

**A**udit



**R**eport

C-17 LANDING-GEAR DURABILITY AND PARTS SUPPORT

Report No. 99-193

June 24, 1999

Office of the Inspector General  
Department of Defense

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June 24, 1999

MEMORANDUM FOR ASSISTANT SECRETARY OF THE AIR FORCE  
(FINANCIAL MANAGEMENT AND COMPTROLLER)

SUBJECT: Audit Report on C-17 Landing-Gear Durability and Parts Support  
(Report No. 99-193)

We are providing this report for your information and use. This is the second in a series of reports on life-cycle management of military aircraft landing gear. We considered management comments on a draft of the report and other documentation that management provided in preparing this final report. Based on further discussion with management, we revised the finding and revised the first recommendation. The C-17 System Program Office comments conformed to the requirements of DoD Directive 7650.3 and left no unresolved issues. Therefore, additional comments are not required.

We appreciate the courtesies extended to the audit staff. Questions on the audit should be directed to Mr. Charles M. Santoni at (703) 604-9051 (DSN 664-9051) (csantoni@dodig.osd.mil) or Ms. Delpha W. Martin at (703) 604-9075 (DSN 664-9075) (dwmartin@dodig.osd.mil). See Appendix B for the report distribution. Audit team members are listed inside the back cover.

A handwritten signature in black ink that reads "Robert J. Lieberman".

Robert J. Lieberman  
Assistant Inspector General  
for Auditing

## Office of the Inspector General, DoD

Report No. 99-193

(Project No. 8AL-3002.01)

June 24, 1999

### C-17 Landing-Gear Durability and Parts Support

#### Executive Summary

**Introduction.** This report addresses C-17 landing-gear durability and tire and brake support. This report is the second in a series on the life-cycle management program for military aircraft landing-gear parts. The first report addressed the serialization of fracture-critical and landing-gear parts for the C-17.

**Objectives.** The overall audit objective was to determine whether the Military Departments were making provisions for landing-gear life-cycle management programs on aircraft acquisition and modification programs. The objective of this segment of the audit was to determine whether the C-17 System Program Office was providing life-cycle management of landing-gear durability and support. We also reviewed the management controls applicable to that objective.

**Results.** Design of the C-17 landing-gear posts and trunnions had not been sufficiently stabilized to enable the C-17 System Program Office to fully project life-cycle management cost of landing-gear support. If the contractor is unable to extend the life of those parts, through redesign, past the 1.5 lifetimes of durability testing warranted in the contract, and those parts are declared life-limited, the Government costs for C-17 landing-gear support over the life of the C-17 fleet could increase \$133.2 million for landing-gear posts and \$5.2 million for trunnion collars. In addition, because of a much higher usage rate than anticipated in the original specifications, support costs could increase as much as \$813.5 million for brakes and about \$29 million for tires over the life of the C-17 fleet. The development of an improved main landing-gear tire could result in potential monetary benefits of approximately \$1.8 million for FYs 1999 through 2005. See the Finding section for details and Appendix E for a summary of potential monetary benefits. Management controls were adequate as they applied to the overall objective.

**Summary of Recommendations.** We recommend that the C-17 System Program Office address life-cycle support costs of the C-17 in its risk assessment program, taking into consideration the premature failures in test results and increased usage of expendable parts in operations; evaluate the improved main landing-gear tire and whether cost benefits justify its procurement; and assess the feasibility of an improved brake design without a redesign of the wheel and axle.

**Management Comments.** The C-17 System Program Office concurred with the recommendations and stated it would continue to address life-cycle support costs in its risk assessment program and program funds as necessary to manage all risks identified. The C-17 System Program Office also indicated that efforts to address the life-cycle cost benefits of replacing the current tire with a new tire that supports three retreads are already in the planning stages. However, a new aircraft modification may increase the gross weight of the C-17, therefore, the tire replacement effort is on hold until the final gross weight of the aircraft is available. The C-17 System Program Office also stated

that it has updated the brake procurement specification, and several vendors have submitted new brake design proposals to the contractor. The complete text is in the Management Comments section of this report.

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## Background

The C-17 is a four-engine, heavy-lift, long-range military transport aircraft with a short take-off and landing capability. The aircraft was designed to modernize the airlift fleet and to improve the ability of the United States to rapidly project, reinforce, and sustain combat forces worldwide. The C-17 provides airlift capability for outsized combat equipment equivalent to the larger C-5 aircraft and provides short-field performance similar to the C-130 aircraft. In August 1981, the C-17 System Program Office selected Boeing Corporation (previously McDonnell Douglas Corporation) to develop the C-17.

The C-17 aircraft program achieved initial operational capability in January 1995 when 12 aircraft were deployed to the 437th Air Wing at Charleston Air Force Base in South Carolina. The Defense Acquisition Board approved the C-17 for Milestone IIIB, full-rate production, in November 1995. At that time, the Defense Acquisition Board approved Air Force plans to procure 120 C-17. Total research, development, and procurement cost was projected at \$42.2 billion.

The C-17 system specifications impose a demanding set of reliability and maintainability requirements. The requirements include an aircraft mission completion success probability of 93 percent, 18.6 aircraft maintenance man-hours per flying hour, and a full and partial mission capable rate of 74.7 and 82.5 percent respectively for a mature fleet with 100,000 flying hours. The C-17 measures approximately 174-feet long with a 170-foot wingspan. Maximum payload capacity is 170,900 pounds, and maximum gross takeoff weight is 585,000 pounds. With a payload of 130,000 pounds and an initial cruise altitude of 28,000 feet, the C-17 has a fuel range of about 5,200 nautical miles. Its cruise speed is approximately 450 knots. The C-17 landing-gear design service life for fatigue, durability, and damage tolerance analyses of structural elements is based on 30,000 flying hours and 18,909 landings<sup>1</sup> (11,291 full-stop landings,<sup>2</sup> 4,592 touch-and-go landings, and 3,026 small austere airfield landings<sup>3</sup>).

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<sup>1</sup> Reference McDonnell Douglas Corporation S001D, "C17A Peacetime Design Mission Profiles," February 2, 1996.

<sup>2</sup> Full stop or normal landing: The aircraft should be capable of safe and routine landings on a 3,950-foot long by 90-foot wide paved runway.

<sup>3</sup> Small austere airfield landing: The aircraft should be capable of maximum effort landings on a 3,000-foot long by 90-foot wide paved runway

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## Objectives

The overall audit objective was to determine whether the Military Departments were making provisions for landing-gear life-cycle management programs on aircraft acquisition and modification programs. The objective of this segment of the audit was to determine whether the C-17 System Program Office was providing life-cycle management of landing-gear durability and support. We also reviewed the implementation of management controls applicable to that objective. See Appendix A for details of the review of the management control program.



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## C-17 Landing-Gear Durability

Designs of certain C-17 landing-gear parts have not been sufficiently stabilized to enable the C-17 System Program Office to fully project life-cycle management cost of landing-gear support. Because the contractor produced brakes that did not meet contract specifications:

- C-17 landing-gear posts and trunnions experienced repeated failures during durability testing.
- Low-cycle-time landing-gear inspections identified main landing-gear post failures.
- Tires and brakes experienced a much higher usage rate than anticipated.

If the contractor is unable to extend the life of landing-gear posts and trunnions, through redesign, past the 1.5 lifetimes of durability testing warranted in the contract, and those parts are declared life-limited, the Government costs for C-17 landing-gear support over the life of the C-17 fleet could increase \$133.2 million for landing-gear posts and \$5.2 million for trunnion collars. In addition, because parts have a much higher usage rate than anticipated in the original specifications, support cost could increase as much as \$813.5 million for brakes and about \$29 million for tires over the life of the C-17 fleet.

## Performance of C-17 Landing Gear, Tires, and Brakes

**Landing Gear.** The landing-gear specification requires the contractor to analytically demonstrate that the landing-gear design can withstand four lifetimes of use. The forward and aft main landing-gear design and the nose landing-gear design analytically demonstrated the ability to withstand four lifetimes of use without failure. The landing-gear specification also requires that the main landing gear and the nose landing gear demonstrate four lifetimes of use through full-scale testing (durability testing).

