



U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF INSPECTOR GENERAL

**FAA Has Taken Steps To Address ERAM
Outages, but Some Vulnerabilities
Remain**

FAA

Report No. AV2019004

November 7, 2018





FAA Has Taken Steps To Address ERAM Outages, but Some Vulnerabilities Remain

Requested by the Chair of the Senate Committee on Commerce, Science, and Transportation, and Chairs of the House Committee on Transportation, and Infrastructure and its Subcommittee on Aviation

Federal Aviation Administration | AV2019004 | November 7, 2018

What We Looked At

The Federal Aviation Administration's (FAA) air traffic controllers use the En Route Automation Modernization (ERAM) system to manage over 3 million high-altitude en-route aircraft a month. Because of ERAM's importance to air traffic management, system outages can significantly impact operations in the National Airspace System (NAS). Our audit objective was to assess the causes of ERAM's outages and FAA's actions to address them.

What We Found

While FAA has taken steps to address the seven ERAM failures since 2014, some vulnerabilities remain. These seven failures included two serious incidents that significantly disrupted the NAS. During one of these incidents, in August 2015, ERAM failed when a software tool at controller workstations overloaded system memory. The incident caused flight delays and cancellations that impacted thousands of flights over several days.

FAA has since taken corrective actions to resolve the causes of these two serious incidents and other issues that caused five less serious outages. However, other issues remain unresolved. For example, FAA has not implemented annual testing of ERAM's contingency plan, as called for by Federal guidelines. In addition, FAA plans to decommission ERAM's existing backup system, the Enhanced Backup Surveillance System (EBUS), due to its incompatibility with upgrades to ERAM. However, FAA has not yet determined whether ERAM's remaining backup capability—the system's redundant dual channel design—will be sufficient to prevent future outages once EBUS is removed. The lack of sufficient backup capabilities could increase ERAM's vulnerability in the event of future unanticipated incidents.

Our Recommendations

We made three recommendations to improve FAA's ability to mitigate future ERAM disruptions. FAA has concurred with one of our recommendations and partially concurred with the other two. We consider all three of our recommendations resolved but open pending completion of planned actions.

Contents

Memorandum	1
Results in Brief	3
Background	4
FAA Has Taken Steps To Address ERAM Outages, but Some Vulnerabilities Remain	5
Conclusion	12
Recommendations	13
Agency Comments and OIG Response	13
Actions Required	14
Exhibit A. Scope and Methodology	15
Exhibit B. Organizations Visited or Contacted	16
Exhibit C. List of Acronyms	17
Exhibit D. Major Contributors to This Report	18
Appendix. Agency Comments	19



Memorandum

Date: November 7, 2018

Subject: ACTION: FAA Has Taken Steps To Address ERAM Outages, but Some Vulnerabilities Remain | Report Number AV2019004

From: Matthew E. Hampton *M.E.H.*
Assistant Inspector General for Aviation Audits

To: Federal Aviation Administrator

The Federal Aviation Administration's (FAA) En Route Automation Modernization (ERAM) system is used by air traffic controllers to safely handle over 3 million high-altitude en-route¹ aircraft a month at its 20 Air Route Traffic Control Centers (Centers). In March 2015, FAA declared ERAM fully operational at all 20 Centers. The Agency considers ERAM—with its automated air traffic control capabilities—as foundational for Next Generation Air Transportation System (NextGen) programs, such as satellite-based navigation and surveillance and a new data link communications system for controllers and pilots.

Because of the importance of ERAM to air traffic management, system outages can significantly impact operations in the National Airspace System (NAS). The Chairman of the Senate Committee on Commerce, Science, and Transportation and the Chairmen and Ranking Members of the House Committee on Transportation and Infrastructure and its Aviation Subcommittee asked us to evaluate recent ERAM outages and FAA's actions to address them.

Accordingly, our audit objective was to assess the causes of ERAM's outages and FAA's actions to address them. We plan to address additional issues related to FAA's ongoing efforts to update ERAM and support current and planned NextGen capabilities in a separate review.

We conducted our work in accordance with generally accepted Government auditing standards. See exhibit A for details on our scope and methodology,

¹ En route traffic travels above 10,000 feet where aircraft reach their cruising altitudes and fly as direct routes as possible between departure and destination points.

exhibit B for a list of organizations we visited or contacted, and exhibit C for a list of acronyms used in this report.

