DEPARTMENT OF DEFENSE

TECHNICAL ASSESSMENT REPORT

C-17 WING STRUCTURAL INTEGRITY

Report No. 93-159 August 24, 1993

Office of the Inspector General

INSPECTOR GENERAL
DEPARTMENT OF DEFENSE
400 ARMY NAVY DRIVE
ARLINGTON, VIRGINIA 22202

August 24, 1993

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE (ACQUISITION AND TECHNOLOGY)
ASSISTANT SECRETARY OF THE AIR FORCE (FINANCIAL MANAGEMENT AND COMPTROLLER)
DIRECTOR, DEFENSE LOGISTICS AGENCY
EXECUTIVE DIRECTOR, DEFENSE SCIENCE BOARD

SUBJECT: Report on the Technical Assessment of C-17 Wing Structural Integrity (Report No. 93-159)

At the request of the Chairman of the Legislation and National Security Subcommittee, the House Committee on Government Operations, we initiated a technical assessment of the C-17 wing structural integrity. The Chairman asked that the IG, DoD, review and report on the cause of the wing static test failure, the recommended solution, and the associated costs. After we began our technical assessment, the Under Secretary of Defense (Acquisition and Technology) commissioned a C-17 Defense Science Board Task Force to review the entire C-17 program. Members of our technical assessment team were selected to serve on the Task Force. The findings of our technical assessment were completed as part of the C-17 Defense Science Board Task Force. We are providing this final report for your information and use. Chairman Conyers has also been provided a copy.

If you have any questions on this technical assessment, please contact Mr. Kenneth H. Stavenjord, Technical Director, at (703) 614-8174 (DSN 224-8174). If you wish, we will brief you on the results of the technical assessment. The planned distribution of this report is listed in Appendix D.

Robert J. Lieberman
Assistant Inspector General
for Auditing

Enclosure

Acronyms

ALCS	Active Load Control System
DPRO	Defense Plant Representative Office
ECP	Engineering Change Proposal
EIRT	Executive Independent Review Team
JIRT	Joint Independent Review Team
MDA	McDonnell Douglas Aircraft Company
PEO	Program Executive Officer
SPO	System Program Office
STV	Static Test Vehicle

Office of the Inspector General, DoD

Report No. 93-159
Project No. 3PT-6004

August 24, 1993

C-17 WING STRUCTURAL INTEGRITY

EXECUTIVE SUMMARY

Introduction. This technical assessment was requested by Congressman John Conyers, Jr., Chairman, Legislation and National Security Subcommittee, the House Committee on Government Operations. The Chairman asked the IG, DoD, to assess the structural integrity of the C-17 following a major wing static test failure. After we began our technical assessment, the Under Secretary of Defense (Acquisition and Technology) commissioned a C-17 Defense Science Board Task Force to review the C-17 program. Members of our technical assessment team were selected to serve on the Task Force. The findings of our technical assessment were completed within the scope of the C-17 Defense Science Board Task Force.

Objectives. The objective of the technical assessment was to evaluate the structural integrity of the wing in view of the wing static test failure and the McDonnell Douglas Aircraft Company's (MDA's) repair plans. We evaluated the root cause analyses of the wing static test failure and the validation of the retrofit design.

Technical Assessment Results. We reviewed the wing static test failure root cause analyses with MDA and Air Force engineers, review teams, and program management officials. We found the analyses to be accurate and complete. The root cause analyses identified three major contributors to the wing static test failure: a computational design error, optimistic design assumptions, and placement of test loads. We have confidence in the root cause analyses and the corrections that resulted from the analyses.

The wing retrofit design is an adequate repair of the wing structure. However, the Government does not consider it to be a final design for all future C-17 aircraft. The wing retrofit design adds a risk of long-term corrosion, which could reduce service life, and requires an additional periodic inspection program. The thermal expansion effects of the steel straps are negligible. The retrofit of wings already produced is complex and must be carried out in difficult working conditions. Also, the Air Force requirement for an aluminum ion vapor deposit on the wing stringer straps may shorten the life of the corrosion protection coatings.

A repaired, retrofitted wing will be used to complete the static test program. The wing will be adequately representative of the retrofitted production wings. Each bay of the retrofitted production wing design will be represented by a qualification bay on one side or the other of the repaired, retrofitted test wing. Although there is an inherent risk in using a repaired wing, the cost and schedule impacts of using a new wing were not warranted.