The terms of the C-17 contract state that the contractor will bear the total costs associated with redesign, production incorporation, and retrofit, if a failure occurs within the first 1.5 lifetimes of durability testing. If a failure occurs after 1.5 lifetimes of durability testing, the contractor is responsible for redesign only and the Air Force is responsible for the cost of production incorporation and retrofit. The C-17 System Program Office has been proactive in holding the contractor responsible for the redesign and retrofit costs associated with parts that failed during durability testing prior to the completion of 1.5 lifetimes of testing. Conversely, a test failure could result in a decision, based on life-cycle cost management criteria that accepts a part with a limited lifetime. Successful completion of analytical and test demonstration would yield a landing gear having no life-limit over the aircraft lifetime.

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The C-17 System Program Office conducted low-cycle-time landing-gear inspections and identified main landing-gear post damage early in the life of the C-17 program. The C-17 System Program Office and the contractor took corrective actions to rework the damaged posts on fielded aircraft. The main landing-gear posts used in the durability tests were reworked after 0.25 lifetimes on an unrelated durability problem. The forward main post failed at 0.45 lifetimes of durability testing. Redesign and testing has been continuing on the main landing-gear posts.

The results of durability tests on the nose and main landing gear components are shown in Appendix B. Appendix B, Figure B-2, shows that the aft main landing-gear trunnion collar initially failed at 0.63 lifetimes. After replacing that trunnion collar with a redesigned trunnion collar, durability testing resumed and the aft main landing gear trunnion collar failed again at 1.60 lifetimes. The trunnion design was redesigned and is undergoing durability testing. Appendix B, Figure B-3, shows that the forward main landing gear trunnion collar initially failed at 0.045 lifetimes. A redesigned trunnion collar was installed and reached 1.0 lifetimes of durability testing on October 21, 1998.

**Tires.** The original specification for C-17 tires required that the nose and main landing-gear tires last 400 landings and that each tire support one retread. C-17 tires use nylon cords to form the carcass on which a rubber formulation is applied. Based on initial usage data, tires were not lasting the required 400 landings. The C-17 System Program Office implemented a field evaluation plan to address tire performance. The contractor developed an improved tire compound to extend the life of C-17 tires. The improved tires increased the number of landings per tire to approximately 180 for the nose tire and 300 for the main tire. The C-17 System Program Office accepted the improved tire, while holding the requirement to retread once. At the same time, the C-17 System Program Office changed the specifications for the nose tire to 180 landings and the main tire to 305 landings.

**Brakes.** The original specification for C-17 brakes required each main landing-gear brake to last approximately 1,950 landings. Based on operational usage, each brake was lasting an average of 600 landings. Each C-17 main landing gear contains a total of 12 brakes. The C-17 brake uses carbon stators and rotors. The brake was designed to withstand an average operating temperature of 320 degrees Celsius. The carbon stators and rotors that comprise the brake are coated with an anti-oxidant that can withstand 450 degrees Celsius without deterioration. The C-17 has a brake temperature indicator in the cockpit. Based on observed brake failures, the brakes were sustaining heat damage. An analysis demonstrated that the actual brake temperature was 1.8 times greater than the temperature readings in the cockpit. When the cockpit brake temperature indicator was reading 320 to 450 degrees Celsius, the actual brake temperature was 575 to 810 degrees Celsius. Therefore, actual brake temperature was exceeding the design capabilities of the brake without the knowledge of the pilots. Analysis of C-17 operations showed that multiple types of landings containing various braking maneuvers were being performed repetitively, without sufficient time for brake cooling. If proper

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cooling time is not allowed, the carbon stators and rotors cannot dissipate the heat and will deteriorate. The rapid cycling of the brakes without allowing sufficient time to cool causes a high-rate of brake failure.

## **Support Costs of C-17 Landing Gear, Tires, and Brakes**

The C-17 System Program Office is working with the contractor to ensure that the contractor corrects the deficiencies in landing-gear parts design that resulted in parts failures during durability testing. Program Office personnel indicated that they, along with the contractor, have thoroughly analyzed the durability test failures. The contractor has redesigned the parts that failed prematurely during durability testing. The contractor, through analysis, expects the redesigned parts to exceed the four-lifetime requirement of durability testing. If the actions taken by the C-17 System Program Office and the contractor result in the achievement of the four-lifetime requirement for the landing-gear posts and trunnions, significant cost avoidance will be achieved. Conversely, if the contractor is unable to extend the life of those parts past the 1.5 lifetimes of durability testing warranted in the contract, the Program Office would have to decide whether to require the contractor to redesign the parts or declare the parts life-limited. The Program Office decision will be based on a comparison of nonrecurring and recurring costs of the new design with the costs required to maintain the fleet with the old part designs. If the Program Office requires the contractor to redesign the parts, the contractor would be responsible for all costs associated with the redesign. The government, however, would be responsible for the cost associated with production, incorporation, and retrofit. Assuming the Program Office decided to life-limit the post and trunnion after they achieve 1.5 lifetimes in durability testing, government life-cycle cost could exceed:

- \$133.2 million to replace the forward main landing-gear posts for the fleet of 120 C-17 (See Appendix B for cost calculations), and
- \$5.2 million to replace the main landing-gear trunnion collars for the fleet of 120 C-17 (See Appendix B for cost calculations).

Tires and brakes have experienced a much higher usage rate in operations than anticipated. Because they have not met the original specifications, Government life-cycle costs could increase by as much as:

- \$29 million to provide additional tires for a fleet of 120 C-17 (See Appendix C for cost calculations).
- \$813.5 million to provide brakes for a fleet of 120 C-17 (See Appendix D for cost calculations).

The C-17 System Program Office needs to address the potential for appreciable increases in life-cycle support cost in its C-17 risk assessment program to minimize the adverse impact of those costs on the total cost of C-17 ownership. The risk assessment should consider the impact of premature parts failures during durability testing, parts failures encountered during operations, Class A

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Mishaps attributed to landing-gear failure, and the ability of the landing gear to either achieve a full life (four lifetimes of durability testing) or a limited life (less than four lifetimes of durability testing), taking into consideration the contractor warranty of 1.5 lifetimes of durability testing.

## **Other Considerations With Respect to C-17 Landing Gear, Tires, and Brakes**

**Landing Gear.** In a typical aircraft development program, production aircraft delivery before the completion of durability testing is common. The C-17 System Program Office concluded airframe durability testing in a timely manner. The airframe durability test was initiated in March 1993 and was concluded in July 1995, corresponding to the delivery of production aircraft number 19. At that point, the C-17 System Program Office opted to fund the contractor to extend the airframe durability test by an additional lifetime beyond the original contract requirement. Initially, the C-17 System Program Office predicted that the landing-gear durability tests would be completed concurrently with the airframe durability test.

The durability testing of the C-17 landing gear was defined by three major test articles: the nose landing gear, the aft main landing gear, and the forward main landing gear. Durability testing of the nose landing gear commenced the first quarter of FY 1995, corresponding to the delivery of aircraft 15. Durability testing of the aft main landing gear commenced the second quarter of FY 1995, corresponding to the delivery of aircraft 18. Durability testing of the forward main landing gear commenced the second quarter of FY 1997, corresponding to the delivery of aircraft 30. Delays in completing durability testing were caused by test machine and main landing-gear part failures. In addition, complications in determining the loads on the forward main landing gear and the design differences between the forward and aft landing gear precluded straightforward prediction of the durability of the forward main landing gear. As of October 1998, the contractor has completed 1.5 lifetimes of durability testing on the forward main landing gear and 1.7 lifetimes of durability testing on the aft main landing gear. Additional testing is required on the forward and aft main landing gear because of replaced parts, which include the post and trunnion collar. The C-17 System Program Office has been diligent in ensuring that the contractor retains the liability to redesign the landing-gear failed parts to satisfy the service-life requirement in accordance with the contract warranty provisions. Further, the C-17 System Program Office has held the contractor accountable for retrofitting the C-17 fleet with redesigned parts. The durability test schedule may not be completed until the delivery of aircraft 54, scheduled for delivery second quarter FY 2000 (See Appendix B). Therefore, the System Program Office may not have a fully qualified landing gear until 45 percent of the entire production of 120 aircraft is complete. The schedule is only valid if no further test problems arise. The C-17 System Program Office could incur major life-cycle cost increases if the landing gear does not successfully complete its durability tests in a timely manner. As shown in Appendix B, the replacement costs for the forward main landing-gear post alone could exceed \$133.2 million over the life of the C-17 fleet.

