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# *Office of Inspector General*

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*Management of Software-Intensive  
Acquisitions for Free Flight Phase 1*

*Federal Aviation Administration*

*Report Number: AV-2000-028  
Date Issued: December 21, 1999*





**U.S. Department of  
Transportation**

Office of the Secretary  
Of Transportation

Office of Inspector General

# Memorandum

Subject: **ACTION:** Report on FAA's Management of  
Software-Intensive Acquisitions for Free Flight  
Phase 1  
Report No. AV-2000-028

Date: December 21, 1999

From: Alexis M. Stefani  
Assistant Inspector General for Auditing

Reply to  
Attn of: JA-1

To: Federal Aviation Administrator

We are currently reviewing the Federal Aviation Administration's (FAA) Free Flight Phase 1 initiative with particular emphasis on cost, schedule, human factors, and software development progress. This interim report provides our observations to date on how FAA can strengthen the management of two Free Flight Phase 1 software-intensive acquisitions. We met with Director of Research and Acquisitions and the Director of the Free Flight Phase 1 Program Office to discuss our results and have taken their comments into consideration in preparing this report. We will provide a full report on the status of all Free Flight Phase 1 technologies at a later date.

Free Flight Phase 1 is the limited deployment of technologies at select locations in the United States to enhance air traffic management and to improve information sharing between FAA and airlines. It offers the potential to improve the flow of air traffic and provide benefits to airspace users, principally commercial airlines.

As part of our review, we analyzed FAA's use of earned value management and software metrics. *Earned value management* and *software metrics* are widely recognized ways to measure progress of large-scale, software-intensive acquisitions. Earned value management<sup>1</sup> goes beyond the two-dimensional approach of comparing budgeted costs to actual costs. It analyzes actual costs and

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<sup>1</sup>Earned value management was pioneered in the 1960's by the Department of Defense as part of its cost, schedule, and control system criteria for managing major weapon systems acquisitions. It has evolved from an accounting technique to a program management tool.

technical progress of a program, compares that data to planned costs, and forecasts how much the program will cost and when it will be delivered. Software metrics measure the attributes of software development such as complexity, productivity, and operational requirements and can help agencies monitor the technical progress of software development. We performed our work from March 1999 to September 1999 in accordance with Government Auditing Standards as prescribed by the Comptroller General of the United States.

## **BACKGROUND**

Free Flight Phase 1 is expected to cost about \$722 million through Fiscal Year 2004, and all Free Flight Phase 1 products are expected to be deployed by December 2002. Over \$600 million of Free Flight Phase 1 funds--or almost 83 percent of the total cost of the effort--will be spent on two new automated controller tools that require extensive software development.

One of these tools, the Center-TRACON Automation System (CTAS)<sup>2</sup> provides controllers with suggested sequences for landing aircraft and runway assignments that can enhance efficiency. Today, controllers rely solely on established procedures, experience, and judgement to make such decisions. The other tool, Conflict Probe<sup>3</sup>, helps controllers analyze airline requests for changes in en route flight plans for more fuel-efficient routings and detects potential conflicts between aircraft. These tools offer significant potential for improving the flow of air traffic and rely on complex software. (The exhibit to this report provides information on Free Flight Phase 1 products and where they will be deployed.)

## **RESULTS-IN-BRIEF**

Software development for new automated controller tools is a major cost and schedule risk to the Free Flight Phase 1 initiative. Of the \$600 million that FAA expects to spend on Conflict Probe and CTAS through 2004, about \$129 million has been obligated through September 1999. Accordingly, the bulk of the work in developing and testing new systems for use in day-to-day operations by controllers at air traffic control facilities lies ahead.

Milestones are aggressive for both CTAS and Conflict Probe and there is little room for schedule slips or unexpected problems. At this stage, Conflict Probe is on schedule with most software development to occur over the next year. The next major milestone for Conflict Probe is a computer hardware review scheduled for late January 2000.

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<sup>2</sup> CTAS refers to two tools, Traffic Management Advisor and Passive Final Approach and Spacing Tool.

<sup>3</sup> Conflict Probe refers to the User Request Evaluation Tool developed by Mitre.

CTAS is experiencing technical problems and concerns exist about contractor performance that may have cost and schedule impacts. According to FAA, it is proving more difficult and time-consuming than expected to transition CTAS from a software-intensive research and development prototype to a production system. For example, since the effort began FAA has replaced one contractor because it could not perform and has made changes in program management.