During the time of our review, McDonnell Douglas Aircraft Company engineers began designing a final production wing to eliminate the wing retrofit straps and stiffeners. MDA is targeting aircraft P-29 to be the first aircraft to receive the new wing, although installation as early as P-25 may be feasible.

We received a cost estimate of $40.7 million for the analysis of the wing static test failure, repair of the static test vehicle, and design of the retrofit. The estimate for the repair/retrofit of aircraft P-1 through P-10 is $56.4 million Estimates were not available for retrofitting the wings of aircraft P-11 and P-12, the addition of the retrofit to aircraft P-13 through the last aircraft to receive the retrofit during production, or the scope and cost of the periodic inspections of wings with the retrofit design. The estimated cost for the design of the final production wing is $32 million.

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This report was prepared by the Technical Assessment Division, Audit Planning and Technical Support Directorate, Office of the Assistant Inspector General for Auditing, DoD. Copies of this report can be obtained from the Secondary Reports Distribution Unit, Audit Planning and Technical Support Directorate, at (703) 614-6303 (DSN 224-6303)

Part I - Introduction

Background

Both wings of the C-17 Static Test Vehicle (STV) manufactured by McDonnell Douglas Aircraft Company (MDA) failed on October 1, 1992, during a structural test. The wings failed at approximately 128 percent of the design limit load for a severe test condition, Test Limit Condition DG-5001. At the failure location, the load was approximately 124 percent of design limit load. The structural test required a demonstrated capability of withstanding 150 percent of the design limit load. Both wings buckled rear to front, cordwise, with a 25- to 50-percent skin fracture. Additionally, extensive structural failures occurred in stringers, spars, and ribs.

On October 5, 1992, the Chairman, Legislation and National Security Subcommittee, House Committee on Government Operations, asked the IG, DoD, to evaluate the condition of the damaged wings, the exact load that caused the wings to buckle, and the recommended solution to ensure the structural integrity of the aircraft. On February 5, 1993, the Chairman reiterated his request for the IG review of the System Program Office's (SPO's) recommended solution to ensure the structural integrity of the wing and added a request that the IG provide costs estimates of the wing failure. Copies of the Chairman's requests are in Appendixes A and B.

MDA formed two teams, a design and test team and a Joint Independent Review Team (JIRT). The JIRT consisted of MDA and Air Force representatives. The JIRT was tasked to analyze the root cause of the failure, make an assessment of the existing stress analyses and component tests, and recommend corrective actions and redesigns.

The Program Executive Officer (PEO) for Tactical and Airlift Programs formed an Executive Independent Review Team (EIRT), which included Government advisors from the Aeronautical Systems Center, Wright Laboratories, and the aerospace industry. The advisors were selected for their knowledge and expertise in aircraft structure design problems. The EIRT evaluated and determined the completeness and adequacy of the wing failure investigations, the adequacy of proposed corrective action plans for wing redesign and retrofit, and presented recommendations to the Air Force.

A Special Technical Review Team, consisting of Air Force and industry experts, was formed to assess the long-term effects of the recommended wing retrofit plan. The long-term effects included corrosion, fatigue, and difficulties in inspection and maintenance.

The Under Secretary of Defense (Acquisition and Technology) commissioned a C-17 Defense Science Board Task Force (Task Force) to review the C-17 program. The Task Force, which included members of our technical assessment team, was to assess the current status of the C-17 and the contractor's ability to successfully complete the C-17 development and transition to production, and to identify changes necessary to ensure program success and reduce risk. The Task Force was divided into integrated project teams. The IG Technical Director prepared structural integrity information for the Integrated Product Team for Systems Engineering and Operational Requirements for incorporation into its report.

Cost estimates associated with the wing failure, retrofit, and redesign are in Appendix C.

Objective and Scope

The objective of this technical assessment was to assess the C-17 wing structural integrity. Our technical assessment focused on the root cause analysis of the wing static test failure; the selected STV repair option and the extent to which the repaired and retrofitted STV wing is representative of a production wing; the test and validation of the retrofit wing design; the final wing design; and the costs associated with the wing failure, retrofit, and redesign.

