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Report to the Chairman, Subcommittee
on Transportation, Committee on
Appropriations, U.S. Senate

June 2000

NATIONAL AIRSPACE SYSTEM

Persistent Problems in FAA's New Navigation System Highlight Need for Periodic Reevaluation



GAO

Accountability * Integrity * Reliability

Contents

| | | |
|------------|---|----|
| Letter | | 3 |
| Appendixes | Appendix I: Objectives, Scope, and Methodology | 28 |
| | Appendix II: Experts Contacted | 31 |
| | Appendix III: FAA Identified Four Alternatives for a Benefit-Cost Analysis | 33 |
| | Appendix IV: Comments From the Department of Defense | 37 |
| | Appendix V: GAO Contacts and Staff Acknowledgments | 38 |
| Tables | Table 1: Development Costs and Schedules for WAAS and LAAS, 1994 Through September 1999 | 9 |
| | Table 2: Summary of FAA's Economic Analysis of Four Alternatives | 35 |
| Figures | Figure 1: The Operating System for WAAS | 8 |

Abbreviations

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|------|--------------------------------------|
| ATA | Air Transport Association of America |
| DOD | Department of Defense |
| FAA | Federal Aviation Administration |
| GPS | Global Positioning System |
| LAAS | Local Area Augmentation System |
| OMB | Office of Management and Budget |
| WAAS | Wide Area Augmentation System |



United States General Accounting Office
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Resources, Community, and
Economic Development Division

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June 12, 2000

The Honorable Richard C. Shelby
Chairman, Subcommittee on Transportation
Committee on Appropriations
United States Senate

Dear Mr. Chairman:

Currently, the Federal Aviation Administration (FAA) relies principally on a ground-based navigation system that uses various types of equipment to assist pilots in navigating their assigned routes and to provide them with guidance for landing their aircraft safely in different types of weather. However, this ground-based navigation system is aging and limited in its geographic coverage. FAA is planning a transition from its ground-based navigation system to a satellite-based system using radio signals generated by the Global Positioning System (GPS) to provide greater geographic coverage, among other things. The Department of Defense developed GPS to support military missions and functions. However, the system is now a dual-use system, and other users—pilots, truckers, and boaters—rely on signals from the GPS satellites to calculate their time, speed, and position anywhere on or above the earth's surface. As part of its efforts to maintain GPS and make it more useful for civilians, in May 2000, Defense ceased its practice of intentionally degrading the accuracy of the GPS signal available for civil use.¹ Furthermore, Defense plans to begin gradually replacing the existing satellites with new ones that will also improve system performance.

Although GPS already provides some critical information to pilots, FAA believes that even with the greater accuracy and other improvements expected from Defense's newer satellites, this system will not satisfy all civil aviation requirements for ensuring safe aircraft operations. For example, FAA requires that its navigation system be unavailable no more than 5 minutes per year for some types of navigation and landing. In contrast, GPS could be unavailable for periods of time equaling up to 4 days per year. To satisfy its requirements, FAA decided in the 1980s to augment

¹ In the past, the Department degraded the accuracy of the GPS signal using a process known as "selective availability."

GPS with other navigational aids—the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System. These systems consist primarily of a network of ground stations that receive, process, and validate data from GPS before transmitting these data to pilots.

In deciding to augment GPS, FAA has conducted several benefit-cost analyses—most recently in 1999. In its latest analysis, FAA estimated that its future investment in this augmented navigation system could exceed \$8 billion from 2000 through 2020.² WAAS is the largest component of this augmented system—37 percent of the total. Over the years, the cost of developing WAAS has increased by over \$500 million primarily because of unanticipated development and additional program support costs. In addition, WAAS has been delayed for over 3 years and has experienced performance problems.

In light of the expected cost of this new navigation system and continuing concerns about WAAS' ability to achieve cost, schedule, and performance goals, you asked us to provide information on whether (1) the Department of Defense's current GPS or its planned improvements for GPS can meet FAA's navigation requirements, (2) the benefits of FAA's chosen approach to an augmented system currently outweigh the cost of this system, and (3) other technologies are available to meet FAA's requirements and users' needs for a new navigation system. In conducting this review, we examined studies and spoke with experts in aviation navigation and related technologies to obtain their views on the capability of FAA's new navigation system and alternatives to that system. Appendix I discusses our detailed scope and methodology. Appendix II lists the experts we spoke with, some of whom represent various technologies.

Results in Brief

According to the studies we reviewed and experts we contacted, the current Global Positioning System does not meet all of FAA's civil aviation navigation requirements for accuracy, integrity, and availability. FAA defines accuracy as the degree to which a navigation system calculates an

² Throughout this report, we refer to the augmented satellite navigation system and its components—including the Local Area Augmentation System and existing ground-based navigation aids—as FAA's new navigation system. This system also provides guidance to help pilots land at airports. Also, throughout this report, unless otherwise specified, costs are presented in "then-year-dollars," which are current dollars, inflated using Office of Management and Budget guidance.

aircraft's true position. Integrity is the ability of a navigation system to provide timely warnings when its signal is providing misleading information that could potentially create hazards for pilots and thus should not be used. Availability is the probability that a navigation system meets the accuracy and integrity requirements. Even though the Department of Defense has made the current GPS signal provided for civilian use more accurate and plans to further improve GPS by, for example, providing an additional, higher-powered signal to combat interference, GPS still will not fully meet FAA's requirements for navigation and landing. This is because GPS does not provide the assurance that its signal will be available virtually all the time.

FAA's 1999 analysis concluded that the quantified benefits of its approach would outweigh the cost. Since completing this analysis, FAA has experienced delays and cost increases primarily because of difficulties in meeting its integrity requirement. As a result, it is unclear whether quantified benefits will still outweigh cost. For example, to meet FAA's integrity requirement—which requires the Wide Area Augmentation System to virtually never fail to warn pilots of potentially hazardous misleading information—we estimate that the agency may need 3 or more years, at an additional cost of between \$200 million to \$240 million, to demonstrate that this requirement can be met. The system, with the ability to provide integrity, was to have been operational by September 2000. We are making recommendations to better ensure that FAA delivers its new navigation system, on time and within budget, and that it meets performance requirements. Transportation and Defense officials as well as the officials from the Satellite Navigation User Group—representing commercial, general aviation, and Defense users—acknowledged the problems encountered in developing the new navigation system. Transportation officials concurred with GAO's conclusions and recommendations.

At the present time, no other navigation technologies—including variations of ground-based and less robust satellite-based systems—are available to meet FAA's requirements and users' needs for precise landing guidance at more airports. The Wide Area Augmentation System is designed to provide such guidance to improve safety and offer access to more airports. However, as noted, this system is experiencing difficulties that cast doubt on whether it will perform as designed at a reasonable cost and be delivered on a reasonable schedule. Moreover, experts in alternative navigation technologies, some of which compete with the Wide Area Augmentation System, told us that users may have overstated their need

for precise landing guidance and that other navigation technologies could satisfy most of these needs.

Background

Currently, civil aviation relies principally on a ground-based navigation system that uses various types of equipment to provide navigation and landing services to pilots in different types of weather. This equipment meets FAA's performance requirements for accuracy, availability, and integrity; however, it is aging and has limitations in its geographic coverage. For example, under today's ground-based navigation system, pilots fly structured routes (referred to as highways-in-the-sky) that may not be the most direct and fuel-efficient. The wider coverage provided by WAAS, coupled with other improvements, would not restrict pilots to these structured routes and would therefore result in more direct and fuel-efficient flights.

To a lesser degree, civil aviation relies on GPS for its navigation needs. The Department of Defense (DOD) maintains a constellation of 24 orbiting GPS satellites for both military and civilian use.³ These satellites are positioned so that at any given time the signals from a minimum of four satellites will be available to users.