Additionally, recent software revisions have caused controller displays to lock up unexpectedly. Free Flight Phase 1 officials told us that they are addressing this concern and have not witnessed a recurrence of it. The next major milestone for CTAS is "functionality testing", or a test that evaluates whether new software will perform operationally as planned. This is expected to be complete in February 2000.

To FAA's credit, the agency is using earned value management, a technique for comparing and forecasting technical progress and costs, for monitoring progress with the two CTAS contractors and plans to use it for Conflict Probe. However, our analysis shows the information reported by CTAS contractors is not adequate and needs improvement.

We found major inconsistencies with CTAS contractors calculating baselines, claiming technical progress, computing cost and schedule variances, and forecasting cost estimates when work is finished. For example, one contractor was using a contract baseline of \$39 million when the correct figure was \$17 million. The contractor for Conflict Probe has not yet fully implemented earned value management because the contract was not definitized until August 1999.

To expedite the work in developing Conflict Probe and CTAS, FAA relied on existing contracts. Conflict Probe requirements (contract value of about \$200 million) were added as a cost plus, incentive fee agreement with a cost ceiling to an existing contract for new controller work stations. The majority of work for CTAS is being performed on a contract (valued at \$207 million) where payments are based on the time spent and materials used by the contractor--payments are not directly linked to the completion of deliverables. *With this type of contract, earned value management can only be used for tracking the contractor's progress. There is no direct linkage between payment and actual work performed, nor are there strong incentives for contractors to control costs or use labor efficiently--all risks are with the Government.*

### **RECOMMENDATIONS**

In the future, FAA should negotiate contracts for software development with earned value management, software metrics, and other appropriate measures as

well as provisions for withholding payments if earned value management analysis shows that progress is not commensurate with costs billed.

To help reduce major cost and schedule risks for Free Flight Phase 1, FAA must obtain reliable earned value management data from its contractors. Also, FAA should expand the software metrics for tracking software development progress with CTAS and require contractors to routinely report on them.

**ANALYSIS AND RECOMMENDATIONS**

***SOFTWARE DEVELOPMENT FOR NEW AUTOMATED CONTROLLER TOOLS IS A COST AND SCHEDULE RISK FOR FREE FLIGHT PHASE 1***

The bulk of Free Flight Phase 1 program funds will be spent on two new controller tools -- CTAS and Conflict Probe. These tools are software-intensive acquisitions that involve developing, refining, and testing an estimated 1.4 million lines of complex computer code, which is expected to increase due to FAA's "build a little, test a little" approach for Free Flight Phase 1. Both CTAS and Conflict Probe must be adapted, or customized, to each site where they are to be installed. The estimated 1.4 million lines of code do not include this site-specific adaptation. The following table provides information on lines of code, expected costs, and the funds obligated to date on these two tools.

Lines of Software Code and Projected Costs for  
Free Flight Phase 1 Controller Tools

<b>Technology</b>	<b>Estimated Lines of Code</b>	<b>Projected Costs Through Fiscal Year 2004 (Dollars in Millions)</b>	<b>Funds Obligated through Sept. 1999</b>
Conflict Probe	526,000	\$328.2	\$ 74.9
Center-TRACON Automation System	832,000	272.5	54.2
<b>Total</b>	<b>1,358,000</b>	<b>\$600.7</b>	<b>\$129.1</b>

Note: Costs include contract and program costs but do not include previous research and development expenditures.

Source: FAA's Free Flight Phase 1 Program Office

Of the \$600.7 million that is expected to be spent on these two controller tools, \$129 million has been obligated through September 1999. The majority of work in developing and testing new software for Conflict Probe lies ahead. FAA

expects to spend \$150.1 million in Fiscal Year 2000 and \$145.5 million in Fiscal Year 2001 on these two technologies.

With respect to schedule, CTAS is expected to be deployed in April 2000 at the Fort Worth Center with deployments to follow at Minneapolis, Denver, Los Angeles, Atlanta, Miami, Oakland, and Chicago Centers. The terminal segment of CTAS will also be deployed at Dallas/Fort Worth, Los Angeles, Atlanta, Minneapolis, St. Louis, and Chicago Terminal Radar Approach Control facilities.<sup>4</sup> Conflict Probe will be deployed beginning in November 2001 at the Memphis Center followed by deployments at Indianapolis, Kansas City, Cleveland, Washington, Atlanta, and Chicago Centers. FAA officials believe these schedules are aggressive with little room for unanticipated problems. All systems are expected to be deployed by the end of 2002.

