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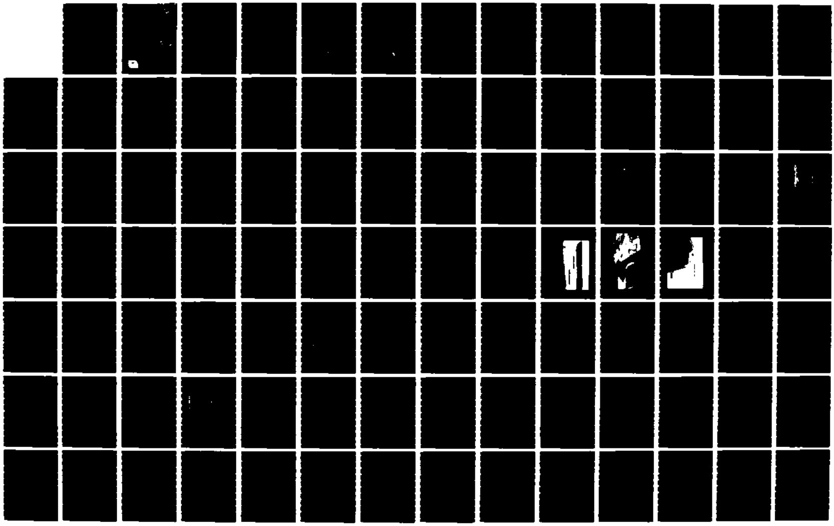

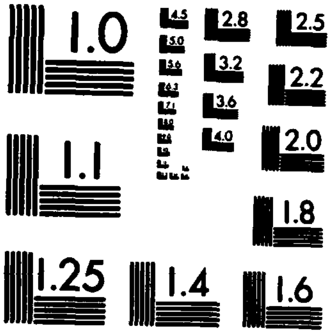
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STRUCTURAL COMPOSITES TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

Frank Crossman
Lockheed Missiles and Space Company
Working Group Chairman

August 1983

The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Prepared for
Office of the Under Secretary of Defense for Research and Engineering
and
Office of the Assistant Secretary of Defense
(Manpower, Reserve Affairs and Logistics)

IDA
INSTITUTE FOR DEFENSE ANALYSES
SCIENCE AND TECHNOLOGY DIVISION

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

This document records the activities and presents the findings of the Structural Composites Technology Working Group part of the IDA/OSD Reliability and Maintainability Study, conducted during the period from July 1982 through August 1983.

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(IDA/OSD R&M STUDY)

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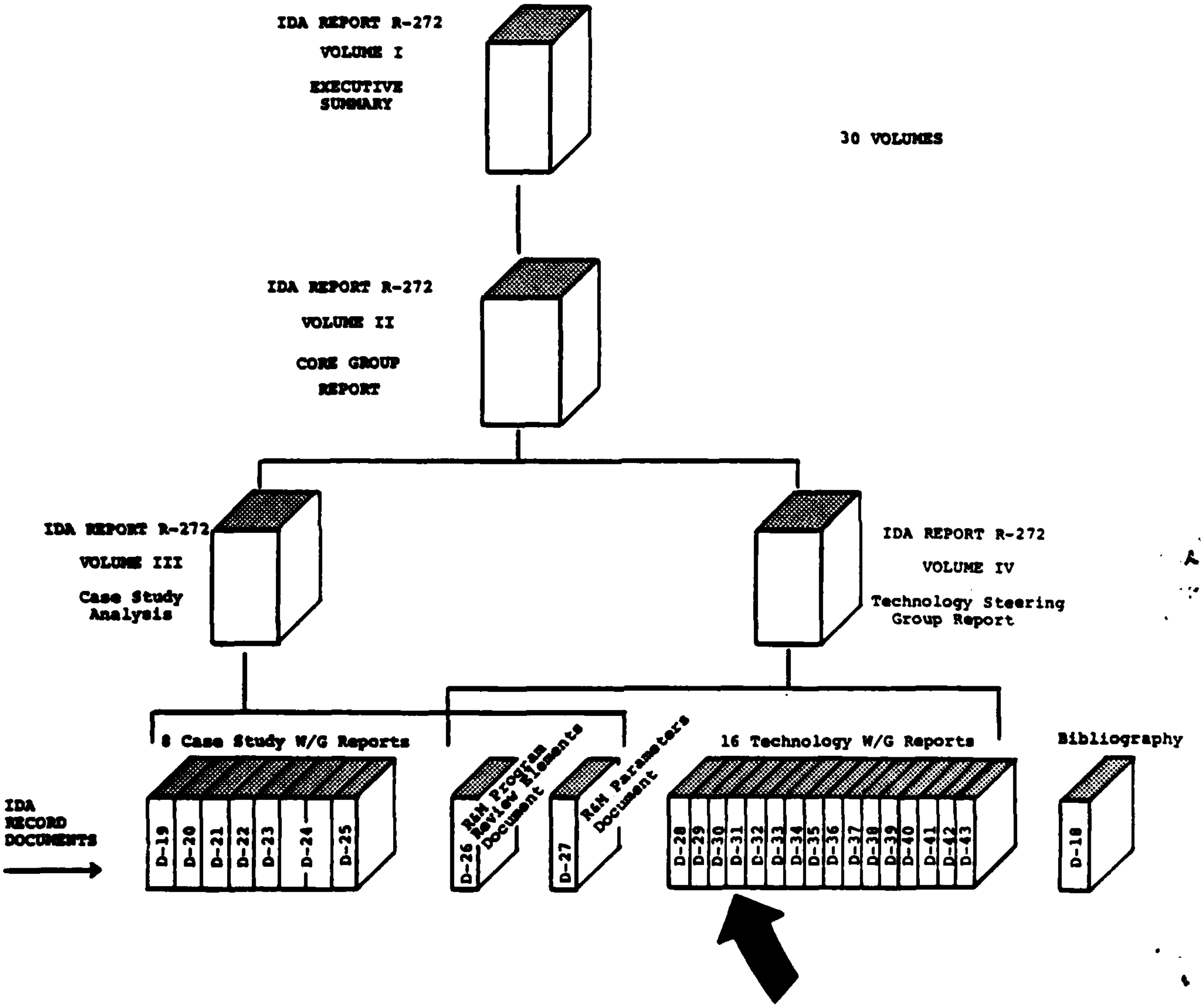
Working Group Chairman

