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REPORT BY THE

Comptroller General

OF THE UNITED STATES

C-5A Wing Modification: A Case Study Illustrating Problems In The Defense Weapons Acquisition Process

The Air Force had data in 1967 indicating airframe weight problems in the C-5A aircraft's original design. These problems eventually led Lockheed, the C-5A manufacturer, to deviate from contract specifications by reducing wing material thicknesses. Not until September 1971, after accepting 40 aircraft, did the Air Force have enough test data to recognize that the C-5A wing might require major structural repair or modification.

On the basis of a series of analyses, DOD eventually approved the wing modification in 1975. After this, the Air Force did not evaluate the technical feasibility of other existing lower cost options. GAO believes no other viable wing repair options remain at this time.

Since early 1970, DOD has made several changes to its acquisition process which should enable it to deal more effectively in the future with problems such as those which occurred on the C-5A program.

This report was requested by the Vice Chairman, Subcommittee on International Trade, Finance and Security Economics, Joint Economic Committee.

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B-201347

The Honorable William Proxmire
Vice Chairman, Subcommittee on
International Trade, Finance
and Security Economics,
Joint Economic Committee

Dear Mr. Vice Chairman:

In your November 4, 1980, letter, you asked us to review the procedures followed by the Air Force in identifying and assessing the C-5A wing cracking problems and in approving the modification program known as H-mod. You expressed a special interest in the relationship between the Air Force and Lockheed, the C-5A manufacturer, and requested that we answer a series of questions plus several separate allegations. These questions and allegations covered a wide range of issues concerning the C-5A program evolution and the propriety of Air Force decisions to modify the C-5A wings. This report presents our views on the various issues you raised.

As your Office requested, we did not obtain written comments from the Air Force or Lockheed. We did discuss the report with both parties, and where appropriate, have incorporated their comments into the report.

As arranged with your Office, unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report.

Sincerely yours,

Milton J. Socolar

for Comptroller General
of the United States

COMPTROLLER GENERAL'S REPORT TO THE VICE CHAIRMAN, SUBCOMMITTEE ON INTERNATIONAL TRADE, FINANCE AND SECURITY ECONOMICS, JOINT ECONOMIC COMMITTEE

C-5A WING MODIFICATION: A CASE STUDY ILLUSTRATING PROBLEMS IN THE DEFENSE WEAPONS ACQUISITION PROCESS

DIGEST

The need for extensive modifications of the C-5A wing is but the latest of a series of problems plaguing the Air Force's acquisition of this heavy-duty aircraft. This GAO review of the circumstances surrounding the management of the wing modification program--known as H-mod--confirms the findings of other procedural and technical reviews disclosing problems throughout the 17-year history of the C-5A. These problems have also occurred in other Defense weapon systems acquisitions.

GAO made this review in response to a request from Senator William Proxmire, Vice Chairman of the Subcommittee on International Trade, Finance and Security Economics, Joint Economic Committee. Senator Proxmire asked GAO to answer a series of questions and review allegations about the procedures followed by the Air Force in identifying and assessing C-5A wing problems and in approving the $1.5 billion H-mod program in then-year dollars.

WHY DID THE WING CRACKS OCCUR?

Airframe weight problems, which were known by the Air Force to exist in Lockheed's original designs, eventually led Lockheed to deviate from contract specifications by reducing wing material thicknesses. This action substantially reduced the aircraft's service life below the 30,000 flight hours desired.

By 1967, the Air Force had engineering design data which indicated that Lockheed's wing designs might impair future C-5A operational capabilities. At that time, Air Force technical advisors recommended that the feasibility of accelerating structural tests be considered, but because of established production milestones, Lockheed indicated it would be unable to do so.

In 1969 and 1970, a static test article failure and the discovery of fatigue cracks in a flight test aircraft provided some evidence of the wing cracking problems. At this time, the Air Force had retained the rights to negotiate a settlement for deficiencies which it had already identified. In May 1971, recognizing that Lockheed had serious financial problems which could jeopardize the completion of the C-5A program, the Department of Defense directed the Air Force to convert the fixed-price, incentive C-5A contract to a cost-reimbursement, fixed-loss contract. This fixed-loss settlement also relieved Lockheed of any liability to correct deficiencies in aircraft which had already been delivered and required the Government to bear the cost of any fix, no matter what it entailed or when it was installed.

Not until September 1971, after the fixed-loss settlement had been executed, did the Air Force have enough structural test data to recognize that the C-5A wing might require significant rework, modification, or replacement.

In view of the stated military need for the C-5A, the circumstances surrounding the C-5A program in the late 1960s and early 1970s, and the absence of more advantageous alternatives at the time, the Air Force had few choices but to accept the deficient aircraft. (See p. 36.)

IS INDEPENDENT TESTING NEEDED?

In the original C-5A program, the Air Force included the C-5A structural test requirements in its contract with Lockheed and was dependent on the company for the test results. The concurrent development and production of the C-5A, Lockheed's control over the test program, and the late structural test schedules, prevented the Air Force and Lockheed from promptly correcting the deficiencies. Because it lacked an independent testing capability for the C-5A then, the Air Force had no way of assuring itself that the required test information could be obtained in a timely manner.

Air Force Systems Command officials reported that the late scheduling of C-5A structural tests, and not the quality of testing, prevented the Air Force from incorporating design changes without disrupting aircraft production. They also indicated that, since then, no technical issues have surfaced concerning the quality of testing.

Over the years, the Air Force has upgraded its Aircraft Structural Integrity Program. This program includes revised aircraft engineering design requirements and now requires that at least one lifetime of fatigue testing be completed before making a production decision. The Air Force also has oversight procedures for monitoring a contractor's performance of the structural tests. The revised structural design and test requirements, coupled with the existing oversight procedures, should provide more timely test results. If the Air Force properly implements its revised structural test requirements and maintains adequate oversight of contractor testing programs, GAO sees no need to incur the added cost of an independent test capability for identifying problems similar to those on the C-5A wings. (See p. 21.)

WERE MODIFICATION ALTERNATIVES ADEQUATELY EVALUATED?

Air Force requirements and joint Air Force-Lockheed analyses dictated the H-mod configuration as it exists today. The first decision in early 1973 to merely rework certain C-5A wing components was based on technical data analyzed after the 1971 test failures. Later in 1973, the Air Force approved center and inner wing box replacements in lieu of rework because Lockheed estimated these replacements would cost less. After H-mod contract award, data on the adverse effects of C-5A aerial refueling operations convinced the Air Force to replace the outer wing box as well. Given the series of reviews, the outside technical oversight, and the existing knowledge of aircraft fatigue phenomena, GAO believes that the Air Force took reasonable steps to assure itself of acquiring the best data available on C-5A wing problems and solutions through the 1976 decision to replace the outer wing box.

In GAO's opinion, the Air Force's unyielding commitment to its 1973 decision to achieve an additional 30,000-hour service life objective subtly and increasingly drove each succeeding analysis to a single conclusion--major wing structure replacements. In March 1977, the Rand Corporation suggested that the C-5A might remain operational until the end of the century with a lower service life objective (15,000 to 20,000 hours). This suggestion, and concerns about protecting C-5A flight safety through H-mod program completion, led the Air Force to initiate the Structural Information Enhancement Program in 1977.

GAO found no reason to question the thoroughness of the analyses conducted by Lockheed and the Air Force during this program or the validity of their results. At that time, however, lower service life objectives were not considered and alternative wing repair options were omitted even though data existed which indicated the H-mod would cost at least $400 million more than the original program estimate, new structural information would be developed, and only a small percentage of the H-mod work had been completed.

On the basis of Lockheed's Structural Information Enhancement Program analyses, the Air Force lowered the C-5A flight safety limit to 7,100 hours which, in its opinion, increased the urgency for the wing modification. Because of the way the fleet is being managed and because the first operational aircraft will undergo modification beginning in February 1982, GAO believes that no viable wing modification alternatives other than the H-mod remain at this time. (See pp. 51 to 52.)

WAS SOLE-SOURCE AWARD JUSTIFIED?

Given the results of an Air Force competition feasibility study and the positions taken by the potential competitors, GAO believes that the Air Force's sole-source award of the H-mod design and development contract to Lockheed was appropriate. At the time of the decision to proceed, the Air Force believed the H-mod was urgently needed. No other potential source was interested in competing for the work because only Lockheed had the expertise and facilities to perform the H-mod development work at lower costs and in the time schedule desired. Ultimately, this sole-source award locked the Government into Lockheed for the fabrication and installation of the wings.

ARE WING MODIFICATION WARRANTIES ADEQUATE TO PROTECT THE GOVERNMENT'S INTEREST?

Lockheed was unwilling to warrant the C-5A's service life after modification. Instead, Lockheed and the Air Force negotiated limited warranties on the fatigue and flight test articles; a 1-year, 5,000-cumulative flying hour design warranty starting with the delivery of the first modified aircraft; and a 1-year materials and workmanship warranty on each aircraft. The H-mod contract requires the Government to pay the full cost for correcting deficiencies covered by the warranties, but under certain provisions, Lockheed's fee will be reduced. Once the flying hour design warranty expires, the Government will be totally responsible for repairing any fatigue damage that occurs. On the basis of discussions with officials of aerospace companies other than Lockheed, GAO believes the limited warranties in the H-mod contracts apparently are consistent with commercial warranty policies. (See pp. 65 to 67.)

WHAT LESSONS CAN BE LEARNED?

It is now widely acknowledged that using fixed-price contracting and that Government noninterference during the development phase of a major system result in loss of flexibility both to the Government and to the contractor. The C-5A wing problems discussed in this report make up only one group of a series of interrelated problems affecting the cost, schedule, and performance of this aircraft. Other considerations which would prevent these problems from occurring include

--using contracting as an important tool of system acquisiton, not as a substitute for managing acquisition programs;

--adopting contract practices and Government-contractor relationships which will encourage both parties to work together to achieve the most cost-effective approach to satisfy the mission needs;

--limiting concurrent development and production, and adhering to orderly and sequential design, test, and evaluation, where feasible; and

--avoiding undue dependence on the contractor to identify problems in new systems under development, which might affect the safety and system integrity. (See p. 78.)

Because of its experiences during the C-5A procurement program and during other weapons system procurements since then, the Department of Defense has periodically revised the major system acquisition process. Essentially, these revisions, which address GAO's concerns, have been designed to improve the Secretary of Defense's ability to control new program starts, to provide the Secretary with greater visibility and control over critical acquisition milestones, and to increase the services' flexibility to tailor procurement strategies so they fit individual program needs.

Recent GAO reports indicate that weapons system effectiveness and program management issues continue to surface. The changes to the acquisition system already made or in process since the early 1970s, in themselves, cannot guarantee that problems will not occur in the future. However, these changes, if properly implemented, should enable Defense to deal more effectively with these issues on current and future major acquisitions.

AGENCY COMMENTS

In early November 1981, GAO met with representatives of the Office of Secretary of Defense and the Air Staff to discuss the report's contents. These officials indicated that the report was factual and presented a reasonable summation of the C-5A's program history.

Lockheed also reviewed a draft of this report and considered it a fair representation of the facts.

C o n t e n t s

ABBREVIATIONS

AFPRO	Air Force Plant Representative Office
AFSC	Air Force Systems Command
AFWAL	Air Force Wright Aeronautical Laboratories
ALDCS	active lift distribution control system
ASD	Aeronautical Systems Division
GAO	General Accounting Office
IOC	initial operational capability
RMP	representative mission profile
SIEP	Structural Information Enhancement Program
SLMP	Service Life Management Plan
WLIP	Wing Life Improvement Program

CHAPTER 1

INTRODUCTION

Since 1975, the Air Force has been pursuing a program to replace the defective wings on the 77 C-5A cargo aircraft. In mid-1980, new information surfaced which seemed to contradict the technical data used to justify this program. During August and September 1980, Senator William Proxmire, Chairman of the Subcommittee on Priorities and Economy in Government, 1/ Joint Economic Committee, held hearings to clarify the origins and extent of the wing defects. Subsequently, on November 4, 1980, Senator Proxmire asked us to review the Air Force's procedures in identifying and assessing the wing problems and in approving the wing modification program known as H-mod.

Senator Proxmire also asked us to answer 12 specific questions and to assess allegations which were made during the 1980 hearings. (See app. II.) This report contains the results of our review into the procedural aspects of the H-mod program approval, and to some extent, addresses the technical justification for replacing the wings rather than repairing them.

C-5A AIRCRAFT AND H-MOD DESCRIPTIONS

In the early 1960s, the aging airlift force could not keep pace with increasing U.S. requirements for rapid, strategic mobility. The first step taken to upgrade airlift capabilities was the acquisition of the all-jet C-141 cargo aircraft. At that time, however, the C-141 could transport only about 65 percent of the Army's equipment. To further increase U.S. mobility capacity, the Air Force began a procurement program in 1964 for the C-5A, a large jet aircraft capable of moving military equipment too large to move in the C-141.

Among the original C-5A performance requirements, the Air Force specified an aircraft having (1) a structural capacity of 200,000 pounds transportable to 2,700 nautical miles, (2) an unimproved runway operations capability, and (3) a 30,000-flying hour service life objective. The C-5A has failed to demonstrate these capabilities, as well as other operational requirements, because Lockheed did not comply with contract specifications and took certain actions during the aircraft's production which resulted in widespread cracking in the wings.

After considering various alternatives to obtain a 30,000-hour service life, the Air Force contracted with the Lockheed-Georgia Company, the C-5A manufacturer, for the design of the H-mod. Under the initial program, the Air Force planned to replace only the center and inner wing boxes while reworking the

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1/Senator Proxmire is now Vice Chairman, Subcommittee on International Trade, Finance and Security Economics, Joint Economic Committee.

outer boxes on all 77 aircraft. (The photograph on p. 3 illustrates major C-5A wing modification structural components.) After the H-mod contract was awarded in December 1975, the Air Force approved outer wing box replacement in lieu of rework because the boxes were being damaged during aerial refueling operations. As of May 31, 1981, the H-mod program consisted of a 12-year, $1.5 billion development and production effort scheduled for completion in fiscal year 1987. Instead of achieving only the original C-5A service life objective, this modification will actually extend the aircraft's life by 30,000 or more flight hours.

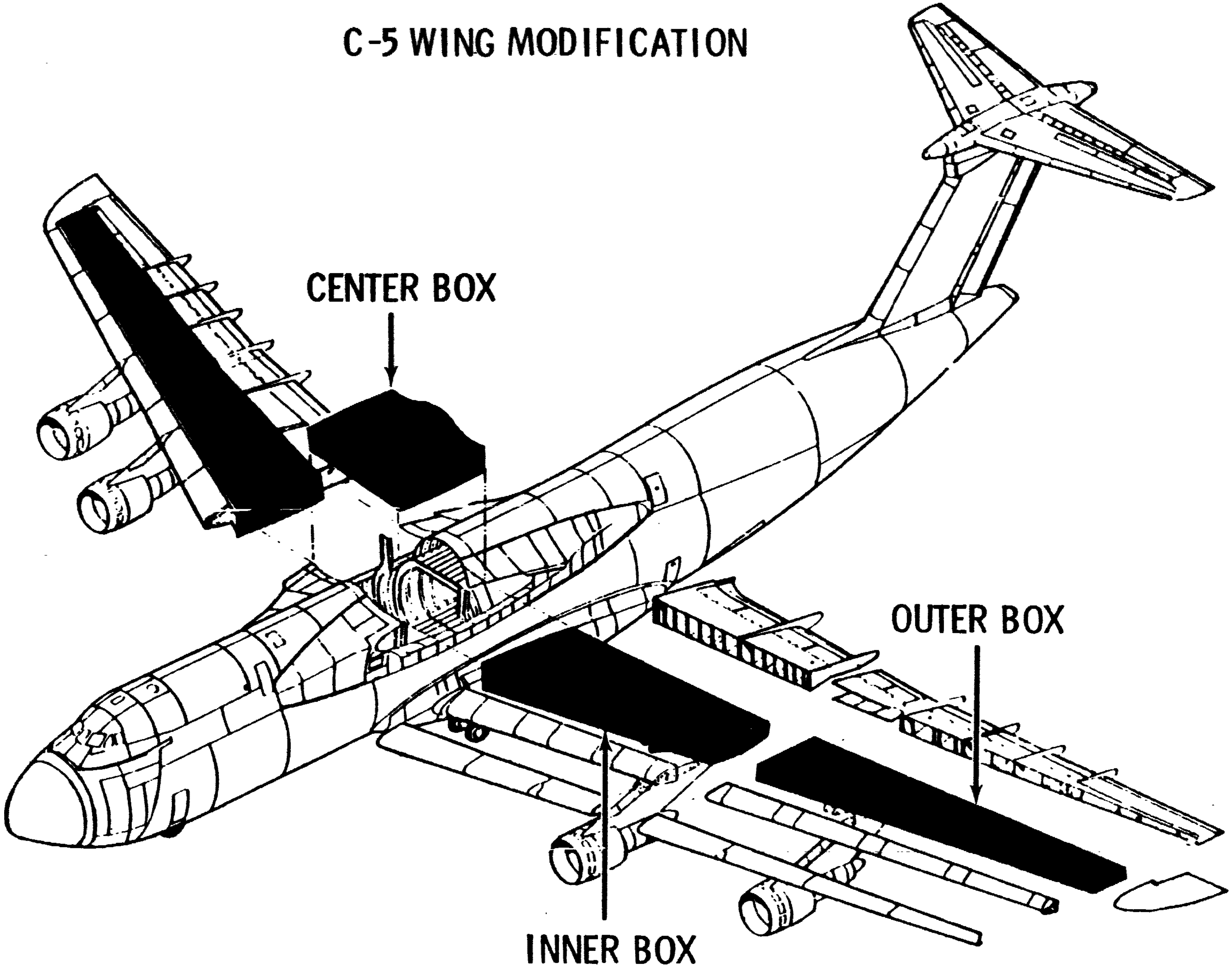
C-5A ACQUISITION HISTORY

Paralleling the need for additional airlift capacity were Department of Defense attempts to alter the weapons system procurement process. During the 1950s and early 1960s, weapons system contracting was based almost exclusively on design competition limited to the development phase. At the same time, the use of cost-reimbursement contracts increased steadily as a means for adapting military requirements to rapidly advancing technologies. Companies which were awarded development contracts gained financial and technical advantages over their competitors, frequently forcing sole-source negotiations for the follow-on production contracts. In addition, these companies would intentionally underbid the development phase, commonly called "buy-in" bidding, knowing their losses could be recovered during production. As a result, the procurement system was susceptible to abuse and cost overruns became a major problem.

Also, the Government had a difficult time trying to make contractors correct design defects revealed during testing or a system's operational use. This situation occurred because the contractors submitted most major design drawings to the Air Force program office for approval. In many instances, Air Force engineers revised design details until they met Government requirements. Hence, when design deficiencies arose, the contractors would refuse to fix them within the existing contract scope. Case after case, the Armed Services Board of Contract Appeals ruled that contractors were entitled to reimbursement of additional costs and fees for resolving design problems since the Government had been a party to the design process.

In the mid-1960s, Defense management adopted the total package procurement concept to prevent buy-in bidding, reduce cost overruns, instill greater competition throughout the acquisition process, and assign the contractor total responsibility for system design. Defense officials believed this procurement concept was applicable to proposed weapons systems whose performance requirements could be defined accurately and whose major technologies were at hand. The concept, as envisioned, integrated all development, production, and as much support as was practical into a single, fixed-price contract containing firm cost, schedule, and performance guarantees.

C-5 WING MODIFICATION



Assuming that the C-5A was merely a scale-up of the C-4 the Secretary of Defense approved the total package concept for the C-5A procurement in February 1965, making it the first of several major weapons systems acquired in this manner. Three companies offered proposals for the airframe contract, and in September 1965, Defense selected the Lockheed-Georgia Company to manufacture the C-5A.

The initial contract covered C-5A research, development, test, and evaluation, including 5 test aircraft, 53 production aircraft (Run A), the option price for 57 additional aircraft (Run B), and a planning formula for yet another 85 aircraft (Run C). The contract target and ceiling costs totaled approximately \$1.3 and \$1.7 billion, respectively, for research, development, test, and evaluation and Run A.

Lockheed's proposed performance guarantees exceeding minimum specifications were established as firm requirements. For example, instead of a basic requirement to carry 200,000 pounds up to 2,700 nautical miles under specified operational parameters, Lockheed claimed that 220,000 pounds could be carried over 3,000 nautical miles. Other similar claims were made during source selection, and these also were incorporated into the C-5A contract.

Upon contract award, Lockheed assumed full and associated risks for the design, development, production, and ultimate performance of the C-5A aircraft, including the integration of Government-furnished jet engines manufactured by General Electric. The Government, in a corresponding action, relaxed or eliminated certain program management controls practiced in previous procurements and began to follow a policy of "disengagement." By pursuing this policy, the C-5A Program Office increased Lockheed's freedoms to perform within the scope of the contract and refused to approve or to agree with contract changes which would have been perceived as limiting Lockheed's responsibilities.

Technical and financial problems leading to fixed-loss settlement

When Lockheed was selected to produce the C-5A, the Air Force knew that weight and drag problems existed. Further accentuating these problems was a last minute proposal for increasing wing surface area to meet takeoff and landing requirements. This proposal caused Lockheed to undertake a major redesign effort which continued into 1966, even though contract schedules did not change. Ultimately, the Air Force notified Lockheed that it had deviated from contract specifications by reducing the wing material metal below contractually required thicknesses. Lockheed engineers expected new materials, improved manufacturing processes, and sound quality assurance to offset adverse effects the lighter wings had on C-5A structural integrity.

Concurrent with the technical difficulties, Lockheed began to experience cost problems. Lockheed underestimated the engineering hours required to design the aircraft and had intentionally underbid subcontract costs. The buildup of the Vietnam War compounded cost increases by spawning a "seller's market," which forced subcontract prices higher than anticipated and increased material leadtimes. Inflation also increased to rates that could not be foreseen. Although cost increases were evident in early 1966, the Program Office did not learn that costs might exceed the contract ceiling price until early 1968. According to a 1969 Air Force C-5A program review, senior Defense and Air Force officials agreed in June 1968 to restrict the internal reporting of the cost increases. These officials also decided not to publicize the overrun because Lockheed disagreed with the Air Force's cost estimates and because of possible damage to the company's commercial position. A projected $2 billion cost overrun, however, eventually was disclosed during an Air Force official's testimony before the Joint Economic Committee in November 1968.

In January 1969, the Air Force exercised Run B, but it limited the Government's obligation to advance buys of only 23 aircraft. The Air Force later notified Lockheed in November 1969 that the 23 aircraft would make up the final buy and that no funding would be available beyond this order. Lockheed stated that the Air Force had ordered the 57 Run B aircraft and had partially terminated the contract. During January 1970 Lockheed formally appealed the Air Force's decision limiting Run B to 23 aircraft.