Prototypes of CTAS and Conflict Probe are in use today, but they have evolved as research and development initiatives. Considerable work is required to make them more functional, reliable, and maintainable for use by controllers. CTAS is a research product of the National Aeronautics and Space Administration (NASA) and is based on a computer language that is widely used commercially. Computer Sciences Corporation and Sterling Software are responsible for developing and refining CTAS for operational use. Conflict Probe is a research product developed by the Mitre<sup>5</sup> Corporation and is based on a computer language that is no longer in widespread use. Lockheed Martin is responsible for developing the software code for Conflict Probe.

In addition to improving the reliability and maintainability of the code, FAA and its contractors face challenges in developing software that accurately replicates airspace rules, air traffic control procedures, and the decision-making process used by controllers. FAA refers to this as "*site adaptation*". Both CTAS and Conflict Probe introduce new capabilities that do not exist today and seek to replicate how controllers think. *In essence, new tools must be customized for each location and successfully capture the logic controllers use to make decisions, such as which runway to assign to an aircraft.* Free Flight Phase 1 officials agree that site adaptation for CTAS and, to a lesser extent, Conflict Probe represent significant risks facing Free Flight Phase 1.

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<sup>4</sup> Terminal Radar Approach Control Facilities, commonly referred to as "TRACONS", sequence and separate aircraft as they approach and leave busy airports.

<sup>5</sup> Mitre's Center for Advanced Aviation Systems Development is FAA's federally funded research and development center.

## Progress and Problems

At this stage, Conflict Probe is on schedule and the next significant milestone is a review of computer and display equipment scheduled for late January 2000. Lockheed Martin is in the initial stages of writing new software for Conflict Probe and the majority of software development is expected to occur over the next year.

Free Flight Phase 1 officials told us that CTAS software development is proving much more difficult and time consuming than first imagined. For example, one CTAS contractor was released because it could not perform and FAA has made changes in program management. Moreover, recent software revisions have caused controller displays to lock up unexpectedly. Free Flight Phase 1 officials told us that they are addressing this concern and have not witnessed a recurrence of it.

According to Free Flight Phase 1 officials, Computer Sciences Corporation's test program for CTAS is inadequate and contractor test personnel are inexperienced at system level testing and algorithm development. There is a risk that the CTAS software may be delivered with undiscovered defects, there will be schedule slips, and test procedures may not meet test objectives.

Free Flight Phase 1 officials believe that planned risk mitigation efforts, such as assistance from NASA, replanning efforts by Computer Sciences Corporation, and improved coordination between CTAS contractors, will improve software development and testing procedures. The next major milestone for CTAS is "functionality testing"--a test that evaluates whether new software will perform as planned. FAA expects this to be completed in February 2000. FAA officials agree that more disciplined use of earned value management and software metrics may have given them earlier insight into the health of software development for CTAS.

### ***PROACTIVE MONITORING OF SOFTWARE DEVELOPMENT PROGRESS CAN MINIMIZE RISKS BY IDENTIFYING PROBLEMS EARLY***

As part of our review, we examined the Free Flight Phase 1 Office's implementation of earned value management and software metrics. Both are yardsticks for measuring progress and can help spot problems before they have major impact on the program's cost and schedule.

#### Earned Value Management Can Be Strengthened

The Free Flight Phase 1 Office is using earned value management but we found that there is considerable room for improvement. By analyzing program status,

earned value management forecasts how much the program will cost and when it will be delivered. Earned value management requires accurately gathering and reporting contract data that (1) indicate work progress; (2) relate cost, schedule, and technical accomplishments; and (3) are valid, timely, and able to be audited by contractors or the Government.

To illustrate, assume a contract calls for laying 4 miles of taxiway in 4 weeks costing \$4 million. After 3 weeks of work, only \$2 million has been spent. By comparing planned versus actual expenditures, the project appears to be well under estimated costs. However, earned value management reveals that the project is in trouble – although \$2 million has been spent, only 1 mile of taxiway has been laid. Based on the value of work done, the project will take 12 weeks (3 weeks per mile times 4 miles) and will cost \$8 million (\$2 million per mile times 4 miles). When compared to the planned 4 weeks and \$4 million to lay 4 miles of taxiway, *earned value data give managers an indicator that trouble lies ahead*. While developing software is more complicated than our example, earned value management is widely used by the Department of Defense and others to measure progress with software development.