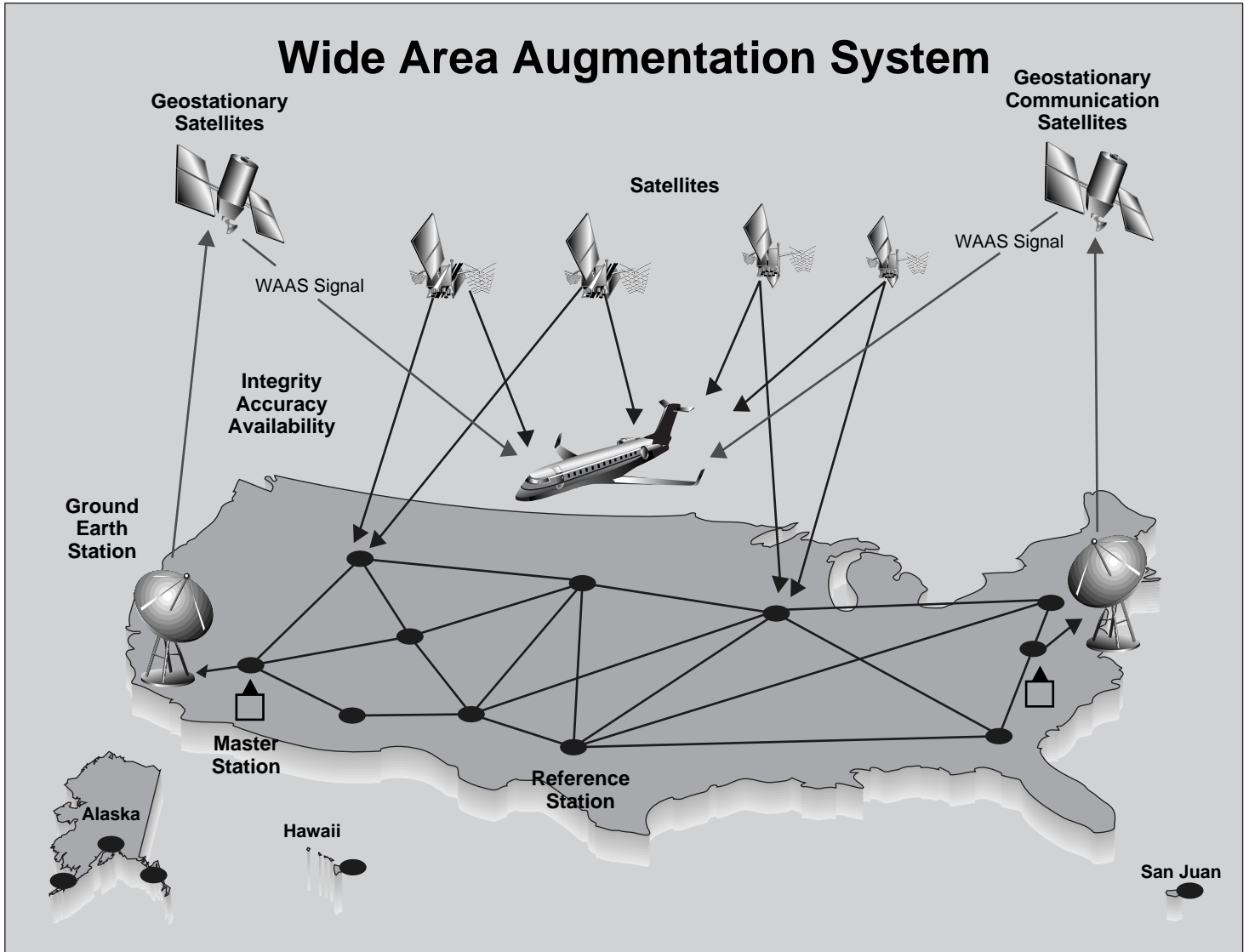
FAA is developing a new navigation system to augment GPS in order to provide broader geographic coverage, among other things. The largest component of this system is WAAS. When fully developed, WAAS could comprise a network of up to 76 ground stations and three to four geostationary communications satellites. (see fig. 1.) The WAAS network is being designed to provide the same level of service as today's ground-based equipment and is expected to support navigation through all phases of flight as well as nonprecision and category I precision landing approaches for a wider geographic area.⁴ In a nonprecision approach, the pilot relies on instruments on board the aircraft to guide it safely from a height ranging from between 700 and 400 feet above touchdown. In contrast, in a category I precision approach, the pilot relies on instruments to provide an aircraft with safe vertical guidance to a height of not less than 200 feet above touchdown. Currently, pilots can make precision approaches at only about

³ Replacement satellites will be launched as needed.

⁴ Navigation guidance is provided to pilots through all phases of flight—at high altitudes and in areas close to airports.

625 airports. With WAAS, FAA estimates that it may be possible to expand this capability to approximately 3,300 airports, thus providing benefits to more users. To obtain the full benefit from WAAS, it would be necessary for these airports to incur costs for items they would need for providing greater access at 200 feet, such as airport lighting systems, which could cost between \$1 million to \$2 million per airport system. Additionally, many pilots are not now qualified to fly these precision approaches and will therefore need training to obtain the full benefits of WAAS.

Figure 1: The Operating System for WAAS



Source: FAA.

As part of its augmentation of GPS, FAA, in partnership with industry,⁵ is also developing the Local Area Augmentation System (LAAS) to support, among other things, even more stringent precision approach guidance than expected from WAAS. For example, in these approaches, LAAS is expected to provide pilots with safe vertical instrument guidance to heights ranging from less than 200 feet to down to the runway surface. While LAAS is independent of WAAS, it is also expected to complement WAAS and provide precision approaches at airports where WAAS does not provide sufficient geographic coverage. LAAS will require the development, testing, evaluation, and fielding of a new generation of ground stations—up to 160. In January 1998, FAA approved development costs and schedules for LAAS. At that time, FAA estimated that LAAS would cost \$530 million and would be operational by 2003.

Table 1 shows the history of development costs and schedules for WAAS and LAAS.

Table 1: Development Costs and Schedules for WAAS and LAAS, 1994 Through September 1999

Dollars in millions

| | As of | | | |
|------------------------------|--------------|----------------------|------------|----------------------|
| | 1994 | Jan. 1998 | Jan. 1999 | Sept. 1999 |
| Types of costs | | | | |
| Total WAAS development costs | \$508 | \$1,007 ^a | \$1,007 | \$2,484 ^b |
| Total LAAS development costs | ^c | \$530 | \$530 | \$720 ^d |
| Schedule Information | | | | |
| WAAS' initial capability | June 1997 | July 1999 | Sept. 2000 | Sept. 2000 |

⁵ Beginning in fiscal year 1999, FAA established a partnership with interested commercial entities for the purpose of developing LAAS. FAA expects this partnership to culminate in the development of a certified category I precision approach using LAAS by the end of fiscal year 2002.

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| | As of | | | |
|--|-----------|-----------|------------------|------------|
| | 1994 | Jan. 1998 | Jan. 1999 | Sept. 1999 |
| Schedule Information | | | | |
| WAAS' full capability | Dec. 2000 | Dec. 2001 | To be determined | Dec. 2006 |
| LAAS' first site implementation ^c | | 2003 | 2003 | 2003 |
| LAAS' last site implementation ^c | | 2006 | 2006 | 2010 |

Note: Since 1996, FAA has been including life-cycle costs, which include costs for developing, operating, and maintaining projects. The current life-cycle cost estimate for WAAS is \$3,187.6 million.

^a The Jan. 1998 program development costs for WAAS include the prime contractor costs, development of standards and procedures, technical engineering and program support, and the first year of costs for satellites.

^b The Sept. 1999 estimate for WAAS development costs includes \$1.3 billion in satellite service acquisitions through 2020. In earlier estimates, satellite service acquisition costs were included in the cost of operating WAAS.

^c Costs and schedules were not developed until 1998.

