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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 summarizing our recent report Embedded Computer Systems: Significant Software Problems on C-17 Must Be Addressed (GAO/IMTEC-92-48, May 7, 1992), as part of the Subcommittee's hearings on the C-17 aircraft program. This is one in a series of reports we have recently issued on major weapons systems' software development.

Realizing the importance of software to the C-17's mission, the Subcommittee asked us to assess the Air Force's management of the aircraft's software development, and to identify any software problems that could increase future risks to the program. We found that the C-17 program is a good example of how not to develop software for a major weapons system. Program officials initially assumed that software was a low-risk part of the C-17 program, and did not adequately assess or manage its software development. Program officials subsequently found that they often lacked specific knowledge about software problems when they first occurred, and did not ensure that the prime contractor--Douglas Aircraft Company, McDonnell Douglas Corporation--took timely corrective action.

After software problems became a major concern in 1988, Douglas and the Air Force increased the emphasis on software development and acted to improve software management. Unfortunately, these actions alone were not enough to keep software development and

testing on schedule. As a result, the Air Force and Douglas took a number of development shortcuts to meet flight test schedules. For example, shortcuts in pre-flight testing may make initial test results unreliable, and may reduce the computer capability of the early C-17 aircraft. In addition, other actions taken to reduce schedule delays may result in substantially higher software maintenance costs when the C-17 is eventually fielded.

BACKGROUND

The Air Force plans to buy 120 C-17 aircraft for approximately $36 billion. This new transport aircraft is designed to airlift large payloads and oversized cargoes onto small airfields. It will be the most computerized, software-intensive transport aircraft ever built, with 19 different embedded computers incorporating over 80 microprocessors and about 1.3 million lines of software code. These computers are essential for the C-17 to accomplish its mission, and are intended to eliminate the need for a navigator and flight engineer--the first transport aircraft with such a capability.

The Air Force began the C-17 program in 1981, contracted with Douglas in 1982, and entered full-scale development in 1985. The C-17 development program is now over 2 years behind schedule and, according to the Air Force, $1.5 billion over the Air Force's 1985 initial development cost estimate of $4.1 billion. In

addition, DOD estimates that Douglas will exceed the $6.6 billion contract ceiling price for development and the first two production options by over $800 million. Under the fixed-price contract, Douglas is responsible for all costs above the ceiling price.

At the start of the development program, the Air Force planned to use proven technology and existing operational software to reduce the complexity and technical risks associated with C-17 software development. The Air Force intended that software developed for the first aircraft would satisfy all of the C-17's operating requirements. However, both Douglas and the Air Force underestimated the difficulty and scope of the software development effort. As development progressed, Douglas and its subcontractors began to rely more on software to meet mission requirements and resolve serious aircraft hardware problems. The total number of specific software subsystems on the C-17 grew from 4 in 1985 to 56 in 1990.

NEITHER THE AIR FORCE NOR DOUGLAS ADEQUATELY MANAGED SOFTWARE DEVELOPMENT

Because the Air Force underestimated software complexity, it did not contractually require Douglas to follow many basic software planning steps, institute good quality assurance practices, or separately track and report the status of software development

activities. Consequently, the Air Force often lacked specific knowledge about software development problems as they occurred and, due in part to contractual constraints, did not ensure that Douglas would take corrective action. As awareness of software development problems grew, both the Air Force and Douglas acted to address these problems and the schedule delays that had occurred. Unfortunately, this increased attention came too late to effectively manage the degree of risk associated with the C-17's development.

When the test aircraft flew on September 15, 1991--19 months after originally scheduled--it contained only about two-thirds of the newly-developed software needed for the C-17 to meet all of its operational requirements. Because of problems and delays in developing and testing the software, the Air Force allowed Douglas to delay completion and installation of many mission-critical software functions. Douglas had planned to add the missing functions with incremental software upgrades on the second production aircraft (designed to test avionics software), then scheduled for delivery in December 1991.

However, because Douglas diverted much of its resources away from software development and testing of the production aircraft to complete first flight of the test aircraft, the C-17 schedule has suffered delays. The Air Force now estimates that the second

production aircraft will be available next month, but it will not have all of the required software until late this year.

Even with this adjusted schedule, the Air Force allowed Douglas to take a number of other shortcuts to meet the first flight target date. These shortcuts have increased the risk of completing software development and testing. Douglas and its subcontractors completed software coding and pre-flight software testing without approved specifications. As of this past February, the Air Force had not approved any of the C-17's draft software specifications. Douglas also conducted concurrent pre-flight testing and deleted planned software tests. In one case, Douglas eliminated the entire (and perhaps the most important) test of the C-17's ability: to take off and land on short runways. While these shortcuts may have been necessary to keep to schedule, the test results may not be reliable and software problems may go undetected.

Computer system development decisions were also made that may well drive up long-term hardware and software maintenance costs over the C-17's expected 25-year life span. The Air Force did not require Douglas to develop adequate system integration documentation. Thus, the Air Force may have great difficulty upgrading, testing, and maintaining C-17 computer systems once the C-17 is in operation.

The Air Force has also established a very complex and potentially expensive software maintenance environment by developing C-17 software in a diverse assortment of languages. This multiple language environment will likely escalate software maintenance costs, though the Air Force may eventually convert some C-17 software to the DOD standard language--known as Ada--when making major software modifications.

In addition, the C-17's embedded computers need sufficient spare processing and memory capacity to service future growth. Because of the unanticipated complexity of the software, however, Douglas has been unable to meet the spare capacity for several of the most critical computers. To allow first fight to take place last September, the Air Force waived this spare capacity requirement. Because plans to restore the reserve capacity of these computers remain unresolved, the risk that expensive replacements or upgrades to computer hardware will be required earlier than they would otherwise occur has been increased.

In the Fiscal Years 1992-93 Defense Authorization Act, the Congress slowed the C-17 production schedule and restricted contractor funding until program milestones have been met. In addition, the Congress directed DOD to assess C-17 mission capabilities (referred to as an "Early Operational Assessment") following completion of the first 50 hours of the operational

flight test. This assessment is scheduled to be completed by the end of this year.

CONCLUSIONS AND RECOMMENDATIONS

We endorse congressional efforts to slow the program and to require an assessment of C-17 operational performance prior to large-scale production. We believe the assessment should include a thorough analysis of the type of software development risks that we have highlighted today and noted in our report. Accordingly, we have recommended that the Secretary of Defense expand the assessment to

-- evaluate the impact of software risks on the C-17 development and flight test program and determine how the Air Force intends to mitigate these risks,
-- evaluate the Air Force's plans to ensure that software support documentation is adequately prepared and approved,
-- assess the Air Force's strategy for evaluating the merits of converting software to Ada when major software modifications are made, and
-- determine ways to reduce the impact of limited computer capacity on long-term maintenance costs of the C-17.