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**Tires.** The current C-17 tire was improved through the use of a new rubber formulation. The contractor was exploring further improvements to the C-17 tire. The contractor was participating in a generic research and development project to improve tire life in conjunction with the Air Force and aircraft tire manufacturers. The project was funded through the Air Force Manufacturing Technology Program and received additional funding support from the C-17 contractor and aircraft tire manufacturers. The project undertook the development of a C-17 main tire that can support three retreads, satisfy Federal Aviation Administration tire certification standards, and accommodate C-17 weight growth beyond 585,000 pounds. The project yielded a design that adds two nylon plies to the carcass of the tire and a greater tread thickness to satisfy the ability to retread the tire three times. The tire would possess the same rubber formulation as the current C-17 tire. The C-17 System Program Office rejected the tire design because of weight increases to the aircraft. If the tire were to be fully developed and qualified, it would weigh approximately 35 to 40 pounds more than the current tire, which would add an additional 420 to 480 pounds of weight to the C-17, a weight increase to the aircraft of 0.08 percent. As delineated in Appendix C, the new main tire has the potential to save approximately \$8.8 million over the life cycle of the C-17 fleet. Potential monetary benefits are summarized in Appendix E. The C-17 System Program Office should evaluate the tire redesign based on the small remaining development costs, minimal weight penalty to the aircraft, and significant life-cycle costs avoided.

**Brakes.** The C-17 System Program Office performed studies that show that redesigning the brakes could increase the brake volume by 20 percent. The volume increase would require redesign of the wheel and axle to accommodate the increased size of the brake. Wheel and axle redesign would affect the load paths and, thus, affect the rest of the gear design. Such an extensive modification would require the initiation of a new durability test. The C-17 contractor conducted a limited study on the use of improved brake materials. A redesign of the landing gear wheel and axle is not a consideration in the improved brake material study. The data in Appendix D demonstrate that at the current rate of brake replacement C-17 brake life-cycle cost could increase over planned cost by as much as \$813.5 million. The increased brake life-cycle cost provides sufficient justification for the C-17 System Program Office to pursue the use of improved materials for brake design modification.

## Conclusion

Acquisition reform initiatives include improving management of life-cycle cost while initiating actions to shift budgetary resources from support to modernization and combat resources. Based on the durability-testing schedule, the contractor will have produced almost half of the C-17 before completing landing-gear durability testing. Until durability testing of the landing gear is completed, the C-17 System Program Office will not be able to accurately project or program appropriate support funding. Further, because expendable parts have experienced a much higher usage rate than anticipated, the life-cycle costs of those parts could increase appreciably. The cost avoidance of potential increases in life-cycle support costs for the C-17 is a challenge that the C-17 System Program Office needs to resolve. The C-17 System Program

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Office needs to address these issues in its C-17 risk assessment program to minimize the adverse impact of life-cycle support cost on the total cost of C-17 ownership. Further, the C-17 System Program Office needs to determine the benefits of developing the improved main landing-gear tire and the feasibility of developing an improved brake without redesigning the wheel and axle.

## **Recommendations, Management Comments, and Audit Response**

**Revised and Deleted Recommendations.** Based on discussions with the Program Director, C-17 System Program Office, we revised the finding and the first recommendation of a draft of this report and requested Management Comments on those revisions. Management's Comments on those revisions are included in the Management Comments section.

**We recommend that the Program Director, C-17 System Program Office:**

- 1. Address the life-cycle support costs of the C-17 in its C-17 risk assessment program taking into consideration the pre-mature failures in test results and the increased usage of expendable parts in operations until appropriate life-cycle support costs can be accurately programmed.**
- 2. Evaluate the improved main landing-gear tire and determine whether total-ownership-cost benefits would justify its procurement.**
- 3. Determine whether the contractor can develop an improved brake design through the use of improved materials without a redesign of the wheel and axle.**

**Management Comments.** The C-17 System Program Office concurred with the recommendations and stated it would continue to address life-cycle support costs in its risk assessment program and program funds as necessary to manage all risks identified. The C-17 System Program Office also indicated that efforts to address the life-cycle cost benefits of replacing the current tire with a new tire that supports three retreads are already in the planning stages. However, a new aircraft modification may increase the gross weight of the C-17, therefore, the tire replacement effort is on hold until the final gross weight of the aircraft is available. The C-17 System Program Office also stated that it has updated the brake procurement specification, and several vendors have submitted new brake design proposals to the contractor. The complete text is in the Management Comments section of this report.

**Audit Response.** The C-17 System Program Office management comments are fully responsive. If the System Program Office decides to replace the current tire with one that supports three retreads or to develop an improved brake design, the information on monetary benefits associated with those decisions should be provided to the Inspector General, DoD.

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# Appendix A. Audit Process

## Scope

We conducted this economy and efficiency audit from January through November 1998 and reviewed data covering March 1994 through October 1998. To accomplish the objective, we:

- examined the multi-year production contract F33657-96-C-2059 and the Flexible Sustainment Contract F33657-97-C-0008, including statements of work, warranty coverage, and related correspondence;
- reviewed maintenance data for the C-17 landing gear;
- examined C-17 test reports for landing gear and related engineering analyses of those tests; and
- Discussed issues and contractor corrective actions on C-17 landing gear tests with the C-17 System Program Office, the operational and training commands, and the contractor.

**DoD-Wide Corporate-Level Government Performance and Results Act Goals.** In response to the Government Performance Result Act, the Department of Defense has established 6 DoD-wide corporate-level performance objectives and 14 goals for meeting the objectives. This report pertains to achievement of the following objective and goal.

**Objective:** Fundamentally reengineer DoD and achieve a 21<sup>st</sup> century infrastructure. **Goal:** Reduce costs while maintaining required military capabilities across all DoD mission areas. **(DoD-6)**

**DoD Functional Area Reform Goals.** Most major functional areas have also established performance improvement reform objectives and goals. This report pertains to achievement of the following functional area objectives and goals.

### **Acquisition Functional Area.**

- **Objective:** Deliver great service. **Goal:** Deliver new major Defense systems to the users in 25 percent less time. **(ACQ-1.1)**
- **Objective:** Internal reinvention. **Goal:** Minimize cost growth in major Defense acquisition programs to no greater than 1 percent annually. **(ACQ-3.4)**

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## Methodology

**Use of Computer-Processed Data.** We reviewed computer-processed data from the on-line Maintenance System for Airlift (the GO81 system). We evaluated the competency and completeness of data. We established that data were accurate for the specified audit purpose, but were not complete. The incomplete data did not affect the results of this audit.

**Use of Technical Assistance.** We used technical support from the Engineering Branch, Technical Assessment Division, Audit Follow-up and Technical Support Directorate of the Office of the Assistant Inspector General for Auditing, DoD. We did not use statistical sampling procedures for this audit.

**Audit Period and Standards.** We conducted this economy and efficiency audit in accordance with auditing standards issued by the Comptroller General of the United States, as implemented by the Inspector General, DoD, and accordingly included such tests of management controls as we deemed necessary

**Contacts During the Audit.** We visited or contacted individuals and organizations within DoD and the Boeing Corporation, Long Beach, California. Further details are available on request.