We interviewed the Air Force PEO for Tactical and Airlift Programs and engineers in the C-17 SPO, Wright Laboratories, the Defense Plant Representative Office (DPRO), and MDA. We conducted a portion the technical assessment as part of the C-17 Defense Science Board Task Force.

The technical assessment team included members of the Technical Assessment Division, Audit Planning and Technical Support Directorate, augmented by the Corrosion Group Leader, National Institute of Standards and Technology. The team had extensive experience in engineering, metallurgy, design, testing, manufacturing, and program management.

Part II - Findings

Finding A. Root Cause Analysis

The root cause analysis of the C-17 wing static test failure was accurate and complete. MDA and review teams identified three major contributors to the failure: a computational design error, optimistic design assumptions, and placement of test loads.

Analysis and Review Teams. The MDA design and test team and the JIRT analyzed the failure and recommended corrective action. The EIRT evaluated the completeness and adequacy of the failure investigations and the corrective action plans.

The EIRT reported that a corrected analysis revealed the margin of safety in the failure area relative to the loads at failure to be negative 7 percent rather than the positive 40 percent calculated before the failure. The 47-percent difference came from a computational design error (17 percent), optimistic design assumptions (3 percent from finite element analysis refinements, 7 percent from design allowables, and 13 percent from the degree of end fixity), and placement of test loads (7 percent).

Design Computations. The C-17 cargo aircraft wing design, fabrication, and assembly were similar to the MDA's commercial DC-10. However, the elimination of stringer 17 between the access doors in the upper wing surface was a significant deviation. The resultant spacing between stringers 16 and 18 was more than 13 inches. Upper surface stringer spacing elsewhere on the wing is approximately 6 inches.

The original calculations of effective compressive area inappropriately used the full width of skin acting with the stringers between the fuel access doors. The error resulted in an overstatement of the margin of safety in that area.

Design Assumptions. Assumptions used in the original finite element analysis, design allowables, and end fixity of beam columns were contributing factors to underestimating the wing structural stresses. There were minor discrepancies between the drawings and the upper cover modeling in the nonlinear finite element stress analysis. To better account for some of the failure effects, MDA constructed a fine grid model and derived nonlinear solutions. In addition, MDA ran the new models with actual test article loads.

Original assumptions for the plastic bending allowable, ultimate shear strength, and the circular interaction equation were not conservative. In addition, original stress analyses did not account for such things as beam column effects due to aerodynamic loads, tank pressurization, and nonlinear column effects.

The end fixity used in the original beam column analyses was not conservative for many wing locations. Adequate consideration was not given to the light ribs, the way the ribs are attached to the stringers, the large stringer areas and inertias, and column lengths.

Test Load Placement. The placement of test loads also contributed to the wing static test failure. Multiple hydraulic actuators and loading pads, adhesively bonded to the wing, were used to apply and distribute loads on the wings. The loads were designed to simulate the actual loads the wing will encounter during various flight conditions. However, the pads were not distributed uniformly over the wing, partly due to access doors. More important, the nonuniform loading was not taken into consideration in the stress analyses. As a result, there was more stress on the stringers than calculated, causing a smaller margin of safety. Subsequent calculations revealed that the wing would have failed even with uniform loading, but at a value closer to the design ultimate load.

Conclusion. The technical assessment team reviewed the root cause analysis with MDA design engineers, Air Force engineers, review teams, and Air Force program management officials. The root cause analysis of the wing static test failure was accurate and complete. The technical assessment team has confidence in the root cause analysis and resultant corrections.

Finding B. Wing Retrofit Design and Installation

The wing retrofit design should provide an adequate repair of the wing structure. However, the design adds technical risk from possible installation quality and long-term dissimilar metals problems. The installation is complex and must be carried out in difficult working conditions. Further, the requirement, imposed by the Air Force, for an aluminum ion vapor deposit on the repair straps could shorten the life of corrosion protection coatings. The retrofit has a long-term risk of wing corrosion and requires a periodic inspection program.

Retrofit Options. Five options for correcting the wing deficiencies were presented to the Air Force by the EIRT:

Option 1 - full structural modification with no restrictions,

Option 2 - no structural modification with restrictions,

Option 3 - partial wing structural modification with possible restrictions,

Option 4 - limited structural modification with 20-degree aileron/spoiler active load control system (ALCS) and no restrictions,

Option 5 - minimum structural modification with 30-degree aileron/spoiler ALCS and restriction with single hydraulic system failure.

