United States General Accounting Office

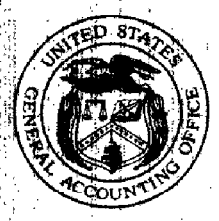
GAO

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

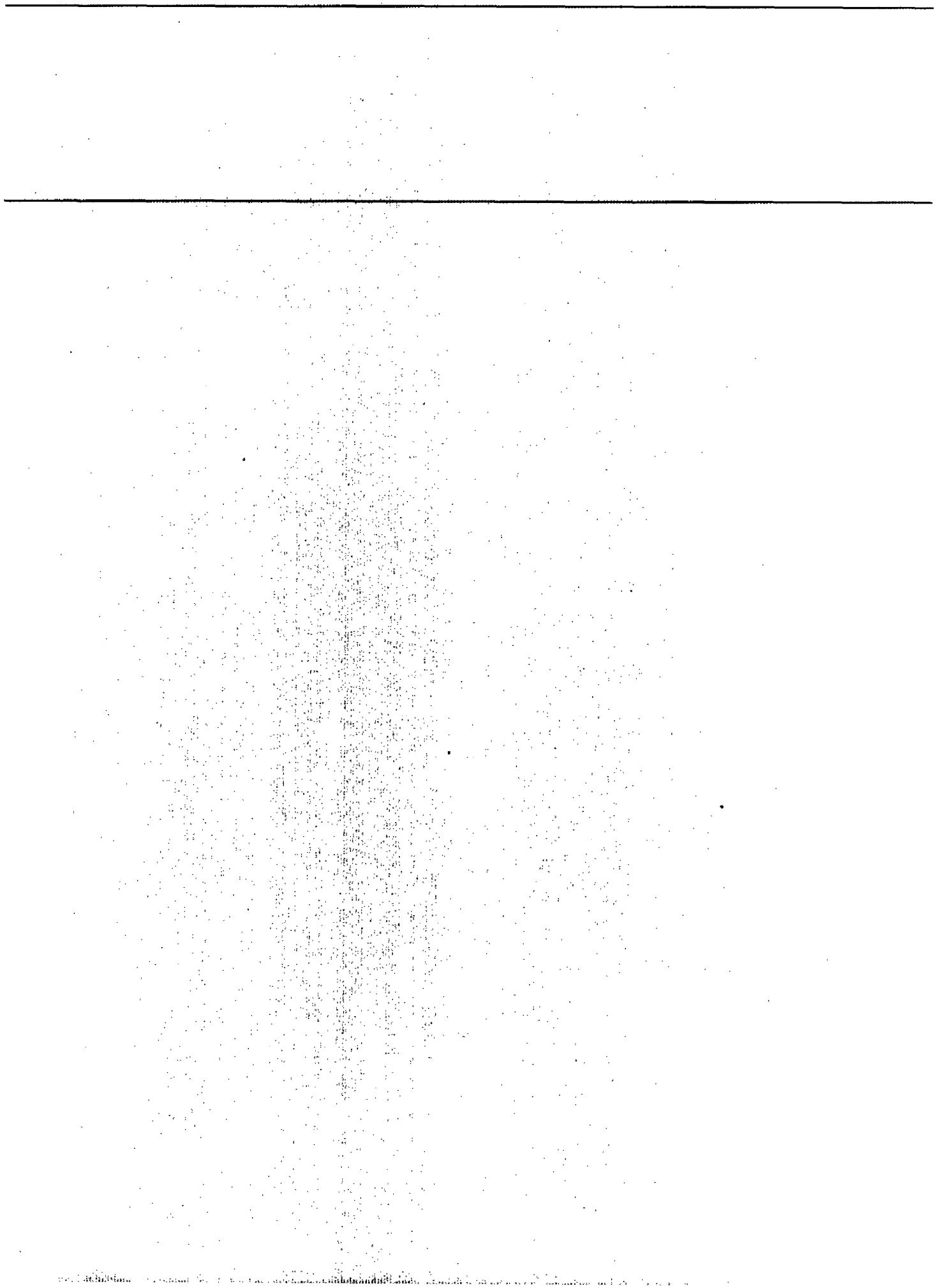
December 1991

AIR TRAFFIC CONTROL

Software Problems at Control Centers Need Immediate Attention



GAO/IMTEC-92-1



GAO

United States
General Accounting Office
Washington, D.C. 20548

145584

Information Management and
Technology Division

B-245699

December 11, 1991

The Honorable Frank R. Lautenberg
Chairman, Subcommittee on Transportation
and Related Agencies
Committee on Appropriations
United States Senate

Dear Mr. Chairman:

In the past, you have expressed concern about potential performance shortfalls in the computer systems the Federal Aviation Administration (FAA) uses to perform its mission of controlling air traffic in a safe, orderly, and expeditious manner. FAA's ability to minimize and resolve system software problems is critical to meeting this mission, especially since modernization delays will require the agency to operate current systems longer than originally anticipated. Therefore, in response to your request, we are reporting to you on (1) the extent to which computer software problems are affecting FAA control of air traffic en route between airports and (2) whether FAA's actions to minimize and resolve these problems are timely and effective. A detailed explanation of our objectives, scope, and methodology is contained in appendix I.