## Management Control Program

DoD Directive 5010.38, "Management Control (MC) Program," August 26, 1996, requires DoD managers to implement a comprehensive system of management controls that provides reasonable assurance that programs are operating as intended and to evaluate the adequacy of those controls.

**Scope of Review of Management Control Program.** In accordance with DoD Directive 5000.1, "Defense Acquisition," March 15, 1996, and DoD Regulation 5000.2-R, "Mandatory Procedures for Major Defense Acquisition Programs (MDAPS) and Major Automated Information System (MAIS) Acquisition Programs," March 16, 1996, acquisition managers are to use program cost, schedule, and performance parameters as control objectives to carry out DoD Directive 5010.38 requirements. Accordingly, we limited our review to management controls directly related to life-cycle management of landing gear. We did not assess the adequacy of management's self-evaluation of the controls.



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**Adequacy of Management Controls.** We did not identify a material management control weakness, as defined by DoD Directive 5010.38. Management controls were adequate as they applied to the overall objective. Appendix E summarizes potential monetary benefits.

## **Summary of Prior Coverage**

During the last 5 years, no prior coverage specifically addressed the objectives covered in this audit.

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## **Appendix B. Landing-Gear Durability and Cost**

The landing gear specification requires the contractor to analytically demonstrate that the gear design can withstand four lifetimes of use. Both the main landing-gear design and the nose landing-gear design analytically demonstrated the ability to withstand four lifetimes of use without failure. The landing-gear specification also required that both the main landing gear and the nose landing gear demonstrate four lifetimes of use through full-scale durability testing. The durability testing of the C-17 landing gear had been defined by three major test articles: the nose landing gear, the aft main landing gear, and the forward main landing gear. The test schedules and accomplishments are in Figures B-1, B-2, and B-3 for the nose landing gear, aft main landing gear, and forward main landing gear. The landing-gear testing did not start until 2 years after the program started durability testing on the airframe. Durability testing of the landing gear was scheduled to coincide with durability testing of the airframe, which was completed in FY 1995. At the time of this audit, durability testing was not scheduled to be complete until the delivery of aircraft 54 in the second quarter of FY 2000, after 45 percent of the total aircraft have been delivered.

Components in both the nose and main landing gear designs had failed during durability testing. A component that demonstrates four lifetimes of use without failure during testing is considered to safely withstand one lifetime of actual use. Basically, the four lifetimes of testing are divided by four to determine actual life. We performed a detailed cost analysis for two critical components of the main landing gear, the forward and aft main landing-gear trunnion collars and the forward main landing-gear post.

### **Forward and Aft Main Landing-Gear Trunnion Collars**

The forward and aft main landing-gear trunnion collars had repeated failures during durability testing, as shown in Figures B-2 and B-3. The trunnion collar and post are depicted in Figure B-4.

The forward main landing-gear trunnion failed at 0.045 lifetimes of test and was subsequently redesigned. The redesigned forward trunnion was installed in the test fixture, and testing resumed. Testing of the redesigned forward trunnion had reached 1.0 lifetimes in durability testing on October 21, 1998. Further testing of the forward trunnion will resume in the summer of 1999.

The aft main landing-gear trunnion collar failed at 0.63 lifetimes and was subsequently redesigned. The redesigned aft trunnion was installed in the test fixture, and testing resumed. The redesigned aft trunnion collar failed at 1.60 lifetimes. Accounting for the scatter factor of four, the failure corresponds to an actual life of 0.40. Testing of the aft landing gear was on hold for 2 years because of post redesign.

For the purposes of this discussion, the contractor is responsible for all cost, of redesign, production, and retrofit up to 1.5 lifetimes; therefore, we assume that the trunnion collars would, at contractor expense, eventually exhibit at least

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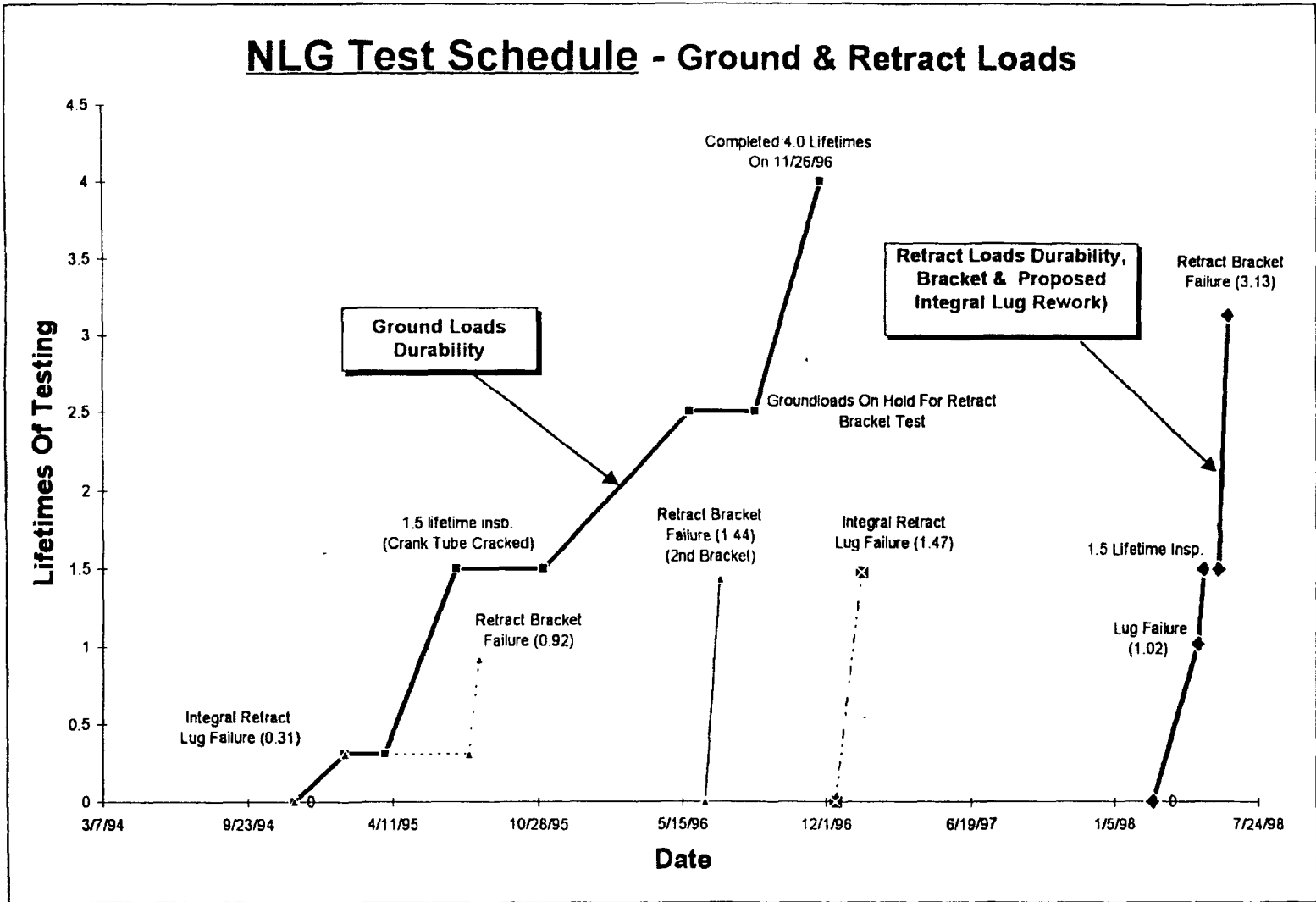
1.5 lifetimes in durability testing. If the contractor is not able to extend the life of the trunnion through redesign past 1.5 lifetimes and the trunnion is declared life-limited, the government would be responsible for the cost of production and retrofit. Each trunnion collar would then have to be replaced every 0.38 (1.5/4.0) lifetimes of use, corresponding to no more than three trunnion collars used over the life of the aircraft. Each aircraft has four trunnion collars. The cost per trunnion collar is \$5,380. The cost to replace four trunnion collars two times over the life of the aircraft would be \$43,040. Therefore, the government's cost to replace the trunnion collars for the fleet of 120 aircraft over the life of the fleet would be approximately \$5.2 million.