Retrofit Option Selected. The Air Force selected Option 1. Based on reports from the EIRT and JIRT and recommendation from the C-17 System Program Director, the Assistant Secretary of the Air Force (Acquisition) approved a course of action outlined in the C-17 Program Director's memorandum of March 4, 1993:

> The full structural modification option to correct the design deficiencies is the preferred option from an overall program perspective.
>
> The planned repair of the static test article is generally acceptable and will be sufficient to demonstrate compliance with requirements. This repair includes meeting the EIRT's repair guidelines.
>
> The currently planned retrofit/production fix for the wing is technically acceptable. The production fix should be, and will be, "productionized" at the earliest date, i.e., resized aluminum stringers will be phased in and the steel strap eliminated.
>
> An active wing load alleviation system for the C-17 offers substantial benefits in terms of growth capability and life extension, and as such is a very good planned improvement candidate for the aircraft. A recommendation will be forwarded when a MDA engineering change proposal (ECP) is developed, and will include funding resources required to accomplish the improvement.

Retrofit Description. The retrofit design solution for the wing upper surface problem includes:

- attaching stainless steel straps to the stringers,
- attaching stiffeners to various ribs and spars, and
- adding a stringer between fuel tank access holes.

A 0.940-inch wide, 0.090-inch thick stainless steel strap, with the end tapered to 0.030-inch, is fastened to the bottom of the aluminum stringers. Titanium protruding heal pull-type Hi-Lok bolts, and 1035 or 1050 cadmium coated high-carbon steel (MS 21042) nuts and aluminum alloy 7075-T6 (NAS 1252) washers are used to fasten the stainless steel (17-7 CRES) strap to the 7150-T 7751 aluminum alloy stringers. The strap will be spliced with anther strap fastened to the stringer web wherever rib cap interference exists or where clearance to run the strap under a stringer does not exist.

MDA developed a strap coil machine to feed the steel strap under the bottom of the stringers and a Q-matic machine to clamp, locate, and drill 3/16-inch diameter holes, spaced approximately 1.5 inches apart, through the strap and the stringer.

Corrosion reduction measures are being implemented to physically isolate the stainless steel straps from the aluminum stringers. The measures include an aluminum ion vapor deposit on the steel straps, fuel tank coating on the straps and stringers, faying surface sealant between the straps and the stringers, and edge sealing.

The wing retrofit will add 700 to 800 pounds to the weight of the aircraft. The weight added by the retrofit is approximately the same as the weight previously removed by a weight-reduction decision. MDA decided to replace the 7050 aluminum alloy material of the upper wing skin and stringers with 7150 aluminum alloy, resulting in a 775-pound weight reduction.

Wing Retrofit Design Validation. The wing retrofit design was validated with corrected analyses, component tests, and corrosion tests. The full-scale static tests were restarted in July 1993.

MDA conducted compression analyses using revised methodologies for unmodified as well as redesigned structure components. Additionally, MDA accomplished finite element analysis and development tests of the modified wing structure. Development tests verified the design of structural components with stainless steel strap splices and reinforcements.

Corrosion associated with the dissimilar metals introduced by the retrofit design was tested with both a 100-day alternate salt water immersion test and a 672-hour salt fog exposure test. The extent of corrosion, however, is time and environment dependent and not easily quantifiable.

Wing Retrofit Installation. The retrofit solution to the wing static test failure requires installation work in difficult conditions, in the small spaces between ribs of completed wing boxes. Experience with the installation is limited to the STV where the conditions were less difficult due to the wing being partially disassembled. Production aircraft through P-12 will require retrofitting. Production aircraft following aircraft P-12 will receive the retrofit during the wing assembly. MDA is targeting P-29 to be the first aircraft to receive the final production wing design, with P-25 as the goal. The wing retrofit is not planned for test aircraft T1 or the Durability Test Vehicle.

In addition to the difficult installation work conditions, the retrofit is extensive and complex. Concerns about the difficulty of the retrofit were also expressed by the EIRT:

> Experience indicates that these modifications [retrofits] are seldom accomplished as fast and as easily as originally anticipated. Difficulties are often times encountered with manufacturing tolerances, warpage, spring back, fastener removal, and re-assembly operations. Such difficulties could put pressures on both the program costs and schedules.