Results in Brief

Software problems at air route traffic control centers continue to occur and disrupt the air traffic control system. Since 1987, when FAA implemented new hardware to assist in controlling flights en route between airports, almost 4,000 system software problems have been reported. As of June 30, 1991, over 1,600 of these problems were unresolved. FAA considers about 74 percent of these unresolved problems to have the potential to adversely affect the air traffic control system. Such problems can impair air traffic controllers' ability to track aircraft and cause delays in aircraft departures.

FAA's efforts to resolve software problems have neither been timely nor completely effective. Software problems have remained uncorrected for an average of 18 months and many have the potential to disrupt the en route system. Further, FAA's effectiveness in reducing problems is limited because it uses temporary fixes for software problems. These temporary fixes, while necessary to address immediate problems, often remain in place for a long time, sometimes up to several years. They also increase the risk of additional interruptions, such as an outage last year

at the Los Angeles Center, which led to a number of aircraft delays and a disruption of air traffic operations.

FAA attributes its backlog of software problems and continued reliance on temporary fixes to a lack of necessary resources. However, it has not developed a plan identifying the resources needed to maintain the en route system until modernization is completed, and it lacks key tools to estimate the resources required for such maintenance.

Background

FAA's air traffic control mission is to promote the safe, orderly, and expeditious flow of civilian and military aircraft. To accomplish this mission, air traffic controllers communicate weather information, instructions, and clearances to pilots and other personnel; maintain safe distance between airplanes; and guide aircraft departures and approaches. Controllers perform these activities at either airport towers, terminal radar approach control facilities,[1] or en route facilities.

En route facilities, also known as air route traffic control centers, provide separation and other services for aircraft flying between airports.[2] FAA maintains 20 of these centers in the continental United States, with each typically responsible for more than 100,000 square miles of airspace. In 1990 the 20 centers controlled about 38 million flights, a figure FAA projects will increase to over 50 million flights by 2005. Appendix II shows the location and areas of control of the 20 centers.

The system of computers currently employed at the 20 centers comprise part of the largest, most complex real-time air traffic management system in the world. Air traffic controllers at the centers use the data processed by these computers to help control aircraft movements. For example, controllers use computer-processed information detailing airplane identity, position, altitude, speed, and direction to help maintain safe separation of aircraft.

FAA's current computer hardware system at the centers, known as the Host, was implemented in the late 1980s to add processing capacity and improve safety and efficiency. To accommodate the new Host hardware,

[1]Terminal radar approach control facilities are responsible for sequencing and separating aircraft arriving at or departing from airports.

[2]Aircraft operating under instrument flight rules or in specially designated airspace are followed by air traffic controllers. By contrast, aircraft operating under visual flight rules generally maintain their distance from other aircraft on a "see and avoid basis." These aircraft are not required to file flight plans, but must follow FAA rules governing where they can fly.

FAA modified the existing software, originally written in the 1960s, rather than rewriting it or acquiring new software. Since then, FAA has continued to modify the centers' software to add enhancements or correct problems. FAA plans to further modernize the air traffic control system by replacing hardware, software, and controller workstations at the centers with the new Advanced Automation System. However, full implementation of this system, including complete software replacement, has been delayed until the late 1990s. Accordingly, the current Host system, with its modified software, will have to be operated and maintained longer than originally anticipated.[3]

Corrective Maintenance of Center Software Is Critical

Correcting software problems to ensure computer systems perform as intended is one of the primary maintenance activities needed to keep a computer system operational and responsive to user needs. When software is repeatedly modified because of adaptive enhancements or corrective maintenance, its reliability[4] and maintainability[5] often decrease as the total number of enhancements and corrections grows. While software does not break in the same way that computer hardware fails, it can malfunction because of design, logic, or coding errors. According to Federal Information Processing Standards Publication 106 on Software Maintenance, "software tends to deteriorate with age as a result of numerous fixes and patches. If a system is more than 7 years old, there is a high probability that it is outdated. . . While this code was adequate and correct for the original environment, changes in technology and applications may have rendered it inefficient, difficult to revise, and in some cases obsolete."