We appreciate the courtesies and cooperation of Department of Transportation representatives during this audit. If you have any questions concerning this report, please call Matthew E. Hampton, Assistant Inspector General for Aviation Audits, at (202) 366-0500.

cc: The Secretary
DOT Audit Liaison, M-1
FAA Audit Liaison, AAE-100

Results in Brief

While FAA has taken steps to address the failures ERAM experienced since 2014, some vulnerabilities remain.

Our review focused on seven ERAM failures that occurred since 2014, including two serious incidents—one at Los Angeles Center in 2014 and one at Washington Center in 2015—that significantly disrupted the NAS. During the incident at Washington Center in August 2015, ERAM failed when a software tool at controller workstations overloaded the system’s memory and caused both of the system’s primary and secondary channels² to fail, leading the Center to declare ATC Zero³ and suspend all air traffic in the facility’s airspace. The incident lasted over 5 hours and caused flight delays and cancellations that impacted thousands of flights over several days. The Los Angeles Center outage was caused by software problems that FAA had previously identified prior to the failure, but the Agency had considered them low risk and determined that immediate action was not necessary. FAA has since taken corrective actions to resolve these problems as well as other software and hardware issues that caused five less serious outages, the last of which occurred in October 2016. However, other issues that may impede ERAM’s recovery from unanticipated events remain unresolved. For example, FAA has not implemented annual testing of its contingency plan for ERAM, as called for by National Institute of Standards and Technology (NIST) guidelines.⁴ Finally, FAA plans to decommission ERAM’s existing backup system, the Enhanced Backup Surveillance System (EBUS), as early as April 2019 due to its incompatibility with system upgrades that FAA is undertaking. However, FAA has not yet determined whether ERAM’s internal backup capability—the system’s redundant dual channel design—will be sufficient to prevent future outages once EBUS is removed. The lack of sufficient backup capabilities could increase ERAM’s vulnerability in the event of future unanticipated incidents.

We made three recommendations to improve FAA’s ability to mitigate future ERAM disruptions.

² ERAM’s design architecture includes two redundant synchronized channels—a primary channel and secondary channel—designed to help prevent a total system outage from occurring.

³ ATC Zero is declared when an air traffic control facility management determines that the facility cannot safely provide air traffic services.

⁴ NIST develops and issues standards, guidelines, and other publications to help Federal agencies manage cost-effective programs to protect their information and information systems and implement the Federal Information Security Management Act of 2002.

Background

In 2002, FAA awarded a contract to Lockheed Martin for ERAM that now exceeds \$2.1 billion. The system contains over 2 million lines of software code. In September 2012,⁵ we reported that software-related problems significantly delayed ERAM's implementation and resulted in hundreds of millions of dollars in increased costs. As a result of these problems, FAA did not declare ERAM fully operational at all 20 Centers until March 2015, over 4 years later than it had planned.

Figure 1. A Controller Using ERAM and Associated Air Traffic Systems



Source: National Air Traffic Controllers Association

ERAM makes up part of the foundation of a range of NextGen capabilities in FAA's plans, including the Data Communications (DataComm)⁶ and Automatic Dependent Surveillance—Broadcast (ADS-B) capabilities.⁷

⁵ *Weaknesses in Program and Contract Management Contribute to ERAM Delays and Put Other NextGen Initiatives at Risk* (OIG Report No. AV2012179), September 13, 2012. OIG reports are available on our website at <http://www.oig.dot.gov/>.

⁶ DataComm provides a digital link for text messages between controllers and pilots.

⁷ ADS-B is satellite-based surveillance technology that an aircraft uses to determine its position via satellite navigation, and periodically broadcasts it and other flight information to a ground system that provides the information to air traffic controllers.

ERAM's design includes two redundant synchronized channels—a primary channel and secondary channel. This design allows air traffic controllers to seamlessly switch from one channel to the other, and its redundancy is meant to provide ERAM with backup capabilities without the need for a dedicated backup system. In the event of a failure in one channel, the other should take over air traffic control without interruption. This redundancy is also meant to prevent a total system outage in the event of a failure in the primary channel and allow operations to continue during routine maintenance procedures. In addition, to augment ERAM's redundancy, FAA has maintained EBUS, which was the backup system of ERAM's predecessor, called the Host Computer System (HCS).