The Special Technical Review Team was formed to assess the long-term effects of the retrofit. The Team concluded:

> The proposed repair/retrofit is unprecedented in its scope with the USAF and commercial experience available to the team. ... It was the team's consensus that the repair/retrofit design adds long-term technical risk to the C-17 program that was not there prior to the static test failure.

If the retrofit is not properly installed, risk of corrosion could be increased. Also, the quality of the installation is dependent on foreign object damage control, a consistent issue for the C-17. As part of the C-17 Defense Science Board Task Force, we recommended the development of rigorous retrofit installation inspection criteria and requirements for both the contractor and the DPRO.

The wing retrofit has not yet been accomplished on a delivered, production aircraft. However, the retrofit of P-1 was ahead of schedule at the time of our assessment. Since the contractor has a lack of experience with the retrofit, there is medium risk in meeting retrofit schedules for the first 12 aircraft. In view of the schedule risk, we recommended, as part of the C-17 Defense Science Board Task Force, that additional attention be paid to finalizing and proofing the retrofit plans.

Corrosion. When dissimilar metals are attached to each other and are exposed to an environment or environments that allow ions to travel between the exposed surfaces, the metals are said to be galvanicly coupled. Galvanic coupling of dissimilar metals increases the corrosion rate of the more active metal, which is the aluminum alloy in the C-17 wing.

If the critical areas are coated and are free of flaws, skips, or scratches, the negative effects of the galvanic coupling of the more active metal can be minimized. However, it is virtually impossible to coat all of the aluminum alloy surfaces and maintain them flaw free. Any deterioration of the coating on the stainless steel will greatly accelerate corrosion.

The stainless steel straps will be fastened to the stringers with specially designed equipment, after the coatings have been applied. Avoiding damage to the coating during the procedures will be a challenge, and some damage will occur, even with the best procedures and care. Some small areas on the stainless steel strap will be exposed to the environment as will some areas on the aluminum alloys. If the coating on the straps starts to rapidly degrade, then the corrosion at the small flaws on the aluminum will increase.

The EIRT and JIRT expressed concern about the potential for galvanic corrosion with the introduction of dissimilar metals. The Air Force Special Technical Review Team reviewed the potential corrosion problem. The Air Force Special Technical Team report stated that the corrosion potential for dissimilar metals is reduced by physically isolating one of the two dissimilar metals with organic (nonconductive) coatings. The Air Force Special Technical Review Team recommended that all prudent corrosion prevention techniques be incorporated to minimize the corrosion risk, including a sacrificial coating of a 1-mil pure aluminum layer applied to the stainless steel strap by ion vapor deposition.

MDA's proposal for mitigating the potential corrosion problem included most of the measures recommended by the Air Force Special Technical Review Team. Those measures included fuel tank coating of the stainless steel strap to provide a primary barrier to corrosion and sealing of faying surface and edges in areas wetted by fuel to provide an additional barrier to preclude intrusion of environment. However, the MDA disagreed with the Special Technical Review Team's recommendation concerning aluminum coating of the steel stainless strap. MDA contended that its proposed corrosion prevention measures, without the aluminum ion vapor deposit, would provide adequate protection against corrosion. The Air Force, however, continued to require the aluminum ion vapor deposit.

Our analysis of the proposed corrosion prevention planned for the stainless steel straps and aluminum stringers raised a concern about including the aluminum ion vapor deposit on the stainless steel straps. Two types of flaws are possible for the ion vapor deposit coated straps: flaws that expose only the aluminum ion vapor deposit layer and flaws that expose the ion vapor deposit aluminum layer and the underlying stainless steel. Atmospheric exposure test results over a 20-year period showed that the maximum penetration of commercially pure aluminum (alloy 1100) varied from 0.035 to 0.70 mils per year. Based on those results, we would expect the ion vapor deposit aluminum layer to extend the time before exposure of the stainless steel by just over a year, even without a galvanic couple. However, we were concerned that once the stainless steel was exposed, the galvanic attack of the aluminum ion vapor deposit layer and removal of the coating would occur at a rate greater than that which would occur in the absence of the aluminum layer. Our concern was that the rate of exposure of the cathodic surface, the stainless steel strap, and the resultant increase in current source would more than offset the beneficial effects of the aluminum ion vapor deposit's consumption of current.