During litigation of this dispute, cost and technical problems continued, and in January 1971, Defense informed Lockheed that no precedent existed for advancing funds beyond the contract ceiling. Defense also informed Lockheed that the C-5A program disputes could be settled if Lockheed accepted a $200 million fixed loss. Lockheed accepted this proposal, and in May 1971, the C-5A contract was amended to a cost-reimbursement, fixed-loss instrument by Supplemental Agreement 1000. Within 4 months after this settlement, two major C-5A wing test articles failed, conclusively demonstrating serious weaknesses existed. One wing broke before fulfilling static strength requirements, while the other, in only 15,000 test hours, had cracked beyond effective repair.

C-5A wing problem studies and analyses

Between November 1971 and 1973, the Air Force and Lockheed performed three major studies to identify both the nature of the wing problems and the potential solutions. On the basis of these analyses, the service life safety limit was fixed at 6,500 hours, given prolonged aircraft use similar to that occurring in 1972. In November 1973, the Secretary of the Air Force accepted the conclusions of these studies and recommended that the Air Force proceed with the H-mod. Funding problems, as well as Defense concerns over concurrency and the feasibility of competition, Lockheed began fabricating production wing articles in August 1980. Given the current schedule, the first C-5A will be submitted for modification during February 1982 and will be completed 1 year later. By 1984, Lockheed hopes to achieve a modified aircraft delivery rate of 1.5 per month, completing the modification program in July 1987. (See app. I for a chronology of major C-5A program events.)

OBJECTIVES, SCOPE, AND METHODOLOGY

Over the years, the C-5A acquisition program has been noted for its problems involving contractor cost overruns, engineering design deficiencies, and allegations that these issues, at times, had been concealed from the Congress and the public. The nature and extent of these problems have been discussed in a variety of documents available to the public, and they have been aired during various congressional hearings. We believe that much of this information goes well beyond the issues addressed in Senator Proxmire's request. For this reason, we did not attempt to make a comprehensive review of all C-5A cost and performance issues. Instead, we focused our work only on that information which was relevant to the wing cracking problem and subsequent modification.

Starting with the original acquisition program and continuing through the H-mod effort, we evaluated Air Force procedures used in identifying and resolving the C-5A wing defects. We also updated the cost, schedule, and performance status of the H-mod program through May 1981. In addition, we

--reviewed Defense directives and Air Force policies, regulations, and procedures on aircraft structural integrity requirements;

--examined C-5A contract files for aircraft performance guarantees, test requirements, obligations under correction of deficiency provisions, Government and contractor rights pursuant to Supplemental Agreement 1000, and the warranties granted by Lockheed for H-mod performance;

--read documented histories of the C-5A procurement and discussed important events noted therein with Air Force officials who were involved with the procurement at the time;

--studied previous GAO reports which addressed the C-5A program from 1969 to 1975;

--reviewed the various technical studies upon which the H-mod was justified and interviewed the participants of these study groups concerning their conclusions and recommendations;

--evaluated the adequacy of the H-mod warranties granted by Lockheed, the decision to negotiate sole-source with Lockheed for the H-mod, and the need for independent testing capabilities by discussing these matters with several Defense contractors and reviewing related Air Force studies; and

--reviewed H-mod budget, cost, and other financial data.

Because the C-5A program dates back more than 15 years, we cannot ensure that we have identified and reviewed all important and historical documents. Time constraints prevented us from completely reviewing the C-5A contract files, which have become voluminous. Finally, our limited expertise in structural engineering prevented us from assessing the technical accuracy of the analyses which resulted in the C-5A wing modification decision. The availability of fracture mechanics who had not worked on the C-5A was limited, and therefore, we did not pursue the matter.

We performed our review at

--Headquarters, Departments of Defense and the Air Force, Washington, D.C.;

--Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio;

--Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio;

--San Antonio Air Logistics Center, Kelly Air Force Base, Texas;

--Air Force Plant Representative Office, Lockheed-Georgia Company, Dobbins Air Force Base, Georgia; and

--Lockheed-Georgia Company, Marietta, Georgia.

We also made visits to and held discussions with various officials at the following locations:

--Headquarters, Air Force Systems Command, Andrews Air Force Base, Maryland.

--Headquarters, Air Force Logistics Command, Wright-Patterson Air Force Base, Ohio.

--Military Airlift Command, Scott Air Force Base, Illinois.

--60th Military Airlift Wing, Travis Air Force Base, California.

--Defense Contract Administration Services Offices, Birmingham, Alabama, and Nashville, Tennessee.

--AVCO, Inc., Nashville, Tennessee.

--Southwest Research Institute, San Antonio, Texas.

--Center for Fracture Mechanics Analysis, Washington University, St. Louis, Missouri.

--Boeing Military Airplane Company, Wichita, Kansas.

--Boeing Commercial Airplane Company, Seattle, Washington.

--General Dynamics, San Diego, California.

--Lockheed Aircraft Corporation, California Division, Burbank, California.

--Rockwell International, Los Angeles, California.

--Douglas Aircraft Company, Long Beach, California.

--Rand Corporation, Santa Monica, California.

--Fatigue Technology, Inc., Seattle, Washington.

--National Taxpayers Union, Washington, D.C.

Our discussions at these latter locations centered primarily on the technical aspects of the wing problems, on quality assurance, on warranties the Government can expect from private aircraft manufacturers, and on the feasibility of completing the H-mod program. Many of the individuals interviewed had been connected with Air Force-financed technical studies or had sat on Air Force Scientific Advisory Board committees which periodically reviewed C-5A wing modification analyses and decisions.

We performed our review in accordance with GAO's current "Standards for Audit of Governmental Organizations, Programs, Activities, and Functions."

AGENCY COMMENTS

In early November 1981, we met with representatives of the Office of Secretary of Defense and the Air Staff to discuss the report's contents. These officials indicated that the report was factual and presented a reasonable summation of the C-5A's program history.

Lockheed also reviewed a draft of this report and considered it a fair representation of the facts.

CHAPTER 2

THE POTENTIAL FOR C-5A WING DEFICIENCIES EXISTED BEFORE LOCKHEED COMPLETED AIRCRAFT DESIGN AND STRUCTURAL TESTING

Airframe weight problems were known to exist by the Air Force in Lockheed's original designs. During Lockheed's development of the C-5A, the company deviated from contract specifications by reducing wing material below contractually required thicknesses. This action reduced substantially the aircraft's service life below the 30,000 flight hours desired. Even though the Government was dependent on Lockheed to furnish contract compliance information under the total package procurement concept, the Air Force had knowledge during the C-5A source selection that Lockheed's proposed cost, schedule, and performance guarantees were unrealistic. By 1967, the Air Force had acquired engineering data from Lockheed which indicated the wing designs might impair future C-5A operational capabilities. At that time, Air Force technical advisors suggested that Lockheed consider the feasibility of accelerating airframe structural tests so the potential impacts of suspected deficiencies could be defined more accurately. Lockheed indicated it would be unable to revise the test schedule, and the tests did not start until 1970. As a result, the Air Force did not obtain empirical evidence of the wings' limited capabilities before obligating the Government to buy 81 aircraft.

In our opinion, the Air Force's dependence on Lockheed for structural test results delayed the disclosure of actual wing deficiencies. In essence, the concurrent C-5A development and production, Lockheed's control over the structural test program, and the late scheduling of the structural tests prevented the Air Force and Lockheed from promptly correcting the deficiencies. Nevertheless, the quality of fatigue testing over time has not been a problem, and because the Air Force has periodically updated its aircraft structural integrity requirements, which required testing before starting production, we found no basis to conclude that an independent fatigue test capability is needed today.

TECHNICAL AND MANAGERIAL ISSUES CONCERNING C-5A WING PROBLEM ORIGINS

In December 1964, the Air Force released the C-5A Request For Proposal to three members of the aircraft industry: Boeing, Douglas, and Lockheed. Request For Proposals were also released to Pratt & Whitney and to General Electric for the engine. Each airframe company received notification that (1) contract award would be made to the source whose proposal demonstrated the greatest cost effectiveness over a 10-year period and (2) the system would have to comply with all minimum performance requirements. In February 1965, the Secretary of Defense approved total package procurement for the C-5A program. Within this environment, the Request For Proposals not only had to specify performance and schedule requirements for supporting system development but also had to define operational and maintenance requirements so the contractor could prepare life-cycle cost estimates. To maintain competition throughout source selection, each competitor signed firm, binding model contracts incorporating the performance and cost guarantees on which final selection was based.

Among the numerous performance requirements, each airframe competitor guaranteed empty weight, payload, range, and takeoff and landing distances. The interrelationships of these specifications and the Air Force's demand for high performance operational requirements forced the competitors to design near 100-percent effectiveness in all system elements. This situation presented a difficult design problem, offering little opportunity to compromise requirements, and immediately distinguished the C-5A system from other preceding aircraft developments.

The specifications provided little margin in any design area. Maximum engine thrust, wing aerodynamic loading chosen for cruise efficiency, and specified takeoff and landing performances set both the gross weight limits and the drag characteristics. Similarly, engine fuel consumption and the payload and range specifications established the allowable airframe empty weights.

The Air Force acknowledged these interrelationships early in the C-5A program definition phase. Because previous aircraft production costs showed a proportional relationship to the aircraft weight, the Air Force also created an analytical airframe weight model for evaluating the impacts of design changes. However, once each offeror completed the initial system design, which it believed to balance the performance requirements, any subsequent departure resulted in substantial risks of failing to meet performance guarantees. For example, an attempt to improve takeoff and landing capabilities might have increased airframe weight and decreased the payload and range. Attempts to improve the payload and range by decreasing weight could have degraded the takeoff and landing capabilities.

Source selection

In August 1965, the Air Force selected General Electric to build the C-5A engines because its proposal was judged technically superior. In the same month, the C-5A source selection board recommended that Boeing be selected for the airframe contract since its design met all requirements, posed the least development risks, and offered the most cost-effective system. Lockheed offered the lowest target cost, but the board concluded that the company's design was unbalanced and contained takeoff and landing deficiencies. The board also believed that any Lockheed redesign to meet performance specifications elevated the risk of achieving schedule requirements. Douglas' proposal contained a series of performance deficiencies, and the necessary redesign created a high schedule risk.

On September 1, 1965, the Air Force notified each potential airframe contractor that deficiencies existed in its proposal. Three days later, the companies submitted their revised proposals. Boeing made some minor changes to improve aircraft performance. Lockheed substantially redesigned its aircraft, adding 600 square feet to the wing surface area and changing the flap span, thrust reversers, and engine inlets. Douglas proposed even more extensive design changes to correct range and landing deficiencies. Subsequently, the board briefed the source selection authority on two occasions, recommending unanimously that Boeing be awarded the contract.

In the board's opinion, Boeing continued to meet all requirements and offered the most cost-effective program. While Lockheed's offer was approximately $300 million less than Boeing's, redesigned aircraft proposal (1) failed to meet one landing requirement, (2) added weight to an airframe that was already heavier than the others, (3) presented grave risks in meeting schedule requirements with a potential 6- to 12-month delay, and (4) raised the probability of target cost overruns. Douglas' proposal improved its overall system cost effectiveness, but its design changes, like Lockheed's, included cost and schedule risks.

Regardless of the claims made in the revised proposals, the source selection board warned the selection authority that the offerors who had redesigned their aircraft included only preliminary performance estimates. These estimates were contained in changes to earlier proposal drawings and were not supported by detailed backup data. According to the board, substantially more time and testing were required to ensure that the changes did not impair handling qualities or structural dynamics.

On September 30, 1965, Defense selected Lockheed for the airframe contract. The source selection authority, with the advice of 20 senior Air Force officers, considered Lockheed's proposal, including its lower acquisition cost and better loading and cargo carrying flexibility, to be in the best interests of the Government. On December 17, 1965, the C-5A contract with Lockheed was completed and released for distribution. The contract target costs for the development effort and production Runs A and B, including the General Electric-manufactured engines, totaled $2.272 billion. The contract also set the date of C-5A initial operational capability--delivery of the 16th aircraft--for December 1969.

<u>C-5A weight and drag problems</u>

Historical weight growth trends vary widely from airplane model to airplane model and are sensitive to several extraneous factors, such as schedule pressure, weight control efforts, and the degree of weight concern in the original designs. Given the interrelationships of various C-5A performance requirements and their dependence on airframe weight, Lockheed emphasized weight control from contract inception. In its initial proposal, Lockheed offered an empty weight over 302,000 pounds. The weight specified in the formal December 1965 contract exceeded 318,000. Much of this weight increase was associated with Lockheed's redesigned wing that included 600 additional square feet.

By early 1966, Lockheed estimated further weight gains of over 3,300 pounds, reflecting the changes needed for drag reduction. Preliminary wind tunnel tests disclosed that Lockheed's C-5A designs exceeded the drag target by more than 14 percent, which could have reduced the aircraft's payload capability by 36,000 pounds over a given distance. As a result, Lockheed redesigned the aircraft's nose, wing, and gear pod fairings and the aft fuselage.

In June 1966, Lockheed informed the C-5A Program Office that the C-5A continued to experience serious weight problems, even though the company had pursued extensive control efforts. Among its efforts, Lockheed had set up a subcontractor weight control program; increased the use of lighter materials, such as titanium, fiberglass, and beryllium; employed a new lighter weight fastener system; and reduced the material thicknesses in the cargo floor supporting structure. To obtain even greater weight reductions, Lockheed proposed that the Air Force reduce 16 contract specifications which were believed to be conservative. These changes would have eliminated the in-flight refueling and anti-icing systems and reduced several structural requirements.

In early 1967, Lockheed advised the Air Force that weight empty, takeoff and landing distances, and initial cruise altitude guarantees might not be met because of difficulties in achieving weight, lift, and drag targets needed for required performance. Further, Lockheed admitted that it could miss the weight guarantee by several thousand pounds. The Air Force responded that Lockheed had not adequately emphasized these performance requirements and reminded the company that the contract required compliance with all specifications at the time of aircraft delivery. Subsequently, Lockheed and General Electric jointly proposed to increase the engine thrust in consideration for deleting the guaranteed empty weight. Air Force officials rejected the proposal because it jeopardized the engine development and because they saw no benefit accruing to the Government by granting Lockheed the requested contractual relief. Also, deletion of the weight guarantee would most likely have resulted in additional weight growth, offsetting advantages gained from increased thrust.

Since Lockheed had no apparent engineering program to meet the contractual guarantees, the Air Force notified Lockheed on February 1, 1967, that its failure to meet the requirements constituted a condition endangering performance within contract terms. Accordingly, Lockheed was given 30 days either to remedy the condition or to prepare a satisfactory plan to do so; otherwise, the Government might terminate the contract for default. In late February, Lockheed formed a special corporate team to prepare detailed plans for achieving its contractual guarantees.

This action apparently appeased the Air Force, and it withdrew plans to terminate the contract.

In March 1967, Lockheed's corporate team reported its findings, which were reviewed by an Aeronautical Systems Division (ASD) advisory group. The group consisted of over 20 aerodynamic and structures experts from the academic community, the Air Force, and the National Aeronautics and Space Administration. ASD tasked the group to assess C-5A performance and to determine the adequacy of Lockheed's recovery plan. The advisory group concluded in April 1967 that Lockheed had been doing a competent job and that all specified performance, except landing distance and empty weight, appeared within reach. The group estimated landing distance and empty weight would likely exceed guarantees by 250 feet and 4,000 pounds, respectively. However, regarding airframe weight, the group noted that average stresses in primary structures exceeded standard design practices with little or no allowance for conservative uncertainty or factors of ignorance. Stress levels were abnormally high because Lockheed had used lighter gages of aluminum than were contractually specified for the wing boxes. With these lighter gages, Lockheed reduced the weight of the C-5A wing by about 10,000 pounds, which raised the risk of greater fatigue damage but also increased the prospect that performance and weight guarantees would be met. Lockheed expected to compensate for the higher stresses and potentially increased fatigue damage rates by using new fastener technology, improved manufacturing techniques, and better quality assurance procedures.

Although Lockheed's design improved overall aircraft efficiency, the advisory group warned that Lockheed's failure to predict the aerodynamic loads accurately could mean a restricted flight profile or an entirely new wing structure. The group recommended several analyses and tests be conducted to ensure that the best possible design information was available throughout development. Included in these recommendations was a suggestion that the feasibility of accelerating wing and fuselage testing be considered. In the group's opinion, fatigue test results were needed before their scheduled 1970 release, since small component tests were unlikely to show the aircraft's overall fatigue tolerances. Lockheed, however, indicated that, because of established production milestones, it was impossible to make a fatigue test article available sooner than the scheduled delivery date in 1969.

Cost problems

In early 1966, several developments surfaced which gave indications of program cost growth. Inflationary effects started to have an impact as wage, overhead, and general and administrative rates began to rise. Lockheed, in its cost proposal, had also deliberately undercut its lowest subcontractor bids by 10 percent because it believed a "buyer's market" would prevail during subcontract negotiations. However, rising costs became apparent when major subcontracts were negotiated at much higher prices than anticipated. Compounding these problems were the additional engineering efforts required by Lockheed's aircraft design changes proposed the previous September.

The design refinement of the wing, together with the redesign to reduce drag and the changes made to control weight, contributed to the late release of engineering data to subcontractors and to Lockheed's manufacturing branch. This late release disrupted the production schedule and increased costs during attempts to recover the schedule. New tools had to be made, items had to be installed out of sequence, and more overtime had to be approved. Also, Lockheed's weight control program involved greater use of materials, such as titanium which, in addition to costing more, required changes in the manufacturing processes, finer tolerances, and increased labor costs.

The expansion of the Vietnam War during the late 1960s further aggravated Lockheed's cost problems. Demands placed on the general economy, and on the aerospace industry in particular to support that effort, increased inflation rates above those predicted and lengthened leadtimes for needed parts and supplies. As a result, Lockheed's costs continued to increase, and in late 1968, a potential $2 billion overrun became public.

Schedule problems

During early C-5A system definition, disagreements arose concerning the most advantageous date for the aircraft's initial operational capability (IOC). The Commander, Air Force Systems Command, insisted that the aircraft could not become operational before 1971 or 1972, while the Commander, Military Airlift Command, was willing to sacrifice potential performance for an earlier IOC in fiscal year 1969.

In mid-1964, the Secretary of Defense indicated that the attractiveness of a C-141 and C-5A airlift mix rested on its ability to meet a post-1968 airlift requirement at a lower cost than continuing only C-141 procurements. Although the outsize cargo capability would be valuable, it did not justify, in his opinion, the expense for such a small number of aircraft unless the aircraft could be available by the end of calendar year 1969. Given this guidance, the Air Force finally opted for an IOC in December 1969, predicated on an August 1, 1965, contract award.

After its selection in September 1965, Lockheed disagreed with the specified IOC date in the C-5A contract. Since the contractor would be obligated to pay $12,000 a day for each aircraft not delivered by the end of each specified month, Lockheed believed it should be allowed a later IOC to compensate for the 2-month delay in the scheduled contract award date from August 1, to September 30, 1965. The Air Force considered an IOC of 1969 to be essential and maintained its entitlement to demand delivery on the original schedule. Through negotiations, the schedule differences were resolved in the Air Force's favor.

Even with the airframe weight and drag problems, Lockheed tried to meet its schedule obligations until January 1969. Overtime and out-of-sequence installations proved futile, and a supplemental agreement to the contract extended IOC by 4 months. The agreement recognized that schedule difficulties arose even before the original contract award. Eventually, the IOC was slipped a total of 6 months to June 1970 because of manufacturing control problems.

C-5A contract restructuring

The C-5A contract with Lockheed contained a formula for redetermining the target price of the 57 aircraft, Run B option, on the basis of a ratio of Run A actual costs to Run A target costs. During 1968, the Air Force became increasingly concerned with C-5A cost growth and with the possibility that a "reverse cost incentive" would be created in the contract if the option for Run B production quantities were exercised for 33 or more aircraft, or for a program total of 91 or more aircraft. Beyond this point, every dollar spent on Run A would increase the contract ceiling price by more than a dollar.

The C-5A contract required the Air Force to decide on the exercise of the Run B option in January 1969. On January 17, 1969, the Air Force issued Supplemental Agreement 235, obligating funds for purchasing long-lead items for 23 additional aircraft. This supplemental agreement formed the focal point of Lockheed's dispute on the C-5A contract. According to the Air Force position, Supplemental Agreement 235 limited the repricing formula to only 23 of the 57 aircraft in Run B. Lockheed maintained that as a result of the exercise of the Run B option, the repricing formula should be applied to all 57 aircraft.

Because of the unresolved reverse incentive problem, increased costs, budgetary constraints, and a reassessment of airlift requirements, the Air Force decided to limit its procurement of the C-5A to 81 aircraft instead of 115 aircraft under the Run A and B options. On November 21, 1969, the Air Force issued Change Order 521 effecting a final order of the 23 Run B aircraft then on contract. Lockheed contended that the November 1969 change order amounted to a partial termination of the 115 aircraft program which the Air Force had, in effect, ordered by exercising its option for Run B. More specifically, Lockheed contended that, by exercising the option, the Government became obligated to reprice the entire contract according to the formula, on the basis of 57 Run B aircraft. Under this approach, the price would be computed for 115 aircraft, the percentage of profit or loss on 115 airplanes would be calculated, and the percentage would be applied to the cost of the 81 airplanes to determine the price to the Government. In January 1970, Lockheed filed an appeal with the Armed Services Board of Contract Appeals.

The Air Force maintained that the Government's liability was effectively limited, since the funds obligated for long-lead items covered only 23 aircraft in Run B and, as noted above, under the terms of Supplemental Agreement 235, the repricing formula should be applied to the Run B target cost for 23 aircraft only.

These positions formed the principal dispute and the one docketed with the Armed Services Board of Contract Appeals. However, several other disputes arose under the contract, including disagreements over how payments for abnormal inflation should apply to the repricing formula, the allocation of initial tooling costs, and the contract ceiling percentages applicable to spares and new work added to the contract.

In a previous report, 1/ we noted that Lockheed informed Defense in 1970 the company was experiencing financial problems, jeopardizing completion of contractual performance requirements in the C-5A, Cheyenne helicopter, Short-Range Attack Missile motor, and shipbuilding programs. The dollar amount of claims and disputes in these programs made it impossible for Lockheed to finance contract requirements pending the outcome of litigation before receiving further reimbursements from the Government. Both the Defense Contract Audit Agency and GAO 1/ reviewed Lockheed's financial data and concluded that the company would need Federal financing to complete the C-5A program.