The safety and effectiveness of en route air traffic operations is highly dependent on the ability of the software at centers to reliably perform its key functions of monitoring aircraft. However, maintaining this software when problems occur is increasingly difficult because of the software's increasing complexity. Much of the operational software at centers was originally written over 20 years ago and has had frequent modifications. Further, about 25 percent of the approximate 1.23 million lines of software code at each center is written in basic assembly language; the remaining 75 percent is written in the JOVIAL programming

[3]Air Traffic Control: Continuing Delays Anticipated for the Advanced Automation System (GAO/IMTEC-90-63, July 18, 1990); Delays in Critical Air Traffic Control Modernization Projects Require Increased FAA Attention to Existing Systems (GAO/T-IMTEC-91-14, June 14, 1991).

[4]Reliability is the extent to which software performs its intended functions.

[5]Maintainability is the effort required to locate and correct errors in software.

language. An assembly language, in which each statement usually corresponds to one machine language statement, is much more cumbersome to use and maintain than a higher-level programming language, such as JOVIAL, in which each statement generally corresponds to more than one machine language statement.

To meet the challenge of maintaining center software and resolving problems, FAA and contractor personnel at the FAA Technical Center located at the Atlantic City, New Jersey, International Airport, and at each air route traffic control center, are responsible for the problem identification and resolution process. Appendix III provides details regarding these responsibilities and FAA's process for resolving software problems.

Unresolved Software Problems Impair Air Traffic System

Although implementation of the Host hardware increased the reliability of the en route system, reported software problems continue to occur. From 1987, when the hardware was initially implemented, to June 30, 1991, 3,992 software problems were reported. Of these reported problems, 2,331 were resolved through corrections to the software or other methods; however, 1,661 reported problems were not resolved. Seventy-four percent of these unresolved problems were considered by FAA to have the potential to adversely affect the air traffic system by causing system interruptions or otherwise disrupting the flow of information to air traffic controllers.

System Hardware More Reliable but Many Software Problems Remain Unresolved

Implementation of the Host hardware helped increase the efficiency and reliability of the en route system. Fewer hardware-based system interruptions and outages have occurred because the new hardware's increased capacity has provided more storage and faster data processing capability. In addition, when system interruptions and outages do occur, the new hardware enables the system to recover more quickly.

Despite the hardware's increased reliability, however, software problems continue to occur. As shown in Figure 1, 3,992 software problems were reported since June 1987. As of June 30, 1991, FAA considered 2,331 of these problems to be closed or resolved. The remaining 1,661 problems were unresolved, although solutions are currently being developed for some of these. The number of unresolved problems has remained about the same since 1990; although FAA has recently increased the rate at which it is resolving problems, the number of new problems has also grown at about the same rate.