## **Forward Main Landing-Gear Post**

The main landing-gear posts experienced damage during early operations and failure during durability testing. The forward and aft main landing-gear posts were redesigned and are no longer interchangeable. As shown in Figure B-3, the forward main landing-gear post failed at 0.45 lifetimes of use. The failure corresponds to an actual life of 0.11. The contractor is responsible for the cost to redesign, produce, and retrofit up to 1.5 lifetimes. Therefore, we assumed that the forward landing-gear posts would, at contractor expense, eventually exhibit at least 1.5 lifetimes of durability testing. If the contractor is not able to extend the life of the forward main landing-gear post through redesign past 1.5 lifetimes and the trunnion is declared life-limited, the Government would be responsible for the cost of production and retrofit. At 1.5 lifetimes of durability, each forward landing-gear post would then have to be replaced every 0.38 (1.5/4.0) lifetimes of use, corresponding to no more than three forward landing-gear posts used over the life of the aircraft. Each aircraft has two forward main landing-gear posts. The cost per forward main landing-gear post is \$277,536. The cost to replace two forward main landing-gear posts twice over the life of the aircraft would be \$1,110,144. Therefore, the government's cost to replace the forward main landing gear for the fleet of 120 aircraft over the life of the fleet would be approximately \$133.2 million.

The landing gear component replacement costs are approximated and do not include additional maintenance burdens or the cost of aircraft downtime.