At the time of our review, contractor methods for earned value management for new controller tools were inadequate. Earlier this year, we shared our concerns with Free Flight Phase 1 staff. Specifically, we identified that the contractor for Conflict Probe had not fully implemented earned value management. Additionally, we pointed out that CTAS contractors – Computer Sciences Corporation and Sterling Software -- were presenting earned value management data that contained significant inconsistencies. For example,

- CTAS contractors were incorrectly using contract baselines. As the foundation of earned value management, the contract baseline is the basis to measure contractor's performance. At the time of our review, one contractor was using a contract baseline of \$39 million when the correct figure was \$17 million.
- One CTAS contractor was improperly claiming earned value and incorrectly calculating variances. For example, the contractor purchased and received computer hardware for \$1 million, paid only the first of two installments of \$500,000, but improperly reported a favorable cost variance of \$500,000.
- CTAS contractors were inaccurately forecasting estimates at completion. Because of inconsistencies with earned value and variance calculations, forecasts at completion were incorrect and the CTAS program manager could not identify specific areas that required attention.

FAA's monthly program reviews for Free Flight Phase 1 reflected our concerns and described CTAS contractor data and methods used for earned value management as, among other things, not meaningful, flawed, lacking discipline, and skewed. Moreover, an additional internal FAA analysis of CTAS confirmed significant deficiencies in contractor earned value management techniques for CTAS.

Earned value management techniques have not yet been fully implemented for Conflict Probe. The contract with Lockheed Martin for Conflict Probe was definitized in August 1999. According to a Free Flight Phase 1 official, FAA received the first earned value management report for Conflict Probe in December 1999. According to FAA, the contractor is experienced with earned value management and should provide FAA with meaningful earned value management reports.

The Free Flight Phase 1 Office has taken steps to address deficiencies with contractors' earned value data and has informed the contractors of problem areas to address with associated timeframes for corrective action. By receiving accurate earned value data, FAA will enhance its oversight of software development. In turn, FAA can identify and correct elements of the Free Flight Phase 1 program that require attention.

#### Free Flight Phase 1 Software Metrics Should Be Expanded

In addition to earned value management, we also reviewed FAA's use of software metrics to assess software development progress. Software metrics are analytical measures of the well-being of a program's software development and can be used independently of earned value management. *Software metrics measure the attributes and characteristics of software development and compare progress to expectations.* In other words, software metrics can provide decision-makers with insight into the health of a software intensive acquisition and nature of specific problems.

FAA's self-assessment of Conflict Probe and CTAS research and development software provides valuable information into the nature and scope of challenges that lie ahead. March 1999 assessments of CTAS and Conflict Probe found that a significant number of CTAS and Conflict Probe functions are highly complex, the quality of code is a concern, and the vast majority of existing research and development code is difficult to maintain. There is a direct relationship between these factors (complexity, quality, and maintainability) and design errors and defects. In turn, software defects can translate into higher costs and schedule slips.

Software metrics are being used by the Free Flight Phase 1 Program Office, but additional metrics are needed to provide better insight into the overall status of the CTAS program. CTAS software metrics focused primarily on staffing and the number of units coded and tested without providing insight into planned progress. Potentially useful software metrics for assessing progress on CTAS software could include complexity (correlation between design complexity and design errors/defects), productivity (deliveries of code per staff month that result in an acceptable and usable system), scrap and rework (code needing to be modified or discarded), volatility (the amount of code added, modified, or deleted to meet requirements) and supportability (average time to correct a deficiency).<sup>6</sup>

Given the results of the technical assessments of CTAS and Conflict Probe regarding code complexity, quality, and maintainability, improved software metrics could help FAA better manage the development and deployment of new controller tools. Free Flight Phase 1 officials agree that improved software metrics would prove beneficial. *The Free Flight Phase 1 Program Office needs to determine which software metrics would be most useful for CTAS and begin tracking them.* As noted earlier, there are a number of metrics that FAA could use to help monitor progress. This will give both the contractors and the Free Flight Phase 1 Program Office more direct insight into the health of software development.

### Observations on Free Flight Phase 1 Contracts

To move forward quickly with the new controller tools, FAA used existing contracts. The contract for Conflict Probe with Lockheed Martin (valued at about \$200 million) is a modification to the existing Display System Replacement contract (which provides new controller displays at en route facilities) and was definitized in August 1999 as a cost plus, incentive fee agreement with a cost ceiling.