Figure 1: Number of Unresolved Software Problems Since Host Conversion

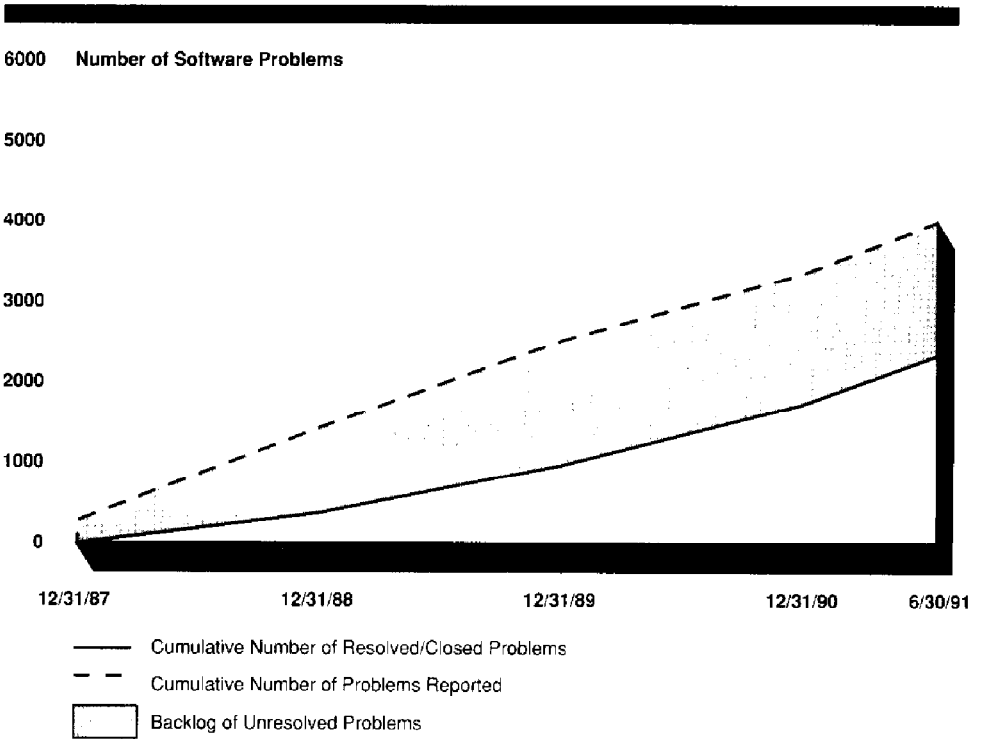
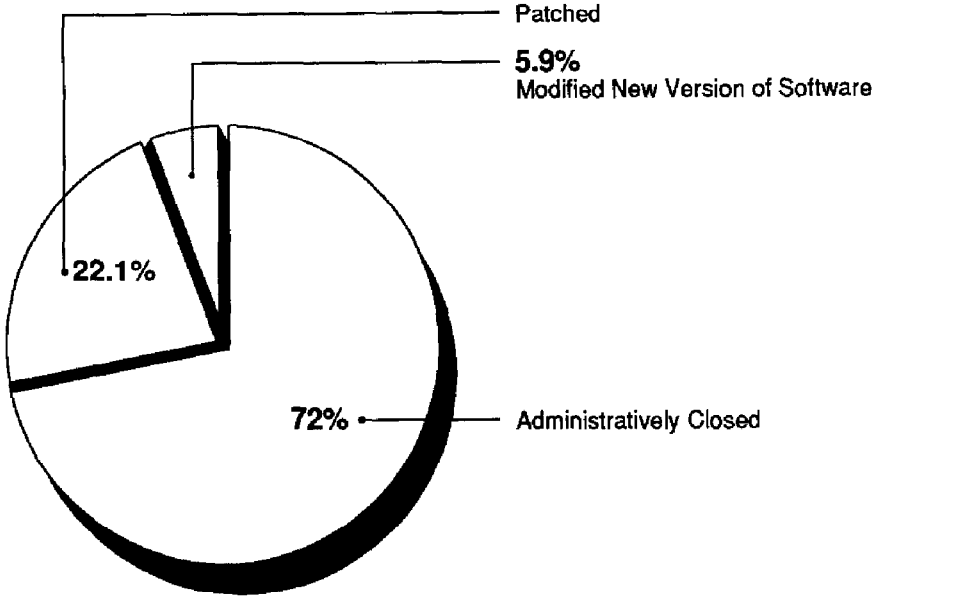


Figure 2 shows the disposition of the 2,331 software problems that were resolved or closed between 1987 and 1991.

Figure 2: How FAA Closed or Resolved 2,331 Software Problems as of 6/30/91



As indicated above, the reported problems were resolved in a variety of ways. They were either (1) administratively closed because they duplicated previously identified problems or could not be confirmed as valid software problems; (2) temporarily fixed by writing modifications or "patches" to correct errors in the software program currently operating at centers; or (3) permanently closed by making modifications to a new version of the source code,[6] developed and tested at the FAA Technical Center, and then retested and implemented at each center.

Software Problems Can Lead to System Interruptions

Software problems, if serious enough, can lead to temporary system interruptions—most lasting only seconds, but some lasting several minutes or more. For example, during the 27-month period from October 1988 to December 1990, the 20 centers reported 863 system interruptions caused by software problems, including 81 that FAA classified as system outages because they lasted more than 1 minute.[7] System interruptions and outages caused by software problems can have a serious impact, such as (1) reducing air traffic controllers' ability to track aircraft because of anomalies on controller display screens or the failure to

[6]Programmers write software in a variety of languages such as FORTRAN, COBOL, and assembler. The code they write is called source code.

[7]While outages are individually significant, in total the 81 outages represent .01 percent of the operating time of the 20 centers during the measured period.

receive all data needed, or (2) delaying aircraft departures because of the system's loss of aircraft flight plan data. However, when these problems occur, system recovery features and back-up hardware and software help ensure safe air traffic operations.

FAA assigns priorities to its software problems on the basis of their level of severity. FAA defined about 72.5 percent of its unresolved software problems to be medium priority, meaning they have the potential to adversely affect the air traffic system. In addition, 23, or about 1.4 percent of the unresolved problems, were considered high priority, defined as having the potential to seriously degrade air traffic system operations, such as affecting air traffic controllers' ability to track aircraft. FAA periodically reassesses assigned priorities. For example, high-priority problems that do not reoccur or cannot be replicated may be later downgraded to a lower priority.