^d The Sept. 1999 LAAS cost increase is due in part to FAA now planning to acquire up to 160 systems. In earlier cost estimates, FAA only planned to acquire 143 systems.

Source: FAA.

FAA is retaining about 30 percent of its ground-based navigation infrastructure to address concerns about the vulnerability of the GPS signal, which WAAS relies on, and to support those users who choose not to purchase the equipment that must be used with WAAS. This infrastructure, along with WAAS and LAAS, make up the components of FAA's new navigation system. Both WAAS and LAAS would require airlines and general aviation users to purchase on-board equipment for receiving signals from this new technology. These purchases are expected to occur over time, as the new navigation system is developed.

WAAS and LAAS are being developed under a single FAA integrated product team, which includes representatives from FAA's aircraft certification and acquisition organizations. FAA established cross-functional teams to help ensure that systems are developed and implemented in an efficient and effective manner. These teams are to be empowered to make decisions affecting systems and services, from their inception to their eventual disposal or termination. The effective operation of the integrated teams is key to FAA's goal of producing timely, cost-effective acquisitions.

GPS Needs Augmentation to Meet FAA's Civil Aviation Navigation Requirements

Studies we reviewed, experts we contacted, and DOD officials we interviewed, agreed that to meet FAA's civil aviation requirements, FAA must augment even the improved GPS. For example, according to a 1999 Johns Hopkins University study,⁶ augmentation was needed because GPS failed to meet the critical requirement of system availability, which is the probability that at any given time a navigation system will meet the accuracy and integrity requirements for a specific phase of flight.⁷ FAA defines accuracy as the degree to which an aircraft's position, as calculated by its navigation system, conforms to its true position. Integrity is the ability of a navigation system to provide timely warnings when its signal is providing misleading information that could potentially create hazards for pilots and thus should not be used for navigation. This study considered the impact of DOD's decision to stop intentionally degrading the accuracy of the signal for civilian use and concluded that augmentation was still necessary. In May 2000, DOD actually stopped degrading its signal for civilian use. As a result, the predicted accuracy for civilian use will increase from about 100 meters (about 300 feet) to 20 meters (about 60 feet). However, FAA requires an accuracy of about 7.6 meters (about 23 feet) for landing aircraft.

⁶ This study, entitled *GPS Risk Assessment Study, Final Report* (Jan. 1999), was conducted by the Johns Hopkins University Applied Physics Laboratory and was co-sponsored by FAA, the Air Transport Association, and the Aircraft Owners and Pilots Association. According to the Air Transport Association, the primary purpose of this study was to determine the capability of the augmented GPS signal using WAAS and LAAS.

⁷ Continuity and service volume are also considered major requirements, and they are derived from the accuracy, integrity, and availability requirements. Continuity is the probability that a navigation signal will meet accuracy and integrity requirements continuously for a specified period. Service volume is the area of coverage for which a navigation signal will meet availability requirements.

Moreover, Defense plans to begin gradually replacing the existing satellites with new ones that will have an additional higher-powered signal to help combat interference and improve overall system performance. However, even with these improvements, GPS still falls short in meeting the requirement that it be available virtually all of the time. For example, the Johns Hopkins study found that GPS could be unavailable for periods of time equaling up to 4 days per year for en route navigation.^{8, 9} In contrast, FAA requires that its navigation system be unavailable no more than 5 minutes per year for en route navigation and nonprecision approaches. Furthermore, GPS alone does not provide guidance for precision approaches.

In addition, an expert we spoke with noted that FAA's efforts to augment GPS are in line with those of other nations to augment a navigation system based on global satellites.¹⁰ Nations with navigation systems based on global satellites will likely augment the signal provided by the global system in order to maintain surveillance over civil navigation services. This would enable them to independently monitor—from the ground—the usability of the GPS signals and provide GPS status for their air traffic controllers and aircraft.

⁸ En route navigation occurs when planes are in transit over the continental United States.

⁹ According to DOD, GPS' availability is contingent upon the alignment of satellites with the earth's rotation.

¹⁰ Europe and Japan are currently developing augmentation systems.

Integrity Issues and Other Problems in Developing WAAS Raise Questions About Whether the Quantified Benefits of FAA's New Navigation System Outweigh Its Cost

According to FAA's 1999 analysis, its new navigation system yielded quantified benefits that exceeded costs over the period 2000 through 2020, but development problems—principally related to proving the WAAS integrity requirements—will raise costs, making it unclear whether quantified benefits still exceed the cost of the new system. Also, in the short term, because of the delays resulting from these problems, users will not receive the benefits they expected from the system later this year, such as greater capability to land at more airports in bad weather. Additional costs are occurring because FAA has not appropriately overseen its contractor¹¹ and has underestimated software costs. Finally, it has been suggested that the system's cost may be higher if performance problems indicate that FAA needs to maintain separate navigation equipment at the airport.

¹¹ The Raytheon Company has been the prime contractor since May 1996.

FAA's Chosen Alternative Yielded Net Benefits, but Problems Will Most Likely Reduce These Benefits

In 1999, in response to a congressional request, FAA reevaluated its plans for a new navigation system.¹² As part of this reevaluation, FAA conducted a benefit-cost analysis of four alternatives. According to FAA's analysis, continuing with the WAAS/LAAS system, coupled with using about 30 percent of the agency's current ground-based infrastructure as a backup to WAAS, would yield the greatest net quantified benefits (dollar value of benefits minus costs),¹³ regardless of whether passengers' time savings are included.^{14, 15} According to FAA, for 2000 through 2020, there is an 80-percent chance that the net benefits of its preferred alternative are about \$2.5 billion if passengers' time savings are counted and \$72 million if these savings are not counted. Expressed another way, the benefit-cost ratios for these two scenarios are 2.4 and 1.1, respectively.¹⁶ The benefit-cost analysis also identified at least 11 benefits that were not quantified. Included among these were safety benefits, such as improved surface surveillance, as well as operational benefits, such as enabling more landings at airports whose operations are today limited by the lack of ground-based navigational aids.¹⁷ According to FAA, its decision to pursue this approach had the support of major users.¹⁸ (See app. III for a discussion of FAA's analysis.)

¹² See *Satellite Navigation Investment Analysis Report*, Federal Aviation Administration (Sept. 25, 1999).

¹³ As an alternative to the benefit-cost ratio, for which the present value of benefits is divided by the present value of costs, analysts sometimes calculate the present value of net benefits. This value is equal to the present value of benefits minus the present value of costs.

¹⁴ DOT values passenger time from \$22 to \$33 per hour, depending on the nature of air travel. In 1998, our review of the economic literature found that no consensus exists on the validity of valuing small increments of time, in part because passengers might not perceive and value time savings of as little as 30 seconds.

¹⁵ It should be noted that the other three options had benefit-cost ratios of less than 1.

¹⁶ A benefit-cost ratio is a measure of the relationship between the present value of a project's benefits and costs. Since benefits are divided by costs, any ratio above 1.0 indicates that the project is cost-beneficial; any ratio below 1.0 indicates that the project is not cost-beneficial.

¹⁷ Data were not available to quantify 5 of the 11 benefits. For the other six, FAA determined that the benefits would derive from WAAS, combined with other technologies, and therefore did not attempt to separate and quantify the WAAS benefits.

¹⁸ The Satellite Navigation User Group—which includes representatives from commercial, general aviation and Department of Defense users—was created to achieve a consensus throughout the user community and within FAA for making the transition to the new navigation system. In Mar. 2000, this group reaffirmed its support for WAAS.

While we did not conduct a detailed benefit-cost analysis, we believe that under certain conditions the quantified net benefits of FAA's chosen alternative, without passenger value of time, could be negative, and the benefit-cost ratio could be less than 1. This could occur because of added costs resulting from delays or other problems. Furthermore, these delays could have implications for FAA and users.