Our concerns were confirmed by viewing specimens from MDA's 672-hour salt fog tests. Although notched specimens both with and without the ion vapor deposit coating passed the salt fog test, the specimen with the ion vapor deposit coating revealed that the galvanic attack of the aluminum ion vapor deposit layer and removal of the coating occurred at a greater rate than that which occurred in the absence of the aluminum layer.

Removal of the requirement could extend the life of the coating thereby reducing galvanic action of the stainless steel straps. Further, removal of the requirement would save the Government about $30,000 per aircraft. As members of the C-17 Defense Science Board Task Force, we recommended reviewing the requirement for the ion vapor deposit with a view to removing the requirement. We also made the recommendation in a memorandum to the C-17 System Program Director, July 29, 1993.

Management of the corrosion risk introduced by the retrofit design will require an inspection program. The Special Technical Review Team recommended that "a limited analytical condition inspection of service aircraft be planned" and that a sample of the fleet be inspected at 5- to 6-year intervals to provide early warning of developing problems. The layered structure of the wing retrofit design is difficult to inspect. Since a nondestructive inspection technique is not available, the Special Technical Review Team recommended the removal and inspection of steel strap splice plates that will be installed on the stringer web at some ribs. The Special Team also recommended the acceleration of a program to develop a nondestructive inspection technique to replace the tear-down and visual inspection.

Thermal Expansion. The thermal coefficient of expansion for aluminum is twice that of steel. Therefore, there are thermally induced stresses introduced by the retrofit design of attaching stainless steel straps to aluminum stringers. The Air Force and MDA assessed the induced stresses for two conditions, a hot day on the ground and a cold soak to -40 degrees Fahrenheit, the worst case. The cold soak condition resulted in a 5,000-pound-per-square-inch tension stress in the aluminum stringer flange and a 14,000-pound-per-square-inch compression stress in the steel strap. The Air Force reported that since the tension in the aluminum flange increased the allowable buckling and offsets any decrease in allowable buckling in the steel strap, the net effect of the difference in thermal coefficients of expansion is negligible. The Air Force also reported that preliminary durability analysis with the thermal stresses indicated adequate wing life.

Conclusion. We consider the current wing fix design an adequate repair design. However, we do not consider the current wing fix design acceptable as a final design solution for the remainder of the C-17 production. The current wing fix design adds technical risk from potential long-term corrosion and from added complexity and difficulty in installation. Inspections of a sample of the

C-17 fleet at 5- to 6-year intervals will be required. In addition, the Air Force requirement for aluminum ion vapor deposit on the retrofit straps may shorten the life of corrosion protection coatings.

Stainless steel can be used with aluminum and, if properly isolated, will only minimally accelerate corrosion of the aluminum alloy. However, the wing modification will affect the risk of corrosion of the wing. The most crucial factors in determining the extent to which the wing retrofit will accelerate corrosion of the aluminum alloys of the wing are the quality of application and stability of the coating on the stainless steel straps.

Finding C. Static Test Wing Repair and Retest

A repaired and retrofitted wing will be used for the remainder of the wing static test. Each bay of the retrofitted production wing design will be tested by a representative bay on at least one side of the wing used for the static test.

Static Test with Repaired Wing. Several issues surround the use of a repaired and retrofitted wing instead of a new wing for the remainder of the static tests. The repaired wing presents an inherently higher risk in the validity of the static tests and in flight safety. The risk stems from the possibility of a failure in the repaired areas and from the extent to which the repaired wing is not representative of nonrepaired wings.

The SPO and the EIRT established qualification criteria and reviewed extensive data for the rework, retest concept. All areas that would experience overtesting were reviewed and analyzed in detail. For each of those areas, MDA calculations showed reasonable positive margins of safety at maximum test loading. The wing was inspected extensively for damage outside the failure area. Damaged areas have been repaired. The repaired wing was designed to eliminate eccentricities in the rework splices that should prevent bending.

The repair design provides a qualification area for each wing bay. However, the qualification area may be on only one side of the aircraft. Analyses of the stresses predicted in the retrofitted production wing design and the stresses predicted in the qualification areas of the repaired, retrofitted test wing design provided assurance that the test wing was representative of retrofitted production wings. The differences in the calculated stringer maximum stresses between the two wing designs were found acceptable by the JIRT and the EIRT.