With respect to CTAS, the contract with Computer Science Corporation (valued at \$207 million) is a labor hour contract, which is being used to buy time at a specified hourly rate including indirect costs, profit, and materials at cost. The contract with Sterling Software (valued at \$700,000) is a purchase order against a General Services Administration Schedule with a time and materials financial arrangement. With these types of contracts, there is little positive incentive for cost control or labor efficiency. Although the contractors are submitting earned value management reports, FAA does not have the necessary contractual tools to

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<sup>6</sup> Many recognized authorities on software development, such as the U.S. Air Force's Software Technology Support Center and the Software Engineering Institute of Carnegie Mellon University, have highly developed software metrics that may prove useful for Free Flight Phase 1.

withhold payments if progress is not satisfactory. This leaves FAA with little flexibility other than terminating a contract if performance problems arise.

The Free Flight Phase 1 Office recognizes the drawbacks to using time and material contract vehicles for CTAS development and is considering options, including using alternative pricing arrangements, award fees, and incentives. This is an important lesson for other modernization efforts--FAA should avoid such arrangements when contracting for software intensive efforts in the future.

### **RECOMMENDATIONS**

Software development for Conflict Probe and CTAS represent risks to the cost and schedule of FAA's Free Flight Phase 1 initiative. FAA has opportunities to take proactive steps to strengthen oversight of software development. Enhanced earned value management and software metrics will allow FAA decision-makers to recognize problems sooner and to take corrective actions.

We recommend that FAA:

1. For future software contracts, negotiate contracts with provisions for earned value management and software metrics. Contracts should include methods for withholding payments if the use of earned value management techniques by contractors is not adequate or progress is not commensurate with costs billed.
2. Require Free Flight Phase 1 contractors to correct deficiencies and fully implement reliable earned value management techniques.
3. Identify and define specific software metrics for Free Flight Phase 1 technologies, and require software development contractors to report on software metrics at periodic management reviews.

### **ACTION REQUIRED**

In accordance with Department of Transportation Order 8000.1c, we would appreciate receiving your written comments within 30 working days. If you concur with our finding and recommendations, please indicate for each recommendation the specific action taken or planned and the target dates for completion. If you do not concur, please provide your rationale. Furthermore, you may provide alternative courses of action that you believe would resolve the issues presented in this report. We are continuing our review of the Free Flight Phase 1 program and will issue a separate report on that work.

We appreciate the cooperation and assistance provided by you and your staff. If you have any questions, please call me on 366-1992, or Mr. David A. Dobbs, Acting Deputy Assistant Inspector General for Aviation, on 366-0500.

**FREE FLIGHT PHASE 1 TECHNOLOGIES**

<b>Capability</b>	<b>Functions</b>	<b>Planned Locations</b>
<b>CONFLICT PROBE</b>  (USER-REQUEST EVALUATION TOOL)	Provides en route controllers with future conflict situations, up to 20 minutes prior to the start of the conflict, and allows controllers to grant user requests for routes or resolve conflicts through the use of trial planning capability.	<u>CENTER</u> Atlanta Chicago Cleveland Indianapolis Kansas City Memphis Washington, D.C.
<b>CENTER-TRACON AUTOMATION SYSTEM</b>  • Traffic Management Advisor - Single Center  • Passive Final Approach and Spacing Tool	Helps aircraft transition from en route to terminal airspace by generating statistics and reports about the traffic flow, and computes the scheduled time of arrival and runway assignments for each aircraft.	<u>CENTER</u> Atlanta Chicago Fort Worth Denver Los Angeles Miami Minneapolis Oakland
	Calculates and displays landing sequence numbers and runway assignments.	<u>TRACON</u> Atlanta Chicago Dallas/Fort Worth Los Angeles St. Louis Minneapolis
<b>COLLABORATIVE DECISION MAKING</b>	A collection of tools that allow the FAA and participating airlines to electronically exchange and analyze flight, capacity and status information.	Air Traffic Control System Command Center and Participating Airline Operation Centers
<b>SURFACE MOVEMENT ADVISOR</b>	Provides real-time data about aircraft position and estimated touchdown time to ramp control operators.	<u>AIRPORTS</u> Atlanta Chicago Dallas/Fort Worth Detroit Newark Philadelphia Teterboro