Figure B-1. Nose Landing-Gear Test Schedule





# LANDING GEAR DURABILITY TESTS - AFT MLG SCHEDULE

AIRCRAFT SYSTEMS IPT

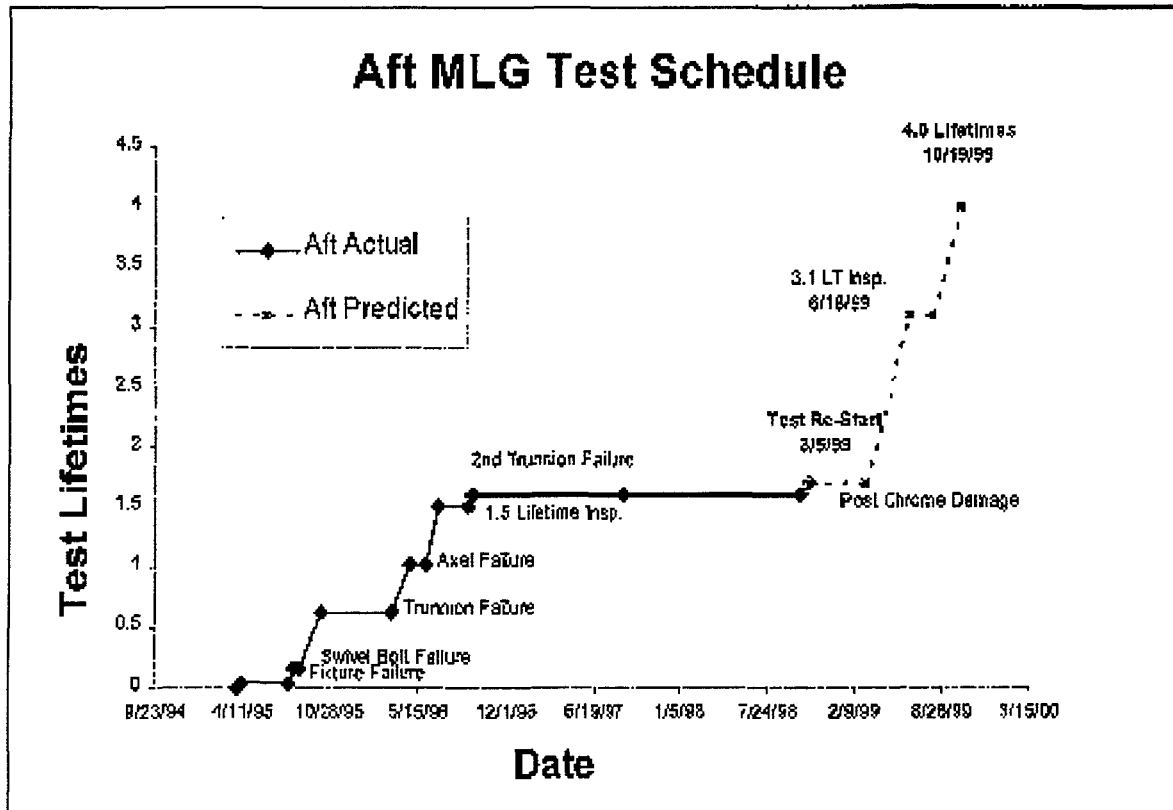


Figure B-2. Aft Main Landing-Gear Test Schedule



# LANDING GEAR DURABILITY TESTS - FWD MLG SCHEDULE

AIRCRAFT SYSTEMS IPT

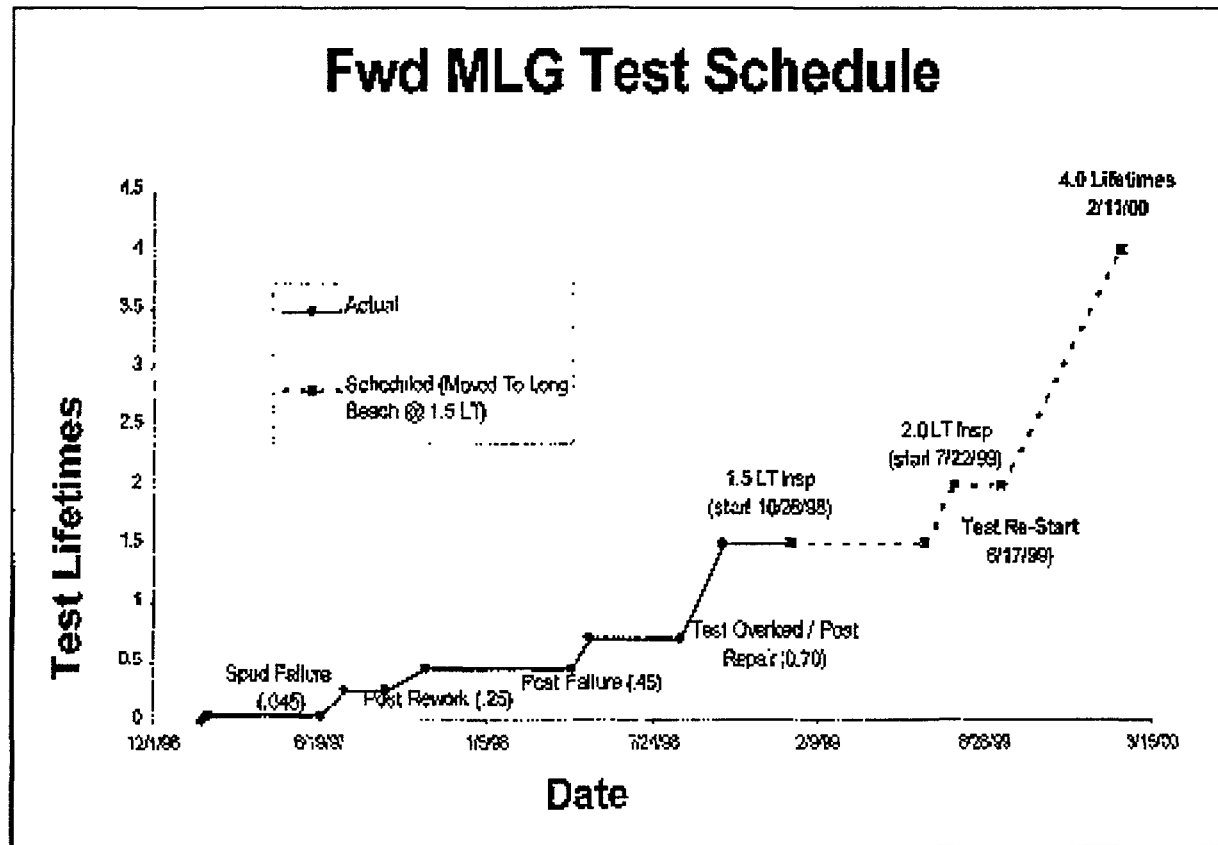


Figure B-3. Forward Main Landing-Gear Test Schedule

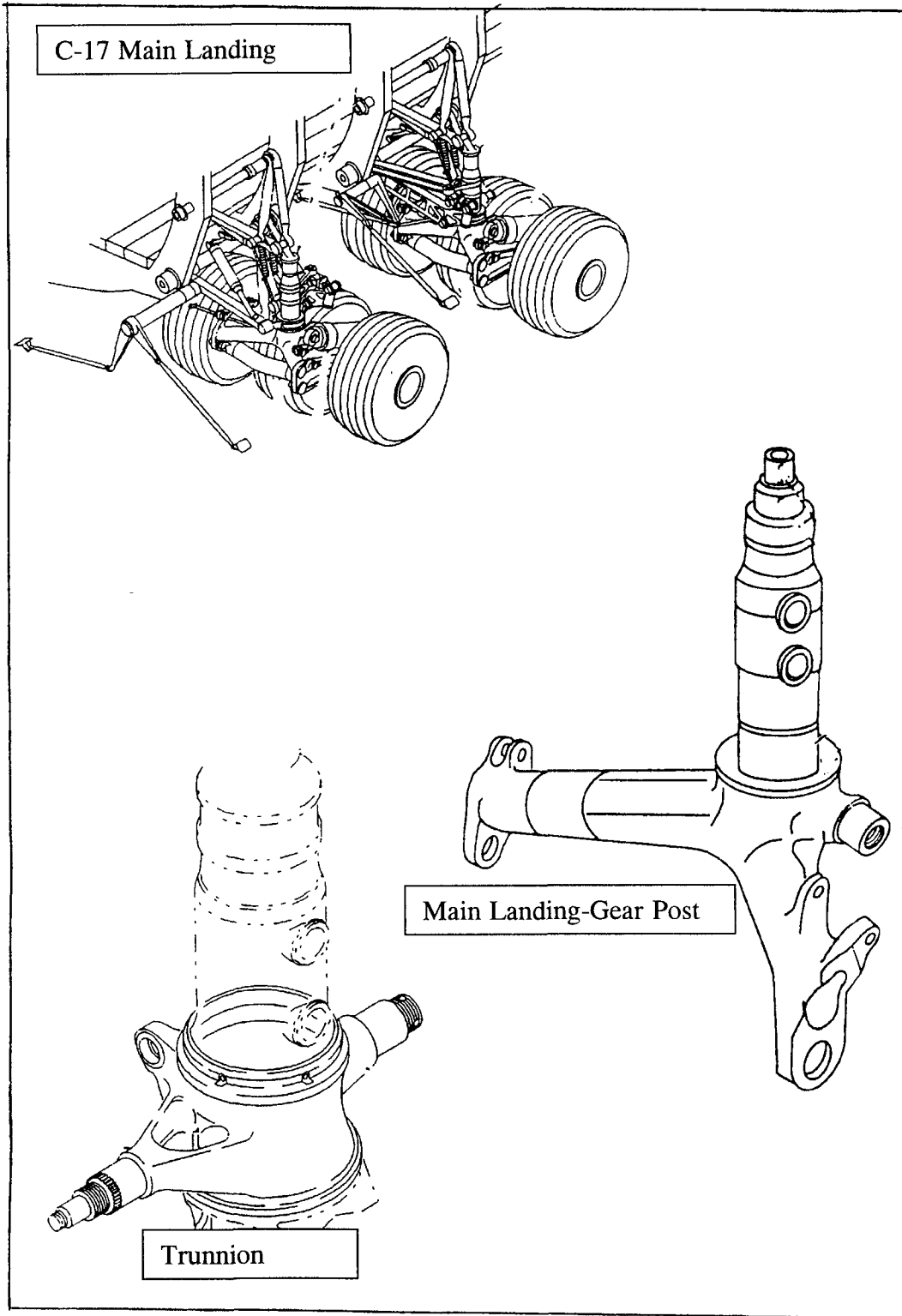


Figure B-4. Drawings of the C-17 Main Landing Gear

## Appendix C. Cost Analysis of the C-17 Tires

**Original Tire Specification.** The original tire specification called for tires that would last 400 landings and support one retread. The C-17 design specification calls for the landing gear to withstand 18,909 landings over the life of the aircraft. Therefore, 18,909 landings divided by 400 landings per tire equals 47 tires to be used during the life of the C-17. Each aircraft has 12 main landing-gear tires. Replacing the 12 main tires 47 times over the life of the aircraft would result in 564 main tires being used. Main tire replacement for the fleet of 120 aircraft would result in 67,680 tires.

Cost of original tire ( $X + 0.8x^1 = 67,680$ tires)	
$X = 37,600$ new tires x \$1,725	\$64,860,000
$0.8X = 30,080$ retreads x \$863	25,959,040
Life-cycle cost to replace current tires	\$90,819,040

**Current Tire Specification Rate.** Based on initial usage data, tires were not lasting the required 400 landings. The C-17 System Program Office implemented a field evaluation plan to address tire performance. The contractor developed an improved tire compound to extend the life of C-17 tires. The improved tires increased the number of landings per tire. The C-17 System Program Office accepted the improved tire, while holding the requirement to retread once. At the same time, the C-17 System Program Office changed the specifications for the nose tire to 180 landings and the main tire to 305 landings.

The current tire specification calls for tires that would last 305 landings and support one retread. The C-17 design specification calls for the landing gear to withstand 18,909 landings over the life of the aircraft. Therefore, 18,909 landings divided by 305 landings per tire equals 62 sets of tires to be used during the life of the C-17. Each aircraft has 12 main landing-gear tires. Replacing the 12 main tires 62 times over the life of the aircraft would result in 744 main tires being used for each aircraft. Main landing-gear tire replacement for the fleet of 120 aircraft would result in procuring 89,280 tires to support life-cycle maintenance of the C-17.

Cost of current tire ( $X + 0.8x = 89,280$ tires)	
$X = 49,600$ new tires x \$1,725	\$ 85,560,000
$0.8X = 39,680$ retreads x \$863	34,243,840
Life-cycle cost to replace current tires	\$119,803,840

Life-cycle cost of tires will increase \$28,984,800 over planned cost (\$119,803,840 - \$90,819,040).

**Development of an Improved C-17 Tire.** The contractor was exploring a main tire alternative that would support three retreads but at a higher gross weight. The contractor was participating in a generic research and development project to improve

<sup>1</sup> Based on historical retread data, only 80 percent of tires will be in a condition permitting retread.



tire life in conjunction with the Air Force and aircraft tire manufacturers. The project was funded through the Air Force Manufacturing Technology Program and received additional funding support from the C-17 contractor and aircraft tire manufacturers. The project undertook the development of a C-17 main tire that can support three retreads, satisfy Federal Aviation Administration tire certification standards, and accommodate C-17 weight growth beyond 585,000 pounds. The project yielded a design that adds two nylon plies to the carcass of the tire and a greater tread thickness to satisfy the ability to retread the tire three times. The tire would possess the same rubber formulation as the current C-17 tire. Remaining development of the improved main tire is \$49,260. The main tire would weigh approximately 35 to 40 pounds more than the current tire. That would add up to 480 pounds per aircraft for main tires, representing approximately a 0.08 percent growth in aircraft weight.

The improved main tire specification would provide for tires that would last 305 landings and support three retreads.