The following examples indicate the types of effects of these unresolved software problems.

- A series of high-priority outages at the Los Angeles, Houston, and Salt Lake City centers between September 1989 and April 1990 were caused by software sub-program defects. Characterized by continuous multiple aborts of their systems, these outages ranged in duration from 13 to 24 minutes. In one instance, air traffic was temporarily controlled with a back-up system until the system was restarted with the previous day's software program, resulting in the need to reenter lost aircraft flight planning information. In May 1991, FAA downgraded this unresolved problem from high to medium priority because the problem had not recurred since April 1990.
- In September 1989, a medium-priority software problem at the Oakland center affected several air traffic sectors and resulted in "considerable controller confusion and hardship" involving aircraft identification. According to FAA records, two other centers experienced similar software problems.
- In December 1989, a flight strip software processing problem caused an 11-second interruption in an operational program at the Boston center. As of June 1991, this medium priority problem had not reoccurred in Boston or at any other centers, and was not being actively pursued by the FAA Technical Center.

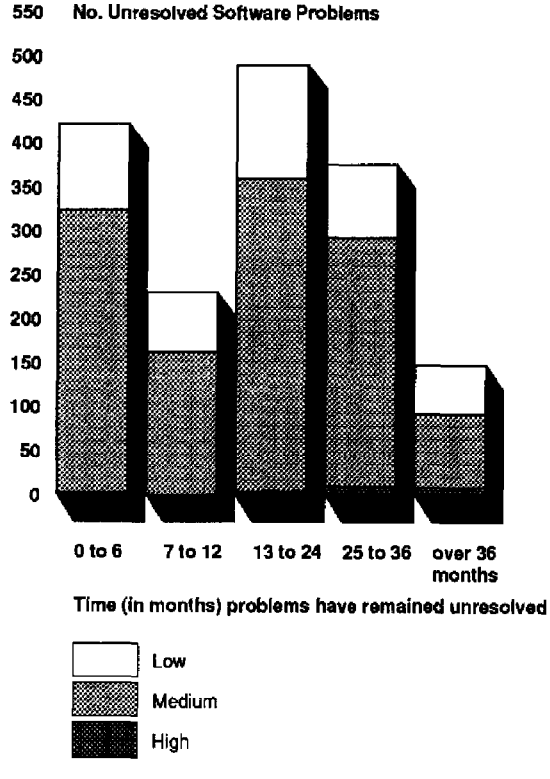
FAA Actions to Address Software Problems Are Not Timely or Completely Effective

Although FAA has addressed many of the software problems reported since 1987, a large backlog of unresolved problems remains. These problems have been unresolved an average of about 18 months. Further, FAA has allowed temporary solutions to remain in place for extended periods of time rather than permanently revising software. FAA attributes its inability to address this backlog of problems to a lack of staff resources. However, the agency has not developed a plan that identifies the resources needed to maintain system software until the Advanced Automation System is implemented.

Many Software Problems Are Not Being Resolved in a Timely Manner

Of the 1,661 unresolved software problems, about 61 percent of the problems were open over 1 year, including about 31 percent that were open 2 years or more. As shown in Figure 3, many of the older problems have the potential to adversely affect the air traffic system.

Figure 3: Unresolved Software Problems by Months



FAA officials stated they do not have (1) a formal strategy to guide their efforts in reducing the current backlog of software problems, or (2) established criteria for resolving future problems in a timely manner. The FAA official responsible for deciding which problems to resolve added that FAA tries to address the most serious software problems first, on the basis of subjective evaluations of problem severity and frequency, and resource availability.

Reliance on Temporary Solutions Can Increase Risk of Additional Problems

Because many problems require immediate resolution, often FAA must initially "patch" software code. Such patching involves identifying the problem, writing corrective code in assembly or JOVIAL language, and testing and implementing the additional code. This testing is less comprehensive than the testing done to incorporate changes into a new version of software.

While patching provides a quick remedy, it also increases the risks of additional software problems. The code written for patches and the requisite jumps between the baseline source code and additional patched code make it more difficult to trace the logic and functionality of the software. As a result, testing and maintaining patched code is more difficult.

Patching also makes the air traffic control system more susceptible to interruptions or other disruptions. One such situation occurred at the Los Angeles Center in July 1990 when, during the morning rush, a 77-minute software outage of the primary system resulted in 57 aircraft delays, each averaging 22 minutes. The outage was attributed to an attempt to introduce multiple patches to the operating program.

