range between $1,500 and $5,000 per aircraft.

Costs of the Satellite-Based System

The costs of the satellite-based system are not directly comparable with those of ground-based systems. The satellite-based system has components that will be used for multiple purposes. For example, the satellite navigation information provided by systems such as the GPS will support not only a variety of applications, such as approaches, landings, and departures, but also applications in all other phases of flight. Also, the information may be used to supplement the MLS during approaches, landings, and departures, thereby eliminating the need for the precision DME, which is the MLS component that provides aircraft with information on distance to the runway. In addition, the GPS information can be used to support a large number of nonaviation uses, including surface and maritime applications. As a result, it is difficult to allocate the percentage of the total system's cost to a particular phase of flight, such as a precision landing. The costs of a GPS-based system will be incurred by three parties: DOD, FAA, and users.

Costs to DOD

DOD has incurred the cost to develop and implement the GPS. DOD estimates that it will spend over $10 billion dollars on the GPS. DOD is also responsible for operating and maintaining the system, including replacing satellites, as needed.

The cost of the current GPS satellite, Block IIA, is $48.0 million; the cost for preparing and launching one of these satellites is $41.7 million, not including system development and operation costs. The next generation of GPS satellites—Block IIR—is estimated to cost $27.8 million per satellite.

Costs to FAA

Although FAA will not incur the costs of operating and maintaining the GPS, the agency will incur significant costs to enhance the accuracy, integrity, and availability of the system so that the system can be used to support a variety of civil aviation applications, including precision landings. For example, FAA estimates that it may need to install 700 ground stations, at a total cost of $315.8 million, to enhance the accuracy of the GPS.[6] Also, FAA will incur costs to develop approach procedures and certify the equipment needed to support the satellite-based system. Moreover, because the GPS will provide coverage to all the runways in the country, FAA may incur substantial costs when installing or enhancing lighting systems needed for precision landings.

Costs to Users

Certain users are paying some of the costs to develop the satellite-based precision landing system. For example, Northwest Airlines is currently incurring costs for developing and testing the system, including the cost of developing advanced approach procedures. In addition, many users plan to install GPS receivers whether or not the GPS is enhanced to support precision landings. This is because the GPS can be used for a variety of other navigational purposes.

[6]This cost is in 1992 dollars.

The GPS receivers for air carriers currently cost between $18,000 and $92,047; however, these receivers have not yet been certified for precision landings. Because the GPS receivers may initially be combined with other on-board equipment, such as the inertial reference system (IRS) and the FMS, air carriers may also have to purchase this additional on-board equipment. The cost to the user is $160,000 for the IRS and, as noted earlier, between $500,000 and $775,000 for the FMS package.

In comparison, the GPS receivers for general aviation aircraft currently cost between $3,500 and $10,000; however, these receivers have not yet been certified for precision landings. It is expected that these receivers will not need to be combined with other on-board equipment.

If the enhanced GPS can be used for all phases of flight, some of the current navigation equipment on the ground and in the aircraft could be phased out. For example, the GPS may allow the United States to retire nondirectional beacons, VORS, and DMES. In the long run, this would reduce the costs of avionics to users and the costs that FAA incurs yearly to maintain and replace some of these systems.

The United States has recently announced that once the GPS becomes operational, it will provide services free of charge for an unlimited period of time. However, users may incur costs if the GPS is enhanced with additional satellites provided by another source. For example, although the-then Soviet Union offered GLONASS free of charge for 15 years once the system becomes operational, the user could be charged fees to use GLONASS after this period lapsed. Also, because other satellite systems could be used to enhance the GPS, no guarantee exists that these systems will be free of charge.

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