Cost of improved tire ( $X + 0.8X + 0.48X + 0.19X = 89,280$ tires) <sup>1</sup>	
$X = 36,146$ new tires x \$1,725	\$ 62,351,850
$1.47X = 53,134$ retreads x \$863	45,854,642
Life-cycle cost to replace improved tires	\$108,206,492

#### Calculation of Avoided Costs

Life-cycle cost to replace current tires	\$119,803,840
Life-cycle cost to replace improved tires	108,206,492
Life-cycle cost avoidance	\$ 11,597,348
Less life-cycle cost increase in fuel consumption <sup>2</sup>	2,794,032
Net Life-cycle cost avoidance	\$ 8,803,316

**Life-Cycle Cost Avoidance for Tires.** If the improved tire is successful, the C-17 System Program Office could avoid \$8,754,056 (\$293,444 per year times 30 years, less development cost of \$49,260)<sup>3</sup> for main landing gear tires over the lifetime of the C-17 fleet with the improved tire design. This would provide an 7 percent cost avoidance on tires.

<sup>1</sup> Based on historical retread data, only 80 percent of the original tires will be in a condition permitting retread the first time; only 60 percent of the first retreads will be in a condition permitting a second retread, and only 40 percent of the second retreads will be in a condition permitting a third retread.

<sup>2</sup> Based on life-cycle cost reduction used by the C-17 System Program Office in deriving benefits in weight reduction of 536 pounds on the tail of the aircraft.

<sup>3</sup> Cost avoidance is based on potential of the C-17 System Program Office ability to avoid cost of \$293,444 per year, by developing the new tire design, times the 6 years in the current budget for a total potential cost avoidance of \$1.8 million.

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## Appendix D. Cost Analysis of C-17 Brakes

### Brake Specification

This analysis uses a worst case scenario, and does not take into consideration that some parts can be salvaged and used to rebuild brakes. The brake specification states that the brake should last 1,950 landings before replacement. The C-17 specification provides that the C-17 would last 18,909 landings. Therefore, 18,909 landings per lifetime divided by 1,950 landings per brake equals 9 times that the brakes would be replaced during the life of the C-17. Each aircraft has 12 brakes. Replacing the 12 brakes 9 times over the life of the aircraft would result in 108 brakes being used. Brake replacement for the fleet of 120 aircraft would result in 12,960 brakes.

The cost of each brake	\$ 25,678
Number of brakes	X 12,960
Cost to replace brakes per specification	<b>\$332,786,880</b>

### Brake Usage Rate

The current brake usage is resulting in brake replacements after 600 landings instead of the specified 1,950. Therefore, 18,909 landings per lifetime divided by 600 landings per brake equals 31 times that the brakes would be replaced during the life of the C-17. Each aircraft has 12 brakes. Replacing the 12 brakes 31 times over the life of the aircraft would result in 372 brakes being used. Brake replacement for the fleet of 120 aircraft would result in 44,640 brakes.

The cost of each brake	\$ 25,678
Number of brakes	X 44,640
Cost to replace brakes per specification	<b>\$1,146,265,920</b>

### Conclusion

Life-cycle cost of brakes could increase as much as \$813,479,040 over planned cost (\$1,146,265,920 - \$332,786,880).

The brake replacement costs are approximated and do not include additional maintenance burdens or the cost of aircraft downtime.

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## Appendix E. Summary of Potential Benefits

<u>Recommendation Reference</u>	<u>Description of Benefit</u>	<u>Amount and Type of Benefit</u>
1	<b>Program Results.</b> Reduces risk by establishing reasonable expectations of life-cycle support cost.	Nonmonetary
2	<b>Economy and Efficiency.</b> Reduces total-ownership-cost for C-17 tires.	Funds put to better use of \$1.8 million (\$293,444 x 6 years) for FYs 1999 through 2005 from the Operation and Maintenance, Air Force, appropriation (program element 21X2020)
3	<b>Economy and Efficiency.</b> Maximizes potential of increasing brake capability without redesign of the airframe.	Undeterminable. Amount is subject to result of redevelopment.

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## **Appendix F. Report Distribution**

### **Office of the Secretary of Defense**

Under Secretary of Defense for Acquisition and Technology  
Deputy Under Secretary of Defense (Logistics)  
Director, Defense Logistics Studies Information Exchange  
Director, Strategic and Tactical Systems  
Under Secretary of Defense (Comptroller)  
Deputy Chief Financial Officer  
Deputy Comptroller (Program/Budget)

### **Department of the Army**

Auditor General, Department of the Army

### **Department of the Navy**

Assistant Secretary of the Navy (Financial Management and Comptroller)  
Auditor General, Department of the Navy

### **Department of the Air Force**

Assistant Secretary of the Air Force (Acquisition)  
Program Executive Officer, Airlift and Trainer Programs  
Program Director, C-17 System Program Office  
Assistant Secretary of the Air Force (Financial Management and Comptroller)  
Commander, Air Force Materiel Command  
Commander, Aeronautical Systems Center  
Commander, Air Mobility Command  
Commander, 437th Military Airlift Wing  
Commander, Air Education and Training Command  
Commander, 97th Air Mobility Wing  
Auditor General, Department of the Air Force

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## **Other Defense Organizations**

Director, Defense Contract Audit Agency  
Director, Defense Logistics Agency  
    Director, Defense Contract Management Command  
Director, National Security Agency  
    Inspector General, National Security Agency  
Inspector General, Defense Intelligence Agency

## **Non-Defense Federal Organizations and Individuals**

Office of Management and Budget  
General Accounting Office  
    Technical Information Center  
    National Security and International Affairs Division

## **Congressional Committees and Subcommittees, Chairman and Ranking Minority Member**

Senate Committee on Appropriations  
Senate Subcommittee on Defense, Committee on Appropriations  
Senate Committee on Armed Services  
Senate Committee on Governmental Affairs  
House Committee on Appropriations  
House Subcommittee on Defense, Committee on Appropriations  
House Committee on Armed Services  
House Committee on Government Reform  
House Subcommittee on Government Management, Information, and Technology,  
    Committee on Government Reform  
House Subcommittee on National Security, Veterans Affairs, and International  
    Relations, Committee on Government Reform

# Department of the Air Force Comments



DEPARTMENT OF THE AIR FORCE  
AIR FORCE PROGRAM EXECUTIVE OFFICE  
WASHINGTON DC




10 June 1999

MEMORANDUM FOR DOD IG

FROM: AF PEO/AT  
1230 Air Force Pentagon  
Washington, DC 20330-1230

SUBJECT: Response to DoD IG Draft Audit Report "C-17 Landing Gear Durability and Parts Supportability" (Project No 8AL-3002.01)

Attached are our comments to the subject draft report. Thank you for revising the initial report as well as working the attached comments in a pre-coordinated fashion with the C-17 Program Office. Please notify Lt Col Kevin Keck at 588-7704 if any further action is required.

  
ROBERT W CHEDISTER  
Brigadier General, USAF  
Program Executive Officer,  
Airlift, Trainers, Modeling and  
Simulation

Attachment:  
C-17 Response

**C-17 System Program Office**  
**Response to DoD IG Draft Audit Report**  
**“C-17 Landing-Gear Durability and Parts Supportability”**  
**(Project No. 8AL-3002.01)**

**EXECUTIVE SUMMARY / RESULTS**

*Comment:*

(3<sup>rd</sup> sentence) Brakes are experiencing higher usage than identified in the Boeing procurement specification. However, the usage is in line with the Air Vehicle Specification, which is our baseline for weapon system performance. Recent brake reliability information (March 1999) from the G081 Automated Maintenance System shows that the one-year cumulative mean full-stop landings between removals is 1,455 and the lifetime cumulative mean is 1,324. At this level of reliability, we expect no supportability cost growth for brakes. The attached graph shows the improvement in brake life. For tires, the change to the life requirement in the Air Vehicle Specification was fully coordinated with the user (AMC), and the increased costs have already been accounted for in supportability plans

**EXECUTIVE SUMMARY / SUMMARY OF RECOMMENDATIONS**

*Concurrence.*

We will continue to address life-cycle supportability costs in our risk assessment program, and we will program funds as necessary to manage all risks we identify. Also, efforts to address the life-cycle cost benefits of replacing the current tire with a new tire that supports three retreads are already in the planning stages. However, a new aircraft modification may increase the gross weight of the C-17. So, the tire replacement effort is on hold until the final gross weight of the aircraft is available. Finally, we have updated the brake procurement specification, and several vendors have submitted new brake design proposals to the contractor.