By letters dated December 30, 1970 to the Chairmen, House and Senate Committees on Armed Services, the Deputy Secretary of Defense outlined his proposals for resolving the disputes and claims surrounding the military programs in which Lockheed was participating. Concerning the C-5A, he indicated that two alternatives existed with which to settle the disputes:

--Reduce the number of peripheral issues in dispute by negotiation and allow the core of the disagreements to proceed through litigation. The litigation basically would concern the question of whether the Air Force exercised an option for 81 airplanes or for 115 airplanes and the corresponding application of the repricing formula. The Air Force and Lockheed, over several weeks of discussion, concluded that the litigable disagreements would result in a financial settlement ranging from an approximate $25 million recovery by Lockheed against the United States to about a $480 million liability or loss by Lockheed.

--Settle the entire dispute by eliminating all issues and impose a fixed loss on Lockheed. Such a settlement would prevent any performance incentive fees or profits on initial spares and added work related to the scope of the contract which Lockheed otherwise might have earned.

1/"Financial Capability of Lockheed Aircraft Corporation to Produce C-5A Aircraft" (B-169300, Apr. 12, 1971).

Because the Deputy Secretary of Defense believed that the C-5A was essential for the national defense and that the program's timely completion was necessary for improving U.S. airlift capabilities, he considered the last alternative as preferable. After studying the fact, he concluded that a $200 million fixed loss was a reasonable figure upon which to settle.

Initially, Lockheed declined to settle for a $200 million fixed loss and elected to proceed with the litigation. However, costs incurred by Lockheed had reached contract ceiling and Defense found no precedent for advancing money beyond that specified in the contract during the course of litigation. Since Lockheed did not have the money to continue performance under the C-5A contract while pursuing the litigation, it agreed to accept the $200 million loss.

Under its authority to facilitate the national defense, and in accordance with the agreement reached with the Lockheed Aircraft Corporation, the Department of Defense directed the Air Force to enter into Supplemental Agreement 1000 with the corporation, which converted the fixed-price incentive, C-5A contract to a cost-reimbursement contract with a provision for the fixed loss of $200 million. This agreement was entered into in May 1971. The Government's obligations were made subject to applicable statutory restrictions and the availability of appropriations. Lockheed was relieved of any liability for C-5A deficiencies which the Air Force had already accepted, but it agreed to fix all deficiencies at cost and no fee on aircraft accepted after the agreement became effective. The corporation also gave up any right to profit for aircraft production, production of initial spares, or added work within the scope of the 81-aircraft program. Lockheed also waived all claims arising under the original C-5A contract, including those in litigation.

Static and fatigue test article failures

The C-5A wing is constructed of many overlapping panels connected through drilled holes with fasteners. These panels were drilled and reamed at the same time. If the holes were damaged while being drilled or reamed, cracks would start and spread among the connected panels during use of the aircraft. The wing is designed to withstand fracture of a single panel, but the cracking of two connected panels could result in the fracture of the entire wing and subsequent loss of the aircraft. The weaknesses in Lockheed's C-5A wing designs became evident during static tests of wing strength, during fatigue tests to determine aircraft service life, and during flight tests.

To determine the wing's ability to withstand load level requirements, the contract required a static test program. In static testing of the wing, a nonflying test article was instrumented and subjected to certain tests, such as wing bending by mechanical means, to determine the wing's structural strength up to 150 percent of design limit load.

To determine the service life of the aircraft, the contract also required a fatigue test program. In fatigue testing, a non-flying test article was instrumented and subjected to repeated loads by mechanical means, simulating various flight conditions and payloads. The contract required the structure to be tested to four lifetimes (120,000 test hours) which would demonstrate a 30,000-hour service life.

In July 1969, the first failure of the static test article occurred in the wing near the fuselage (wing station 120) at 124 percent of the design limit load. The Air Force attributed the failure to a design error in the wing. Lockheed later corrected that error by structurally modifying the test article and operational aircraft. In January 1970, the Air Force identified the first fatigue cracks in the wings of a flight test aircraft.

As a result of the structural deficiencies identified during static and flight testing, the Secretary of the Air Force convened the Air Force Scientific Advisory Board in February 1970 to review the C-5A wing structural failures. In addition, he requested the board to review the aircraft's performance, avionics, and landing gear. The board reported to the Secretary in June 1970 that the modifications designed and introduced by Lockheed to correct the design error at wing station 120 were adequate, but high stress levels identified in the wing raised serious doubts whether the wing could meet the 30,000-hour service life. The board recommended an additional fatigue test article be built to speed up wing fatigue tests and to identify more quickly the wing's specific fatigue problem areas.

Fatigue testing of the original fatigue test article (X998) began in January 1970. In October 1970, shortly after the advisory board reported to the Secretary, a cracking problem occurred at 9,000 test hours. Lockheed repaired the test article, and testing continued until September 1971 to 15,000 hours (the equivalent to a 3,750-hour service life), at which time a general cracking of the inner and center wing sections occurred. The fatigue cracks were of the type and magnitude that would normally not be expected to occur until the completion of fatigue testing at 120,000 test hours.

As recommended by the advisory board in June 1970, Lockheed built an additional wing fatigue test article (X993) to identify more quickly the wing's specific fatigue problem areas, but the test article was not intended to establish the wing's fatigue endurance. Cracks occurred in this test article at about 9,000 test hours and general cracking of the lower wing surface occurred by June 1972 at 33,000 test hours. By June 1973, portions of this article had been tested to 60,000 test hours, at which time further fatigue testing was stopped.

Later inspection of both fatigue articles identified extensive cracking in the inner and center wing structures. The Air Force attributed the extensive cracking to high stress levels inherent in the wing design, ineffective fasteners in the wing panels, and the difficulty of mating the large, stiff, contoured parts of the wing and joints.

After the static test article was corrected in 1969, testing resumed and continued until September 1971, when a massive failure occurred in the outer wing at 126 percent of design limit load. A structural modification was not designed because the Air Force believed that static strength of the wing could not be substantially increased. As a result of this failure, the Air Force restricted C-5A payloads to 80 percent of contract specifications.

AIR FORCE DEPENDENT ON LOCKHEED FOR C-5A CONTRACT COMPLIANCE DATA

The competitive environment, assumptions, and motivations of Lockheed, plus the Air Force's efforts to have a "tight contract" during the definition phase resulted in negotiations of a contract with Lockheed which was difficult to meet on schedule at target cost. The self-control features built into the total package contract did not in themselves force Lockheed to perform in the best interests of the Government.

Because the Air Force implemented total package procurement shortly after its conception, without previously developed or defined procedures and contractual standards, the C-5A Program Office had to establish its own policies as the program evolved. As a result, interpretations and definitions of control and visibility to be exercised by the Air Force varied widely among the service's and Lockheed's personnel. The Air Force was not required to approve Lockheed's detailed designs and formed a management philosophy of noninterference or disengagement. Although the policy of disengagement was never defined, it was represented by an Air Force intent not to approve or to agree with changes to the C-5A contract which would limit Lockheed's responsibilities under the total system performance responsibility clause. This clause required that the Air Force avoid detailed program management but retain visibility if controls became necessary.

Disengagement procedures exercised in conjunction with the fixed-price incentive contract allowed Lockheed considerably more engineering prerogatives for meeting contractual requirements. These procedures were not unique to the total package concept, but their successful use depended on obtaining an adequately defined development and qualification program. In essence, total package concepts envisioned the Air Force prescribing certain cost, performance, and schedule requirements, and then waiting to see if the contractor were successful.

Established Defense and Air Force management information systems, such as cost and schedule compliance reports, did not provide the needed contract performance data. For example, Lockheed's periodic cost and budget reports did not contain sufficient information for the Air Force to identify the potential for cost overruns, even though Lockheed knew that engineering staff-hours to design the C-5A greatly exceeded the original program estimate. The relinquishment of program control also extended into the Air Force's evaluation of Lockheed's product. An official of the Air Force Plant Representative Office (AFPRO) at the Lockheed-Georgia Company told us that AFPRO was instructed to remain disengaged from Lockheed's testing activities, even though the office had observed questionable contractor actions. After Supplemental Agreement 1000 became effective, the Air Force assumed control of Lockheed's actions, but by this time, most of the primary test requirements had been accomplished.

Regardless of the Air Force's dependence on Lockheed for contract compliance and engineering data, information had been made available as early as 1967 which indicated potential wing problems. In addition, wing strength and material deficiencies were known to exist in 1969 before either the C-5A fatigue tests had begun or the first production aircraft had been accepted. Without a separate independent C-5A testing capability at that time, the Air Force had no way of assuring itself that the tests were conducted promptly.

NO NEED FOR INDEPENDENT TESTING CAPABILITIES

The Air Force Wright Aeronautical Laboratories (AFWAL) maintains a structures test facility at Wright-Patterson Air Force Base, Ohio, which, with some modification and the acquisition of some unique test fixtures, could have accommodated full-scale fatigue testing on the C-5A. The facility normally is used for a mix of static and fatigue tests covering basic research and exploratory, advanced, and engineering development and is completely independent of aircraft manufacturers. However, contractor data may be used in support of operational systems. Air Force officials believe that this in-house testing capability is needed to (1) advance basic understanding of fatigue phenomena, (2) establish procedures and standards for fatigue testing, and (3) maintain engineering expertise so AFWAL personnel, when called upon, can assist ASD systems program offices in the audit of contractors' structural fatigue test.

In 1965 the Air Force considered several national test facility concepts for conducting in-house, production-type fatigue testing. The concepts were analyzed at that time because certain large aircraft and space structures, such as the C-5A, supersonic transport, advanced manned strategic aircraft, and the mobile airspace defense system had been proposed or programed. Although a test facility at Palmdale, California, was considered the most cost-effective alternative among those evaluated for construction, an AFWAL official told us that the facility never received sufficient priority within the Air Force's facilities program. In addition, many of the large aircraft structures programs either were canceled or never funded.

According to Air Force Systems Command (AFSC) officials, a large in-house, production-type structural fatigue test facility is not needed. Even if the Air Force had such a capability, it would not be independent of the aircraft manufacturer. Contractor support would be needed to set up the test, maintain the test article, evaluate defects, and design repairs or modifications. In addition, AFSC believes

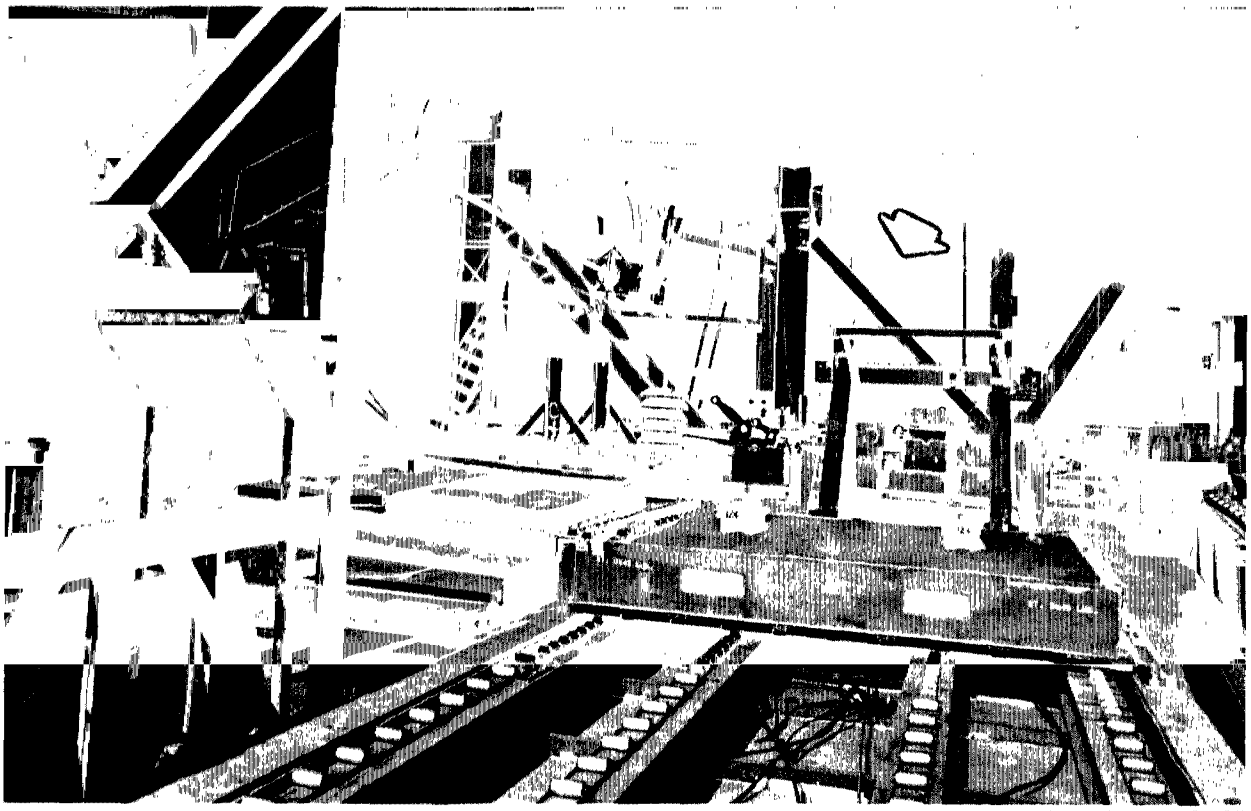
--routine maintenance of facilities, equipment, and personnel on standby awaiting intermittent requirements for testing would be impractical and

--scheduling problems would arise if more than one aircraft had a requirement for fatigue testing at the same time.

Regarding the C-5A wing defects, AFSC officials stated that the late scheduling of the structural tests within the concurrent acquisition program, and not the quality of testing, prevented the Air Force from incorporating needed design changes without completely disrupting the aircraft's production. Because no technical issues have surfaced over the quality of contractor fatigue testing since the C-5A program and because the Air Force has access to the contractors' test facilities, AFSC believes that it is not only more appropriate but also more economical for the aircraft manufacturers to continue performing the fatigue tests.

We contacted several members of the aerospace industry concerning their feelings about an independent or Government-operated national test facility. Generally, these industry members agreed with the AFSC position. They believed the potential distance of their facilities from a national test site would create logistics and personnel problems. Engineers would have to be assigned to the test facility, and when deficiencies occurred, the designs for repair and the installation of fixes could not be done at the same speed as if the tests were conducted in the manufacturers' facilities. They also indicated that fatigue testing facilities are used after production to evaluate various structural improvements, whether self-initiated or required by design defects. A national facility might restrict the testing of these ongoing efforts because of scheduling problems with other aircraft.

Our review demonstrated that fatigue tests on an aircraft like the C-5A would require a large, costly dedicated area in which the test article and associated equipment can be kept over a long period. Generally, fatigue test programs involve prolonged use of unique steel fixtures which support the test article, plus hydraulic equipment and computer systems to create and control simulated aerodynamic stress loads. The following photograph shows the C-5A's modified wing supported by the fatigue test stand at the Lockheed-Georgia Company. During the development of new aircraft, additional equipment for wing static testing and fuselage testing also would be needed.



SOURCE: U.S. AIR FORCE

MODIFIED C–5A WINGS IN THE FATIGUE TEST STAND AT LOCKHEED-GEORGIA COMPANY

Aircraft Structural Integrity Program

Through the 1960s, the Air Force believed four lifetimes of fatigue testing would adequately demonstrate the structural integrity of new aircraft. As we noted earlier, Lockheed had a contractual requirement to test the C-5A for 120,000 hours or four lifetimes, and in September 1971, these tests disclosed conclusively that serious wing design deficiencies existed. During the tests, however, Lockheed retained total system performance (design) responsibility, and given the policy of disengagement, Air Force personnel normally responsible for test oversight had unclear duties. Because of (1) C-5A test failures, (2) structural deficiencies in other aircraft, such as the F-111, (3) an expanding knowledge of fatigue phenomena, and (4) emerging technologies for predicting fatigue damage accumulation more accurately, the Air Force placed more emphasis on structural integrity considerations during the early design phases.

Since 1970, the Air Force has periodically updated the standards and methods of design, developmental test and evaluation techniques, and design verification procedures to improve the structural capability of its aircraft. These various structural requirements are enumerated in the Aircraft Structural Integrity Program. In essence, the contractor must prepare a structural integrity master plan documenting its approach for fulfilling the program's tasks and must design the aircraft to certain prespecified damage tolerance and durability standards.

The actual structural integrity achieved is then verified through fatigue testing and a series of analyses which must be reviewed and approved by the Air Force. Under the Airlift Structural Integrity Program, at least one lifetime of fatigue testing is required before a production decision is made.

Compliance with the Aircraft Structural Integrity Program

Both ASD and AFPRO contribute to the assurances that the contractor has fulfilled the requirements of the Aircraft Structural Integrity Program. ASD has primary oversight responsibility for fatigue testing and AFPRO supports ASD by providing on-site, daily surveillance.

Regarding the C-5A wing modification fatigue tests, ASD engineers approved the test plan and procedures and ASD and AFPRO engineers jointly monitored Lockheed's examination of the test instrumentation. In addition, ASD engineers were present during Lockheed's periodic inspections of the test article (every 2,500 test hours) and during the major structural inspections which were conducted after 30,000 and 60,000 test hours. Finally, the Air Force Scientific Advisory Board also reviewed the test results after the first 30,000 hours and expressed no concern about the modification's structural integrity. In the board's opinion, the modification durability performance equaled or surpassed that achieved by any other military or commercial aircraft during the first life time of testing.

CONCLUSIONS

The Air Force had engineering design data in 1967 which indicated that Lockheed's wing designs might impair future C-5A operational capabilities. In 1969 and 1970, a static test article failure and the discovery of fatigue cracks in a flight test aircraft provided some evidence of the wing problems. However, not until September 1971, did the Air Force have enough structural test data to recognize that the C-5A wing might require significant rework, modification, or replacement.

The Air Force included the C-5A structural test requirements in the total package procurement contract with Lockheed. The Air Force's dependence on Lockheed for structural test results and the late scheduling of the tests within the concurrent development and production program prevented the Air Force and Lockheed from incorporating needed design changes without disrupting C-5A production. By not keeping a separate, independent C-5A test capability at the time, the Air Force had no way of assuring itself that the required test information could be obtained promptly.

Since the disclosure of C-5A wing problems, the Air Force has periodically revised its Aircraft Structural Integrity Program which, at present, requires at least one lifetime of fatigue testing before a production decision can be made. The revised structural test requirements, coupled with the Air Force's existing oversight procedures for monitoring a contractor's test program, should provide more timely test results. If the Air Force implements and follows the revised structural test requirements and maintains adequate oversight, it should not need to incur the added cost of an independent test capability for identifying problems like those which developed in the C-5A wings.

CHAPTER 3

LOCKHEED AND AIR FORCE EVALUATIONS OF PROPOSED ALTERNATIVES DICTATED THE C-5A H-MOD CONFIGURATION

The 1971 static and fatigue test article failures convinced the Air Force that major C-5A wing modifications would be necessary to achieve specified cargo capabilities and the desired 30,000-hour service life. Shortly after these failures occurred, the Air Force funded the first of several engineering evaluations and technical reviews which assessed both the causes of the wing deficiencies and the possible alternative solutions. These evaluations and reviews continued into 1976, and together, formed the basis for the present H-mod configuration.

The different review teams consisted of various structural and aerodynamic experts from the Air Force, Lockheed, the aerospace industry, and the academic community. Because of its position as the original C-5A designer, its knowledge of C-5A design idiosyncracies, and its familiarity with the history and extent of the C-5A wing defects, Lockheed played a major role in most Air Force C-5A wing defect analyses. Lockheed furnished data for evaluation by others, supplied engineering personnel for some of the review teams, and conducted some of the assessments under the original C-5A contract. In fact, Lockheed's analyses under the 1973 Service Life Management Plan led the Air Force to conclude that new center and inner wing boxes were needed. The decision to replace the outer wing box occurred after the 1975 H-mod go-ahead decision, when data concerning wing fatigue damage arising from aerial refueling operations became available.

BASIS FOR H-MOD CONFIGURATION

Between 1971 and 1973, the Air Force funded three major engineering analyses of C-5A wing problems: the Independent Review Team, the Wing Life Improvement Program, and the Service Life Management Plan. These analyses and reviews, plus C-5A aircraft field experiences, comprised the available information from which the Secretary of the Air Force originally approved the H-mod in November 1973. In addition, ASD convened at least three separate advisory groups between 1974 and 1976 to review C-5A wing modification program developments and to recommend the best courses of action.

Independent Review Team and the Wing Life Improvement Program

As noted in chapter 2, the C-5A production program contained extensive static and fatigue testing requirements. Originally, Lockheed built two test articles for wing testing: X999 for static testing and X998 for fatigue testing. Testing on X999 ended in June 1972, 9 months after the second major failure. These tests confirmed only a 150,000-pound payload capability at a 2.5g load factor (2.5 times the force of gravity), far short of the 220,000-pound contractural requirement. To increase the payload capability by 40,000 pounds, the Air Force began operating the C-5A with the ailerons manually uprigged to relieve structural loading. This operating configuration, known as the passive lift distribution control system, also provided some fatigue life benefits but increased drag and reduced mission range by 2 to 3 percent.

Lockheed initially based X998 fatigue testing on the stress levels associated with the specific operational requirement or 15-mission profile scenario. After widespread cracking occurred at 15,000 test hours, Lockheed made the necessary repairs and lowered the stresses on the test article because the Air Force had adopted a less damaging 14-mission profile scenario and had incorporated the passive lift system. Testing continued under this lower stress spectrum until 24,000 test hours, when extensive damage prohibited any further useful data being collected.

At the recommendation of the Scientific Advisory Board, Lockheed had also built a second fatigue test article, X993, and accelerated its testing to identify problems in advance of X998. Lockheed tested this article under the 15-mission profile scenario but simplified the test program so the cyclic test rate could be increased. Cracking occurred on the lower surface at about 9,000 test hours, and the Air Force eventually directed Lockheed to convert X993 to an upper surface test only.

Given this series of problems, the Air Force recognized that the C-5A wings would require major repairs and/or modifications if the 30,000-hour service life were to be attained. In January 1972 the Air Force formed the Independent Review Team to conduct an in-depth structural review of the C-5A program. The team

--reviewed and assessed test and operational usage data,

--evaluated and developed fixes for known problem areas,

--identified and investigated potential problem areas, and

--prepared a matrix of all options from which cost-effective combinations for optimizing the wing life could be selected.

The review team, which operated outside the normal C-5A program organization and activities, consisted of approximately 120 engineering personnel from the aerospace industry and the Air Force who were relatively unfamiliar with the C-5A and its problems. Of these 120 individuals, approximately 30 came from the Lockheed Corporation's California Division, including the 4 technical review committee leaders, and from the Lockheed Missiles and

Space Company. The Lockheed-Georgia Company also furnished about one-third of the technical staff which either had not worked on the C-5A or had received assignments to technical areas in which they had not previously worked. The remaining staff-members came from aerospace companies other than Lockheed and from the Air Force.