FAA has recently begun a major effort to replace ERAM's original hardware, which has been installed since 2004, and upgrade elements of the operating system by 2025. FAA also plans to add software enhancements with new capabilities that other NextGen programs need ERAM to provide through a series of upgrades. The Agency currently estimates costs for two of these efforts at over \$575 million through 2023.

FAA Has Taken Steps To Address ERAM Outages, but Some Vulnerabilities Remain

While FAA has addressed issues that caused ERAM's outages since 2014, system vulnerabilities remain. FAA experienced ERAM failures—including major failures at Los Angeles and Washington Centers—caused primarily by software problems that FAA has taken steps to address. However, FAA has not yet fully addressed human factors and testing limitations that contributed to the outages. Furthermore, FAA currently plans to decommission EBUS starting in 2019, but has not yet determined whether ERAM's built-in backup capabilities will be sufficient on their own to prevent failures and outages.

FAA Has Implemented Corrective Actions for Seven ERAM Failures Since 2014

We reviewed seven ERAM failures that occurred since April 2014, including two serious failures at Washington and Los Angeles Centers that resulted in outages that caused significant disruptions to air traffic. Five other ERAM failures, the last of which occurred in October 2016, subsequently revealed additional hardware and software issues, even though the failures had little or no impact on the NAS. As detailed below, FAA has taken a number of steps to address the issues that caused these outages.

In April 2014, an Erroneous Flight Plan Crashed ERAM at Los Angeles Center

Description and Impact: A flight plan for a military aircraft (a surveillance training mission) flying above 60,000 feet caused a sequence of events that resulted in flight data memory overload and the failure of both ERAM channels. The Center attempted to switch to EBUS, but it also failed. As a result, facility managers declared ATC Zero, which suspended operations and cleared the Center's airspace, and in coordination with FAA's Command Center, initiated a ground stop for Los Angeles International Airport. The event impacted air traffic operations with over 400 flight delays reported throughout the NAS and as many as 365 cancellations just in the Los Angeles Center airspace alone. According to FAA the event lasted for about 2 hours, but the impact on the traveling public throughout the NAS lasted for over 24 hours.

Corrective Actions and Cause: FAA addressed the cause of the outage with an emergency software patch. In later software updates, the Agency added permanent software fixes that increased the size of ERAM's flight data memory.

During its post-incident analysis, FAA found that a month prior to the outage, a software test team at the William J. Hughes Technical Center in New Jersey⁸ had identified the software flaw that caused the failure. However, FAA considered the flaw to be low risk, and no action was taken at that time. FAA planned a future software update that would reduce the possibility of outages, but the April 2014 outage occurred before this update was implemented.

In August 2015, a New Controller Tool Overloaded ERAM at Washington Center

Description and Impact: A new controller preference software application tool for controller workstations resulted in the failure of both ERAM channels and led the Center's management to declare ATC Zero. The new software caused ERAM's memory to accumulate excess data over a period of several weeks, which ultimately overloaded the system's memory and caused ERAM's primary and secondary channels to fail. The resulting outage lasted for over 5 hours; almost 4 hours were spent at ATC Zero, which resulted in the clearing of all aircraft from the Center's airspace (see figure 2). The outage resulted in 492 flight delays reported in Washington Center airspace and contributed to more than 3,400 flight delays and 640 cancellations nationwide, along with impacting international air traffic entering the NAS. While the event was eventually

⁸ The Technical Center conducts research and development, test and evaluation, and verification and validation in air traffic control, communications, navigation, airports, aircraft safety, and security.

downgraded to an ATC Alert,⁹ the ripple effects adversely impacted air traffic and travelers across the country for several days.

Figure 2. Depiction of Aircraft Redirected Around Washington, DC, During the Outage in August 2015



Source: Flightradar24 (with permission), a commercial service that provides live air traffic using ADS-B and FAA radar surveillance data. We added the Washington Center boundary.

Corrective Actions and Cause: FAA directed all Centers to stop using the new controller application and issued a software resolution that mitigated the problem. Technicians at the Technical Center implemented an automated tool to monitor ERAM's data storage limits to aid in the detection and prevention of system degradation and failure. The tool allows the Technical Center to remotely monitor ERAM operations and to detect abnormal system functions and notify affected Centers of possible problems before they occur. FAA engineers informed us that this tool prevented failures at Washington and New York Centers after the August 2015 event.