The Requirement for System Integrity Will Delay WAAS Deployment and Was Not Addressed in a Timely Manner by FAA Management and the Integrated Product Team

In December 1999, FAA found that the WAAS design could not be relied upon to satisfy the agency's requirement for system integrity for precision approaches, which stipulates that WAAS cannot fail to warn pilots of misleading information that could potentially create hazardous situations more than once in 10 million approaches. Consequently, FAA has determined that it will not make its scheduled date of September 2000 to begin providing an initial capability for precision guidance (category I approaches) through WAAS.¹⁹ The delay could have implications for FAA, system users, and equipment manufacturers. For example, FAA may need to buy new ground-based navigation equipment or maintain existing equipment longer than expected—maintaining existing equipment costs about \$170 million annually, according to FAA. Likewise, system users and equipment manufacturers could question the wisdom of making further investments in WAAS technology. Because of these implications, FAA, with users' support, has decided to provide only a limited precision guidance capability with WAAS by 2002.²⁰ FAA has yet to determine when WAAS will achieve its initial capability. However, FAA and major user groups contend that they still will receive benefits from a limited WAAS. Using information provided by FAA and its experts, we estimate that resolving the integrity problem could potentially delay making WAAS' initial capability available by 3 years or more and add approximately \$200 million to \$240 million to the cost of developing WAAS.

¹⁹ WAAS' initial capability was defined as vertical guidance of 200 feet above touchdown with a one-half to three-fourths mile visibility and a 19.2 meter vertical protection limit in which an aircraft can maneuver and still land safely. This capability was to be available 95 percent of the time to about 50 percent of the continental United States.

²⁰ By 2002, FAA plans to provide vertical guidance of 350 feet above touchdown with one mile visibility and a 50 meter vertical protection limit in which an aircraft can maneuver and still land safely. This capability is to be available 95 percent of the time to about 75 percent of the continental United States.

To satisfy the integrity requirement, FAA and its contractor plan to make changes to improve the calculations for better identifying misleading information that could potentially create hazards for pilots; these changes will cause software changes and may result in hardware upgrades. A team consisting of FAA officials, its contractor, and consultants proposed these changes and plans to be actively involved in ensuring that they will result in proving the system's integrity performance. By the end of 2000, the team expects to determine what, if any, changes may be needed to the WAAS design to achieve precision approaches down to 200 feet above touchdown.

The difficulties in proving the integrity requirement have occurred largely because FAA management and the integrated product team underestimated the complexity of resolving the integrity issue and, as a result, failed to recognize the seriousness of the problem. Moreover, FAA did not closely monitor the contractor's effort to demonstrate integrity, and members of the team did not have a clear understanding of their roles. Consequently, team members did not effectively communicate with each other and the contractor. Lack of monitoring and poor communications have been recurring problems in FAA's air traffic control modernization program. For example, in 1996, we reported that inadequate oversight of contractors' performance was a major contributor to FAA's recurring cost, schedule, and performance problems with other projects in the modernization program.²¹

According to a WAAS study group FAA convened in October 1997, it would be difficult to prove WAAS' stringent requirements. Therefore, FAA would need both a sound mathematical approach and evidence acquired through operational experience.²² This group's conclusions were validated in December 1997, when according to FAA, it discovered at a key project milestone that the contractor did not have an adequate plan for proving the WAAS integrity requirement. Over the next 21 months, FAA, its experts, and the prime contractor attempted to resolve the integrity issue; however, not until September 1999, when the aircraft certification members of the integrated product team became actively involved, did FAA fully understand the difficulty in trying to prove this requirement. We found that FAA's progress in resolving this issue was hampered because (1) the

²¹ See *Aviation Acquisition: A Comprehensive Strategy is Needed for Cultural Change at FAA* (GAO/RCED-96-159, Aug. 22, 1996).

²² *Final Report of the WAAS Study Group* (Oct. 16, 1997).

contractor took about a year to submit the limited results of its assessment of the integrity issue and (2) the integrated product team was slow to respond to advice from other FAA experts that the contractor's integrity assessment was inadequate.

FAA officials agreed that they should have monitored this situation more closely but provided three reasons for not addressing the integrity problems more promptly. These reasons largely concerned the actions of FAA's senior management and the integrated product team for WAAS:

- Competing priorities between FAA's acquisition and aircraft certification organizations, which are part of the integrated product team, negated the effectiveness of this team's approach for meeting the agency's WAAS goals. This situation may have developed because FAA's aircraft certification organization is more accustomed to being involved after a project is developed, rather than actively participating throughout its development. As we reported in 1996, FAA's product teams have not always forged true partnerships across organizational "stovepipes."²³
- A shortage of in-house technical expertise and the team's attention to other important issues, such as systems engineering, prevented the team from monitoring the situation more closely.
- FAA did not have a sufficiently defined process for identifying and conveying to the contractor the results that would be acceptable for proving WAAS' integrity.

Moreover, some team members did not feel empowered to take actions to address performance issues because they did not believe that they had senior management's support in dealing with contractor-related problems. In addition to these internal problems, an FAA official told us that the contractor lacked sufficient expertise to prove the integrity requirement. In any case, after being alerted to the difficulty in proving this requirement 2 years ago, FAA is only now beginning to pay it serious attention.

²³ See *Aviation Acquisition: A Comprehensive Strategy is Needed for Cultural Change at FAA* (GAO/RCED-96-159, Aug. 22, 1996).

Underlying these problems is a basic issue of how FAA decided to proceed with WAAS' development. Essentially, FAA took an acknowledged high-risk approach: It agreed on a design for the system and established milestones for system deployment before completing the research and development needed to demonstrate the system's capability. If FAA continues along this path, it could incur significant costs for other system components, such as satellites, to make the design fully operational—without knowing whether the system will meet its performance requirements. A FAA senior manager acknowledged that, in hindsight, the agency should have placed more emphasis on how it would prove WAAS' integrity performance prior to agreeing to a design for the system. As we have reported for other FAA modernization projects, when the agency attempts to combine different phases of system development in an effort to more quickly implement systems, it repeatedly experiences major performance shortfalls, which lead to delays and additional costs.²⁴

Recognizing these problems, FAA is in the process of implementing a new approach to developing WAAS. Under this approach, before making additional investments, FAA plans to allow time for collecting and evaluating data on (1) system performance, (2) the extent to which users have purchased equipment, and (3) the availability of emerging new technologies for the new navigation system. In essence, FAA plans to reevaluate WAAS at critical points—"checkpoints"—in its development.

We believe that reevaluating WAAS at checkpoints should provide critical information for deciding about the need for future investments. Moreover, such checkpoints would allow FAA to better assess whether it should shift resources to other parts of the navigation system, such as LAAS, to meet users' needs. While FAA recognizes the need for checkpoints, it has not developed a detailed plan explaining when these checkpoints would occur, what they would accomplish, and who would be responsible for overseeing them. We also believe that it would be prudent for FAA to have progress on WAAS independently validated at the established checkpoints before the Congress approves additional funding.

²⁴ See *Air Traffic Control: Observations on FAA's Air Traffic Control Modernization Program* (GAO/T-RCED/AIMD-99-137, Mar. 25, 1999).

Software Development Problems Are Likely to Cause Delays

Given past problems and the amount of and potential complexity associated with the remaining systems engineering development effort—including developing algorithms to resolve the integrity issue—we believe that the WAAS software effort will continue to experience delays. For example, the schedule for the initial WAAS capability has already slipped 14 months—from July 1999 to September 2000—largely because of problems in developing the WAAS design, which led to more software development. At the end of its initial phase, WAAS will have approximately 350,000 lines of code and 370,000 additional lines or more of code will be required before the system becomes fully operational.²⁵ According to FAA, this additional code will be needed to, among other things, provide for the security of the system and to expand its operating capability.

We have reported on numerous occasions that in acquiring software, FAA has not adequately detailed its design requirements and overseen contractors' development of the software.²⁶ Software development—the most critical component of key FAA modernization programs—has been the Achilles' heel of FAA's efforts to deliver programs on time and within budget.