The review team's efforts continued over a 14-month period, much of which was spent at Lockheed, and its progress was periodically reviewed by an advisory group which included technical experts from the National Aeronautics and Space Administration, Massachusetts Institute of Technology, National Science Foundation, Boeing, and the Air Force. The review team concluded that the C-5A, except for the wing, could attain a 30,000-hour service life. Regarding the wing, the team believed that, on the basis of 14-mission profile usage, (1) economical fixes would not exist after 7,000 to 10,000 flying hours because of the potential crack sizes and numbers and (2) the safety limit should be limited to 6,500 hours because of possible damage levels in one or more of the adjacent, overlapping wing panels. 1/ The review team indicated, however, that the wing service life could be extended, and it developed nine plans incorporating various combinations of load alleviation systems, fastener changes, rework, and modifications. Engineering cost estimates for these nine plans ranged from about $3.4 million to approximately $334 million in 1974 dollars, excluding operational and maintenance costs over the aircraft's projected life. The following chart depicts the proposed life extension combinations, plus the operational life projections and estimated costs.

1/Assuming an initial crack of 0.03 inch in a panel (about the upper bound of the initial manufacturing flaw size from X998 results), the panel would fail at approximately 13,000 hours, but this assumes no safety factor. The review team believed a safety factor of two, cutting the 13,000 hours down to 6,500, gave a reasonable basis for setting the operational interval for the C-5A before the first safety inspection.

INDEPENDENT REVIEW TEAM'S PLANS

Plan	Fuel management and passive LDCS (notes a and b)	Fuel management and passive LDCS clipped wing tips	Fuel management and active LDCS	Fastener change and local reinforcement	Rework wing boxes			New wing boxes			Operation life (hours)		
					Center wing	Inner wing	Outer wing	Center wing	Inner wing	Outer wing	New aircraft	Average for aircraft already in use	Cost (millions)
B	X										10,200	9,250	$ 3.37
C		X									16,100	12,550	9.43
D			X								20,400	14,000	44.89
E	X			X	X						28,000	25,300	172.43
F		X		X	X						34,000	28,700	186.99
G			X	X	X						46,000	36,550	188.37
H					X	X	X				60,000	60,000	256.66
J					X		X		X		60,000	60,000	325.28
K							X	X	X		60,000	60,000	333.74

a/Fuel management - A load alleviation mechanism, whereby the weight of the wing fuel is managed to relieve upbending and to increase fatigue life.

b/LDCS - lift distribution control system.

In April 1972 and concurrent with the Independent Review Team's efforts, Lockheed conducted the Wing Life Improvement Program (WLIP) to determine the estimated life of the existing C-5A wing structure and to develop alternatives for extending its service life. WLIP, conducted under the original C-5A contract, grew out of earlier Air Force-directed wing improvement investigations where Lockheed had evaluated the feasibility of modifying production aircraft during their assembly. Subsequent static test data, the status of the fatigue test program, and an increasing number of engineering change proposals dictated that these investigations be updated.

Under WLIP, Lockheed identified five immediate structural changes needed to achieve at least a 7,500-flight hour plateau and also proposed two separate life extension plans: one to attain 15,000 flight hours through local rework, repair, and fastener changes and another to reach a 30,000-hour life by redesigning the center and inner wing boxes. Lockheed estimated the costs of the two proposals to be $54 million for the local repairs or over $207 million for the new center and inner wing boxes, excluding the costs of a new static or fatigue test article.

In March 1973, the Secretary of the Air Force received briefings on the review team's and WLIP's results. At that time, he directed the Air Force to proceed with the review team's Plans D and H, which were two of nine plans developed, as the near- and long-term solutions, respectively.

The choice of Plan D recognized the C-5A wing structural changes already underway or planned. Basically, Plan D proposed supplementing the passive lift system with an automatic or active lift distribution control system (ALDCS) and included a fuel management system to distribute wing fuel weight more effectively. ALDCS senses wing loads, and when these loads change, the system automatically adjusts the ailerons to reduce wing bending.

According to the Air Force, the Secretary recommended Plan D to lengthen the service life of the C-5A so sufficient time would be available to incorporate the long-term solution (Plan H) before reaching the safety limit. The Secretary's choice of Plan H recognized the risks inherent with the lesser plans (E, F, and G) which would have achieved fairly acceptable operational life capabilities but relied heavily on new fastener technology. At the time of the Secretary's decision, this new technology had been in use for only a few years, and neither Lockheed nor the Air Force had data concerning the technology's long-term fatigue benefits. While the Secretary chose a more expensive alternative to lower suspected modification risks, he did not opt for the most expensive alternative, Plan K. By the end of 1977, the Air Force had incorporated ALDCS in all C-5As for approximately $15.5 million, and it continued to pursue Plan H as subsequently modified.

The original Plan H called for extensive fastener changes to the center, inner, and outer wing boxes and also included (1) new, redesigned planks for the center and inner wing lower surfaces, (2) local reinforcement of the center and inner wing upper surfaces and the outer wing lower surface, and (3) modified joints where the center and inner wing boxes met (wing station 120).

While the Independent Review Team was examining the C-5A problems, additional data became available through continuing fatigue, component, and structural demonstration tests which could not be included in the study. The Air Force, therefore, directed Lockheed to develop a wing fix implementation plan based on Plans D and H with the needed alterations resulting from the additional data. Lockheed conducted this effort, known as the Service Life Management Plan, between February and July 1973.

Service Life Management Plan

Under the Service Life Management Plan (SLMP), Lockheed modified Plan D to include special wing inspection techniques and a structural monitoring, fault detection system. Lockheed also restructured Plan H by adding some new types of fasteners and altering some of the review team's suggested structural changes.

During its SLMP effort, Lockheed noted that the modified Plans D and H involved substantial modification and rework of the existing structure so it decided to consider different replacements of major structural components and report these as variations to the baseline SLMP. Variation 1 included a new center wing box with modified Plan H changes on the inner and outer wings. Variation 2 consisted of new center and inner wing boxes with modified Plan H changes on the outer wing. Variation 3 called for new center, inner, and outer wing boxes.

Presuming an October 1, 1973, go-ahead date, Lockheed proposed a 4-phase modified Plan H design, development, fabrication, and installation program. Total cost estimates for this proposed program exceeded $628 million. However, Lockheed informed the Air Force that SLMP was a study, not a proposal, so the cost and schedule estimates could not be considered firm. As shown on the following page, Lockheed also reported the costs of the possible variations as incremental adjustments to the baseline, modified Plan H.

Lockheed SLMP Cost Estimates

Plan H and variations	Costs Incremental	Total
		(millions)
Baseline modified Plan H		$628.28
Variation 1: center wing box	(+) $ 6.87	635.15
Variation 2: center and inner boxes	(-) 38.15	590.13
Variation 3: center, inner, and outer boxes	(+) 18.36	646.64

In November 1973, the Secretary of the Air Force received a briefing on the SLMP results. According to Lockheed's findings, the extensive modifications required for the center and inner boxes were more expensive than buying new structures. The Secretary agreed with this position, and Variation 2, the least expensive SLMP alternative, became the focal point for further wing life improvement studies.

PURSUIT OF VARIATION 2 (H-MOD)

Following the Secretary's approval of the H-mod, the C-5A Program Office prepared a performance Request For Proposal asking Lockheed to submit a firm proposal for the design and test phase on a sole-source basis. Lockheed responded in April 1974 indicating that the center and inner wing boxes, as well as the outer wing lower surface, would have to be replaced. As a result of proposed structural changes which were additive to the Variation 2 configuration, ASD convened an advisory group to review the need for these structural alterations.

The advisory group, chaired by a technical expert from the academic community and consisting of individuals from aerospace companies other than Lockheed and from the Air Force, reported that its conclusions and recommendations were based on C-5A Program Office and Lockheed findings rather than on an independent committee assessment. Although the justifications for replacement instead of rework were not convincing, the group believed that subsequent ASD reviews would provide the data with which to resolve the issues. The group also indicated that Lockheed analyses showed the Independent Review Team may have underestimated crack growth rates. If this were the case, then economical repairs for the cracks might not exist given the modification schedule.

Specifically, the advisory group concluded that

--a new center box was consistent with Plan H and the plan should be used;

--both the C-5A Program Office and Lockheed strongly recommended a new inner box based on manufacturing practicalities and cost tradeoffs, and if their studies were correct, then a new inner box appeared best; and

--Variation 2 with some fastener changes to the outer wing upper surface, in lieu of the Lockheed's proposed outer wing changes, would fulfill the 190,000-pound payload capability, damage tolerance requirements, and fatigue life criteria.

The Air Force considered the advisory group's conclusions to agree in principle with the suggested wing configuration changes, except for the outer wing lower surface replacement. Accordingly, Lockheed's design proposal was modified, and in November 1974, the Air Force negotiated with Lockheed to begin the H-mod design effort. This contract, however, was not awarded because of delays caused by concerns over reprograming actions, competition, and concurrency in development and production.

1975 advisory group review

In January 1975, ASD formed another advisory group, which consisted of Air Force officials and included four individuals from the preceding advisory group review. The Commander, Air Force Logistics Command, requested this new group to (1) obtain recommendations on how the command should maintain and track C-5A airworthiness through H-mod completion and (2) define any additional actions, if considered necessary.

During the advisory group's meetings, Lockheed presented briefings on the results of those tasks which it had been directed to perform in preparation for the review. Military Airlift Command officials also provided information on C-5A operational use at that time. The advisory group concluded that the risks associated with H-mod implementation milestones were higher than previously assumed and recommended that the modification of each aircraft begin approximately 2,000 flying hours earlier than planned. The group's revised modification schedule was based on new analytical techniques concerning crack growth rates rather than on classical fatigue analyses. The group also determined that the C-5A safety limit ranged from 8,000 to 10,000 flying hours under prolonged use at 1973 projected mission profiles.

Unlike the Independent Review Team's safety limit of 6,500 hours, the advisory group's predicted limit did not include a safety factor. The group reported, however, that the 10,000-hour limit incurred higher risks than if used on the F-4 fighter, while the 8,000-hour limit posed risks comparable to the F-4, yet were higher than allowed on new aircraft. Because no safety margins had been incorporated into the flying hour limit and because safety would be degraded beyond 8,000 to 10,000 hours by possible widespread cracking in adjacent panels, the advisory group recommended that the Air Force use the 8,000-hour safety limit for planning purposes.

H-mod program go-ahead

As a result of an April 1975, C-5A program review, Defense authorized the Air Force in June 1975 to proceed with the design and fatigue test phases of the H-mod program. Defense, in its program approval, also identified certain areas of concern and instructed the Air Force to resolve these issues.

Among its concerns, Defense objected to the degree of concurrency between H-mod development and production, noting that, under the existing schedule, Department of Defense Directives 5000.1 and 5000.3 concerning proper test and evaluation would have to be waived. Defense directed the Air Force to continue efforts toward fulfilling the directives' requirements. Also, Defense questioned the variance between Air Force and Office of Secretary of Defense cost estimates and suggested the Air Force resolve the disparities when contractor production estimates became available. Finally, Defense believed the options to compete later phases of the H-mod program should be retained and advised the Air Force that these options should be studied further and maintained throughout the development effort. (See ch. 6 for more details on Air Force actions to resolve Defense concerns and issues.)

1976 advisory group review

After the 1973 Israeli airlift, the Air Force recognized a greater need for its aircrews to be proficient in aerial refueling operations. Accordingly, the Military Airlift Command increased crew training in this mission area. As the training continued, information became available suggesting that crack growth rates in the C-5A's outer wings had increased because of higher stresses associated with the aerial refueling operations.

In March 1976, ASD asked the advisory group to review two proposed outer wing modifications which would offset damage accumulation when aerial refueling the C-5A. This particular advisory group consisted primarily of technical experts from the academic community and aerospace companies. Most of the group's participants had also participated in either the Independent Review Team or earlier advisory group reviews. On the basis of Lockheed and C-5A Program Office briefings, the advisory group concluded that

--reworking the outer wing was still technically acceptable, but acquisition costs, life-cycle costs, and available technical data suggested the Air Force should buy a new outer wing and

--the 8,000-hour safety limit, assuming passive and active lift distribution control system benefits, was still valid.

As a result of the advisory group's review, the Air Force incorporated an engineering change proposal into the H-mod contract which added the new outer wing to the design and development effort.

CONCLUSIONS

The present H-mod configuration has evolved from a series of Air Force and Lockheed studies which received periodic review by technical experts from within and outside the Air Force. Lockheed's analytical results, with C-5A Program Office concurrence, dictated the H-mod configuration as it exists today.

The Air Force's decision to proceed with the Independent Review Team's Plans D and H was based on risks associated with those other plans which involved less work and lower costs but which also relied on new, unproven fastener technology. Later decisions to replace the center, inner, and outer wing boxes were based on cost estimates of the various alternatives and on additional technical data obtained from continued testing and operational C-5A usage.

Given the series of reviews, the outside technical oversight, and the existing knowledge of aircraft fatigue phenomena, we believe the Air Force assured itself of acquiring the best data on C-5A wing problems and solutions available through the 1976 decision to replace the outer wing box. In our opinion, Lockheed had to be actively involved in all of the reviews because of its familiarity and engineering expertise associated with the original C-5A design philosophies and the voluminous technical data concerning aerodynamic loads, material properties, operational stresses, and crack growth rates--all of which affected the wing's service life. Further, the only means remaining in which the Air Force might have obtained an independent wing life assessment would have been an analysis of the data from one or more of the studies by an outside engineering firm. However, the independence of such an analysis could have been questioned on the basis that (1) Lockheed would have had to supply most of the data, (2) the engineering firm would have been under contract with the Air Force, the sponsors of the C-5A program, or (3) sufficient, unbiased engineering expertise would not have been available since many of the Nation's aircraft structural fatigue experts had already participated in previous C-5A program reviews.

CHAPTER 4

REASONS FOR AIR FORCE ACCEPTING

DEFICIENT C-5A AIRCRAFT

The Air Force learned of the potential for serious wing problems as early as April 1967. The actual existence, though not the extent, of the wing deficiencies became known in July 1969, when the first static test failure occurred. At the time of this failure, no aircraft had been accepted by the Air Force. Lockheed corrected this first static failure, but by September 1971, other serious static and fatigue problems had arisen, and the Air Force had already accepted 40 aircraft.

Air Force officials were aware of these problems but believed they had little recourse except to continue accepting deficient C-5As. Throughout the period that deficient C-5As were delivered, the Air Force and Lockheed tried to identify a permanent solution. Eventually, Lockheed received wing modification contracts containing profits of over $150 million.

AIR FORCE KNEW C-5As TO BE DEFICIENT UPON THEIR ACCEPTANCE

We found that Air Force officials took precautions in determining whether C-5As met contractual quality standards before their acceptance. The Air Force officially accepted the first C-5A on December 16, 1969. Four days before this event, the contracting officer issued Change Order 550 to the C-5A contract. In effect, this change order stated that the Air Force would accept C-5A aircraft with wing skins which were deficient in thickness (the basic cause of the C-5A's reduced service life), but all rights to negotiate a settlement for the deficiency would be reserved. Furthermore, all Government rights under the Correction of Deficiencies Clause in the contract would be preserved. Change Order 550 covered all the C-5As that Lockheed eventually produced.

In May 1971, just 1 week before Supplemental Agreement 1000 was executed, the Air Force again notified Lockheed that the wings were deficient. This notification alerted Lockheed that cracks discovered in the fatigue test articles would prevent the wings from meeting the contractually required life at those locations. This deficiency notice was then incorporated in aircraft acceptance forms.

Department of Defense Form DD-250, "Material Inspection and Receiving Report," included the formal document by which the Air Force accepted C-5As from Lockheed. A C-5A shortage and variance report accompanied each DD-250 and listed equipment shortages and deficiencies known to exist on each aircraft at the time of its acceptance.

We reviewed the shortage and variance reports for each of the 80 C-5A 1/ aircraft accepted by the Air Force and found that the wing deficiencies had clearly been noted on 74 reports. The deficiencies may also have been contained in the remaining six shortage and variance reports, but associated engineering reports, needed for a detailed analysis, were missing from the files.

Given that rights to negotiate a settlement for identified deficiencies had been retained under Change Order 550, Air Force officials told us that the service accepted the aircraft because acceptance constituted the most prudent alternative at the time. When the fixed-loss settlement of the original C-5A contract was implemented in May 1971, Lockheed was relieved of any liability to correct deficiencies in aircraft which had already been accepted. Not until after this settlement was executed, did the real magnitude of the wing problem become fully known. Once Air Force officials realized the severity of the problems, only a few program management alternatives remained. Among these alternatives, the Air Force could have

--continued to accept aircraft as they were produced and use them to the maximum extent possible until a permanent fix would be required;

--refused to accept additional aircraft, letting them accumulate at Lockheed until the fix was implemented; or

--stopped production.

The Air Force chose to pursue the first alternative because, first, under any circumstances, the fixed-loss settlement required the Government to bear the cost of any fix no matter what it entailed or when it was installed. Second, given the significance of the wing deficiencies in terms of problem definition and the potentially high cost for repairs, the final solution could have taken several years. Finally, Defense and Air Force officials believed that the C-5A was essential for the national defense and that the service needed a transport aircraft with C-5A capabilities in the immediate future. Contracts were subsequently let to Lockheed for modification of the wings with profits of over $150 million.

CONCLUSION

In view of the stated military need, the circumstances surrounding the C-5A program in the late 1960s and early 1970s, and the absence of more advantageous alternatives, the Air Force had few choices but to accept deficient aircraft.

1/One aircraft burned before formal acceptance.

CHAPTER 5

C-5A WING FIX ALTERNATIVES EXISTING AFTER H-MOD APPROVAL COULD NOT MEET AIR FORCE-DIRECTED SERVICE LIFE OBJECTIVES

The H-mod configuration has evolved from a series of evaluations which addressed various cost and technical issues. The initial decision in early 1973 to proceed with interim and long-term repair (Plans D and H) was based primarily on technical data developed during the Independent Review Team's analyses and Lockheed's Wing Life Improvement Program. Later that year, Lockheed cost estimates for repairing C-5A wings led the Secretary of the Air Force to approve center and inner wing box replacements in lieu of the structural rework proposed under Plan H.

During at least three modification program reviews, ASD advisory groups reevaluated the various issues and reaffirmed the Secretary's H-mod program approval. Eventually, as more cost and technical data became available, the last ASD advisory group suggested H-mod configuration changes which incorporated a new outer wing box.

The Air Force's unrelenting desire to achieve a C-5A service life of an additional 30,000 flying hours after completing the H-mod has subtly and increasingly constrained each succeeding in-house and contractor evaluation so that over time only a single viable alternative remained--extensive replacement of C-5A wing structures. In 1977, 1979, and 1980, various parties questioned the validity of that service life requirement. Generally, in their opinion, if the requirement were lowered and if the C-5A fleet were managed to preserve its remaining life, then less expensive wing repair options could still be implemented. As a result of some of these concerns, the Air Force initiated the Structural Information Enhancement Program (SIEP) and concluded in 1979 that SIEP demonstrated an increased urgency for the H-mod. However, like so many of the previous Air Force-sponsored C-5A wing defect analyses, SIEP did not consider the validity of the established service life objective or the potential existence of less expensive alternatives.

C-5A SERVICE LIFE LIMITS

Since the major C-5A fatigue and static test article failures in 1971, the Air Force has used a series of analytical models to predict the aircraft's service life. The values given to the variables in the models involve a significant amount of engineering judgment. As additional technical data has been acquired and as the analytical techniques have been improved over time, the predicted C-5A service life has varied, but in our opinion, the variances have not been significant.

C-5A design included fail-safe features

The C-5A wing contains approximately 125,000 holes for the fasteners which connect surface panels to each other and to the remaining structure. Of these 125,000 fastener holes, 30,000 to 40,000 are in areas that engineers consider fatigue critical. The aircraft's potential service life depends on the wing's structural capability to withstand two similar, but separate fatigue damage phenomena associated with the aerodynamic stresses at the fastener holes. First, manufacturing equipment can create a small number of serious initial or "rogue" flaws during the production process. These rogue flaws are about 10 times larger than normal manufacturing damage which can also cause cracks to occur in the fastener holes. If undetected, the rogue flaws can grow to critical lengths and cause catastrophic structural failures. Even without rogue flaws or normal manufacturing damage, cracks still occur in the fastener holes.

Throughout flight operations, the wing's metal structure bends upward and downward, subjecting it to the forces of tension and compression. From a fatigue viewpoint, these forces produce small cracks which can become widespread. This widespread cracking condition weakens the residual strength of the wing panels, and like the initial manufacturing flaws, can also become catastrophic. During an aircraft's development, manufacturers incorporate a combination of fail-safe elements to overcome any uncertainties in the design's damage tolerance capabilities, the potential aerodynamic stresses to which the aircraft may be subjected, and the operational flight profiles once the aircraft is delivered. In addition to the fail-safe elements which minimize the probabilities that fatigue damage will cause catastrophic failures, an analytical technique (fracture mechanics analysis) has been implemented to predict the rates at which fatigue cracks will grow.

One approach to fail safety, typical of commercial airplanes and of the way Lockheed designed the C-5A, incorporates certain aerodynamic structural configurations which can accept single member or wing panel failures without loss of the aircraft. In the commercial industry, fail safety is further enhanced by aircraft designs which ensure that fatigue cracks will become visible long before they become critical and that these cracks will not reach critical lengths during the aircraft's operational life. 1/

Regarding the C-5A, Lockheed designed the wings with a series of overlapping panels to which aerodynamic loads would be transferred if any one of the adjoining panels failed. Fail safety was assured so long as dual panel failures did not occur.

1/The Air Force's design criteria under the revised Aircraft Structural Integrity Program have now included these basic philosophies for the development of new aircraft.

Unfortunately, in some high stress sections of the wing, critical crack lengths are less than 1 inch, and because of the overlapping panel design, these cracks are not easily detected.

If an initial flaw is present in one of the high stress areas and reaches the critical length, the panel could fail without anyone's knowledge. The aerodynamic loads in that area would be transferred to adjoining panels, but widespread cracking, if present in these panels, could potentially cause additional failures and the loss of the aircraft. As a result, the C-5A would not be fail safe when both the critical length of an initial flaw and the condition of widespread fatigue cracking occurred at about the same point in the aircraft's operational use--the exact situation now predicted by the Air Force.

The second approach to structural damage tolerance or fail safety consists of safe crack growth allowances where the manufacturer designs the aircraft and sets inspection intervals so that the maximum expected initial flaw damage will not grow beyond one-half of its critical size during operational use. This approach is generally applied to an aircraft, such as the F-111, which does not have an overlapping wing panel design.

Fatigue versus fracture mechanics analyses

C-5A wing deficiencies which occurred in the late 1960s and early 1970s, plus similar problems in other aircraft procurements, such as the F-111 structural failures, disclosed certain weaknesses in the Air Force's Aircraft Structural Integrity Program. Because these defects ultimately affected the aircraft's safety, the Air Force had to reduce the dependence on fatigue testing and upgrade its capabilities for early discovery of potential weaknesses in contractors' engineering designs.