Software and Hardware Issues Also Caused Less Serious Incidents Between 2014 and 2016

Our analysis identified five other ERAM failures that occurred between 2014 and 2016 at Memphis, Washington, and Denver Centers that had less serious impact

⁹ An ATC Alert is a precautionary notification that informs Center's support facilities of air traffic related problems.

on the NAS. However, the facilities declared ATC Alerts during four of the incidents, and subsequent analyses revealed additional ERAM hardware and software issues. An ATC Alert is a precautionary notification that informs the Center’s support facilities of air traffic related problems. See table 1 for descriptions of these events and their causes.

Table 1. Other Less Severe Events Between 2014 and 2016

Date and Location	Description of Event and Cause	Corrective Actions
October 2016 Washington Center	ERAM’s primary channel failed and experienced repeated failures. These failures in turn caused failures in controllers’ radar displays and loss of air traffic management capability. No redundancy capability was available because the secondary channel was in testing mode and not available to back up the primary channel for air traffic control. The facility switched to EBUS until the secondary channel was restored to air traffic operations. Because of the successful switch to EBUS, air traffic was not impacted.	This issue was reported to the Technical Center, and a software fix was added in a later update. In addition, the Technical Center is using a tool to help Centers detect and mitigate problems during maintenance activities.
December 2015 Denver Center	A software issue in the processing of one aircraft’s flight caused radar displays at multiple controller workstations to fail on both ERAM channels, resulting in controller’s loss of air traffic control capabilities in four sectors. ¹⁰ Controllers in five other sectors lost the primary channel when they attempted to view the problem aircraft at their workstations. An ATC Alert was issued by the FAA Air Traffic Control System Command Center that lasted about 45 minutes.	The issue was corrected when the problem aircraft landed after a short flight. FAA technicians have identified two other resolutions that they planned to implement in later software updates.
December 2015 Washington Center	ERAM experienced the simultaneous failure of two hard storage drives that store data on system operations. The failure triggered a series of problems that caused ERAM’s monitor and control system to fail, resulting in the loss of channel synchronization which affected internal facility system communications. Technicians restored the system to operational use 2 days later.	FAA and contractor technicians worked together to analyze the cause and developed corrective actions. The Technical Center directed facilities to install a software patch and have spare drives on hand.

¹⁰ Each Center’s airspace is divided into manageable blocks called sectors.

Date and Location	Description of Event and Cause	Corrective Actions
July 2014 Memphis Center	Altitude data sent to Memphis Center from Atlanta Center, which was still running on ERAM's predecessor—the Host Computer System—for a flight routed through Memphis, caused a failure in ERAM's flight data processing software on the primary channel. This software defect had been reported earlier. Ten delays were experienced.	The Technical Center developed a software fix that increased the size of ERAM's flight plan input data field to prevent recurrences.
April 2014 Memphis Center	A software problem allowed a bad flight plan to cause ERAM to rapidly create and cancel over 11,000 flight plans, causing ERAM's flight data processors to overload and crash the system.	FAA developed and added a software fix to ERAM.

Source: OIG analysis of FAA data

Human Error and Testing Limitations Contributed to ERAM's Outages

While ERAM's outages were primarily caused by software issues and one hardware-related issue, human error and testing limitations also contributed to the outages and exacerbated their duration and impact on the traveling public.

Human Error. FAA found that a controller at an adjacent Center contributed to the 2014 outage at Los Angeles Center by making a data entry error. The error caused ERAM to believe that the military aircraft was flying at 7,000 feet rather than above 60,000 feet. To mitigate the possibility of this sort of error, FAA issued a National Mandatory Briefing Item¹¹ that revised instructions for controllers on entering altitude data for very high altitude aircraft.

Inadequate Contingency Plan Testing. Both FAA's post-incident analysis and our work found that FAA does not adequately test ERAM's contingency plan. NIST guidelines require agencies to maintain and regularly test contingency plans for their information systems such as ERAM. According to NIST requirements, these plans should include functioning backup systems, annual testing, and

¹¹ A National Mandatory Briefing Item is a nationwide notification or clarification of changes to or reinforcement of procedures for air traffic control.

details for staff on how to recover the systems in emergencies such as the outages that ERAM has experienced.