To reduce the risks of excessive patching, it is important to eliminate existing patches as soon as possible, by making permanent changes to the software baseline, testing the entire new baseline, and then implementing the new software version at FAA's centers. Although FAA and contractor officials agree that making permanent changes to the software baseline is preferable to constant patching and carryover of patches, FAA often delays converting existing patches to the baseline software program for long periods of time. For example, FAA's current software version, which was operational at 9 centers as of June 1991, contains 310 patches, comprising 172 new patches and 138 carried over from previous software versions, including 34 patches that existed before the Host hardware implementation in 1987.

Recognizing that it needed to minimize patching, FAA, during the course of our review, initiated an effort to reduce the number of patches. By June 1991, 159 of the 310 patches in FAA's current operational software had been eliminated and requisite changes were made to the source code of the next software version to be released later in 1991.

Despite this effort to minimize patching, the frequency of software problems and the need for additional patches could increase significantly because of major functional enhancements that are planned for the centers' systems. For example, new controller workstations being developed under the Advanced Automation System and due to be implemented in the mid-1990s will require revisions to software to permit the integration of the workstations with the centers' current systems.

FAA Has Not Adequately Planned for Its Resource Needs

FAA attributes its inability to reduce its software problem backlogs and its large number of patches to inadequate staff resources. Officials added that the resource constraints may become more pronounced in the future as approaching air traffic modernization diverts resources away from maintaining the existing system. Further, according to a September 1990 FAA report, a shortage of experienced FAA technical staff in the en route automation support area is predicted because of expected attrition and recruiting difficulties. The study also concluded that the long-term prognosis for effective software support from contractors "is extremely poor." This conclusion was based on (1) FAA's software support contractor's projection that over 50 percent of the contractor's en route software support staff will retire by the end of 1994, and (2) a replacement pool of experienced FAA automation specialists no longer being readily available.

Despite these warnings, little planning has been done by FAA to identify the resources needed to maintain the en route system until the Advanced Automation System is implemented. Officials consider their annual budget requests for additional automation support positions to be their plan for current resource needs. However, they recognize that they have not defined a strategy for addressing the important resource issues involved in maintaining center software for many more years.

To assist FAA in its planning, modern automated estimating tools can be very helpful in projecting the amount of effort required to resolve software problems and maintain the system. These tools are especially valuable in validating contractor estimates of resource needs. However,

FAA officials acknowledge that they lack such tools and instead rely on their judgment in estimating resources.

Conclusions

Software problems at air route traffic control centers continue to occur and adversely affect the air traffic control system. In some cases, these problems have caused interruptions in system operations and affected air traffic controllers' ability to track aircraft.

FAA has not been timely in resolving the large backlog of unresolved software problems and in minimizing potential future software-caused system disruptions. Further, FAA's effectiveness in resolving problems is impaired by using patches for long periods of time, thereby increasing the risk of additional problems.

FAA has conducted little planning to identify the resources needed to maintain the en route system until the advanced system is implemented and lacks key tools to assist in estimating resource needs. Such planning is especially crucial because FAA will have to rely on the current automated system until at least the end of the decade.

Recommendations

We recommend that the FAA Administrator direct that the current backlog of high-priority and medium-priority problems involving a significant risk to the air traffic system be resolved as soon as practicable. We also recommend that the Administrator develop and implement a software maintenance plan that includes

- establishing standard time frames, based on problem severity and analysis of risk to the air traffic system, for resolving software problems;
- reducing the inventory of system patches, including establishing milestones for early reduction, and setting goals to minimize future patches;
- identifying the resources needed to maintain system software until the Advanced Automation System is implemented; and
- acquiring modern automated tools that can assist in estimating the amount of effort required to maintain the system and correct software problems.

Agency Comments and Our Evaluation

FAA and Department of Transportation officials acknowledged that software problems were occurring, but added that many were not as serious as was implied by our draft report. Officials stated that some problems occurred only once and others were merely a lack of software

documentation. Officials also stated that FAA had performed initial planning to identify the resources needed to maintain centers' software.

In the report, we applied FAA's own criteria to define the extent and seriousness of reported software problems. Using this criteria, we point out that about 74 percent of the reported problems have the potential to adversely affect the air traffic control system. Our report recognizes that FAA has performed limited short-term resource planning as part of its annual budget request. Such short-term planning does not strategically address the resources needed to maintain center software for the rest of this decade.

Our review was performed from March 1990 through October 1991 at FAA Headquarters in Washington D.C.; the FAA Technical Center at the Atlantic City, New Jersey, International Airport; and at air route traffic control centers in New York, New Hampshire, Florida, Texas, and California. We conducted our review in accordance with generally accepted government auditing standards.