Around the same time, commercial aircraft manufacturers had begun to implement emerging analytical techniques which, used in conjunction with fatigue testing, provided more reliable predictions of an aircraft's service life. These analytical techniques, commonly referred to as fracture mechanics or crack growth analyses, have been incorporated into the Air Force's Aircraft Structural Integrity Program and applied to the C-5A's service life evaluations, as well as to the H-mod design and development.

Fatigue testing

Conventional fatigue testing relied on so-called crack initiation principles. Under fatigue analysis techniques, engineers waited for cracks to appear in the fatigue article and then divided the test hours accumulated at that time by a safety or "scatter factor" of four. The subjective scatter factor attempted to account for variations in individual aircraft usage and provided the basis for estimating when similar cracks would occur in the fleet under operational conditions. For example, a crack appearing after 10,000 fatigue test hours would be expected to occur around 2,500 operational flight hours. Because (1) fatigue testing to four life times required a substantial amount of time, (2) test hours completed at any one point would not always be four times the number of flight hours on an operational aircraft, and (3) a large number of test hours could be conducted before significant cracks became visible, in-service aircraft could surpass either their safety or economical repair limits without the Air Force knowing a problem existed. In retrospect, this situation arose during the original C-5A procurement where the fatigue test program failed to disclose the extent of the wing deficiencies until the Air Force had no choice but to accept the defective aircraft.

Fracture mechanics analysis

The B-1 bomber would have been the first Air Force aircraft developed and produced under fracture mechanics principles. Although the C-5A had already proceeded into production, the Air Force chartered the Independent Review Team to retrace the C-5A's development and apply fracture mechanics techniques in its reappraisal of the aircraft's service life.

Within a fracture mechanics analysis, engineers use computer modeling techniques to assess an aircraft's structural durability and damage tolerance. The engineers

--map fatigue critical areas;

--assume that maufacturing equipment induces flaws or cracks during production;

--establish the distribution of initial flaw sizes and estimate the single largest flaw that can be expected;

--determine the critical or minimum flaw lengths which could cause aircraft structural failures under certain aerodynamic load conditions; and

--predict the rates at which the flaws will grow, depending on such factors as aerodynamic stresses associated with the established mission profiles, and material properties.

To varying extents, the results of these efforts are verified by tests conducted on representative specimens of the aircraft's materials and structural components, fatigue test data, and other empirical data obtained from operational flight experiences. The engineers then use these results to estimate both the aircraft's safety and economical repair limits which later become part of the Air Force's individual aircraft tracking programs. In essence, these analytically derived limits form the primary basis on which the Air Force sets maintenance inspection cycles to insure the aircraft's continued operational safety and to identify needed repairs before they become uneconomical.

Independent Review Team sets original economical repair and safety limits

As noted in chapter 3, the Air Force formed the Independent Review Team during early 1972 to develop options for extending the C-5A's service life. In its analysis, the review team applied fracture mechanics analytical techniques to determine how long the airplane would fly before excessive and costly maintenance actions became necessary and what steps would be needed for maintaining safety during this period. The review team assessed the rates at which cracks would grow given (1) the C-5A's configuration and (2) the 14-mission profile under which the aircraft was being operated in 1972.

The review team identified three major fatigue problem areas concentrated primarily in the center and inner wing sections but considered the lower surface spanwise splices, where the overlapping panels joined, to be the most critical. The review team arrived at this conclusion because the area was characterized by many fasteners, moderately high stresses, and the possibility that a crack in one plank meant a crack existed in the adjacent panel at the same fastener.

On the basis of C-5A fatigue test results and the aerodynamic stresses associated with the 14-mission profile, the review team found that 7 to 10 cracks longer than 0.03 inch would occur in the spanwise splice area of each airplane between 7,000 and 9,000 flight hours. According to the review team, a 0.03-inch crack had reached the limit that could be repaired by redrilling the hole and inserting a single oversize fastener. Beyond 7,000 to 9,000 flight hours, the review team believed that the number of cracks would grow rapidly and that increasing modification, repair, and/or replacement costs could become uneconomical.

From a safety viewpoint, the review team's analysis of the C-5A fatigue articles showed that initial flaws longer than 0.03 inch were possible. Given the expected use of the aircraft, the review team projected that such a flaw would grow to critical length (about 0.8 inch) in 13,000 flight hours, at which time a single panel failure could occur. Since Lockheed had used an overlapping panel design for fail safety, the review team had to consider the effect of damage in an adjacent panel on the strength of the wing when it contained a failed panel.

The strength of the adjacent panel depended on whether it contained any flaws, and if so, their size. The review team found that if an adjacent panel contained a flaw of 0.05 inch or larger at the same fastener, then the structure would not sustain the loads imposed on the average of once per flight. As indicated above, the aircraft was expected to have only 7 to 10 cracks between 7,000 and 9,000 hours, so adjacent flaws were unlikely. However, the crack population grew rapidly beyond that point to unacceptable levels and progressively increased the probability of adjacent damage. As a result, the review team believed a safety factor was needed and set the safe operational interval for the C-5A at 6,500 hours--one-half the time a 0.03-inch crack would grow to critical length. With this safety factor, an initial flaw of 0.1 inch could be tolerated and still not become critical in the operational interval.

1975 advisory group revises the C-5A safety limit

In chapter 3, we reported that ASD chartered its 1975 advisory group to assist AFLC in developing methods for assuring C-5A airworthiness until modification. By the time the group was formed, the Air Force had improved its understanding of fracture mechanics technologies and had conducted research demonstrating that initial manufacturing flaws could be as large as 0.05 inches. In addition, Lockheed crack growth analyses indicated that C-5A fail safety would be degraded beyond 8,000 to 10,000 flight hours given the way the aircraft had been used in 1973. At that time, the Air Force used the C-5A under a set of revised mission profiles, which have eventually become known as representative mission profiles (RMP).

On the basis of the risks associated with the potential sizes of initial flaws and Lockheed's predicted crack growth rates, the group set the safety limit at 8,000 RMP hours for H-mod planning purposes. This limit, unlike the Independent Review Team's 6,500-hour limit, was not factored for safety. The 8,000-RMP hour safety limit applied only to the lower wing surface spanwise splices--that area considered most critical by the review team. The limit remained as the standard against which the Air Force tracked C-5A fatigue damage until the SIEP revised the safety limit downward in 1979.

As mission profiles and aircraft usage changed over the years, fatigue damage associated with those changes (damage rates increase or decrease as use becomes more or less severe) were extrapolated to the damage rates expected under RMP usage. In this manner, the Air Force maintained a single yardstick with which to measure fatigue damage for H-mod planning purposes. Because C-5A use has tended to be less severe since 1973, actual flight hours achieved by most of the aircraft before modification will be greater than the RMP limit. The Air Force expects to fly 56 of the 77 C-5As between 9,000 and 14,300 hours before they are taken out of service to be modified.

RAND CORPORATION QUESTIONS THE NEED FOR H-MOD

In 1976, the Air Force engaged the Rand Corporation to review 1/ and evaluate strategic mobility alternatives for the 1980s. During the early phases of its evaluation, Rand officials recognized that if the C-5A's original service life objective (30,000 hours) was reduced to between 15,000 and 20,000 hours, then several alternatives existed for resolving the wing problems. As a result, Rand decided to assess the various analytical studies on which the need for the H-mod had been based and found that uncertainties surrounded the available technical, operational, and modification cost data. To Rand, these uncertainties suggested that one could not dismiss the possibility that a more austere modification might suffice. Under austere usage, a 15,000-hour service life might allow the C-5A to remain in service until the end of the century without significantly impairing the aircraft's performance.

Lower service life requirements could yield alternate solutions

According to Rand, the Air Force's course of action at the time was based on an assumed 30,000-hour operational life which made major modifications appear to be inevitable. Because of the Air Force's policy to escalate program cost estimates for inflation and because one intent of the modification was to avoid costly and unexpected repairs, it seemed reasonable not to delay the H-mod. In addition, members of the original C-5A design team could assist in an early redesign of the wing. Within this context, the 1975 ASD advisory group set the 8,000-RMP hour limit for planning purposes. In Rand's opinion, the roots of this action rested with the Secretary of the Air Force's 1973 decision that for a 30,000-hour service life, the perceived risks of the less costly alternatives outweighed the costs for the original Plan H.

Rand's report indicated that the Air Force's original plan in 1965 was to operate each aircraft for 30,000 hours, or approximately 17 years, at the estimated usage rate of 1,800 hours a year. Average annual use between 1973 and 1976, however, ranged only from 550 to 650 hours per aircraft. Even after completing the H-mod, the Air Force projected average annual use of about 700 hours. At this rate, the C-5A would have at least 42 years of service remaining after modification and 28 years of peacetime service if a 5,000-hour increment were set aside for contingencies.

Rand believed that if a life objective of less than 30,000 hours were found to be a more credible basis for a major modification decision, then the basic premise underlying past judgments

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1/"Strategic Mobility Alternatives For the 1980s" (Mar. 1977, Rand Corporation, Santa Monica, Cal.).

would have been fundamentally altered. Considering a 15,000- to 20,000-hour life objective and setting aside hours for aircraft use through 1978 and for contingencies, Rand estimated that the remaining peacetime service could range from 9 to 34 years beyond 1978. This range depended on the actual usage rates and on the service life benefits accruing from the active lift distribution control system (ALDCS) which had recently been installed.

For planning purposes, ASD had used an ALDCS life extension factor of 25 percent. In contrast, Rand believed certain C-5A fatigue test results indicated that the benefits might be as high as 43 percent at the wing's life limiting area (lower surface spanwise splices). The following chart shows the number of years that Rand expected the C-5A to remain in service beyond 1978 given (1) a 15,000- to 20,000-hour service life objective, (2) usage rates varying between 550 and 700 hours per year, (3) the different ALDCS benefit numbers, and (4) a 5,000-hour set-aside for contingencies.

Rand's Predicted Service

Life Extensions Beyond 1978

		Life extension due to ALDCS (percent)			
		25		43	
		Annual use (flying hours/aircraft)			
Service life objective in service life hours (note a)	Mission use typical of	700	550	700	550
		Remaining life of aircraft (years/date)			
15,000	1973	9 (1987)	11 (1989)	10 (1988)	13 (1991)
	1976	11 (1989)	15 (1993)	13 (1991)	17 (1995)
20,000	1973	18 (1996)	22 (2000)	20 (1998)	26 (2004)
	1976	22 (2000)	30 (2008)	26 (2004)	34 (2012)

a/Based on the 1973 mission use and the 1974 configuration (no ALDCS).

Rand indicated that service life objectives ranging from 15,000 to 20,000 hours could satisfy C-5A service requirements from 9 to 34 years and that the Air Force should reexamine the 30,000-hour requirement. In Rand's opinion, a C-5A life objective, roughly one-half of the stated requirement, may have formed a credible basis for making a major investment decision and could have yielded alternative solutions saving several hundred million dollars.

Technical uncertainties surrounding
the 8,000-RMP hour safety limit

Rand found it difficult to relate C-5A fatigue test results to the expectations of what would likely happen with in-service aircraft because the test spectrum only approximated the expected operational aerodynamic stresses. In addition, mission use simulated during the test later became less severe during actual in-service operations. Modifications, such as ALDCS, reduced wing bending and lowered operational stresses even more, and Lockheed incorporated design changes for those localized areas considered to be weak or susceptible to fatigue damage.

Concerns about C-5A fatigue test procedures and analytical methods used to interpret the test results produced questions about the validity of the information that had been developed to date. These questions, according to Rand, had been resolved more by conservative engineering judgment than by relevant research. The 8,000-RMP hour safety limit had been set for planning purposes and should not have been viewed as the point at which widespread fatigue cracking would have occurred. Rand found no evidence from either the fatigue tests or from special inspections of in-service aircraft to cause concern that the C-5A wing would achieve widespread cracking at 8,000-RMP hours. Therefore, the technical basis for the 8,000-RMP hour limit was confined to several assumptions and calculations. Among these were the assumptions that

--manufacturing damage extended to two lower surface wing panels at a common fastener hole,

--initial damage occurred in the most highly stressed wing areas,

--initial flaws remained undetected during inspections,

--Lockheed's calculated rate (8,000 RMP hours) for a 0.05-inch crack to grow to its 0.8-inch critical length accurately reflected crack growth rates in operational aircraft,

--the aircraft would encounter a severe aerodynamic load causing a panel with a 0.8-inch crack to fail at about 8,000 RMP hours,

--adjacent panels would have sufficient cracking to cause aircraft failure, and

--the remaining structure could not withstand the loads transferred to it by the failure of the first two panels.

Simple changes in these assumptions could cause wide variations in the analytically derived safety limit. Rand investigations disclosed that the crack growth rates upon which the limit was based may have been overstated and that ALDCS benefit numbers may have been understated. If this were true, then the safety limit could have been much higher than the Air Force had predicted. In addition, an Air Force Flight Dynamics Laboratory calculation, using the same set of assumptions from which the 8,000-RMP hour limit had been derived, yielded an 11,000-hour limit, plus or minus 3,000 hours, with 90 percent confidence that the crack growth time would be at least 8,000 hours.

In late 1976, Rand met with individuals from the Air Staff, C-5A Program Office, and Lockheed to discuss some of its preliminary findings. Various points of agreement were reached and have been summarized below.

--If the 30,000-hour requirement were still a reasonable objective, then most likely no reasonable cost-effective alternative existed other than the planned H-mod.

--One consideration in the technical evaluation of the C-5A's structural integrity beyond the 8,000-hour limit was that the 30,000-hour requirement imposed on ASD meant that the wing boxes eventually would have to be replaced. Thus, the 8,000-hour plateau should not be viewed as the point when widespread fatigue cracking would occur.

--Given an alternative service life requirement, more cost-effective alternatives to the H-mod might exist.

--More information was needed concerning the structural integrity of the C-5A configuration at that time.

--The 30,000-hour requirement, the future requirements for outsize airlift capacity, and the alternatives for meeting that capacity needed to be reassessed.

Subsequently, the C-5A Program Manager informed Rand that the agreements, as stated, represented fairly the results of the 1976 meeting. He indicated that the Air Force recognized the uncertainties associated with the 8,000-hour number and agreed that additional information was needed. In the manager's opinion, the Air Force's avoidance of larger service life projections was not a defensive action but an attempt not to build false hopes.

In its March 1977 report on strategic mobility alternatives for the 1980s, Rand recommended several information enhancement initiatives which would result in better problem definition, identify actions capable of extending the existing service life limit, and disclose whether other wing modification alternatives could be implemented. Rand recommended further that these initiatives be carried out by a panel of independent specialists and that their work be evaluated by an additional panel of senior aerospace industry representatives to ensure objectivity. As an apparent response to these recommendations, the Air Force initiated the Structural Information Enhancement Program (SIEP).

SIEP RESULTS IN A REDUCED C-5A SAFETY LIMIT

In September 1977 the Air Force convened a Scientific Advisory Board to (1) review whether SIEP's proposed organization and tasks would meet stated objectives, (2) identify program limitations, and (3) provide recommendations. The board approved the proposed program and emphasized the importance of those tasks associated with developing an aircraft tracking program and with analyzing nondestructive inspection capabilities. Furthermore, while the board emphasized that SIEP should not be used to delay the H-mod, it also deemphasized the need to search for a more precise safety limit.

After the board's program approval, Lockheed submitted a proposal and received approval in January 1978 to proceed with the technical tasks. The SIEP approval was contained in a change to the original C-5A contract under which Lockheed performed the work at cost and no fee. SIEP continued until mid-August 1979 when the Scientific Advisory Board made its final technical review. Although budgeted for over $9 million, program costs totaled about $7.1 million.

Because SIEP involved a wide range of aerodynamic and structural integrity theories, all of which are rooted in the engineering discipline, we did not have the technical expertise to evaluate the validity of the program's results. However, we did assess whether SIEP results were the outcome of an independent analysis, as had been recommended by the Rand Corporation. We based our assessment on discussions with many of the SIEP participants, including some Scientific Advisory Board members. The following section summarizes SIEP objectives, tasks, organization, and findings.

SIEP objectives, tasks, and organization

SIEP had two objectives: reassess and supplement all actions needed to protect structural safety of each aircraft until H-mod and investigate approaches ensuring limited safe flight to H-mod in the event of adverse SIEP results, findings during in-service aircraft inspections, and/or changes in operational requirements. Notably, both of these objectives related to safety of flight until H-mod, but SIEP did conduct a risk analysis for possible C-5A flight beyond the initial or rogue flaw safety limit. Other areas of endeavor associated with the two stated objectives included

--reassessment of the rogue flaw safety limit;

--assessment of the general or widespread cracking limit;

--development of an aircraft tracking program to update periodically the aerodynamic loads, ALDCS benefits, and aerial refueling effects; and

--assessment of SIEP's impact on C-5A operational use to establish a force management plan until the H-mod would be completed.

To fulfill these tasks, Lockheed and the Air Force conducted new analytical studies, reviewed existing data, and developed new data for analysis. Regarding the last effort, Lockheed (1) conducted over 260 tests on representative C-5A wing material and structural specimens, (2) disassembled and inspected the right wing of one C-5A, Air Force serial number 214, and (3) evaluated various nondestructive inspection equipment.

The San Antonio Air Logistics Center had overall responsibility for SIEP management and for oversight of Lockheed's contractual performance. The Center and Lockheed received continuing program guidance from the SIEP Steering Committee. The committee met on 10 occasions during the 2-year program and generally consisted of seven individuals, all but one of whom were either Air Force or Lockheed personnel. In addition, the Air Force assigned one of its engineers to serve at Lockheed's facilities as an onsite technical director. This engineer remained on-site throughout the duration of SIEP and periodically reported to the Air Logistics Center on Lockheed's progress.

SIEP results

In general, SIEP participants concluded that the rogue flaw safety limit should be reduced and that general or widespread cracking conditions could occur throughout the fleet somewhere between 6,700 and 7,500 RMP hours. In the eyes of senior Air Force officials and the Scientific Advisory Board, these results further enhanced the urgency of the H-mod. They also formed the basis on which the C-5A fleet will be managed until the H-mod is completed.

Rogue flaw limit

According to SIEP documents and participants, Lockheed reassessed the analytical and test data on which the 8,000-hour safety limit had been based. The reassessment included evaluations of the flaw model (analytical assumptions concerning crack sizes, shapes, locations, and fastener fit), material properties, aerodynamic loads and stress spectra, and the crack growth model. Lockheed used both existing and new data to conduct these analyses, finding that most of the previous calculations' elements had been satisfactory. However, Lockheed revised the crack growth methodology to incorporate more conservative factors for newly identified problems. Lockheed found that loose fasteners could adversely affect crack growth rates and that the C-5A wing's metal properties varied by a factor of two between the best and worst material. Under the revised methodology, SIEP concluded that the C-5A safety limit for the inner wing, lower surface spanwise splices, should be reduced from 8,000 to 7,100 RMP hours.

Other C-5A structure safety limits

With the same revised model, Lockheed recalculated the safety limits for the outer wing's most fatigue critical area and for the nonwing structure (fuselage and tail section). The safety limit for the outer wing increased from 13,400 to 14,200 RMP hours. 1/ In the nonwing structure, Lockheed initially selected 91 potential safety of flight problems. Lockheed chose these 91 problem areas by surveying C-5A fatigue test article reports, in-service aircraft experience, previous fatigue and fracture mechanics analyses, and the Independent Review Team's nonwing structure review. Eventually, Lockheed eliminated all but nine locations--six fuselages and three tail sections--for detailed safety analyses by appraising each potential or recorded failure to see whether a crack at those locations could cause the loss of an aircraft.

Lockheed conducted a damage tolerance analysis for each of the nine locations based on post H-mod usage. Lockheed also performed additional studies to establish the relative severity of past, present, and future aerodynamic loads compared with the loads applied on the fatigue test article. Lockheed found that safety limits for the six fuselage locations ranged between 46,900 and 536,500 flight hours after H-mod. Similarly, the three tail sections exhibited post H-mod safe life limits of 62,800 to 93,300 flight hours. In Lockheed's opinion, adequate fuselage and tail section life remained to support a 30,000-hour wing.

No engine pylon supports were evaluated during the analysis. Lockheed and the SIEP Steering Committee agreed with the Independent Review Team's previous assessments. Successful pylon fatigue testing, the pylons' fail-safe design, and general structural configuration removed any potential for these components to be life limiting.

1/Each wing section which is subjected to similar stresses and contains similar structural components has been identified for tracking purposes. Each of these sections has its own computed safety limit. Because of the different aerodynamic loads and stresses these sections experience during flight and because of the differences in their construction, each accumulates fatigue damage at different rates. For example, the inner wing critical area may have accumulated damage equivalent to 5,000 RMP hours of use while the outer wing critical area could have accumulated 10,000 RMP-equivalent hours of damage in the same number of actual flight hours. (See p. 52 for further details on this phenomenon and the aircraft tracking program.)

Widespread cracking limit

The purpose of SIEP's widespread cracking assessment was to estimate when this condition would occur based on the teardown inspection of aircraft 214 and to conduct a risk analysis of possible wing failure given the inspection findings. In 1977, the Air Force had set the C-5A's widespread cracking limit as that point in time where crack population and size distribution would produce a high risk of wing failure if another panel had failed. At that time, the Air Force defined the acceptable risk as a failure probability of 1 in 10,000 per individual C-5A flight.

The Air Force flew aircraft 214 to what it considered the equivalent of 8,000 RMP hours and then sent it to Lockheed for wing disassembly. Subsequently, analysis of the aircraft disclosed that it had accumulated only 6,700 RMP-equivalent hours of damage. According to an Air Force engineer, this 1,300-hour difference occurred because of the inadequacies in the individual aircraft tracking program. Until the completion of SIEP, when the tracking program was updated, AFLC had tracked the C-5As on the basis of fatigue theories rather than on fracture mechanics principles. As the fatigue tracking data had been extrapolated to RMP-equivalent damage, which was based on fracture theories, variations in the aircraft 214's operational use created the unexpected discrepancies.

During the wing's disassembly, Lockheed eliminated approximately 300 panels for analyses. Overall, more than 23,000 fastener locations and 44,000 single layer holes were examined. Lockheed sent approximately 30 of these panels to the Southwest Research Institute for an independent analysis. According to Institute officials,

--49 of 1,885 fastener locations were inspected for proper fit and slightly over 10 percent were found out of tolerance or below minimum dimension specifications;

--90 flaws were found in over 3,660 holes inspected, of which 46 were determined to be cracks; and

--27 of the cracks were considered critical (perpendicular to stress forces, meaning their growth would continue).

The Institute determined that only 13 of the 27 critical cracks were caused by fatigue, while the remaining 14 resulted from either mechanical damage or corrosion. Upon completion of its analyses, the Institute returned the panels to Lockheed. Except for a few outer wing panels, all of those inspected by Lockheed and by the Institute were sent to the Air Force Materials Laboratory which then identified a few additional cracks. The following chart summarizes the findings of the wing teardown.