However, FAA has not conducted this annual testing as required. According to FAA officials, testing of ERAM's contingency plan is not practical at Centers due to the adverse impact the testing could have on ERAM's performance. Instead of the annual testing required by NIST, FAA has used scheduled and unscheduled maintenance activities, conducted primarily by maintenance technicians, to serve as opportunities to exercise the contingency plan in ERAM's operational environment. However, air traffic controllers, the primary user of ERAM, are not gaining experience in reacting to and recovering from outages that ERAM has experienced. Relying on maintenance activities alone, rather than a fully planned and complete annual test, prevents the participation of other key staff, such as controllers, focusing only on the maintenance staff that is present. As a result, FAA may not be able to ensure that all air traffic and maintenance technician staff who play critical roles in recovery operations can effectively respond to a failure in air traffic operations.

Insufficient Contingency Plan Training. FAA also does not adequately provide the training for staff on ERAM's contingency plan. Under NIST guidelines, users of ERAM, such as air traffic controllers and maintenance technicians, must attend seminars, briefings, and refresher training annually at a minimum. According to FAA officials, in 2016 the Agency conducted a table-top scenario-driven exercise at all 20 Centers. These exercises worked through an outage scenario and trained the staff in how they should respond. However, staff who attended informed us that while the training was effective, they were concerned because some key air traffic staff and managers did not attend. Moreover, FAA has not conducted the training annually, as NIST requires. The lack of formal annual contingency training for both technicians and air traffic controllers made it difficult for FAA to respond effectively to ERAM's failures and reduce the duration and severity of some of the outages.

In response to recommendations we made in a January 2017 report,¹² FAA is developing long-term requirements for contingency planning and controller training. Although the Agency is making progress, it is unclear when these new requirements will be implemented. These recommendations remain open, and we will continue to monitor FAA's progress in implementing them.

¹² *Although FAA Has Taken Steps To Improve Its Operational Contingency Plans, Significant Work Remains To Mitigate The Effects of Major System Disruptions* (OIG Report No. AV2017020), January 11, 2017.

FAA Has Not Yet Determined Whether ERAM's Backup Capabilities Will Be Sufficient To Prevent Future Outages

The two most serious outages—in April 2014 at Los Angeles Center and in August 2015 at Washington Center—highlighted the importance of a backup system or other backup recovery capabilities for ERAM.

ERAM's original design did not include a dedicated backup system. FAA believed that ERAM did not need one due to the redundancy provided by the system's dual channel design. This design was intended to prevent outages because it allows for seamless switching between the two channels without impacting air traffic control should a problem occur in the active channel. The Agency believed this redundancy would make it unlikely that a problem in one channel could migrate to the other channel. In addition, to provide additional backup capabilities during ERAM's implementation, FAA planned to temporarily maintain EBUS, its pre-existing backup system, before phasing it out completely beginning in 2015, to rely solely on ERAM's dual channels.

However, problems experienced during and since ERAM's implementation have shown that the system remains susceptible to dual channel failures. As a result, FAA decided to maintain EBUS much longer than intended because air traffic controllers currently rely on EBUS for backup. However, with FAA's ongoing and planned upgrades to ERAM, which will span the next 7 years, EBUS will soon become incompatible with the new hardware. As such, FAA plans to begin phasing out EBUS in April 2019, leaving ERAM without a backup system to supplement the system's redundant dual channels. Moreover, normal day-to-day maintenance requirements—as well as the planned hardware and software upgrades requiring significant testing—will leave air traffic facilities periodically¹³ relying on a single ERAM channel instead of two. The lack of additional backup capabilities may increase the risk of significant disruptions to the NAS if ERAM were to fail.

Despite this risk, FAA has not yet assessed whether ERAM's built-in backup capabilities will be sufficient to protect the system from failure once EBUS is removed. According to NIST's *Contingency Planning Guide for Federal Information Systems*,¹⁴ for systems such as ERAM—which FAA has classified only as a moderate

¹³ Day-to-day maintenance requirements, such as software testing, aeronautical chart updates, and other requirements, periodically results in the lack of an available secondary channel, leaving controllers with only one channel instead of two to control air traffic. During the October 2016 incident at Washington Center, the primary channel began to fail and the secondary channel was not available to switch air traffic control, only the facility still having EBUS prevented an outage.