FAA Underestimated Annual Costs for Maintaining Software

Even if all navigation system and development issues were resolved, the quantified cost of the new navigation system is likely to outweigh the quantified benefits because FAA underestimated the cost of maintaining software by between 120 percent to over 200 percent, according to our analysis.²⁷ That is, we found that FAA's estimate of \$85 million for WAAS software maintenance, which includes the staffing cost for modifying or adding software throughout the life of the project, was understated by between \$101 million to \$181 million. FAA's estimate differed from our estimate in part because the agency used more optimistic assumptions in two instances. First, FAA assumed that 7 percent of the software would be changed annually throughout the life of the project. In our analysis, however, we assumed that 10 percent of the software would be changed

²⁵ Software size is usually measured in lines of code. A line of code is a set of instructions for the computer to perform a certain task and is one basis for estimating costs for items such as the coding, analysis, design, and test efforts required for producing the line of code.

²⁶ See *Air Traffic Control: Immature Software Acquisition Processes Increase FAA System Acquisition Risks* (GAO/AIMD-97-47, Mar. 21, 1997).

²⁷ This assumes no value to any passenger time savings.

annually. We made this assumption because (1) FAA's own data suggested that an annual factor of between 5 percent to 10 percent could be used and (2) the model we used suggested that for software projects such as WAAS, annual software change could approach 10 to 20 percent. Second, FAA assumed that the government would maintain the software and used an hourly labor rate of \$75 per hour—the rate the agency uses when it maintains software in-house. FAA's own data suggested that having the government maintain the WAAS software would be optimistic, given its considerable complexity and safety-of-life purpose and the government's unfamiliarity with the software's development. For our analysis, we used the prime contractor's software labor rate of \$127 per hour because the contractor is very familiar with the software's development and well qualified to maintain it.

Two Experts in Navigation Technology Believe Separate Equipment Must Be Used in Conjunction With WAAS

Costs for WAAS may also be higher than FAA anticipates if, as some navigation experts believe, separate equipment is needed at airports. This equipment would be used to monitor the information WAAS provides to aircraft as they approach an airport for a landing. Currently, FAA has no plans to have such equipment in place. But these two experts note that FAA has always ensured safety by requiring such equipment and that the WAAS design should conform to this requirement.

To illustrate the need for such equipment, these experts noted that local conditions around an airport, such as interference from man-made and natural occurrences, may affect the GPS signal. The WAAS reference station, which would send corrections to an aircraft, might be located hundreds of miles from the airport and might not pick up these local conditions. Local navigation equipment would factor in local conditions and their effect on an aircraft's true position. Without such information, these experts maintain that a pilot will not have the critical information needed to land safely. Even though this occurrence has not been observed in tests to date, experts contend that the lack of observance is not proof that it will not occur.

In response, FAA stated the agency's experts have reasoned that the WAAS design and the location of the reference stations are sufficient to account for and correct any inaccuracies in the GPS signal. FAA disagrees that separate, independent monitoring equipment is necessary because, given the WAAS design, an airport-based monitor will not provide the required integrity. This might occur because an airport monitor could receive its information from a set of GPS satellites that are different from those that

are providing information to the aircraft. Nevertheless, FAA asked its experts to model extreme conditions, and these experts have yet to detect local inaccuracies. FAA also notes that it will not provide guidance for the category I precision approaches until it has had an opportunity to evaluate operational data and feedback from pilots. As it gains experience, FAA acknowledges it may need to make changes to WAAS, which could increase the cost of the WAAS investment.

Other Technologies Do Not Meet FAA's Requirements and Users' Needs, but Experts in Competing Technologies Contend That Some Needs Are Overstated

At the present time, alternative technologies, including other ground-based and less robust satellite-based systems, fall short in meeting FAA's requirements and users' needs.²⁸ WAAS is designed to provide precise position and landing guidance (category I precision approaches) to meet FAA's requirements and users' needs for improved safety and greater access to more airports. The alternative technologies cannot meet FAA's requirement for category I precision approaches. However, according to several experts supporting alternative technologies, they believed users overstated the level of precision needed to safely land at more airports and therefore a less robust WAAS or other technologies could satisfy users' needs. However, FAA contends that WAAS serves other purposes in addition to serving users' needs. FAA told us that other modernization efforts depend on the precise position information expected from WAAS and that if the agency were to rely on technologies other than WAAS, it would have to consider redesigning these other projects.

Other Technologies Cannot Provide Category I Precision Approaches

Experts on technologies that compete with WAAS acknowledge that, unlike WAAS, these technologies cannot provide vertical guidance to a height of not less than 200 feet above touchdown (category I precision approaches) at more airports. Users—primarily general aviation pilots—told FAA that they need this level of precision. It is important to note that FAA has yet to demonstrate if and when WAAS will provide users with guidance for category I precision approaches.

²⁸ In considering FAA requirements and users' needs, it is important to factor in the cost of providing precision landing guidance. FAA notes that it could provide this guidance through technologies such as instrument landing systems at all runway ends in the United States, but this would be cost prohibitive.

While recognizing that other technologies cannot provide category I precision approach guidance, these experts question whether such guidance is needed. They note that providing users with access to more airports depends upon factors other than the precise position information WAAS offers. For example, to experience the full benefits of WAAS, airports would need to invest in infrastructure, such as lighting systems, and pilots would need training to fly precision approaches into these airports. Given this potential investment and other considerations, these experts, who support technologies that compete with WAAS, pointed out three different available combinations of ground-based and satellite-based technologies that could meet the vast majority of users' needs for precise landing information at a lower cost than WAAS: (1) Long Range Navigation (LORAN C), a ground-based navigation system that provides position and timing information to both aviation and nonaviation users;²⁹ (2) a scaled-back WAAS, which would not provide category I precision approaches; and (3) LORAN C with an enhancement known as Eurofix. For example, according to a 1998 study conducted for the Department of Transportation, the cost to develop and operate LORAN C is estimated at over \$600 million for 2000 through 2015.³⁰ Similarly, the cost to develop and operate WAAS during this period is estimated at \$2.3 billion. Most of the difference in cost is attributable to the fact that WAAS would rely on newly launched geostationary satellites, which LORAN C does not need.

These experts maintain that the competing technologies, combined with on-board equipment that provides an increased vertical guidance capability, can guide users down to a height of about 250 feet and therefore achieve "near" precision approaches.³¹ They therefore contend that a less costly technology than the WAAS now contemplated could still meet the vast majority of the aviation community's needs for precise landing information—especially for general aviation users, who are expected to benefit the most from WAAS. At runways where a 200-foot minimum

²⁹ LORAN C was originally designed as a primary navigation system for the maritime community. This technology is ground-based and can provide an independent navigation service that does not rely on GPS.

³⁰ *An Assessment of the Proposed Phase Out of the LORAN C Navigation System*, Booz-Allen & Hamilton, Inc., July 17, 1998.

³¹ Users can receive vertical guidance from different types of equipment. For example, some commercial aircraft are currently equipped with flight management systems that are coupled with altimeters to provide vertical guidance. Using this equipment, pilots can make "near" precision approaches.

category I approach is critical, these experts stated that these requirements could be satisfied by LAAS.

According to FAA, it analyzed the technical capability of these three alternatives as part of its 1999 reevaluation of its plan for a new navigation system. It rejected the LORAN C and scaled-back WAAS alternatives because they did not provide the precision navigation guidance expected from WAAS. The agency rejected the Eurofix alternative because it did not meet the integrity requirements for precision approaches. FAA also believes that the alternative technologies and on-board equipment would bring pilots down to about 350 feet, not the 250 feet the experts contend could be achieved. Moreover, implementing these technologies would shift a large cost from the government to general aviation system users—to purchase additional equipment estimated at about \$1,000 to \$4,000 per aircraft—and yet these users would still be limited in their ability to land at more airports in foul weather. A group representing major users reaffirmed its support for WAAS, with the expectation that it will provide category I precision guidance. In addition, according to an interest group representing general aviation aircraft owners and pilots, these individuals support FAA's approach because while proponents of the three alternative technologies make claims about their capabilities, these capabilities have yet to be validated. Furthermore, owners and pilots are not in favor of changing the design of the new navigation system after FAA and aviation manufacturers have agreed to specifications for equipment design and invested hundreds of millions of dollars in this new design.