	LABORATORY			
	Lockheed	Southwest Research Institute	Air Force Materials Laboratory	TOTAL
ALL CRACKS	1,243	46	74	1,363
CRACKS WITH GROWTH SIGNIFICANCE	838	27	66	931

In total, the reported mechanical damage in the fastener holes and the number of fasteners below minimum tolerances led SIEP to conclude that the potential for a 0.05-inch rogue flaw to exist in the fleet had been raised significantly. Cracks were found in all areas inspected indicating an early stage of widespread cracking had developed. In addition, more than 25 percent of the holes disclosed a potential existed for substantial repairs if extensive fastener-pulling inspections were attempted on inservice aircraft.

Using this data, a risk analysis was then conducted by Air Force personnel under SIEP to determine the impact that contingency operations and flights beyond the 7,100-RMP hour limit might have on aircraft safety. The analysis concluded that the probability of losing a C-5A, given widespread cracking and a single panel failure, exceeded the 1 in 10,000 set by the Air Force in 1977. Further, the potential for an aircraft loss increased as the force approached the rogue flaw safety limit.

According to Air Force documents, commercial aviation operations consider the probability of single flight failure to be acceptable if the risk lies somewhere between 1 in 1 billion and 1 in 100 million. In contrast, military aviation operations now consider 1 in 1 million to be an acceptable level of risk, and has accepted 1 in 10,000 for short-term B-52D use. Extrapolating aircraft 214's teardown data to the fleet, SIEP calculated that the single flight probability of losing a C-5A would be about 1 in 10,000 at 7,100 RMP hours, but this probability increased to 1 in 250 by 7,600 RMP hours. Since various options for extending safe flight beyond 7,100 RMP hours imposed unacceptable operational restrictions, the urgency for H-mod increased, while the development of an improved and reliable aircraft tracking program became increasingly more important.

Updated C-5A inspection plan

One of SIEP's tasks involved developing a program for managing the C-5A fleet until H-mod completion. This task culminated in the Force Structural Maintenance Plan under which the Air Force conducts various inspections to ensure continued aircraft safety. Under SIEP's recommended criteria, the Air Force divided the wing into two categories: structure which has reached its local safety limit and structure which has not. Because of the variations in local stresses associated with the different structural components, a significant difference in damage accumulation rates occurs at each location. As a result, the Air Force further subdivided the lower wing surface into approximately 70 zones for inspection and tracking purposes.

For those zones which have reached or surpassed their safety limit (13 zones), the Air Force requires that a 100-percent general inspection be conducted at the time the zone reaches the safety limit and that these inspections be repeated on intervals equal to one-half the time in which a detectable flaw would grow to critical length. These criteria revealed a major inspection burden, so field inspection procedures were established to minimize the operational impact. For those aircraft which cannot be removed from service but contain lower wing surface zones that have surpassed the general inspection interval, Military Airlift Command maintenance personnel must inspect these zones every 100 flight hours to clear any operational restrictions.

These 13 zones, even though they have reached their safety limit, differ from the lower surface spanwise splice area which limits the aircraft life to 7,100 RMP hours in that they generally contain only a few fasteners, and they are more accessible for inspection. As a result, the Air Force has determined, given the H-mod program schedule, that it is more cost effective to inspect these zones and repair them as needed than to approve permanent fixes.

The Air Force conducts a third set of inspections, sampling inspections, on those remaining lower wing surface zones which have not reached their safety limit. The Air Force requires that sampling inspections be conducted in each zone at one-half the time an assumed initial flaw of 0.05 inch would have grown to critical length. Only a portion of the fasteners in a zone is inspected since the purpose of sampling inspections is to provide continuing assurances that any one zone on an individual aircraft has not experienced more rapid cracking than anticipated.

On the basis of the results of these three inspections, the Air Force may impose or remove operational restrictions, whichever is required to ensure as many aircraft as possible remain in service until modification. In its March 1980 operations plan, the Military Airlift Command severely restricted the use of nine aircraft because they were approaching safety limits. These restrictions impose varying limits on the payloads, types of missions, and number of flight hours for each of the nine aircraft. More or fewer aircraft could be similarly restricted in subsequent operations plans depending on how the command uses its aircraft and how that use relates to fatigue damage accumulation.

The various inspections and restrictions are based on fracture mechanics analytical results and the teardown of aircraft

214. One Air Force engineer told us that every crack found in aircraft 214's wing could have been repaired by redrilling the hole for a single oversize fastener. Furthermore, the various inspections discussed above have not identified significant cracking problems. Neither of the conditions, however, prevents the existence of a 0.05-inch initial flaw in one of the C-5A's lower wing spanwise splice areas. Also, present nondestructive inspection equipment which uses X-rays, electrical current, or sound to detect cracks will not, with any degree of confidence, identify cracks hidden by the overlapping panels.

Scientific Advisory Board generally agreed with SIEP findings

In August 1979 Lockheed and Air Force personnel briefed Scientific Advisory Board members on SIEP results. The board generally accepted SIEP's recommended safety limit reduction and its conclusions arising from the teardown inspection. Since 9 or 10 C-5As would reach the revised safety limit before modification, the board believed a reduced flying hour program should be set up for these aircraft with high flying hours. In its opinion, the safe crack growth approach to aircraft tracking was the only acceptable method for the C-5A. Classical fatigue analysis did not lend itself to safe limit predictions when widespread cracking existed. Moreover, the teardown results identified the trouble spots which could be inspected as necessary.

An aircraft normally can fly beyond the safety limit providing that the wing structure is accessible for inspection. The problem with the C-5A wing's spanwise splices and other localized trouble spots is that expensive and/or time-consuming fastener removals would be required for the inspections. SIEP analyses indicated that various options for flying beyond the safety limit would place too many unacceptable restrictions on operational use. Other SIEP evaluations of wing residual strength in the event of dual panel failures showed that the remaining strength of the intact structure was insufficient for adequate safety even with severe flight restrictions.

The Scientific Advisory Board accepted SIEP's conclusions that flight restrictions not be used to ensure aircraft safety beyond the safety limit. In lieu of these restrictions, SIEP proposed various fastener removal inspections. However, the board expressed deep concern about these inspections because of their cost, impact on service use, and the potential for additional hole damage. At an October 1979 meeting, Lockheed and Air Force officials agreed on a revised inspection program (Force Structural Maintenance Plan), which would maintain safety but minimize fastener removals. Further, the board recommended the Air Force speed up development work on certain nondestructive inspection technologies.

Finally, the board commended the Military Airlift Command on its force management policies. At that time, the C-5A fleet was still capable of fulfilling high-priority, special missions. According to the board, the command's skillful management had permitted a slight increase in daily usage. The active lift distribution system had reduced damage accumulation and other flight restrictions were contributing to this goal. Damage to the outer wing had also diminished after the command reduced aerial refueling training, thereby lowering the number of flightcrews who had aerial refueling currency from 184 to 96. The board believed that reduced training, restricted missions, and special restrictions on aircraft with high flying hours would lead to increasing constraints on fleet usefulness; thus, wing modifications should begin in 1982.

Lower C-5A service life alternatives not evaluated during SIEP

One Scientific Advisory Board member told us that his previous experience in C-5A wing problem reviews had already convinced him that a new wing was needed, even before SIEP began. He recognized that a reevaluation of the C-5A service life goal might have altered SIEP results and recommendations, but the Air Force never chartered SIEP participants or the board to conduct such an evaluation. The following quote from the Scientific Advisory Board's 1977 report approving SIEP organization and tasks confirms that the program began without including considerations for lower C-5A service life goals under which the Rand Corporation believed less costly alternative solutions for the wing problems might arise:

> "Potentially, the C-5A is by far the most efficient airlift/ cargo aircraft ever contained in a military inventory. However, as a consequence of the Peacetime Management Plan to minimize damage accumulation to the wing structure, this potential is not being realized, fuel and airlift capacity are being wasted, and crew morale is being damaged. The operational restrictions are regarded by the Committee as most severe: payloads held generally below 25 tons where 50 would be much better; utilization held to 1.5 hours/day as compared with three times that much on C-141A; no tactical training; reduced number of landings; excessive pilot-tours; etc.
>
> Basically, all of these restrictions are due to an airframe safety limit which is generally recognized as being in the vicinity of 8,000 RMP hours. Already 18 aircraft are under special constraints because of high time accumulation, and others will enter this category soon.
>
> The continual search for a more 'precise' figure for the flight hour safety limit does not seem very realistic in light of the inherent limitations of inspection and analysis techniques. <u>There exists a consensus both on its general magnitude and on the need for major replacements to wing structure to ensure that the 30,000 hour goal originally specified for the C-5A will be attained</u>. A firm

commitment to production phases of the H-mod program has already been delayed by two years from original plans. It can be delayed no longer, consistent with flight safety and with USAF's [U.S. Air Force's] ability to meet its airlift commitments for the 1980s." (Underscoring added for emphasis.)

Some SIEP and Scientific Advisory Board participants stated that, in their view, SIEP findings were so serious that other viable alternatives to H-mod no longer existed. This belief is clearly supported by the board's final report accepting SIEP conclusions and recommendations in which it stated:

"The Committee reminds its readers that in 1977 it decried the constraints placed on the C-5A's usefulness by the impending 8,000 RMP hours safety limit and concluded that a firm commitment to production phases of the Wing Modification (Wing Mod) program 'can be delayed no longer.' It has found nothing in the additional information accumulated since that date which gives the slightest justification for any change to that principal conclusion.

At the August 1979 meeting attention was called to the Milestone III scheduled for December 3, 1979, to progress on the pacing cyclic tests, and to agreement on firm budget plans for the high-cost years of Wing Mod. Nevertheless, there remains some apprehension that the program might encounter further delay or roadblocks somewhere in the budget approval cycle. The Committee believes that the avoidance of any such problems is a matter with substantial consequences for national security. Wing Mod must proceed-and proceed on the presently anticipated schedule--in order to avoid such unfortunate events as loss of aircraft, partial force grounding or deterioration in strategic airlift capability.

There are those who have proposed that Wing Mod might be further postponed or that partial alternatives such as extensive hole repair and fastener replacement might be adopted. The Committee renews its earlier findings that small differences among various estimates of the C-5A flight hour safety limit are insignificant in comparison with the goal of 30,000 hours. The fundamental difficulties to be remedied by Wing Mod are general in nature and center on factors such as excessively high 1-g stresses throughout major areas of the lower wing structure. These factors cannot be corrected by modification programs much less extensive than the major primary structural replacements contained in Wing Mod. The 'will-o'-the-wisp' of a quick, cheap fix must be abandoned by all concerned." (Underscoring added for emphasis.)

On two occasions, we attempted to elicit comments from the Chairman of the 1977 and 1979 board meetings concerning SIEP, but he declined to discuss these issues plus the other areas which Senator Proxmire had requested us to review. In his refusal, the Chairman cited that (1) he was no longer a member of the board, (2) the board's findings were a matter of public record, and (3) his schedule prevented him from meeting with us.

Throughout the course of our review, we found no evidence that the Air Force ever reevaluated the C-5A service life objective regarding its impact on H-mod alternative considerations, particularly once Defense had approved the H-mod program in June 1975. Like Rand, we believe that if the Air Force had objectively reviewed possible lower service life goals in conjunction with austere force management procedures, then other, less costly wing repair options might have become viable solutions.

The decision in late 1973 to proceed with the H-mod configuration was based primarily on Lockheed cost estimates of wing rework versus wing replacement. By 1976 and before SIEP started, the Air Force had substantial evidence that the H-mod program would cost at least $400 million more than the original program estimate of about $900 million. Given the substantial difference in predicted costs, the new data which SIEP would be developing, and the low percentage of H-mod work completed, 1977 seems to have been the most appropriate time to reconsider H-mod alternatives.

Our discussions with individuals in the aerospace industry indicated that one company had developed and improved over time a fastener hole expansion technique--one of the techniques considered by the Independent Review Team--which might have extended the C-5A's service life to the lower goals discussed in the Rand report without major structural replacements. Although the company had conducted in-house tests on representative C-5A material specimens with some favorable results, SIEP's objectives, as well as the Air Force's failure to reevaluate the impacts of varying service life goals, prevented this hole expansion technique and other possible options, such as those proposed by the review team, from being analyzed at the most appropriate time in the H-mod program's development.

Discussions with Military Airlift Command officials disclosed that each C-5A has been assigned a specific date on which its modification will begin. Currently, the command is managing the fleet so that each aircraft will have used up as much of its remaining RMP hours before being sent to Lockheed. Assuming that the 7,100-RMP hour safety limit is valid and given both the command's present fleet management practices plus the February 1982 modification start date, we see no other alternative but to continue with the H-mod as programed at this time.

In our opinion, a minimum of 2 to 3 years would be required to evaluate the technical feasibility of alternative C-5A wing repair options, prepare a Request For Proposal, obtain and assess potential contractors' proposals, and select a contractor. During that period, the Military Airlift Command may have to ground several C-5As for safety reasons.

At the end of calendar year 1980, 14 C-5As had less than 1,000 RMP hours of life remaining at the fatigue critical, inner wing location, and yet another 38 aircraft had only between 1,000 and 2,000 RMP hours remaining. Under present Military Airlift Command operational requirements, C-5As accumulate on the average about 300 RMP hours annually at the inner wing location. As a result, many of the 52 C-5As with less than 2,000 RMP hours remaining could be grounded in the next 2 to 4 years. If a contingency were to arise in this period, RMP hours would be accumulated at an even faster rate and additional C-5As would have to be grounded.

OTHER ISSUES RAISED DURING 1980 HEARINGS

In addition to his 12 specific questions, Senator Proxmire asked us to address allegations which were raised by a member of the SIEP Steering Committee during 1980 hearings before the Subcommittee on Priorities and Economy in Government, Joint Economic Committee. (See app. II for a summary of these issues.) Some of these issues have already been discussed in previous chapters of this report. Our findings on the remaining issues are discussed briefly in the following sections.

In mid-1977 the C-5A safety limit could have been 11,000 hours

This issue arose primarily because the Rand study team had found that both the average or mean crack growth rates and ALDCS benefits had been overstated and underestimated, respectively, during earlier calculations of the C-5A safety limit. In both cases, more representative or accurate data would have resulted in a higher safety limit. Whether that limit would have been in excess of 11,000 hours, we are not qualified to say. However, Rand did point out that the Air Force Flight Dynamics Laboratory, using the same set of assumptions on which the 8,000-RMP hour limit was based, calculated an 11,000-hour limit plus or minus 3,000 hours. Obviously, significant amounts of engineering judgment were involved in establishing the values for the variables used to calculate the safety limit.

Given SIEP's stated objectives, we found no evidence to question either the thoroughness of the analyses or the validity of the results. A review of SIEP final reports indicated that mean crack growth rates apparently had been used in the 7,100-RMP hour limit. In addition, Air Force officials told us that although ALDCS benefit numbers were not used to adjust the safety limit yardstick, the benefits accruing to each individual aircraft were incorporated into the individual aircraft tracking program. Various Air Force officials stated that SIEP results were extrapolated to the C-5A fleet so RMP-equivalent damage for each aircraft, and therefore the number of RMP hours accumulated, was adjusted upward or downward based on the aircraft's individual ALDCS benefit before the fracture mechanics tracking program began.

In a 1976 meeting, Air Force and Lockheed officials agreed the C-5A wing might last 12,000 to 14,000 hours

Discussions with Rand officials disclosed that they could not remember the specific agreements reached concerning the 12,000- to 14,000-hour number. At the meeting they had proposed that the session be taped, but Lockheed officials objected. According to Rand officials, no transcript or minutes of the meeting existed.

Air Force participants at the meeting stated that they agreed the widespread cracking limit might not be reached until 12,000 to 14,000 hours but, on the basis of their own analyses, they doubted it. In their opinion, the widespread cracking condition, as predicted at the time, would occur earlier around 10,000 hours. These participants told us that given the projected time a 0.05-inch crack would grow to critical length, they would have never agreed the rogue flaw safety limit ranged between 12,000 and 14,000 hours. They also said that SIEP results showed widespread cracking could be present at about 7,000 RMP hours, which refuted earlier expectations that the condition might not occur until some higher number of hours.

Steering Committee members had insufficient data to assess Lockheed's SIEP findings

The SIEP Steering Committee Chairman told us the Technical Director advised the group on several occasions during the group's meetings that if they required more information, raw data was available at Lockheed for their personal review. The Chairman was unaware of any Steering Group or Scientific Advisory Board members who requested to see the data except for the one individual who raised issues concerning SIEP's validity at the 1980 hearings. Unfortunately, this individual was not satisfied with the data he eventually received.

CONCLUSIONS

SIEP was established in response to uncertainties arising from Rand's study of strategic mobility alternatives for the 1980s and from Air Force concerns with C-5A flight safety through H-mod completion. On the surface and given the stated objectives, SIEP appears to have been a thorough analysis. However, the program did not meet Rand's recommended criteria for independence or breadth of analytical endeavor. Rand had suggested that C-5A structural information enhancement initiatives be carried out by a panel of independent specialists and that their work be evaluated by another group of senior aerospace industry officials. Although the Scientific Advisory Board, consisting of aerospace industry representatives and individuals from the academic community, reviewed SIEP objectives, tasks, and results, Lockheed developed most of the data and conducted most of the analyses.

Rand also recommended that the initiatives considered lower C-5A service life goals. With more reliable H-mod cost data existing at SIEP's outset, objectives which included a reevaluation of the C-5A service life requirement might have resulted in lower cost wing repair options being considered. Yet, the Air Force did not conduct such a reevaluation once the Defense Department approved the H-mod in June 1975.

In our opinion, the Air Force's unyielding demand for an additional 30,000-hour service life served as the overriding determinant in the H-mod configuration as it exists today. At the time of SIEP's undertaking, the Air Force had one last opportunity to determine whether there were acceptable, less costly alternatives which potentially could have saved the Government millions of dollars. As of this date, we no longer believe viable options remain.

CHAPTER 6

C-5A WING MODIFICATION

CONTRACT AND PERFORMANCE ISSUES

Up to this point, the report has dealt primarily with the studies and decisions leading to the H-mod program approval and with the Air Force's reevaluations of the program's requirements. However, questions had also been asked about (1) the propriety of the Air Force's decision to award Lockheed a sole-source H-mod design contract and the resulting impact on H-mod production competition, (2) the adequacy of the warranties under the two H-mod contracts, and (3) the effects the H-mod might have on C-5A performance characteristics. This chapter summarizes our findings on these issues and contains updated H-mod program cost and schedule status as of May 31, 1981.

COMPETITION FEASIBILITY

During 1973 and early 1974, the Air Force examined the feasibility of competing all or part of the wing modification program. In its opinion, a competitive procurement would have been extremely difficult to conduct on an equitable basis since Lockheed possessed certain inherent advantages as the original C-5A manufacturer. For example, Lockheed had 10 years of experience in designing, producing, and modifying the aircraft and had participated in all of the efforts to extend its service life. The Air Force estimated that competing C-5A wing redesign would delay the H-mod schedule by 2 years: 6 months to rewrite the Request For Proposal and provide potential bidders the basic data with which they could redesign the wing; 1 year for competitors to prepare their proposals; and 6 months for proposal review, contract negotiations, and award.

Because fatigue failures were predicted for the late 1970s and threatened to ground some C-5As, the Air Force decided not to compete the wing redesign and development phases. The service considered only Lockheed to have the specialized technical personnel who could speed up the modification. So in December 1973, the Air Force approved Lockheed as the sole-source H-mod design contractor. The contract, which was awarded in December 1975, maintained the option to compete the production phases. The Air Force, however, acknowledged that the design effort would give Lockheed an even greater advantage for the production contract. In effect, the design contract award locked the Government into Lockheed for the follow-on production effort.

Air Force was directed to reconsider competition

Over the years, the Air Force's requests for the original equipment manufacturer to perform major, follow-on modifications had been advantageous, and generally, had resulted in sole-source procurements. However, the potential benefits of a competitive arrangement and the concern over possible congressional reaction to a $900 million sole-source contract with Lockheed prompted the Air Force to direct another competition feasibility study. The Air Force's study conducted during late 1974 and early 1975, evaluated three separate programs: competition for the fabrication and installation phases as a package, competition for the installation phase only, and performance of the installation phase in-house by the San Antonio Air Logistics Center. The Air Force also explored the possibilities of having a contractor other than Lockheed perform the modification at Air Force Plant No. 6.

To accomplish some of the directed tasks, the Air Force selected two wide-body aircraft manufacturers, Boeing and McDonnell Douglas, for review. The Air Force sent facilities and cost experts to the companies' manufacturing plants for an onsite review of their production capabilities and to assess the possibility of each company competing for the H-mod fabrication and installation phases.

The Air Force determined that both companies had the facilities and technical capabilities to perform the wing modification. Boeing and Douglas officials indicated a willingness to perform the work, but believed that they could not be competitive because

--large amounts of tooling would have to be moved from Lockheed's facilities in Georgia and

--Lockheed had acquired a significant learning curve advantage from prior C-5A work which would be further enhanced during the development of two prototype H-mod wings.

Both companies expressed interest in any competitive approach which provided all bidders an equal opportunity for success, although they offered no suggestions for obtaining this equality. Douglas officials believed, that from a cost standpoint, they could not compete with Lockheed. They also stated that Lockheed was the most qualified to do the work, and therefore, should do so. Boeing officials were interested in any program which competed the entire H-mod effort, but it questioned whether the company could be held responsible for a production aircraft which it had not designed. In their final analysis, Boeing officials had no objections to a sole-source contract award to Lockheed.

As another part of the study, the Air Force evaluated the possibility of performing the entire modification at Air Force Plant No. 6, located adjacent to Lockheed's facilities in Georgia. At the time, Lockheed leased the plant from the Government, and the Air Force considered whether the lease could be terminated and given to another aerospace company for the H-mod program.

The Air Force found that the modification could not be performed in Plant 6 without extensive disassembly of the C-5A tail section--a costly requirement. In addition, Lockheed owned some of the physical plant facilities needed for the modification plus the only building in which the H-mod could be accomplished without aircraft disassembly.

According to the Air Force, use of these Lockheed-owned facilities would have required further negotiations and extensive coordination had another company been engaged to complete the co-dification in Georgia. Douglas officials believed they could operate Plant 6 but still considered Lockheed the best capable contractor since it owned so much of the facilities. While the study determined that it would be feasible to compete the Air Force Plant 6 management contract, C-5A Program Office personnel did not believe that the potential competitors would have been interested.