¹⁴ NIST Special Publication 800-34 Rev. 1, *Contingency Planning Guide for Federal Information Systems* (2010).

risk¹⁵ system—agencies should have recovery strategies that include reliable backup systems.¹⁶ Furthermore, FAA’s guidance on reliability, maintainability, and availability (RMA)¹⁷ points to the need for backup capability for systems such as ERAM. Operational use of ERAM has shown that dual channel redundancy is not always available. Moreover, FAA’s RMA guidance states that for software intensive systems like ERAM, the most significant factor for demonstrating a system’s reliability, maintainability, and availability is *recovery time* from hardware and software failures and not availability requirements.

FAA safety policy¹⁸ also requires that, before removal of any operational component—such as EBUS—from the NAS, a safety analysis must be conducted to identify any residual risk. If FAA finds that EBUS’s removal creates risk, the Agency must decide to either accept the risk or that the risk warrants a new backup system for ERAM.

In July 2017, FAA established a safety review panel to begin the analysis to determine the risks to removing EBUS from the NAS. The panel delivered its draft report to the Agency in November 2017. After reviewing the report, FAA officials tasked the panel to reconvene to examine possible mitigation strategies to eliminate or reduce the assessed risk to enable FAA to decommission EBUS in 2019. The panel reconvened again in March 2018 with no final decision at that time. It resumed its efforts in August 2018 and has continued working to complete its review and recommendations. Once the review is complete, the Agency plans to decide whether to proceed with developing requirements and deploying a dedicated backup system for ERAM.

Conclusion

ERAM is the primary system used by air traffic controllers to manage high-altitude air traffic and foundational to implementing a range of FAA’s planned NextGen capabilities. As such, ERAM system failures can quickly degrade air

¹⁵ NIST, Federal Information Processing Standards (FIPS) Publication 199, *Standards for Security Categorization of Federal Information and Information Systems* (2004) establishes the Government standard for categorization of information and information systems based on low, moderate, and high risk. According to the standards, the loss of confidentiality, integrity, or availability in a moderate impact category system such as ERAM can be expected to have a serious adverse effect on organizational operations, assets, or individuals.

¹⁶ In April 2018, FAA recategorized the risk of 61 systems, including ERAM and EBUS. This recategorization upgraded the systems from low or moderate risk to high. FAA is currently analyzing and implementing the new security requirements for the upgrades to high.

¹⁷ FAA RMA-HDBK-006B, *Reliability, Maintainability, and Availability (RMA) Handbook* (2014).

¹⁸ FAA Order 8000.369B, *Safety Management System* (2016) requires the design and implementation of organizational processes and procedures to include the identification of safety hazards and the control or mitigation of safety risks in aviation operations.

traffic operations and significantly impact the NAS. FAA has taken steps to resolve the problems that caused ERAM's failures between 2014 and 2016. However, several issues remain that leave the traveling public at risk of being impacted by potential ERAM outages. Until FAA sufficiently tests and trains staff on its contingency plans and fully assesses its backup capability, the Agency may remain limited in its ability to mitigate and respond to future ERAM emergencies and outages.

Recommendations

To improve FAA's ability to adequately recover from unexpected ERAM outages, we recommend that the Federal Aviation Administrator:

1. Develop and implement contingency plan testing to validate the effectiveness of techniques and procedures to react to and recover from ERAM outages, with air traffic controllers' and maintenance technicians' participation.
2. Evaluate, develop, and implement training, consistent with NIST guidelines, for maintenance technicians and air traffic control staff for responding to ERAM in degraded system conditions and outages.
3. Upon completion of the safety review regarding removing ERAM's current backup system, determine what backup capability is required for ERAM and then develop and implement that capability.

Agency Comments and OIG Response

We provided FAA with our draft report on August 30, 2018, and received the Agency's response on September 26, which is included as an appendix to this report. In its response, FAA concurred with recommendation 2 and provided appropriate planned actions and completion dates. FAA partially concurred with recommendations 1 and 3. FAA provided alternative actions and completion dates to address the intent of these recommendations. As a result, we consider all three recommendations resolved but open pending completion of planned actions.

Regarding recommendation 1, FAA stated that due to the 24/365 nature of its operations, it is impractical to increase staff participation in training by implementing a single annual training session. The Agency proposed an alternative plan, with a specific implementation date, that would ensure that all employees participate in at least one training session per year. The plan will also

require tracking of staff participation. This plan meets the intent of our recommendation.