**C-17 LANDING-GEAR DURABILITY**

*Comment:*

(2<sup>nd</sup> paragraph, 1<sup>st</sup> sentence) The stated cost increases reflect the maximum potential costs for replacement, with only 1.5 lifetimes of durability testing. To date, our landing-gear durability test programs have all exceeded 1.5 lifetimes, and we are continuing to test to 4 lifetimes.

(2<sup>nd</sup> paragraph, 2<sup>nd</sup> sentence) Without a proactive brake management and improvement program, costs could increase as described in the report. Since the original audit investigation, we have improved the thermal resistance of the brakes and updated the operations and maintenance technical data to reduce excess brake wear caused by improper use in the field. These actions have significantly improved the life of the brakes. As the attached graph of G081 reliability data shows, brake life has improved significantly, and we continue to carefully monitor brake performance to

identify and fix any brake performance issues that could cause increases in life-cycle costs  
(2<sup>nd</sup> paragraph, 2<sup>nd</sup> sentence) Refer to our comment under "Executive Summary / Results "

#### PERFORMANCE OF C-17 LANDING GEAR, TIRES, AND BRAKES

##### -- Landing Gear

###### *Comment*

(4<sup>th</sup> paragraph, 3<sup>rd</sup> sentence) The trunnion collar that failed at 1.60 lifetimes was a redesigned trunnion collar, not an identical one This fact is correctly stated in Appendix B

##### -- Brakes

###### *Comment*

(1<sup>st</sup> sentence) Brakes are experiencing higher usage than identified in the Boeing procurement specification. However, the usage is in line with the Air Vehicle Specification, which is our baseline for weapon system performance

#### SUPPORTABILITY COSTS OF C-17 LANDING GEAR, TIRES, AND BRAKES

###### *Comment:*

(1<sup>st</sup> paragraph, 5<sup>th</sup>-10<sup>th</sup> sentences) The stated cost increases reflect the maximum potential costs for replacement Refer to our comment under "C-17 Landing-Gear Durability "

(3<sup>rd</sup> paragraph) Life-cycle costs are always a significant factor in any changes we consider, and we will continue to address life-cycle supportability costs in our risk assessment program. All the considerations listed in this paragraph are factors we use in making design changes and assessing risk, and we will program funds as necessary to manage all risks we identify.

(2<sup>nd</sup> paragraph, 1<sup>st</sup> bullet) Refer to our comment under "Executive Summary / Results "

(2<sup>nd</sup> paragraph, 2<sup>nd</sup> bullet) Refer to our comment under "Executive Summary / Results."

#### OTHER CONSIDERATIONS WITH RESPECT TO C-17 LANDING GEAR, TIRES, AND BRAKES

##### -- Landing Gear

###### *Comment*

(2<sup>nd</sup> paragraph, last sentence) The stated cost increase reflects the maximum potential costs for replacement. Refer to our comment under "C-17 Landing-Gear Durability "



-- Tires

*Comment*

(2<sup>nd</sup> - 10<sup>th</sup> sentences) Past tire improvement efforts have included the Improved Tire Compound (fielded in 1996) and qualification of a retread process (with first deliveries of retread tires in 1997). Other improvement initiatives include a three-retread tire, which has not reached the stage of a formal proposal from Boeing, and a program called EXLITE proposed through the then-Wright Laboratories. EXLITE proved to be too expensive to pursue.

*Concurrence*

(11<sup>th</sup> - 12<sup>th</sup> sentences) There may be potential cost savings from the development and implementation of a three-retread tire. Efforts to address the life-cycle cost benefits of replacing the current tire with a new tire are already in the planning stages. However, a new aircraft modification may increase the gross weight of the aircraft. So, the tire replacement effort is on hold until the final gross weight is available. Once the new maximum aircraft gross weight is available, we plan to formally direct a cost-benefit analysis for developing an R-3 tire.

-- Brakes

*Comment*

(7<sup>th</sup> - 8<sup>th</sup> sentences) Refer to our comment under "Executive Summary / Results "

CONCLUSION

*Comment:*

(4<sup>th</sup> sentence) Refer to our comment under "Executive Summary / Results."

*Concurrence:*

(7<sup>th</sup> sentence) We will investigate tire improvements in the near future, and the contractor has already received proposals for new brake designs from its vendors.

RECOMMENDATIONS

*Concurrence.*

Recommendation 1: We will continue to address life-cycle supportability costs in our risk assessment program, and we will program funds as necessary to manage all risks we identify

*Concurrence.*

Recommendation 2: We are planning to investigate the costs and benefits of a three-retread tire as soon as potential changes to the aircraft gross weight are final.

*Concurrence:*

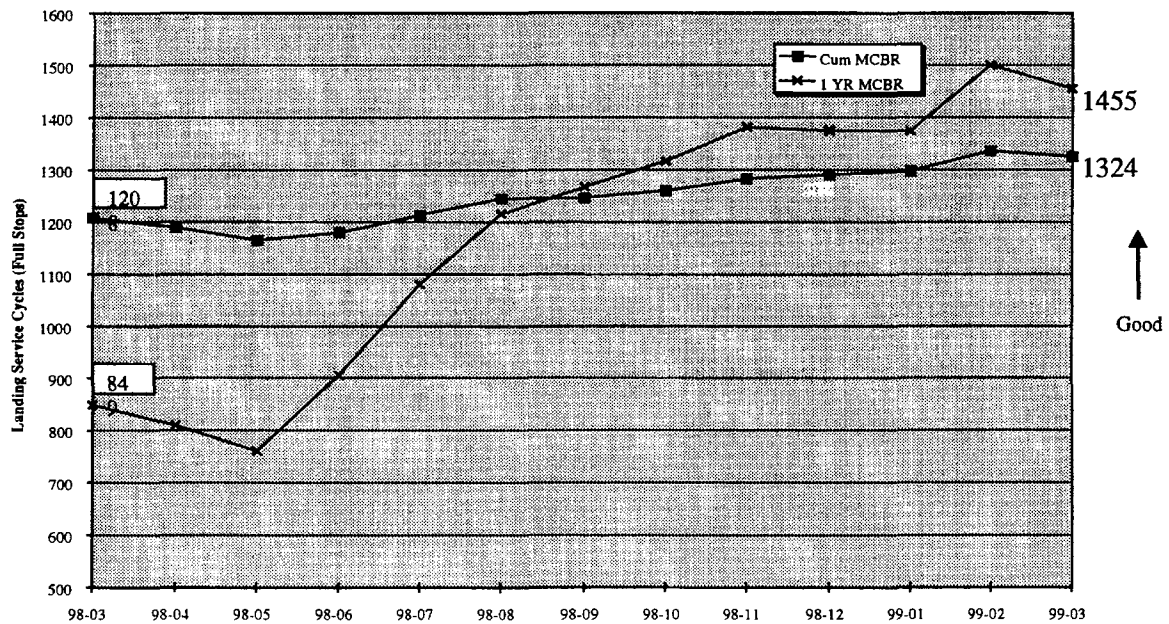
Recommendation 3: The process of investigating costs and benefits of a new brake design has already begun. The contractor has received proposals for new brake designs from its vendors.



USAF AIRLIFT & TANKER

# C-17 MLG BRAKES

## Mean Cycles Between Removals - Unit



## **Audit Team Members**

The Acquisition Management Directorate, Office of the Assistant Inspector General for Auditing, DoD, prepared this report.

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