Using Other Technologies Could Require Design Changes in Modernization Projects That Depend on Precise Position Information

As currently designed, several of FAA's airspace modernization projects depend on WAAS for precise position information and, according to FAA, could not readily be developed without WAAS. While GPS provides position information, WAAS is designed to ensure the integrity of that information. If an alternative technology is used, these programs may need to be redesigned. Chief among these is the Automatic Dependent Surveillance Broadcast, one of a group of technologies designed to allow FAA to implement a new system of traffic management. Under this system, known as free flight, pilots and air traffic controllers would receive more precise information about the location of aircraft in order to improve system safety while allowing airspace and airport resources to be used more efficiently. Specifically, the Automatic Dependent Surveillance Broadcast communicates information about an aircraft's position from on-board equipment that receives signals from global satellites and sends this

information directly to ground receivers and to nearby aircraft. With such information, more aircraft can fly with increased efficiency and safety.

Other projects that depend on precise position information include enhanced systems to warn pilots and air traffic controllers of proximity to the ground and related obstacles. Depending on the application, the effectiveness of these projects might be somewhat reduced in the absence of WAAS. LAAS could provide monitoring if WAAS was not deployed; however, it would only provide for such monitoring at a specific location/airport and would not provide the coverage expected from WAAS.

Conclusions

FAA's recently announced delays in the initial deployment of WAAS, because of difficulties in proving integrity, are likely to delay the benefits and raise the cost of the new navigation system. These delays have not changed FAA's original plans for WAAS, which were based on users' needs. However, if it is determined that WAAS cannot perform as intended, FAA will need to revisit its investment in the new navigation system.

With regard to WAAS integrity, FAA's management and its integrated product team should have addressed these concerns in a more timely manner. FAA recognizes that its management of this new system, particularly WAAS, has fallen short, but its plans for resolving current problems, including the integrity requirement, and preventing future delays are ambiguous. FAA talks about establishing checkpoints to ensure progress and the appropriate use of funds, but it has not developed a plan to assure the Congress that these checkpoints are in place and are likely to function appropriately.

Moreover, program success will only come about if senior FAA management embraces and fully supports the integrated product team concept and establishes an on-going process for the team to reach consensus on how the contractor must demonstrate that a project meets the agency's performance requirements and to convey this information to the contractor. Otherwise, more projects may experience the same problems WAAS encountered.

Finally, our past reviews of FAA's efforts to develop systems show that the agency does not always inform the Congress in a timely fashion of problems it is encountering before requesting additional funds. Potential users also need information on system performance so that they can make informed decisions on the merits of purchasing equipment to use with the

new navigation system. If further delays occur, these users may not continue to support FAA in the development of this new system, as they now do.

Recommendations

To enhance FAA's ability to develop its new navigation system within budget and on time while meeting performance requirements, we recommend that the Secretary of Transportation direct the Administrator of FAA to take the following actions:

- Develop a comprehensive plan that would provide the framework for the agency's future investments in its new navigation system. This plan should establish future checkpoints at which FAA would determine whether (1) the contractor's approach for meeting performance requirements conforms with the agency's guidelines, (2) users' needs have changed, and (3) other technologies have matured and could meet users' needs and the agency's requirements.
- Have an external organization evaluate the agency's progress at these checkpoints and include the results of this evaluation in the agency's request for future funding of the navigation system.

Agency Comments

GAO provided the departments of Transportation and Defense and the Satellite Navigation User Group with a draft of this report for their review and comment.

GAO met with officials from the Department of Transportation, including the Program Manager, Radionavigation and Positioning, Office of the Assistant Secretary for Transportation Policy and FAA's Product Team Lead for the Global Positioning System. These officials acknowledged the problems addressed in the draft report concerning the Wide Area Augmentation System and agreed with the conclusions and recommendations. However, they expressed two major concerns. First, these officials stated that our characterization of the increases in costs for the Wide Area Augmentation System as "cost growth" was misleading because the increases are attributable to cost growth as well as other factors, including a change in how the department calculated project costs. The officials provided revised estimates to reflect total lifecycle costs covering a 20-year period. To address this concern, we revised the draft report to clarify that the cost increases were due to growth as well as other factors, such as additional program support costs. The focus of our review

was system development; therefore, we also clarified our draft report to indicate that the cost estimates represented development costs only.

Second, these officials expressed the view that our discussion of the benefits from the Wide Area Augmentation System implied that users would only benefit if they were able to do the more stringent precision approaches and that airports would need to spend a minimum of \$1 million in infrastructure upgrades to get precision approach capabilities from the Wide Area Augmentation System. These officials maintained that users would receive major benefits from any level of precision guidance into airports and that airports would not necessarily need to upgrade their facilities to provide for these approaches. We agree with the officials that users would receive benefits even from the limited precision approach capability provide by this system and that airports would not necessarily need to upgrade their investment to provide for these approaches. We revised the draft report accordingly. These officials also provided us with technical clarifications, which we incorporated into the draft report as appropriate.

The Department of Defense generally concurred with the draft report. In addition, it offered two comments. First, it clarified the department's strategy for maintaining the Global Positioning System, and we revised the draft report accordingly. Second, it commented that the continued delays in the Wide Area Augmentation System and questions about worldwide interoperability of this augmentation system could create additional cost and schedule delays and adversely impact the department's operations if not addressed. (See app. IV for the Department of Defense's comments.)

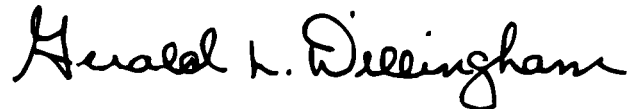
GAO met with representatives from the Satellite Navigation User Group, who generally agreed with the draft report. These representatives reiterated their support for FAA's efforts to field a new navigation system. In light of this, they were concerned that the draft report did not recognize that users would receive benefits even from the limited precision approach capability provided by the Wide Area Augmentation System and that airports would not necessarily need to upgrade their investment to provide for these approaches. We agreed and revised the draft report accordingly. These officials also provided us with technical clarifications, which we incorporated into the draft report as appropriate.

We are sending copies of this report to interested Members of Congress; the Honorable Rodney E. Slater, Secretary of Transportation; the

Honorable William S. Cohen, Secretary of Defense; and the Honorable Jane F. Garvey, Administrator, Federal Aviation Administration. We will also make copies available upon request.

If you have any questions about this report, please contact me at (202) 512-2834. Key contributors are listed in appendix V.

Sincerely yours,

A handwritten signature in black ink that reads "Gerald L. Dillingham". The signature is written in a cursive style with a large initial 'G' and 'D'.

Gerald L. Dillingham, Ph.D.
Associate Director,
Transportation Issues

Objectives, Scope, and Methodology

In light of the expected cost of the Federal Aviation Administration's (FAA) new navigation system and continuing concerns about the ability of the largest component of that system—the Wide Area Augmentation System (WAAS)—to achieve cost, schedule, and performance goals, the Chairman, Subcommittee on Transportation, Senate Committee on Appropriations, asked us to provide information on whether (1) the Department of Defense's (DOD) current Global Positioning System (GPS) or its planned improvements for GPS can meet FAA's navigation requirements, (2) the benefits of FAA's chosen approach to an augmented system currently outweigh the cost of this system, and (3) other technologies are available to meet FAA's requirements and users' needs for a new navigation system.