As agreed with your office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of this letter. We will then send copies to the Secretary of Transportation, the FAA Administrator, and other interested parties. Copies will also be made available to others on request. This report was prepared under the direction of JayEtta Z. Hecker, Director, Resources, Community, and Economic Development Information Systems, who can be reached at (202) 275-9675. Other major contributors are listed in appendix IV.

Sincerely yours,

Ralph V. Carlone

Ralph V. Carlone
Assistant Comptroller General

Contents

Abbreviations

FAA	Federal Aviation Administration
GAO	General Accounting Office
IBM	International Business Machines, Inc.
IMTEC	Information Management and Technology Division

Objectives, Scope, and Methodology

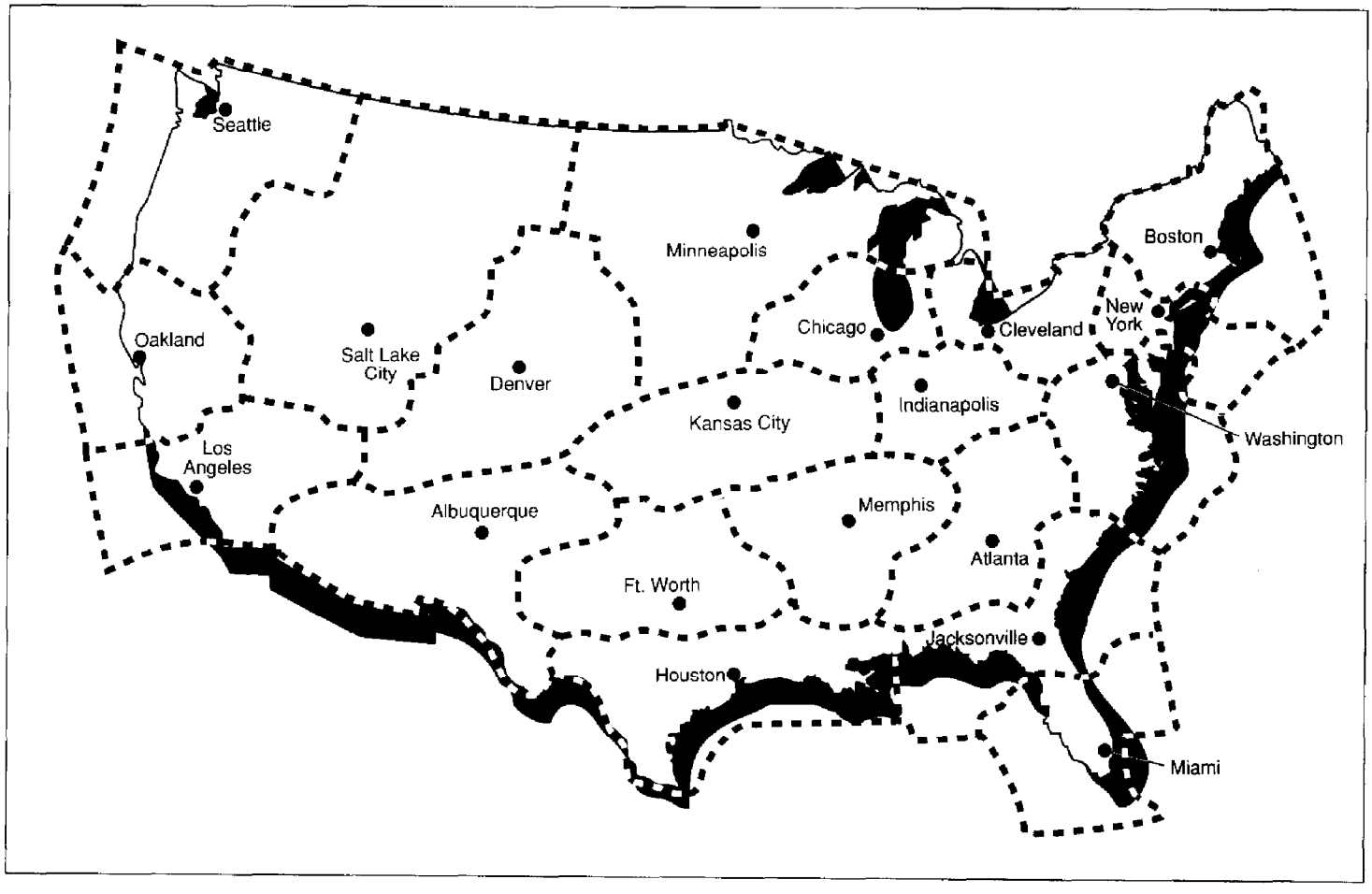
The objectives of our review were to determine (1) the extent to which computer software problems are affecting FAA control of air traffic en route between airports and (2) whether FAA's actions to minimize and resolve these problems are timely and effective.

