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EMBEDDED COMPUTER SYSTEMS

C-17 Software Development Problems

Statement for the record by
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Mr. Chairman and Members of the Subcommittee:

I am pleased to submit this statement for the record as part of the Subcommittee's hearings on the C-17 aircraft program. This statement reflects GAO's work to date on the development and acquisition of C-17 embedded computer systems. We plan to issue a report at a later date.

As you know, the use of embedded computers and complex operating software in weapons systems has increased dramatically, and will continue to do so. Software, however, has been called the Achilles heel of weapons development. It is estimated that 7 out of 10 major weapons systems in development today are encountering major software problems. The C-17 is no exception.

RESULTS IN BRIEF

The Air Force originally anticipated "low-risk" software development for the C-17, but the effort has turned out to be much more complex and risky than planned. The Air Force planned to use existing operational software previously developed and tested for other systems and proven avionics technology to reduce the complexity and technical risks associated with C-17 development. It expected to have full operational functionality for the C-17's first flight, originally scheduled for February 1990.

However, for many critical C-17 functions, the prime contractor--Douglas Aircraft Company, a subsidiary of McDonnell Douglas Corporation--and its team of subcontractors could not simply reuse existing software, but had to develop substantial amounts of new code. Because this was unexpected at the outset, schedules were delayed and development plans changed. The first flight test did not occur until September 15, 1991--19 months after originally scheduled--and did not include many of the critical software functions required for the fully operational aircraft, such as certain key navigational capabilities. These functions are not expected to be ready until the Spring of 1992 at the earliest. Further, in providing software for the first flight test, shortcuts were taken that will likely cause further delays and increased costs.

BACKGROUND

The C-17 will be the most software-intensive transport aircraft ever built. It depends on 56 avionics subsystems and the integration of 1,356,000 lines of software code[1] to perform mission-critical functions such as communications, flight controls, and navigation. These automated systems, which include 18 embedded computers and 55 microprocessor applications, are

[1]This figure includes approximately 614,000 lines of newly developed and 742,000 lines of reused (i.e., government- or contractor-furnished) software.

expected to eliminate the need for a navigator and flight engineer.

At the beginning of the program, the Air Force expected C-17 avionics development to be low-risk since the technology associated with C-17 avionics was not new and featured many systems used on other military aircraft. The Air Force, however, underestimated the difficulty and scope of the software requirements, having identified only four avionics software applications that would require special development and management attention. When the Air Force negotiated a fixed-price contract with Douglas in 1985 for full-scale engineering development of the C-17, it believed software development would be low risk. Douglas had vast experience in developing aircraft, but little experience in developing and integrating complex software with avionics systems.

Neither the Air Force nor Douglas focused management attention on developing and testing software, which Defense oversight officials contend is the primary cause of most C-17 software development problems. As C-17 development progressed, Douglas and its subcontractors relied on computers and software to resolve serious hardware problems, including flight control problems under certain conditions, and to meet mission-performance requirements. By 1988, a series of outside audits had found a number of C-17 software development problems, such as the Air Force's failure to

require an adequate software quality assurance program. Because of the fixed-price contracting arrangement with Douglas, the Air Force did not have the control needed to make changes to the software development approach when problems became evident.

Douglas and the Air Force took some actions to address these problems and tried to make up for the schedule delays that had occurred. Douglas significantly increased management and technical expertise by adding over 140 corporate engineers experienced in electronic avionics systems, system laboratory testing, equipment management, and scheduling and simulation to its avionics and flight-control development teams. In addition, Douglas identified over 60 additional software subsystems that needed stringent software development management attention. The Air Force and Douglas also agreed to defer development and testing of significant software functions to avoid further schedule delays. These functions are being deferred to future versions of the C-17 aircraft.

MISSION-CRITICAL SOFTWARE NOT YET WRITTEN

When the first C-17 aircraft (T-1) flew on September 15, 1991, it contained about 66 percent of the software that needed to be developed to provide full avionics functions. Douglas and the Air Force changed the original software development and test schedule

to focus activities on functions required for the first 100 hours of the flight test program, i.e., basic flying requirements and flight safety functions.

According to the program office, many of the functions not included in the test aircraft are critical to C-17 operational missions, but are not required for basic flying. The specific software functions deferred vary by subsystem, and include such functions as navigational capability for rendezvous and airdrop; providing horizontal and vertical speed commands, and guidance from the navigational subsystems.

Douglas plans to add the missing functionality with two incremental software upgrades. The first of these increments (designated P-2 software) is scheduled for March 1992, and is intended to include most of the C-17's operational software requirements. A later increment, expected to be completed by 1993, is intended to complete the avionics software.

SOFTWARE TESTING APPROACH INCREASES PROGRAM RISK

Actions taken to avoid further flight-test schedule delays have increased the software development risk to the C-17 program. To maintain the C-17's revised flight schedule, Douglas adjusted its initial plans for preflight tests of C-17 avionics software. Although steps were taken to test and validate the software needed

to safely fly the plane, other software testing was deferred to the avionics test aircraft (P-2).

Douglas, along with its team of subcontractors, completed software coding and laboratory testing of the T-1 software without approved specifications for software functions or performance. The Air Force has yet to approve a software specification on the C-17. Current software is being written to unapproved draft specifications. Any changes needed for approval of these specifications could mean that the software may have to be redesigned, rewritten, and retested.

PROGRAM DECISIONS MAY INCREASE C-17 SUPPORT COST

The Air Force has waived requirements for providing reserve computer processing and memory capacity. These decisions may raise C-17 program support costs. Computer systems will function on the C-17 throughout the aircraft's life cycle, estimated at 20 years. During that time, the computer systems will inevitably have to be enhanced to perform new functions and respond to new threats. In order to do this without having to replace hardware, the system must be sized to include enough reserve capacity to permit future growth.

However, the Air Force reduced allowances for reserve processing capacity and memory for several of the most critical computers even before flight testing began. Originally, the C-17 specification required that, in the worst case, no more than 70 percent of the computer's processing capacity and 60 percent of the computer's memory be used during development. However, for the critical warning and caution computer, processing use is up to 77 percent and memory use is up to 69 percent, and further increases in system utilization can be expected as additional software is developed. If the C-17 continues development with reserve processing capacity and memory less than originally specified, expensive replacements or upgrades to computer hardware may be necessary early in the aircraft's life cycle.

In addition, C-17 software is being written in several computer languages (for example, JOVIAL, C, and assembly). Software maintenance--the process of modifying software to correct deficiencies and incorporate new mission functionality, new threats, technological advances, and changes in subsystems after deployment--can account for 70 percent or more of total life-cycle software cost for a weapons system. The Air Force originally specified JOVIAL as the standard computer language for the C-17. However, it relaxed this requirement to allow subcontractors to write software in languages with which they had experience. Thus far, 57 percent of newly developed software and 26 percent of total C-17 software is written in JOVIAL. While the

use of multiple languages is sometimes justified, support and maintenance costs for such software may be higher than for use of a single language.

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We are currently preparing a detailed report for the Committee on the C-17 issues briefly described in this statement. This report will discuss in greater detail the increased risks that the Air Force has taken in its management approach to developing the C-17.