To address the first objective, we consulted with DOD officials and GPS experts. In addition, we reviewed a 1999 study prepared by Johns Hopkins University's Applied Physics Laboratory, sponsored in part by FAA,¹ that assessed, among other things, whether GPS can meet navigation requirements for civil aviation. In addition, we reviewed a 1998 study by the Mitre Corporation, which supports FAA in developing the national airspace system, that analyzed GPS' current and future ability to meet navigation requirements.

To respond to the second objective, we discussed with FAA and the Mitre Corporation, the process they followed to develop a range of alternatives. We reviewed guidance from the Office of Management and Budget (OMB) to identify analytical issues agencies should address when doing benefit-cost analyses. We also reviewed FAA's analysis of the costs and benefits of various technologies to determine whether the agency followed OMB guidance and used empirical data to support its findings. In our review, we also confirmed the reasonableness of the largest costs estimates—for equipment on board the aircraft and additional satellites—with equipment manufacturers, satellite providers, and aviation industry trade associations and special groups, including the General Aviation Manufacturers Association, Aircraft Owners and Pilots Association, the Air Transport Association of America, and the Regional Airline Association. The latter four associations and other users are also part of the Satellite Navigation User Group, which was created to achieve a consensus in the user

¹ The Johns Hopkins University study was performed under contract for the Air Transport Association of America (ATA) and jointly sponsored by ATA, FAA, and the Aircraft Owners and Pilots Association.

community and in FAA for making the transition to the new navigation system.

We also interviewed representatives from the Air Line Pilots Association International and the National Air Traffic Controllers Association to obtain their views on the reasonableness of cost and benefit assumptions made in FAA's analysis. Furthermore, we relied on our past work related to WAAS to compare the process FAA used for, and the results of, its most recent benefit-cost analysis with a similar analysis performed in early 1998. While we did not extensively review the model FAA used to calculate net benefits and benefit-cost ratios, the methodology of this model, including spreadsheet analysis and Monte Carlo Simulation, is commonly used in making such calculations. Finally, we interviewed representatives from Raytheon, the prime contractor for WAAS, to obtain data on the nature and extent of problems in demonstrating that WAAS can meet its integrity requirement and in developing software for navigation. To determine whether FAA's estimates of the costs of software development and maintenance were reasonable, we performed an independent assessment of the contractor's cost estimates using a model known as "CostXpert," which is used in the federal systems acquisition community to, among other things, determine the costs of developing projects using historical costs of completed projects with software development factors similar to WAAS.

Finally, for the third objective, we elicited the views of experts in aviation navigation and related technologies to discuss the capability of other technologies to meet FAA's requirements and users' needs. To accomplish this effort, we provided these experts with detailed data on the alternative technologies developed by the Mitre Corporation that served as the basis for FAA's decision to continue with the new navigation system. We asked these experts a series of questions that focused on whether FAA adequately considered a full range of alternatives and whether they agreed with FAA when the agency rejected certain technologies from its new navigation system. Some of these experts supported WAAS, while others supported technologies that compete with WAAS. Therefore, where we identified conflicting views between the FAA and these experts, we discussed the points of contention openly with both sides to fully understand their positions, and we present the views for and against using alternative technologies. (See app. II for background on the experts we contacted during this review.) Finally, we interviewed FAA officials to discuss whether interdependencies exist between WAAS, LAAS, and other

Appendix I
Objectives, Scope, and Methodology

modernization projects, and the impact of these other efforts if WAAS is not deployed as scheduled or is terminated.

We conducted our work from July 1999 through May 2000 in accordance with generally accepted government auditing standards.

Experts Contacted

Mr. John M. Beukers

Founder, Beukers Laboratories, Inc. (today known as Beukers Technologies, Inc.), a company specializing in the implementation and use of radionavigation systems since 1963. Mr. Beukers is a director of the International Loran Association and the International Navigation Association and also serves as a consultant to the U.S. government, the European Union, and others on radionavigation policy.

Dr. John Diesel

Chief Scientist, Litton Aero Products. Litton Aero is a manufacturer and supplier of inertial navigation and global positioning systems to the aviation industry. Dr. Diesel has analyzed several navigation systems—including GPS, Inertial Reference System, Loran, VHF Omni-directional Range/Distance Measuring Equipment, and Instrument Landing Systems.

Mr. Paul R. Drouilhet

Consultant to the Director of the Massachusetts Institute of Technology's Lincoln Laboratories, where he oversaw programs in surveillance and control technology and air traffic control. Mr. Drouilhet is also the Chairman of FAA's Subcommittee on Air Traffic Services and is an airplane pilot.

Dr. Per Enge

Professor, Stanford University, Department of Aeronautics and Astronautics; Co-Director of the GPS Research Laboratory. Dr. Enge is also a developer of the prototype system and signal for WAAS and a researcher for the prototype of LAAS.

Dr. G. Benjamin Hocker

Principal Research Fellow, Honeywell Technology Center. Currently, Mr. Hocker focuses on the evaluation of technologies that include, among other things, inertial navigation systems.

Mr. George H. Quinn

Until 1994, Mr. Quinn was FAA's National Project Manager for the establishment of the LORAN C navigation system for aviation. Currently,

Mr. Quinn is a self-employed engineering consultant, developing ways to use GPS in vessel tracking systems.

Mr. William Roland

Private consultant. Former Loran C Branch Chief and Commanding Officer of the U.S. Coast Guard's New Jersey Electronics Engineering Center. Mr. Roland recently retired from his position as President of Megapulse, the company responsible for the development and construction of a large part of the world's Loran transmitters.

Dr. G. Linn Roth

President, International Loran Association. Dr. Roth is also the president of Locus, Inc., a developer and manufacturer of spread-spectrum radio modules for integration into industrial, utility, GPS, and high-performance digital Loran receivers for navigation and timing applications.

Mr. Robert Siegfried

Former commercial airline pilot with approximately 24,000 hours of experience. Mr. Siegfried's general aviation experience totals approximately 12,000 hours—including about 1,200 hours operating helicopters.

Mr. Victor Strachan

Director, Strategic Development, Litton Aero Products. Mr. Strachan served as a navigator in the Royal Air Force for 18 years, including 5 years in flight testing. Mr. Strachan is a director of the International Navigation Association and a member of the Civil Aviation Council of the Aerospace Industries Association. Litton Aero is a manufacturer and supplier of inertial navigation and global positioning systems to the aviation industry.

FAA Identified Four Alternatives for a Benefit-Cost Analysis

In 1999, in response to congressional concerns in late 1998 about its proposed investment in WAAS and LAAS and the vulnerabilities associated with satellite navigation, FAA reevaluated whether the investment was sound. As a first step in this reevaluation, FAA identified four alternatives that combined a range of technologies, based on different levels of investment.¹ Three of the four alternatives contained one or more variations of WAAS and LAAS as well as variations of ground-based navigation aids that could serve as the principal backup system. The four alternatives were the following:

- **Alternative I: No WAAS or LAAS.** FAA retains its existing ground-based navigation infrastructure and enhances it to accommodate demand.
- **Alternative II: Simplified WAAS With LAAS.** FAA develops a simplified WAAS, without incorporating precision approach guidance, develops LAAS, and retains about 50 percent of the existing ground-based infrastructure used for navigation and about 30 percent of the ground-based infrastructure used for precision approaches.
- **Alternative III: Less Robust WAAS With LAAS.** FAA develops WAAS with precision approach capability, including LAAS, for more stringent approach requirements, and retains about 50 percent of its ground-based infrastructure.
- **Alternative IV: Full WAAS With LAAS.** FAA develops WAAS with precision approach capability, including LAAS, for more stringent approach requirements, and retains about 30 percent of its existing ground-based infrastructure.