For recommendation 3, FAA provided alternative actions, stating that it plans to complete the ongoing safety review, analyze the results to determine whether any associated hazards exist if the current backup is decommissioned, and implement appropriate countermeasures or mitigations as necessary. These actions meet the intent of our recommendation.

FAA provided a number of comments to our draft report, and we have adjusted the report as appropriate. In addition, FAA expressed the following concerns:

- FAA disputed our assertion that several issues remain that leave the traveling public at risk of impact by possible ERAM outages. FAA stated that all known issues in ERAM have been addressed, and the system has been fully available for the past 24 months. We recognize that ERAM's reliability has improved since the system—a foundational component of NextGen—was introduced in the 2010 timeframe. However, while outages are rare, experience shows they have a cascading effect across the NAS and impact thousands of flights. Addressing our recommendations should better position FAA to mitigate future outages, should they occur.
- FAA claimed that we incorrectly reported that EBUS was intended to be ERAM's backup. This is not the case. As we state in our report, EBUS was only intended to be an interim backup for the transition from the legacy system to ERAM, and FAA retained it as the result of the difficulties that ERAM experienced during implementation. FAA originally planned to decommission EBUS concurrently with the legacy system but decided to retain it as an additional backup until ERAM was more mature. As noted in our report, the issue of a long-term backup system for ERAM remains an ongoing concern and the focus of an Agency work group.

We remain committed to working with FAA to identify opportunities to further improve air traffic operations in the event of an ERAM outage, and welcome further discussion with the Agency regarding our findings in this report.

Actions Required

We consider all three of our recommendations resolved but open pending completion of planned actions.

Exhibit A. Scope and Methodology

We conducted this performance audit between March 2016 and August 2018 in accordance with generally accepted Government auditing standards as prescribed by the Comptroller General of the United States. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

The Senate Committee on Commerce, Science, and Transportation and the House Committee on Transportation and Infrastructure and its Aviation Subcommittee asked us to evaluate the causes of ERAM outages and FAA's actions to address them. Accordingly, our audit objective was to assess the causes of ERAM's outages and FAA's actions to address them. We plan to address additional issues related to FAA's ongoing efforts to update ERAM and support current and planned NextGen capabilities in a separate review.

To assess the causes of the ERAM outages and ascertain FAA's actions to address them, we obtained and reviewed key documents obtained from the Agency. These documents included program plans, investment decisions, program status briefings, schedule information, requirements documents, architectural designs, technical refresh and enhancements efforts impacting ERAM, and software and hardware testing plans and results.

In addition, we interviewed aviation industry officials, such as Aviation Management Associates, and Government experts to gain their historical and current perspective on oversight of ERAM and performed analyses of industry reports from MITRE/Lincoln Labs, Lockheed Martin/Leidos, NIST, and the National Research Council. We interviewed National Air Traffic Controllers Association officials to obtain air traffic controllers' perspective on ERAM outages, ERAM's backup system, and mitigation plans.

We also conducted site visits to 9 of the 20 FAA Air Route Traffic Control Centers (ARTCC) to obtain specific information, briefings, event reports, and contingency plans regarding the ERAM outages that affected that airspace. The ARTCCs visited were Los Angeles, Miami, Memphis, New York, Washington, Kansas City, Chicago, Denver, and Seattle. We chose these nine sites because they had reported a system failure or significant software problem either during or after ERAM implementation. We also visited the FAA Air Traffic Control System Command Center (ATCSCC) which maintains real-time command, control, and oversight of the National Airspace System (NAS) during the ERAM outages.

Exhibit B. Organizations Visited or Contacted

FAA Facilities

FAA Air Traffic Control System Command Center
FAA Program Management Office
FAA William J. Hughes Technical Center
Chicago Air Route Traffic Control Center
Denver Air Route Traffic Control Center
Kansas City Air Route Traffic Control Center
Los Angeles Air Route Traffic Control Center
Memphis Air Route Traffic Control Center
Miami Air Route Traffic Control Center
New York Air Route Traffic Control Center
Seattle Air Route Traffic Control Center
Washington Air Route Traffic Control Center

Other Organizations

Aviation Management Associates
Flightradar24
FlightAware
Lockheed Martin
MITRE Corporation
National Air Traffic Controllers Association
National Research Council
Professional Aviation Safety Specialists