As part of the C-17 Defense Science Board Task Force, we recommended that testing of the repaired and retrofitted test wing proceed. The large schedule and cost impacts of the alternative, replacing the static test wing with a new, retrofitted wing, did not appear to be warranted.

Static tests were restarted July 2, 1993, with the repaired and retrofitted wing. A wing strain survey was completed July 11, 1993, in which the wing was tested to the point at which it previously failed. The purpose of the wing strain survey was to obtain and analyze data on the repaired and retrofit design to determine whether additional changes are necessary. Analysis of the data resulted in the addition of another doubler to a section of the wing centerline rib near the rear spar to prevent local web buckling. Additional testing for the reminder of the static test vehicle was planned during the time that the strain survey analyses were being conducted.

Probability of Additional Static Test Failures. The hardest part of the static test program is still ahead. The wing fuselage intersection is not a typical MDA design. The aft fuselage open-box design is unique. The landing gear testing to ultimate loads just started as of the time of our technical assessment.

Completion of static tests required to clear the C-17 aircraft for 100 percent flight loads and ground loads are scheduled for October and November, 1993, respectively. Comparing the test status, in July 1993, with historical data revealed a significant program risk from another structural test failure. As part of the C-17 Defense Science Board Task Force, we estimated that the static test completion dates would slip 3 to 12 months from the planned completion dates.

Conclusion. The selected option of using a repaired and retrofitted static test wing resulted in adequate representation of the retrofitted production wing design. Although there is an inherent risk in using a repaired wing, the cost and schedule impacts of using a new wing were not warranted.

Finding D. Final Production Wing Design

The structural redesign of the wing to eliminate the retrofit straps and stiffeners has begun. Production aircraft P-25 is the first aircraft being considered to receive the new wing design, with P-29 as the target.

Status. Redesign of the C-17 wing structure is needed to eliminate the long-term technical and quality risks identified in Finding B. MDA's redesign schedule targets installing the first wing of the final production design on aircraft P-29, with possible installation as early as P-25. The schedule will result in 24 to 28 aircraft delivered with the retrofit wing design. As part of the C-17 Defense Science Board Task Force, we recommended that design and production schedules be closely reviewed to determine the possibility of reducing the number of aircraft with the retrofit wing design.

The final production wing design is essentially an increase in the cross-sectional areas of structural members to increase strength. For example, stringers with retrofit stainless steel straps and spars with retrofit aluminum angles will be replaced with stringers and spars of a larger cross-section. The larger stringers and spars will require additional modifications to the ribs, bulkhead caps, clips, and vertical stiffeners.

Full-scale static and durability tests are not planned for the final production wing design. However, component tests will be conducted on critical panels of new wing design. The load distribution, modulus of elasticity, and moment of intertia should be approximately the same between the static test wing and the final production wing. The upper surface is not critical for fatigue. Therefore, the EIRT concluded that the risk from not conducting full-scale static and durability tests on the final production wing was acceptable.

Conclusion. A final production wing design solution should be completed and introduced as soon as possible to eliminate the retrofit staps and stiffeners. Estimates indicate that the P-25 aircraft could be the first aircraft to receive the final production wing design, with P-29 as the target.

Part III - Additional Information

Appendix A. Chairman Conyers' Request, October 5, 1992

ONE HUNDRED SECOND CONGRESS

Congress of the United States

House of Representatives

LEGISLATION AND NATIONAL SECURITY SUBCOMMITTEE
OF THE
COMMITTEE ON GOVERNMENT OPERATIONS
B-373 RAYBURN HOUSE OFFICE BUILDING
WASHINGTON, DC 20515-6149

(202) 225-5147
FAX (202) 225-2373

October 5, 1992

Mr. Derek J. Vander Schaaf
Deputy Inspector General
Department of Defense
400 Army-Navy Drive, Room 1000
Arlington, Virginia 22202-2884

Dear Mr. Vander Schaaf:

Recently it was reported that the wings of the McDonnell Douglas C-17 static article buckled during a stress test. As you know, the Subcommittee on Legislation and National Security of the Committee on Government Operations has followed this program carefully over the last two years. Assistance by the office of the Inspector General has been invaluable in achieving an accurate and independent picture of some very complex technical problems.