In developing the alternatives, FAA made three major assumptions. First, it assumed that the new navigation system would not be the only system that pilots would use to navigate and land—a “sole-means” system—as originally intended. By moving away from this assumption, FAA realized that it would need to retain a backup system. Second, for all the alternatives, FAA assumed that all new commercial jets would be produced with avionics on board the aircraft to help pilots navigate (inertial navigation systems), which would be used in conjunction with other ground-based navigation aids, and that affordable inertial systems would not be available until about 2008. Finally, FAA assumed that the Long Range Navigation (LORAN C) technology would continue to be provided and used by some general aviation pilots until 2008.

¹ In total, FAA considered 12 alternatives for its new navigation system.

After identifying the four alternatives, FAA analyzed the costs and benefits of each. According to this analysis, continuing with the WAAS/LAAS system, coupled with using about 30 percent of its current ground-based infrastructure as a backup to GPS, would yield the greatest net quantified benefits (dollar value of benefits minus costs),² regardless of whether passengers' time savings are included.^{3,4} According to FAA, over the period 2000 through 2020, there is an 80-percent chance that the net benefits of its preferred alternative is about \$2.5 billion if passengers' time savings are counted and \$72 million if these savings are not counted. The benefit-cost analysis also identified at least 11 benefits that were not quantified. Included among these were safety benefits, such as improved surface surveillance, as well as operational benefits, such as enabling more landings at airports where today's operations are limited by lack of ground-based navigational aids. According to FAA, its decision to pursue this approach had the support of all major user groups.⁵

Table 2 summarizes FAA's analysis for the four basic alternatives the agency considered in terms of each alternative's benefit-cost ratio and net benefits, expressed as present values.⁶ FAA considered these alternatives with and without passengers' value of time. As the table shows, the fourth alternative—which is the one FAA decided to pursue—provided a benefit-cost ratio of 2.4, when passengers' value of time are included, and a ratio of 1.1, when these values are not included.

²As an alternative to the benefit-cost ratio, for which the present value of benefits is divided by the present value of costs, analysts sometimes calculate the present value of net benefits. This value is equal to the present value of benefits minus the present value of costs.

³The Department of Transportation values passenger time from \$22 to \$33 per hour, depending on the nature of air travel. In 1998, we reviewed the economic literature and found that no consensus exists as to the validity of using small increments of time, in part because passengers might not perceive and value time savings of as little as 30 seconds.

⁴It should be noted that the other three options had benefit-cost ratios of less than 1.

⁵The Satellite Navigation User Group was created to achieve a consensus throughout the user community and with FAA for making the transition to the new navigation system.

⁶Since benefits are divided by costs, any benefit-cost ratio above 1.0 indicates that the project has benefits exceeding costs, and any ratio below 1.0 indicates that the project has benefits less than costs.

**Appendix III
FAA Identified Four Alternatives for a
Benefit-Cost Analysis**

Table 2: Summary of FAA's Economic Analysis of Four Alternatives

Dollars in millions

| Alternatives | With passenger value of time | | Without passenger value of time | |
|---|------------------------------|--------------|---------------------------------|--------------|
| | Benefit-cost ratio | Net benefits | Benefit-cost ratio | Net benefits |
| I. No WAAS; No LAAS | 1.5 | \$280 | 0.5 | (\$287) |
| II. Simplified WAAS, With LAAS | 1.0 | \$94 | 0.5 | (\$1,007) |
| III. Less Robust WAAS, with LAAS | 2.1 | \$1,857 | 0.9 | (\$25) |
| IV. Robust WAAS with LAAS While Retaining 30 Percent of Ground Infrastructure | 2.4 | \$2,469 | 1.1 | \$72 |

Note: Benefit-cost ratios and net benefits are calculated in present value terms, which account for future benefits and costs, here expressed in 1999 dollars.

Source: FAA.

We found that FAA combined empirical data, where available, with professional judgment to develop its estimates of costs and benefits. For example, FAA's estimates for key cost elements, such as geostationary satellites, on-board aircraft equipment, and ground-based navigation aids, were based on vendor quotes and manufacturer pricing surveys. We independently validated FAA's cost for developing WAAS software and found that it was within an allowable range. Moreover, we found that FAA did not assume that some benefits, such as direct routing—which yields savings from shorter flight times—could only be achieved with WAAS and did not fully attribute these benefits to WAAS as it had in earlier studies.

Furthermore, in accordance with OMB guidance and acceptable practice, FAA identified a number of benefits that could not be quantified because of the lack of verifiable data but that are nonetheless important for decisionmakers to consider when choosing an investment option. For example, OMB guidance notes that a comprehensive evaluation of the different types of benefits and costs, quantified or not, can be helpful in identifying the full range of program effects. We have also reported that estimates of benefits are typically uncertain because of imprecision in both underlying data and modeling assumptions, and it is appropriate to consider nonquantified benefits when choosing investment options. Industry representatives share FAA's views on the nonquantified benefits

the agency has identified, and some believe that these and other nonaviation benefits could be substantial if they could be quantified.

Despite these strengths, we found that one key benefit—FAA’s estimate of the \$4.4 billion in savings achieved by allowing planes to decrease the time needed for an approach to landing—was based largely on professional judgment, without empirical data. This benefit accounted for nearly 42 percent of all quantified benefits. Specifically, FAA assumed that 40 percent of all flights during nonpeak periods could decrease approach time into airports, even though it recognized that the percentage could range from 20 percent to 50 percent during nonpeak periods. Because of the lack of empirical data, we asked FAA to perform a more conservative analysis, assuming that only 20 percent of the flights would benefit. We found that this resulted in a benefit-cost ratio of 1.9 if passenger value of time was counted and a ratio of .8 if not counted.

Comments From the Department of Defense



COMMAND, CONTROL,
COMMUNICATIONS, AND
INTELLIGENCE

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
6000 DEFENSE PENTAGON
WASHINGTON, DC 20301-6000

May 25, 2000

Dr. Gerald L. Dillingham
Associate Director, Transportation Issues
Resources, Community, and Economic
Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Dr. Dillingham:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report, National Airspace System: Persistent Problems in FAA's New Navigation System Highlight Need for Periodic Reevaluation, dated May 9, 2000 (GAO Code 348184/OSD Case 1999). The DoD concurs with comments on the draft report. A comment is provided to improve the technical accuracy of the report and a second comment expresses concern with the program delay and worldwide interoperability.

In the second paragraph of the report in the "Background" section, page 4, the following statement is made: "The DoD operates 27 orbiting GPS satellites to ensure a basic configuration of 24 working satellites at any given time for both military and civilian use." A much more accurate statement of the GPS orbital maintenance philosophy is contained in the 1999 Federal Radionavigation Plan (FRP), paragraph 3.2.1B, which states: "The GPS constellation is configured and operated to provide the SPS signals to civil users in accordance with the GPS Signal Specification. The DoD will maintain a 24-satellite constellation. Replacement satellites will be launched on an expected failure strategy (a replacement satellite is launched when there are indications that a satellite should be replaced)." Recommend that the statement from the FRP replace the above quoted statement from the draft report.

As a National Airspace System user and potential user of the WAAS ranging source integrity and accuracy enhancements for precision approach, the Department is concerned with: (1) the continued delays of the WAAS Program, and (2) worldwide interoperability of this GPS augmentation. Failure to address these concerns could create additional costs and schedule delays for implementation, operational impacts, and difficulty in flying DoD aircraft in foreign countries.

The Department appreciates the opportunity to comment on the draft report.

Sincerely,

Robert M. Nutwell, RADM, USN
Deputy Assistant Secretary of Defense
(C3ISR and Space)



GAO Contacts and Staff Acknowledgments

GAO Contacts

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Belva M. Martin, (202) 512-2834

Staff Acknowledgments

In addition to those named above, Charles W. Bausell, Jennifer W. Clayborne, Richard B. Hung, Peter G. Maristch, John T. Noto, Madhav S. Panwar, Karen A. Richey, and Carol Herrnstadt Shulman made key contributions to this report.

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