Finally, the Air Force study considered whether the Air Force Logistics Command's San Antonio Air Logistics Center had the capability to install the H-mod kits. The Air Force determined that the Center could do the work, but the Air Force Logistics Command and Center officials recommended against it because

--the work would have reduced the Center's flexibility to respond during unforeseen military emergencies,

--the Center's technological capabilities would not have been enhanced by the unique aspects of the wing modification program,

--the rapid buildup of the work force to meet the increased workload and the corresponding layoffs as the work subsided would have caused undesirable personnel turbulence and lowered overall Center efficiency,

--ongoing work at the Center would have had to be moved to other Air Force Logistics Command depots or placed on contract, and

--the modification could not have been accomplished within planned personnel ceilings.

Because of these positions, the Air Force concluded that the San Antonio Air Logistics Center should not install the H-mod kits. In addition, some degree of competition was recognized to be technically feasible since two aerospace industry members were capable and somewhat willing to bid on a portion of the work, but the Air Force recommended proceeding with the sole-source award to Lockheed. In the study team's opinion, a sole-source contract avoided undue delays and lowered the cost and technical risks compared with the competitive modification program.

Air Force reevaluated competition
before the production contract award

The Defense Systems Acquisition Review Council approved the H-mod design and development program in June 1975, but it directed the Air Force to maintain the option for competition in the later program phases. In September 1977, the Air Force held a formal business strategy session to readdress the competition issues. The 1973-74 Air Force competition feasibility study was updated and major airframe manufacturers were asked again about their willingness to bid on the H-mod production effort. Both Boeing and Douglas officials declined the business opportunity. Neither believed they could overcome the advantages that Lockheed had obtained in its performance of the H-mod design, development, and testing. In their opinion, a competitive program which gave all bidders a fair and equal opportunity for success would be difficult, if not impossible, to achieve. Neither Boeing nor Douglas objected to Lockheed receiving the follow-on H-mod contract for fabrication and installation.

With the end of the B-1 bomber program, Rockwell International had a highly skilled, but idle work force and expressed an interest in competing against Lockheed. Rockwell officials recognized that the company did not have adequate facilities to accommodate the large C-5A aircraft. They explored the investment requirements associated with such a facility but found the costs would be too great for the company to be competitive.

The San Antonio Air Logistics Center's capabilities to install the H-mod kits were also reevaluated. The Center conducted a new study finding that it might be capable of performing the work at a lower cost than Lockheed. However, Center officials told us their estimate did not include the costs for the fabrication phase. These costs would have increased if Lockheed had lost the installation work. In addition, the H-mod program would have taken as much as 2 years longer to complete than if all the work were conducted at Lockheed. Again, the Center recommended that it not participate since the installation program would disrupt ongoing tasks and would require major work realignment. Consequently, the Air Force concluded that no viable alternative sources existed for the proposed H-mod production program. In September 1978, the Secretary of the Air Force approved the negotiation of the production phases on a sole-source basis with Lockheed.

H-MOD PROGRAM WARRANTIES

Lockheed was unwilling to warrant the service life of the C-5A after wing modification. Because of the contract strategy established by the Office of the Secretary of the Air Force, the H-mod Program Office obtained during research, development, test and evaluation contract negotiations, limited design warranties on the fatigue and flight test articles and on the modified aircraft. Warranty coverage on the modified aircraft was further expanded during negotiations for the production contract. In total, these warranties require Lockheed to correct design deficiencies and to incorporate the corrections in the test and modified aircraft. The Air Force also obtained a materials and workmanship warranty which covers each modified aircraft for 1 year after its formal acceptance.

Costs to design, fabricate, and install corrections for cited wing deficiencies are allowable under the two H-mod contracts. Under the design and development contract, Lockheed is reimbursed for all warranty costs and, in some instances, receives a 3.07percent fee. For warranty work covered by the production contract, Lockheed's fee will be reduced by an amount equal to 50 percent of the warranty costs. Except for certain materials and workmanship provisions, Lockheed's total liability for warranty costs under this contract is limited to $20 million.

Fatigue article warranty

The Air Force received from Lockheed a fatigue article warranty under the design contract which covered structural design defects occurring in the first 45,000 hours of testing. According to the Air Force, the planned 60,000 hours of fatigue testing would verify that the H-mod design could withstand 30,000 hours of operational use. The Air Force decided to limit warranty coverage only to the first 45,000 test hours because

--it had intended to induce cracks into the fatigue article wings after 45,000 test hours so it could analyze the crack growth rates,

--the H-mod was not a new design but a structural reinforcement of the original design,

--the original wing had been analyzed by structural engineers and the locations of the weaknesses were known,

--a materials properties program was conducted to obtain design data lacking in the original C-5A wing designs, and

--damage tolerance analyses and fatigue testing of over 56 representative component specimens had been conducted in the design phase.

In July 1980 the Scientific Advisory Board reviewed the results of the first 30,000 hours of fatigue testing. In the board's opinion, the fatigue test program would demonstrate that the economic life of the modified C-5A exceeded the 30,000-flying hour operational goal. Further, the board indicated that the test article's durability had been excellent, equaling or surpassing the performace of any other aircraft during its first lifetime of testing. This performance level had been anticipated because of the low aerodynamic stress levels, improved design details, and crack resistant materials. Instead of starting the crack growth analysis after 45,000 hours, the board recommended that the Air Force continue fatigue testing to 60,000 test hours as required by the Aircraft Structural Integrity Program. On April 24, 1981, the fatigue article had completed 60,000 test hours without incurring major deficiencies.

Flight test warranty

The Air Force negotiated the flight test warranty to insure proper reinstallation of components, such as electrical equipment, wing flaps and slats, and hydraulic systems, not altered by the modification. The warranty covers the design and materials and workmanship of the flight test article for up to 1 year after Air Force acceptance or 1,000 flight hours, whichever occurs first. The Air Force accepted the flight test aircraft in January 1981 and the test program is underway.

Flying hour design warranty

The Air Force obtained this warranty coverage to insure the adequacy of production processes, tooling, and procedures. The warranty covers design and materials and workmanship for 1 year after the delivery of the first modified aircraft or for 5,000 cumulative flying hours, whichever occurs first. In the 1-year warranty period, the Air Force expects Lockheed to deliver 17 modified aircraft, and at the planned use rate of 800 hours a year per aircraft, the 17 aircraft should accumulate a combined total of 5,000 hours.

By the time the flying hour design warranty ends, the flight test aircraft will have accumulated over 3,000 flight hours. Any defects found in this aircraft after the expiration of its warranty (1,000 hours) would be written up against one of the 17 aircraft covered by the flying hour design warranty. After this warranty expires, the Government will bear total responsibility for any design defect that might occur.

Materials and workmanship warranty

Lockheed has warranted the materials and workmanship of each aircraft. Given the present H-mod schedule, this warranty should remain in effect until July 1988 or 1 year after Lockheed is scheduled to deliver the last modified aircraft. Initially, materials and workmanship defects will be covered by the flying hour design warranty and will be subject to the $20 million limited liability. After this design warranty expires, materials and workmanship defects will be identified separately for each aircraft and Lockheed will have no limit on its liabilities for their repair.

Industry views

Our discussions with officials of aerospace companies other than Lockheed indicated that they would be hesitant to warrant the service life of any aircraft which they might build for the Air Force. Unlike the commercial airlines, who buy airplanes as designed by one of the airframe manufacturers and who use the planes under fairly rigid flight profiles in accordance with Federal Aviation Administration standards, the Air Force suggests, directs, and approves design changes during the aircraft's development and production for which it must bear responsibility. In addition, once the manufacturer makes delivery, it has no control over how the Air Force uses the aircraft. Use other than in accordance with the mission profiles to which the aircraft was designed would cancel warranty coverage. Finally, these officials agreed that service life warranties could be obtained under certain circumstances, but only at a substantial cost to the Government.

Quality assurance and control

The H-mod Program Manager believes existing quality assurance and control programs and the demonstrated fatigue endurance provide testimony that the Air Force has obtained adequate warranty coverage. To insure that materials meet contract specifications, the Air Force has required suppliers periodically test the material properties and certify their compliance with the appropriate standards. Furthermore, the Air Force has obligated additional funding against the H-mod contracts to cover extensive quality control inspections of fastener holes in various wing structures.

According to the Air Force, before and after each shift in which fastener holes are to be drilled, the performance of the equipment must be verified. In both instances, personnel assigned to drilling operations must drill sample holes in representative metal specimens. If defective holes are found in the specimens before work starts, then either the bit or the entire drill is replaced. Discrepancies noted in the test holes after the work has stopped force the quality control personnel to inspect all of the fastener holes on the production articles which had been drilled with that piece of equipment. In addition, the H-mod contract scope of work requires inspection of (1) 100 percent of the fastener holes in certain fatigue-critical areas, (2) 50 percent of the holes in less critical areas, and (3) at least 10 percent of all fastener holes. When the inspectors find a defective hole, they are then required to inspect all of the holes drilled with the same piece of equipment.

We visited AVCO, Inc., in Nashville, Tennessee, where most of the H-mod wing structure is being fabricated under subcontract with Lockheed, and found that quality assurance procedures had been implemented. Besides AVCO's own quality control personnel, the Government had assigned eight onsite quality assurance inspectors to insure that the wings were built in accordance with contract specifications.

H-MOD COST AND SCHEDULE

Since its start, the H-mod program generally has progressed on or ahead of schedule. Substantial fatigue testing has been completed, flight tests are underway, and kit fabrication has begun. Although significant cost increases have been incurred, they appear reasonable given the changes in the scope of work and Defense-directed schedule requirements.

Cost estimates

The original H-mod program cost estimate in November 1974 exceeded $896 million in then-year dollars. As of May 1981, the Air Force estimated that program costs had increased to $1.55 billion. Except for unforeseen problems which could arise and for changes in inflation rates, H-mod program officials believe the total costs will remain fairly stable. The following chart compares the changes in various cost elements of the original and current estimates.

H-Mod Program Costs

Cost elements	Cost estimates Original	Cost estimates Current
	(millions)	
Phases I and II: design, development, and test	$129.6	$ 176.4
Phase III: kit fabrication	317.5	837.8
Phase IV: kit installation	449.2	450.1
Other: logistics support (spares, support equipment, depot requirements)	a/0	88.8
Total	$896.3	$1,553.1

a/The original estimate did not include logistics support costs.

Costs for Phases I and II increased from $129.6 million to $176.4 million because of several factors, including (1) the addition of a flight test program to the development phase, (2) a slip in the design phase start date from April to December 1975, (3) the decision to replace the outer wing box, which increased the design phase scope of work, (4) a refinement in the estimate to incorporate other changes in the scope of work, (5) the change from program cost estimates to negotiated contract prices, and (6) an increase in inflation rates above those expected. The total cost increases from these factors were offset to some extent by other actions which resulted in cost reductions around $34.7 million. For example, under the Air Force's revised Aircraft Structural Integrity Program, H-mod fatigue testing requirements were reduced from 120,000 to 60,000 test hours, lowering funding needs by $20.9 million. Another $10.7 million has been saved because the successful H-mod fatigue testing program led to a decision reducing damage tolerance testing (crack growth analysis) from 60,000 to 30,000 test hours.

The cost estimate for kit fabrication increased from $317.5 million to $837.8 million for a total of $520.3 million. The new outer wing box configuration, the change in fabrication and installation schedules which reduced concurrency, and the impact of inflation since the original estimate formed the primary reasons for this increase. As of March 31, 1981, less than 1 percent of the production effort had been accomplished so the cost estimate could be subject to change. In addition, the H-mod Program Manager indicated that potential work stoppages at both Lockheed and AVCO in the last quarter of fiscal year 1983 could increase production costs and delay H-mod completion since both contractors have union contracts that expire during that period. The contract permits Lockheed and AVCO to slip the delivery schedule 1 day for each day of a union walkout. The Program Manager also stated that, while not currently a problem, the long leadtimes for aluminum extrusions and heavy forgings could cause delays if the demand for such items increased within the aerospace industry.

Program status

The 12-year C-5A wing modification program, which began in December 1975, has the following major milestone phases.

H-Mod Schedule

Phase	Timespan
Design (Phase I)	Dec. 1975 to June 1978
Prototype and test (Phase II)	Jan. 1977 to June 1983
Kit fabrication (Phase III)	Jan. 1980 to Feb. 1987
Kit installation (Phase IV)	Feb. 1982 to July 1987

Design (Phase I)

The Air Force approved the H-mod configuration and go-ahead as early as November 1973, but the lack of funding and concerns over possible competition and schedule concurrency forced the program to be delayed until contract award in December 1975. In April 1976, Defense directed the Air Force to delay the start of kit fabrication and installation until the H-mod fatigue article had successfully achieved one lifetime of testing. This direction caused the Air Force to slip the originally scheduled H-mod production start date 20 monthe, from May 1978 to January 1980.

Fatigue testing (Phases I and II)

As of April 1981, the H-mod fatigue article, one of the two prototype H-mod wings, had successfully completed 60,000 test hours (two lifetimes of operational use) which, according to the Air Force, demonstrated that the modified C-5A should be capable of achieving 30,000 operational flying hours. At the time the fatigue article reached the 60,000-hour plateau, the fatigue test program was over 1 year ahead of schedule. Lockheed achieved this early success because it included contingencies in the test program to design and implement fixes for major fatigue-related deficiencies which never materialized.

Air Force plans indicate that the fatigue article will be tested for an additional 30,000 hours. The Air Force has been negotiating with Lockheed for the crack propagation and damage tolerance analysis to determine the long-term crack growth characteristics of the wing design. Upon completing these analyses in November 1984, the Air Force plans to disassemble the fatigue article and examine its overall structural condition.

Flight testing (Phase II)

Lockheed completed the installation of the second H-mod prototype wing on the flight test aircraft in May 1980. Between August and October 1980, joint Air Force-contractor flight tests were conducted to assess the modified C-5A's general handling qualities. This preliminary test program, completed approximately 2 weeks ahead of schedule, consisted of 54.4 flight hours, and according to Air Force officials, demonstrated that the modified aircraft's handling characteristics had remained essentially unchanged.

The Air Force formally accepted the flight test aircraft in January 1981 and immediately began a follow-on operational test and evaluation. The follow-on tests will be conducted in two phases and are scheduled for completion in February 1982, at which time the aircraft will have accumulated about 1,200 flying hours. During this period, the Air Force intends to evaluate the aircraft's performance under various required operational scenarios, such as long-range, heavy cargo missions; air refueling; and training missions. Phase I of these follow-on tests lasted about 4 months and focused on the aircraft's flight performance under specified peacetime and wartime mission profiles. Even though final test results had not been published at the time of our review, the Air Force anticipated that sufficient time would remain to incorporate required deficiency corrections in the first production aircraft. The Air Force began Phase II testing in June 1981. Within this phase, the Air Force intends to increase user confidence in the aircraft's operational effectiveness, maintainability, and suitability.

Fabrication and installation (Phases III and IV)

The Air Force awarded the H-mod production contract in January 1980 but limited its obligation to the procurement of necessary long lead items. On July 16, 1980, the Air Force amended that contract authorizing Lockheed to proceed with H-mod kit fabrication. The fiscal year 1980 buy consisted of only four kits because of budget constraints. In December 1980, the Air Force exercised the fiscal year 1981 buy and authorized Lockheed to fabricate an additional 12 kits.

Under the production contract, the Air Force must exercise the first fiscal year option of Phase IV (kit installation) on or before November 1, 1981. This phase is a 5-year program which will begin at the end of flight testing. Lockheed is scheduled to begin modifying the first operational C-5A on February 4, 1982. The first modification will take approximately 13 months with delivery scheduled for March 1983. Lockheed hopes to achieve the anticipated production rate (1.5 modified aircraft per month) with the 15th aircraft in February 1984. As scheduled, the 76th modified aircraft will be delivered to the Air Force by July 1987. However, the Air Force has been considering an increase in the production rate, and the H-mod Program Office expects a decision to be made on this matter by September 30, 1981. If the change were approved, Lockheed would be authorized to attain a full production rate of two aircraft per month, decreasing the time to complete the modification by about 1 year.

Program management remained with ASD until July 1981. Then, H-mod production contract management was transferred to the Air Force Logistics Command's San Antonio Air Logistics Center. After the transfer, ASD retained responsibilities for continuing tasks under the design and development phases and will provide the Air Force Logistics Command with engineering support for design changes which arise during the production program.

The following table summarizes by fiscal year H-mod costs, kit fabrication, and installation options as of May 31, 1981.

H-Mod Cost and Production Options

FY	Phases I and II: Design, test, and evaluation (millions)	Phases I and II: No. of prototypes	Phase III: Kit fabrication (millions)	Phase III: No. fabricated	Phase IV: Kit installation	Phase IV: No. installed	Other resource requirements (Air Force Logistics Command) (millions)	Total
1980 & prio	$135.8	2	$ 87.7	4	$ 0	-	$7.2	$230.7
1981	11.0	-	166.7	12	0	-	44.8	222.5
1982	15.3	-	182.8	18	53.1	5	10.3	261.5
1983	8.7	-	177.0	18	96.8	15	11.4	293.9
1984	5.6	-	223.6	24	101.1	18	4.8	335.1
1985	0	-	0	-	93.4	18	5.1	98.5
1986	0	-	0	-	94.7	18	4.5	99.2
1987	0	-	0	-	11.0	2	0.7	11.7
	$176.4	2	$837.8	76	$450.1	76	$88.8	$1,553.1

H-MOD PERFORMANCE

Fatigue and preliminary flight test results indicate that the H-mod will restore full C-5A strategic airlift capabilities which have been degraded by the current wing's structural deficiencies. While operational flight tests have not been completed, the Air Force expects the H-mod to (1) improve the aircraft's cargo ton-mile output or productivity, (2) reduce logistics support costs, and (3) eliminate costly wing inspections. In addition, the Air Force expects increased payload capabilities will be achieved as a byproduct of the lower operating stresses on the wings once they are replaced.

Present C-5A capabilities fall short of the requirements

Original C-5A requirement documents defined the basic mission as one involving the airlift of 100,000 pounds, 5,500 nautical miles under a maximum 2.5g maneuver load limit (2.5 times the force of gravity). Given the same load limit, these documents also stated that the aircraft should have a 200,000-pound structural capacity at a range of 2,700 nautical miles. Payload requirements increased for emergency operations in which the Air Force wanted an aircraft capable of carrying a 265,000-pound payload 2,500 nautical miles at a 2.25g load factor. The following chart compares C-5A requirements to performance for basic and emergency missions.

Comparison of C-5A Requirements with Performance

Maximum payload (note a)	Specific operational requirements (note b)	Lockheed proposal	Actual as of 5-31-81	After H-mod
Basic mission (note a):	200,000 lbs.	220,000 lbs.	162,832 lbs.	200,000 lbs.
Payload	100,000 lbs.	100,000 lbs.	100,000 lbs.	100,000 lbs.
Range	c/5,500 NM	5,800 NM	5,000 NM	5,150 NM
Takeoff distance (89.5 F)	8,000 ft.	8,000 ft.	8,000 ft.	8,000 ft.
Landing distance (after 4,000 NM)	4,000 ft.	4,000 ft.	4,100 ft.	4,250 ft.
Initial cruise	30,000 ft.	30,000 ft.	30,000 ft.	30,000 ft.
altitude	30,000 ft.	30,000 ft.	30,000 ft.	30,000 ft.
Cruise speed	400 knots (.77 Mach)	440 knots (.77 Mach)	440 knots	440 knots
Service life	30,000 hrs./ 12,000 landings	30,000 hrs./ 12,000 landings	7,100 RMP hrs./ 1,682 landings	d/30,000 hrs./ 12,000 landings
Emergency mission (note e):				
Payload	265,000 lbs.	265,000 lbs.	205,000 lbs.	245,000 lbs.
Range	2,500 NM	2,700 NM	3,250 NM	2,800 NM
Takeoff distance (89.5 F)	10,000 ft.	10,000 ft.	10,000 ft.	10,000 ft.

a/Limiting load factor of 2.50 gs.
b/Requirements established by the Air Force before contract award.
c/NM - nautical miles.
d/Flight hours were 39,000 to over 44,000, depending on actual flight time accrued when aircraft are modified.
e/Limiting load factor of 2.25 gs.

As designed, the C-5A was unable to meet the range and payload requirements. As of May 31, 1981, the Air Force had set the maximum physical payload capability of the aircraft at about 163,000 pounds (2.5g load factor) and limited the emergency payload to 205,000 pounds. The Military Airlift Command has imposed further restrictions and adjusted flight profiles to insure the aircraft achieves at least a 7,100-RMP hour service life and remains operational until its modification. These additional restrictions limit general cargo missions to 25 tons and outsize cargo missions to 50 tons. By reducing the gross takeoff weights, the command hopes to conserve the remaining wing life. The command has also reduced the average daily utilization rate to 1.8 hours per aircraft which only supports minimum training requirements.

H-mod should improve C-5A performance

While the wing modification adds over 17,000 pounds to the airframe weight and will marginally increase landing distances, the Air Force anticipates some range and payload capability improvements without any degradation in aerodynamic characteristics. After C-5A modification, the Air Force will also be able to remove the operational constraints and terminate special safety inspections, both of which had resulted from the poor wing design. The following chart lists some of the changes in C-5A capabilities expected at a normal operating load factor of 2.5gs.

Current and Future C-5A Capabilities

Characteristic	Current capability	Restricted capability	Expected capability with wing mod configuration
Operating weight empty (lbs.)	353,000	353,000	370,000
Maximum fuel capacity (lbs.)	318,000	318,500	332,500
Gross weight at ramp (lbs.)	732,500	712,500	769,500
Maximum payload (lbs.)	162,832	145,000	a/200,000
Range with maximum payload (NM)	3,600	3,600	3,050
Range with 100,000 pound payload (NM)	5,000	4,650	5,150
Range with 145,000 pound payload (NM)	4,000	3,600	4,400
Maximum payload for 5,500 (NM)	80,000	66,000	86,000

a/This maximum payload is stated in terms of normal peacetime limiting load factor of 2.50 gs. During an emergency, the load factor could be reduced to 2.25 gs, enabling the C-5A to carry a maximum payload of 245,000 pounds.

The Air Force projects that the modified aircraft will have a slight increase in range at any given payload. Current C-5A operations require that the ailerons be uprigged to reduce wing bending and that they be placed back in their original position after wing modification. This action, plus the continued use of the active lift distribution control system, will improve aircraft takeoff, climb, and cruise performance and will also partially offset the effects of the airframe weight increase. Actual performance improvements, however, remain to be demonstrated since flight tests will not be completed until early 1982.

CONCLUSIONS

At the time the Air Force decided to proceed with H-mod, it believed the configuration was urgently needed. Only Lockheed had the necessary design expertise, production facilities, and C-5A tooling to do the work at the least cost in the most timely manner. Although other companies expressed interest in the program, they did not object to Air Force H-mod procurement actions. The Air Force decision to award Lockheed the sole-source H-mod design contract locked the Government into Lockheed for the follow-on production effort. However, in our opinion, substantial and unnecessary costs would have been incurred if the Air Force had attempted to conduct a competition. Such an action would not have benefitted the taxpayers' interests.