I wish to call on your expertise again in the matter of the C-17 wing failure during static testing. As a follow-on to your report on the quality of the wing fasteners, I would like for your office to do a thorough examination of the condition of the damaged wings, the exact load that caused the wings to buckle, and the recommended solution to ensure the structural integrity of this aircraft. Please include a summary of the contract requirements that may be affected by this recent structural failure.

Please contact Mr. Eric Thorson of the Subcommittee staff at 202-225-5147 to coordinate this request.

Sincerely,

John Conyers, Jr.
Chairman

ENCLOSURE

Appendix B. Chairman Conyers' Request, February 5, 1993

ONE HUNDRED THIRD CONGRESS

Congress of the United States

House of Representatives

COMMITTEE ON GOVERNMENT OPERATIONS

2157 RAYBURN HOUSE OFFICE BUILDING

WASHINGTON, DC 20515-6143

February 5, 1993

Mr. Derek J. Vander Schaaf
Deputy Inspector General
Department of Defense
400 Army-Navy Drive, Room 1000
Arlington, Virginia 22202-2884

Dear Mr. Vander Schaaf:

In October, 1992, the wings of the McDonnell Douglas C-17 Airlifter static article failed during a stress test. As you know, the Subcommittee on Legislation and National Security of the Committee on Government Operations has followed this program carefully over the last two years. Once again, assistance by the office of the Inspector General has been invaluable in achieving an accurate and independent picture of some very complex technical problems.

I am concerned about the most recent report as to the fix for the C-17 wing. The fix is described as, "strengthening areas around access holes." I would like for your office to do a review of the recommended solution to ensure the structural integrity of this wing. Also would you clarify the recent report that the cost for this fix will be about $50 million. I suspect that the stated figure only pays for the extensive damage to the Static Test Vehicle, and does not address the "eventual" wing redesign, nor the retrofit of those wings already built. Your opinion as to the true cost of repair, redesign, retrofit, and program production delays caused by the wing failure, would be extremely valuable. Please advise us on the cost matter as soon as possible.

Please contact Eric Thorson of the Subcommittee staff at 202 225-5147 to coordinate this request.

Sincerely,

John Conyers, Jr.
Chairman

Appendix C. Cost Estimates

The following data summarizes information in the reports on costs associated with the wing failure, retrofit, and redesign.

Full-Scale Engineering Development	$40,700,000
Lot I repair/retrofit (P-I and P-2)	$11,600,000
Lot II repair/retrofit (P-3 through P-6)	$22,400,000
Lot III repair/retrofit (P-7 through P-10)	$22,400,000
Development of nondestructive inspection technique for strap corrosion	$4,000,000
Final production wing design	$32,000,000

The Full-Scale Engineering Development estimate includes engineering and analysis, laboratory testing, STV wing repair, material, quality assurance, fabrication, manufacturing support, planning, tooling, and logistics support.

The repair/retrofit estimates include material, liaison engineering, quality assurance, fabrication, manufacturing support, and logistics support.

Estimates were not available for retrofitting the wings of aircraft P-11 and P-12, the addition of the retrofit to aircraft P-13 through the last aircraft to receive the retrofit during production, or the scope and cost of the periodic inspections of wings with the retrofit design.

Appendix D. Report Distribution

Office of the Secretary of Defense

Under Secretary of Defense (Acquisition and Technology)
Director, Defense Research and Engineering
Assistant Secretary of Defense (Production and Logistics)

Department of the Air Force

Secretary of the Air Force
Assistant Secretary of the Air Force (Acquisition)
Assistant Secretary of the Air Force (Financial Management and Comptroller)
Commander, Air Force Materiel Command
Program Executive Office, Tactical and Airlift Programs
C-17 System Program Office, Aeronautical Systems Center
Assistant for Product Assurance, Aeronautical Systems Center

DoD Activities

Director, Defense Logistics Agency
Commander, Defense Contract Management Command
Commander, Defense Plant Representative's Office, McDonnell Douglas Aircraft Company, Long Beach, California

Non-DoD Activities

Office of Management and Budget
U.S. General Accounting Office, National Security and International Affairs Division, Technical Information Center

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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 Operations
House Subcommittee on Legislation and National Security, Committee on Government Operations

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