To ascertain the extent of current software problems, we evaluated FAA-generated reports and other information relating to the number, types, status, and severity of software problems reported since the Host computer system was initially deployed in May 1987. We also reviewed data supporting the number of en route system interruptions caused by software problems. We interviewed various FAA officials, including air traffic controllers and automation specialists, at FAA headquarters, the FAA Technical Center, and six air route traffic control centers. We also interviewed International Business Machines Corporation, Inc. (IBM) personnel who were responsible for providing en route system software support, and personnel from NYMA and Diversified International Science Corporation, two subcontractors assisting IBM in its software support effort. In ascertaining the extent of en route system software problems, we relied, to a large extent, on computer-based data processed by FAA's Host Computer information management system and its National Airspace Performance Reporting System. We tested these data and, in our opinion, are reasonably certain that the data were reliable for the purposes used.

To assess the actions taken by FAA to minimize and resolve software problems, we applied generally accepted criteria, such as Federal Information Processing Standards Publication 106, and analyzed FAA's actions. We also discussed software maintenance and problem resolution with FAA personnel at headquarters, the technical center, and six air route traffic control centers. We interviewed IBM personnel located at the FAA Technical Center and the air route traffic control centers. We evaluated reports generated from FAA's Host Computer information management system and other data obtained from FAA to support the number of problems resolved and the methods used to address problems. We also reviewed FAA resource documents and FAA internal studies discussing en route system automation support.

The views of agency officials were sought during the course of our work and their comments have been incorporated where appropriate. In addition, we obtained comments from Department of Transportation and FAA officials on a draft of this report. These comments and our analysis are also included in this report.

Location and Approximate Areas of FAA's 20 Air Route Traffic Control Centers



Responsibilities and Process for Resolving Software Problems

Responsibility for resolving software problems at air route traffic control centers rests primarily with personnel at FAA's Technical Center. Technical center officials are responsible for validating, tracking, and resolving software problems, while personnel at air route traffic control centers identify and report software problems. FAA relies on IBM to provide much of the software maintenance support at the technical center and at air route centers. IBM and its subcontractors assist FAA with problem identification, analysis, and resolution, as well as testing and implementation of solutions.

Software problems are usually identified when software does not function as specified. Each center assigns priorities to problems based on their severity, as defined below.

- Emergency: Prevents the continuing use of current software.
- High: Can result in serious operational degradation to the air traffic system, such as (1) a multiple abort situation that prevents the system from recovering and continuing to operate without procedural overrides, or (2) a problem that affects air traffic controllers' ability to separate and track aircraft.
- Medium: Can adversely affect the air traffic system, such as a single abort situation in which the system automatically recovers after a system interruption and keeps operating.
- Low: Assigned to problems, such as documentation deficiencies, that do not directly affect system operations.

After assigning priorities, centers report problems to the technical center. The technical center then screens reported problems to confirm that they are software problems. Some reports may be rejected because they are not software problems (e.g., the problem results from other causes such as hardware or human errors). After validation, the technical center begins tracking these problems. Open problems are categorized into three broad classes: (1) initial assignment to a technician, (2) resolution is being actively pursued, and (3) resolution not being actively pursued. Problems are closed when they are recognized as duplicates of previously identified problems, or the technical center believes it has adequately resolved them.

Major Contributors to This Report

Information Management and Technology Division, Washington, D.C.

Joel Willemssen, Assistant Director
Prithviraj Mukherji, Senior Technical Adviser
Lynne Goldfarb, Publishing Adviser

Philadelphia Regional Office

Harry E. Benchoff, Evaluator-in-Charge
William J. Gillies, Senior Evaluator
Donald White, Staff Evaluator
Douglas Sanner, Staff Evaluator
Patrick Collins, Staff Evaluator

Additional Information

The first copy of each GAO report is free. Additional copies are $2 each. Orders should be sent to the following address, accompanied by a check or money order made out to the Superintendent of Documents, when necessary. Orders for 100 or more copies to be mailed to a single address are discounted 25 percent.

U.S. General Accounting Office
P.O. Box 6015
Gaithersburg, MD 20877

Orders may also be placed by calling (202) 275-6241.

United States
General Accounting Office
Washington, D.C. 20548

Official Business
Penalty for Private Use $300

First-Class Mail
Postage & Fees Paid
GAO
Permit No. G100