Exhibit C. List of Acronyms

ADS-B	Automatic Dependent Surveillance - Broadcast
ARTCC	Air Route Traffic Control Center
ATC	air traffic control
ATCSCC	Air Traffic Control System Command Center
DataComm	Data Communications
DOT	Department of Transportation
EBUS	Enhanced Backup Surveillance System
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
HCS	Host Computer System
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NIST	National Institute of Standards and Technology
OIG	Office of Inspector General
RMA	reliability, maintainability, and availability

Exhibit D. Major Contributors to This Report

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Appendix. Agency Comments



Federal Aviation Administration

Memorandum

Date: September 26, 2018

To: Matthew E. Hampton, Assistant Inspector General for Aviation 

From: H. Clayton Foushee, Director, Office of Audit and Evaluation,

Subject: Federal Aviation Administration's (FAA) Response to Office of Inspector General (OIG) Draft Report: FAA Has Taken Steps To Address ERAM Outages

The FAA successfully installed the En Route Automation Modernization (ERAM) system, which is the foundation for NextGen and the deployment of upgrades such as System Wide Information Management (SWIM), Data Communications (DataComm), Automatic Dependent Surveillance-Broadcast (ADS-B), and Time Based Flow Management (TBFM). ERAM deployment in the National Airspace System (NAS) was completed in March 2015, and the transition from the legacy "Host Computer System" to ERAM was one of the most complex efforts undertaken by the Agency in its 60-year history. In the more than 3-years that ERAM has been operational, the system has demonstrated that it is highly reliable and meets or exceeds system requirements for availability.

The FAA believes the OIG has mischaracterized key aspects of the current ERAM system status in the draft report, most notably:

- We dispute the OIG's assertion that "several issues remain that leave the traveling public at risk of being impacted by potential ERAM outages." All known issues have been addressed, and ERAM has been 100% available for the last 24 months. Moreover, in any critical NAS system, there are contingency plans in the event of an ERAM outage that would fully maintain the safety of the flying public and keep the NAS operational.
- The OIG erroneously states that Enhanced Backup Surveillance (EBUS) was intended to be ERAM's backup. EBUS was intended to be a transition tool to permit severing interfaces from the old system and enabling those interfaces on ERAM during the transition from Host to ERAM. ERAM does not have a requirement for an independent backup system since its architecture was designed with two functionally identical channels with dual redundancy providing inherent backup capability.
- The OIG erroneously states that there has been no further action/date to resume the work of the safety panel to determine the risks of EBUS from the NAS. FAA

assembled a working group in late August 2018 to explore potential mitigations regarding hazards identified by the *ERAM: EBUS Removal Safety Risk Management Panel*, and they are currently documenting and analyzing their findings.

Upon preliminary review of the recommendations, the FAA partially concurs with recommendation 1 to develop and implement contingency plan testing with air traffic controllers' and maintenance technicians' participation. The FAA believes the intent of the recommendation is to increase ERAM contingency testing participation by air traffic controllers and maintenance personnel by establishing annual testing exercises instead of relying on weekly testing of transferring operations to the alternate channel performed by ERAM technicians and coordinated with on-shift air traffic controllers. Due to the unique 24x365 rotating shift of air traffic controllers, it is not possible to increase participation rates by conducting a single annual exercise versus the 52 weekly tests currently conducted. However, as an alternate action, to ensure that all key employees participate in at least one test per year, we will track participation and schedule additional events as necessary. We plan to implement this recommendation by December 31, 2019.

The FAA concurs with Recommendation 2 to evaluate, develop and implement contingency plan training, as written and plans to implement it by December 31, 2019.

The FAA partially concurs with Recommendation 3 to determine the backup capability required for ERAM and develop and implement that capability after completing a safety review regarding removing ERAM's current backup system. The FAA plans to complete the ongoing safety review, analyze the results to determine whether any associated hazards exist with EBUS removal, and implement the appropriate countermeasures/mitigations, as necessary. FAA does not concur that EBUS is ERAM's backup system and will await the safety panel findings to determine next course of action. We plan to implement this recommendation by December 31, 2019.

We appreciate this opportunity to offer additional perspective on the OIG draft report. Please contact H. Clayton Foushee at (202) 267-9000 if you have any questions or require additional information about these comments.

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