Lockheed was unwilling to warrant the service life of the C-5A after wing modification. The limited warranties contained in the H-mod contract appear to be consistent with the warranty policies of several aerospace industry members.

The H-mod contract requires the Government to pay the full cost for correcting deficiencies covered by the warranties, but under certain provisions, Lockheed's potential fee will be reduced on the basis of contractually designated share ratios. Once the flying hour design warranty expires, the Government will be totally responsible for repairing fatigue damage that occurs. Since the fatigue article has reached 60,000 test hours without major deficiencies, modified C-5As should be capable of at least 30,000 additional flight hours. Flying the aircraft under more severe mission profiles than those to which Lockheed designed the H-mod could substantially reduce the remaining life after modification. However, on the basis of preliminary fatigue test results, Air Force engineers believe the new wing might be capable of achieving 60,000 or more flying hours.

Finally, given the limited data available, we found no evidence suggesting that the airframe weight increase resulting from H-mod will degrade C-5A performance. Air Force officials expect ongoing flight tests may demonstrate some performance improvements.

CHAPTER 7

DEFENSE'S ACQUISITION PROCESS HAS BEEN MODIFIED IN AN ATTEMPT TO PREVENT SIMILAR PROBLEMS

Throughout this report, we have attempted to furnish sufficient detail of the C-5A's 17-year history so readers could not only identify important program decisions and their subsequent impacts on the origin, extent and resolution of the wing cracking problem, but also so they might understand the environment in which these decisions were made. In our opinion, hindsight is not beneficial if only used to criticize; instead, it should help all of us learn from our mistakes.

In the final analysis, Lockheed's deviation from contractually required wing material thicknesses caused the wing cracking problem being experienced today by the C-5A. This decision was shaped by a series of events or situations relating to the aircraft's required performance characteristics and the acquisition strategy at the beginning of the C-5A program. Given that the Air Force authorized Lockheed to begin production before completing the development and testing phases, the full extent of the wing problem was not disclosed until 40 production aircraft had been accepted.

Because of its experiences during the C-5A program and during other weapons system procurements since then, the Defense Department has periodically reviewed and revised the major system acquisition process. Essentially, these revisions have improved the Secretary of Defense's ability to control new program starts from a need and affordability standpoint; provided the Secretary with greater visibility and control over critical acquisition milestones, such as program initiation, full-scale development, and production; and increased the services' flexibility to tailor procurement strategies to fit individual program needs. Even though the acquisition process has evolved over time, the changes cannot prevent program managers or other officials from exercising poor judgment, and weapons system effectiveness and management issues continue to surface.

SUMMARY OF CRITICAL C-5A EVENTS AND LESSONS TO BE LEARNED

As noted earlier, Defense adopted the total package procurement concept in the mid-1960s to prevent buy-in bidding, reduce cost overruns, hold contractors accountable for design deficiencies, and instill greater competition throughout the acquisition process. After problems arose within the C-5A program, as well as in other weapons systems being procured under total package contracts, Defense began to criticize the concept as an acquisition strategy in the early 1970s and prohibited its further use.

Critical C-5A events

In our opinion, Defense's total package procurement approval was only one of several events or situations that created the arena in which C-5A structural failure occurred. Some of the other events or situations included the following:

--The Air Force's demand for certain aircraft performance and operational requirements which forced the C-5A competitors to achieve near 100-percent effectiveness in all system elements leaving the competitors with little opportunity to make design tradeoffs;

--The selection of the original C-5A contractor who offered the lowest bid but whose proposal was neither technically superior nor the most cost effective;

--The imposition of an arbitrary initial operational capability date which was not based on a realistic acquisition strategy or governed by the contractor's ability to perform and which forced the Air Force to authorize Lockheed to begin production before completing the development and testing phases (concurrency);

--The approval of the total package procurement concept given the need for significant concurrency (1) under the false assumption that the C-5A was just a larger C-141 and (2) without adequately defining management procedures or contract standards;

--The reluctance to sacrifice minor performance requirements for a more reliable system, particularly when the potential for serious wing problems and degraded C-5A operational capabilities were known to exist in early 1967;

--The scheduling of C-5A structural tests too late within the concurrent program prevented the Air Force and Lockheed from promptly correcting the deficiencies.

Because of these situations, total package procurement was an unsuitable acquisition strategy for the C-5A. When problems arose, C-5A contract provisions (such as the contractor's total system performance responsibility) coupled with the Air Force's disengagement policy and desire to make Lockheed comply with contractual guarantees, prevented the Program Office from taking any actions which would have been perceived as limiting Lockheed's responsibilities or making the Government a party to the aircraft's design.

Ultimately, in its attempt to fulfill the contract requirement for the empty weight of the airframe, Lockheed reduced wing material thicknesses below contract specifications. Not until the Air Force was ready to accept the first production aircraft in December 1969, did it formally notify Lockheed that rights would be retained to negotiate a settlement for any deficiencies which resulted from the thinner metal.

Lessons to be learned

Although the C-5A was initially procured under a total package contract, some of the decisions and events in that program should be periodically highlighted. Government procurement officials responsible for present and future major acquisitions may occasionally face situations similar to those which arose during the C-5A program. In that event, these officials should recognize the following:

--Contracting is an important tool for system acquisition and is not a substitute for management of acquisition programs.

--Any Government procuring activity should weigh the risks of selecting a contractor whose proposal contains the lowest acquisition or life cycle cost when the proposal is known to include potentially serious deficiencies. If a selected contractor's proposal contains unrealistic cost, schedule, and performance optimism or guarantees, the cost of acquiring that system can eventually become excessive.

--When the contractor and procuring activity determine that the selected acquisition strategies are unsuitable for a given problem, they have a mutual responsibility to revise the strategies and renegotiate any related contractual provisions. By continuing with unsuitable acquisition strategies or contractual instruments, neither the contractor nor the Government can deal effectively with system performance problems that arise.

--When a contractor plans to deviate from contract specifications jeopardizing system safety, service life, or other performance characteristics, the contractor and the procuring activity have a joint responsibility for (1) verifying the potential impact of the change and (2) taking whatever action is appropriate for preserving system integrity before proceding with the planned change.

--While program concurrency may speed the acquisition process, its use can prevent the disclosure of design deficiencies or other problems until substantial amounts of production hardware have been accepted. Concurrency, therefore, increases the risks of costly modifications to obtain desired performance characteristics. The use of concurrency should be limited--preferably to those system acquisitions whose technology is at hand or whose urgent military need has been validated.

--Contract practices adopted should foster a Government-contractor relationship which will encourage both parties to work together to achieve the most cost-effective approach to satisfy the mission needs.

DEFENSE CHANGES TO THE ACQUISITION PROCESS

Over the years, Defense has recognized that inadequacies existed in the acquisition process and has periodically altered its procurement philosophies to provide better oversight. Because of concerns arising from the C-5A procurement program, Defense implemented the "fly-before-buy" concept in the early 1970s, and expressed the need to reduce concurrency and to expand test programs. The Department also issued a new directive, 5000.1, Major System Acquisitions, which (1) established formal reviews at critical program milestones before entering the next phase of the acquisition cycle and (2) identified the Defense Systems Acquisition Review Council as an advisor to the Secretary of Defense during management and technical reviews at the milestone decision points.

In the mid-1970s, the Office of the Secretary of Defense attempted to become more involved with individual weapons system program managers and implemented incremental milestone decision points, particularly after Milestone III, the production decision, to reduce program risks even further. At the same time, the Office of Management and Budget issued Circular A-109, which

--took an integrated view of the entire process and clarified roles of key participants,

--focused high-level attention on front-end decisions that heavily influenced system acquisition outcomes,

--involved industry design teams at the start when maintaining competition is least expensive but most fruitful, and

--induced more complete information about system candidates and enabled a sound choice among them.

By the late 1970s, Defense had revised Directive 5000.1 to implement Circular A-109 and to incorporate our recommendations 1/ for increased Secretary of Defense control over the acquisition process. The Department also reverted to approving more concurrency between development and production to shorten the acquisition cycle. As part of this policy change, Defense emphasized that acquisition strategies be flexible and tailored to the specific weapons system.

1/"Review of the Department of Defense's Implementation of Procurement Reforms" (PSAD-79-106, Sept. 25, 1979).

Even though Defense has made a series of changes to the acquisition process, a recent GAO report 1/ indicates that weapons system effectiveness and program management issues continue to surface. These issues include cost overruns, system affordability, program concurrency, curtailment of needed testing, limitations on operational performance and system cost effectiveness.

Currently, Defense is completing even more revisions to the acquisition process. In early 1981, the Reagan administration embarked on a program to reduce weapons system procurement and operational costs, to make the acquisition process more efficient, to increase program stability, and to decrease acquisition time. Included in this program are 32 recommendations for changes to existing procurement procedures. Because Defense has just begun to implement these recommended changes, which address our concerns, it is too early to assess the impact that they might have on continuing weapons system effectiveness and program management issues.

CONCLUSIONS

Although changes have been made to the acquisition process since the early 1970s in an attempt to prevent the recurrence of problems experienced during the C-5A program, weapons system effectiveness and management problems continue to surface. Likewise, the changes to the process cannot prevent program managers and other officials from exercising poor judgment. We believe the present acquisition process, if carried out properly, should make errors in judgment more visible and enable the Defense Department to deal more effectively with problems arising in current and future major acquisitions.

1/"Review of the Department of Defense's Implementation of Procurement Reforms" (PSAD-79-106, Sept. 25, 1979).

CHRONOLOGY OF MAJOR C-5A PROGRAM EVENTS

Date	Event
December 1964	The Air Force asked Boeing, Douglas, and Lockheed to submit proposals to build the C-5A and all three responded.
February 1965	The Secretary of Defense approved the total package procurement concept for the C-5A.
August 1965	After reviewing the proposals, the source selection board recommended Boeing for the airframe contract because its design met all requirements, posed the least risks, and was the most cost-effective system.
September 1965	All three contractors had some deficiencies in their proposals and had to submit revisions. After the revisions, the source selection board on two subsequent occasions recommended Boeing for the C-5A contract. Defense selected Lockheed because it had a lower price and better loading and cargo carrying flexibility.
December 1965	The C-5A contract with Lockheed was finished and released for distribution.
June 1966	Even though Lockheed had emphasized weight control from contract inception, it had serious weight problems and so informed the Air Force.
January 1967	Lockheed told the Air Force that the weight problems would reduce some performance characteristics, such as takeoff and landing distances.
February 1967	The Air Force was unwilling to grant relief and therefore notified Lockheed that failure to meet performance requirements might constitute grounds for terminating the contract for default.
March 1967	Lockheed responded by preparing detailed plans for achieving the contractural guarantees which satisified the Air Force.

April 1967	An ASD advisory group reviewed Lockheed's revised plans and noted that with the airframe's weight, the average stresses in primary structures exceeded standard design practices leaving little or no allowance for conservative uncertainty or factor of ignorance. The group suggested that Lockheed consider accelerating fatigue testing to determine problems as early as possible. Also, the group concluded that Lockheed's planned design parameters were so optimistic that failure to meet one could result in a substantial redesign or a new wing.
June 1968	First flight of flight test aircraft.
July 1969	The static test article wing failed at 124 percent of the design load limit due to a design error. Static tests were to be conducted to 150 percent of the design load. The problem was corrected by a structural modification.
December 1969	First production C-5A delivered to the Air Force.
January 1970	Fatigue cracks were identified in the wings of a flight test aircraft. Also, fatigue testing began on the original fatigue article.
February 1970	The Secretary of the Air Force convened a Scientific Advisory Board to review the wing failures.
June 1970	The Scientific Advisory Board reported that Lockheed's designs to modify structural problems were adequate but high stress levels identified in the wing raised serious doubts whether wings could meet the 30,000-hour design goal. The board recommended an additional fatigue test article be constructed to expedite tests.
October 1970 - September 1971	Cracking problem identified in fatigue test article at 9,000 hours. Repairs were made and testing continued to 15,000 hours, until September 1971, hours, when general cracking of inner and center wing sections were identified. Cracks of this type and magnitude normally would not be expected until

	after 120,000 hours of testing. (Note: 120,000 test hours equate to 30,000 actual flight hours.)
May 1971	Supplemental Agreement 1000 carried out.
September 1971	Massive failure of static test article occurred in the outer wing at 126 percent of design limit load. No modifications were designed because the Air Force believed static strength could not be increased. C-5A payloads were limited to 80 percent of contract specifications. The maximum payload allowed was 174,000 pounds at 2.0gs. The lift distribution control system was later added to extend possible life. This system also increased cargo capability to about 190,000 pounds.
January 1972 - March 1973	The Independent Review Team conducted an in-depth structural review of the C-5A program to develop alternative approaches for extending wing life. The review team concluded, except for the wing, the C-5A structure was manageable without modification, and the wing life could be extended by load alleviation, fastener changes, and structural design modification. The review team presented nine options developed to extend the aircraft's wing life.
April 1972 - March 1973	As directed by the Air Force, Lockheed conducted a Wing Life Improvement Program to determine the estimated wing life and to develop alternatives for extending the service life of the C-5As. Lockheed recommended wing beef-up and local repairs to extend the wing life slightly and an overall redesign to achieve the full service life.
June 1972	The second wing fatigue test article experienced general cracking of the lower wing surface at about 30,000 test hours.
February 1973 - November 1973	To consolidate the results of all the studies on the wing, the Air Force directed Lockheed to prepare a Service

	Life Management Plan. The plan integrated the results of the other studies. In July 1973 Lockheed recommended that the center and inner wing boxes and lower surfaces of the outer wing be replaced. That recommendation was similar to one of the alternatives suggested by the Independent Review Team. The Secretary of the Air Force was briefed of the results in November 1973.
March 1973	The Secretary of the Air Force selected an active lift distribution control system (a device to reduce high wing stresses) as an interim measure to extend the life of the existing wing structure. This measure was to be followed by a major C-5A wing modification to attain a 30,000 hour service life.
January 1974	The Air Force requested Lockheed to submit a firm proposal to perform the design and test phases of the new wing modificiation.
April 1974	Lockheed responded but indicated the outer wing lower surface, in addition to the inner and center wing boxes, would have to be replaced.
June 1974	After the Secretary of the Air Force's decision to modify the C-5A wing, the Air Force continued to study the deficiencies of the aircraft. An ASD advisory group was convened in June 1974 to review the configuration of the modified wing proposed by Lockheed in the Service Life Management Plan. The group's conclusions were generally in agreement with Lockheed's proposal, except the group did not think the outer wing lower surface needed to be replaced.
November 1974	Lockheed modified its design proposal accordingly and the contract was negotiated. The contract was not carried out, however, because of a lack of funding and the Secretary of the Air Force's concern over competition and concurrency between development and production schedules.

January 1975	The Air Force General Counsel stated that Lockheed was not responsible for correcting wing defects because service life was expressed as a "design goal."
January 1975	The Air Force formed another division advisory group to assess the structural status of the C-5A wing and improvements necessary to extend the service life. The group concluded that the risks were higher than previously thought and recommended that the modification begin at about 8,000 hours.
June 1975	Defense directed the Air Force to reanalyze alternatives to the wing modification and to maintain the ability to compete procurement and installation. It also authorized the design and test phases of the H-mod program but directed the the Air Force to resolve certain concerns over concurrency between development and production schedules.
December 1975	Lockheed was awarded the new wing design and test contract.
March 1976	The Air Force asked the division advisory group to review proposed outer wing modifications which would offset damage accumulation from aerial refueling. The group concluded that a new outer wing was needed. Consequently, the new outer wing box was incorporated into the contract.
April 1976	The Deputy Secretary of Defense directed that the program be restructured so that fabrication of production wings would begin as soon as possible after the successful achievement of one lifetime of fatigue testing.
March 1977	The Rand Corporation's strategic mobility alternatives study for the 1980s stated that various cheaper alternatives to the H-mod existed and that the Air Force should evaluate these.
September 1977 - August 1979	The Air Force established the Structural Information Enhancement Program to

evaluate the fatigue damage on high time aircraft. The program concluded that damage was extensive and that the safety limit should be 7,100 representative mission profile hours.

August 1979 — The H-mod fatigue tests began.

November 1979 — On the basis of its August 1979 review of the Structural Information Enhancement Program, the Scientific Advisory Board agreed that the safety limit should be 7,100 representative mission profile hours.

January 1980 — Lockheed was awarded a long lead contract for the modification production phases.

May 1980 — The fatigue test successfully completed 30,000 cyclic test hours (one lifetime). Two minor structural defects were discovered and were corrected by redesigning new parts and installing them in the test article.

July 1980 — The long lead contract, awarded in January 1980, was amended authorizing the H-mod kit fabrication.

August 1980 — Flight testing of the H-mod prototype began.

October 1980 — The first phase of flight testing was successfully completed.

April 1981 — The fatigue test successfully completed 60,000 cyclic test hours with no significant problems.

APPENDIX II

LLOYD BENTSEN, TEX., CHAIRMAN
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November 4, 1980

Honorable Elmer Staats
Comptroller General
General Accounting Office
Washington, D.C.

Dear Elmer:

This is to request that your office investigate and review the procedures followed by the Air Force in the identification and assessment of defects in equipment and weapons systems procured from private contractors and in steps taken to correct defects. Both your office and the Subcommittee on Priorities and Economy in Government have conducted many inquiries into the C-5A program. Using the C-5A as an example, I would like you to review the procedures followed by the Air Force in the identification and assessment of the wing problems and the decision to approve the modification program known as H-mod. I am especially interested in the relationship between the Air Force and Lockheed, the contractor in this case, and the appropriate division of responsibilities. Among the questions I would like answered are the following:

1. When and how did the Air Force first learn of the wing problem? [See pp. 10, 14, 18, and 36.]

2. Did the Air Force have the independent means to discover the wing problem or was it dependent upon tests conducted by the contractor, test data, and other information generated by the contractor? [See p. 20.]

3. Should the Air Force have its own independent capabilities for testing and obtaining information concerning defects such as those that exist in the C-5A wings, or is it prudent and appropriate for this capability to reside with or be delegated to the contractor? [See p. 21.]

4. Did the Air Force properly exercise its responsibility for ascertaining whether it was accepting delivery of aircraft with major wing defects? [See p. 36.]

5. Did the Air Force properly exercise its responsibility for requiring the contractor to assume the financial burden of correcting manufacturing defects such as the wing defects in the C-5A?

1/This issue is currently being reviewed jointly by GAO and Air Force General Counsels and their findings will be addressed in a seperate report.

GAO note: The page references refer to areas of the report where the subject matter is highlighted. In many instances, the topics are also discussed elsewhere.

Honorable Elmer Staats
November 4, 1980
Page 2

6. Was it appropriate for the Air Force to award a sole-source R&D contract to Lockheed, with respect to correcting the wing problem, and did this have the effect of locking the government into Lockheed for the production contract? [See pp. 61 through 64.]

7. In the various reviews and studies of the wing problem, did the Air Force assure itself of independent means for gathering, analyzing, and assessing information about the wing problem, or were these functions in reality under the control of the contractor? [See pp. 26 through 35.]

8. Did the Air Force adequately consider various options for correcting the wing problem? [See pp. 26 through 35.]

9. On what basis was the decision made to adopt the H-mod for all C-5A aircraft? [See pp. 18 through 20, and 26.]

10. Was the information generated in the Structural Information Enhancement Program (SIEP) adequately analyzed and used in the Air Force decision to approve the H-mod? [See pp. 38 and 48 through 60.]

11. Are the taxpayers' interests adequately protected in the warranty provisions with respect to the future service life of the new C-5A wings under the H-mod program? [See pp. 64 through 67.]

12. What effects will the additional weight by virtue of the H-mod program have on the performance characteristics of the C-5A? [See pp. 72 through 75.]

Dr. Paul Paris has made serious allegations that information generated in the course of the inquiries into the wing problem was improperly or inadequately used, which are summarized in the attachment. Dr. Paris also disagrees with some of the interpretations and conclusions made on the basis of the SIEP data. I would like your review to examine and assess these allegations, as well as the findings and conclusions with respect to the C-5A wing problem in the 1977 Rand Corporation study entitled Strategic Mobility Alternatives for the 1980s.

I would like your staff to provide me with a detailed progress briefing on your inquiry by the March/April time frame followed by a final report.

Sincerely,

William Proxmire, U.S.S.
Chairman
Subcommittee on Priorities and
Economy in Government

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ATTACHMENT: SUMMARY OF MAJOR ALLEGATIONS

MADE BY DR. PAUL C. PARIS

The following summary of Dr. Paris' allegations are based on the testimony presented by him to the Subcommittee on Priorities and Economy in Government on August 25, 1980, and September 16, 1980. In his testimony Dr. Paris alleged:

1. During the course of the Rand Corporation study of the C-5A, misleading data and obscure detailed analysis methods were given to the Division Advisory Group (DAG) of the Aeronautical Systems Division, U.S. Air Froce, chaired by Charles F. Tiffany (for two instances of alleged Lockheed misrepresentations, see page two of Dr. Paris' prepared written testimony). [See pp. 44 through 47.]

2. In mid-1977, if the 8,000 hour safety limit calculation had been corrected for the data that was "misrepresented," the result would have been in excess of 11,000 hours for the safety limit for the C-5A wing. [See p. 58.]

3. At a meeting at the Rand Corporation in late 1976, with representatives of both Lockheed and the Air Force present, it was concluded that the C-5A wing might last 12,000 to 14,000 hours without replacement. [See p. 59.]

4. A tacit assumption of the Structural Information Enhancement Program (SIEP) Steering Group was that since the H-mod of the wing was going to be done, other less expensive options were not to be considered. The Air Force Scientific Advisory Board also shared this tacit assumption. The SIEP studies, in fact, proceeded without exploring the other less expensive options. [See pp. 54 through 58.]

5. Important technical factors necessary for making a final assessment of the current C-5A life remained missing during the SIEP studies. It was assumed that the SIEP Steering Group was to believe Lockheed's final numbers and judgments. No final ALDCs benefit numbers were given to the Steering Group, although they were urgently requested. The methods of handling the effects of fastener loads was changed by Lockheed employees without giving a full explanation to the Steering Group. Lockheed also changed the methodology for computing damage accumulation without explaining it to the Steering Group. [See pp. 51, 52, and 58.]

6. Members of the Steering Group did not have sufficient access to the raw data produced in the SIEP studies. Dr. Paris was not informed that a room containing raw data from the SIEP study had been set aside at Lockheed. [See p. 59.]

7. The DAG and SIEP groups and various SAB groups have relied on studies conducted during and prior to 1972 with respect to the service life of the fuselage and empennage. Questions about fuselage and empennage life were dismissed during the SIEP studies on grounds that earlier studies had determined their life to be at least 30,000 hours. The SIEP data shows, in fact, that the fuselage has an estimated life of substantially less than 30,000 hours. [See pp. 28 and 50.]

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