August 1983

INSTITUTE FOR DEFENSE ANALYSES
SCIENCE AND TECHNOLOGY DIVISION
1801 N. Beauregard Street, Alexandria, Virginia 22311
Contract MDA 903 79 C 0018
Task T-2-126

RELIABILITY AND MAINTAINABILITY STUDY

— REPORT STRUCTURE —



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PREFACE

As a result of the 1981 Defense Science Board Summer Study on Operational Readiness, Task Order T-2-126 was generated to look at potential steps toward improving the Material Readiness Posture of DoD (Short Title: R&M Study). This task order was structured to address the improvement of R&M and readiness through innovative program structuring and applications of new and advancing technology. Volume I summarizes the total study activity. Volume II integrates analysis relative to Volume III, program structuring aspects, and Volume IV, new and advancing technology aspects.

The objective of this study as defined by the task order is:

> "Identify and provide support for high payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvement in R&M and readiness through innovative uses of advancing technology and program structure."

The scope of this study as defined by the task order is:

> To (1) identify high-payoff areas where the DoD could improve current system design, development program structure and system support policies, with the objective of enhancing peacetime availability of major weapons systems and the potential to make a rapid transition to high wartime activity rates, to sustain such rates and to do so with the most economical use of scarce resources possible, (2) assess the impact of advancing technology on the recommended approaches and guidelines, and (3) evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative uses of advancing technology.

The approach taken for the study was focused on producing meaningful implementable recommendations substantiated by quantitative data with implementation plans and vehicles to be provided where practical. To accomplish this, emphasis was placed upon the elucidation and integration of the expert knowledge and experience of engineers, developers, managers, testers and users involved with the complete acquisition cycle of weapons systems programs as well as upon supporting analysis. A search was conducted through major industrial companies, a director was selected and the following general plan was adopted.

General Study Plan

Vol. III ● Select, analyze and review existing successful program

Vol. IV ● Analyze and review related new and advanced technology

Vol. II (● Analyze and integrate review results
(● Develop, coordinate and refine new concepts

Vol. I ● Present new concepts to DoD with implementation plan and recommendations for application.

The approach to implementing the plan was based on an executive council core group for organization, analysis, integration and continuity; making extensive use of working groups, heavy military and industry involvement and participation, and coordination and refinement through joint industry/service analysis and review. Overall study organization is shown in Fig. P-1.

The basic technology study approach was to build a foundation for analysis and to analyze areas of technology to surface: technology available today which might be applied more broadly; technology which requires demonstration to finalize and reduce risk; and technology which requires action today to provide reliable and maintainable systems in the future. Program structuring implications were also considered. Tools used to accomplish

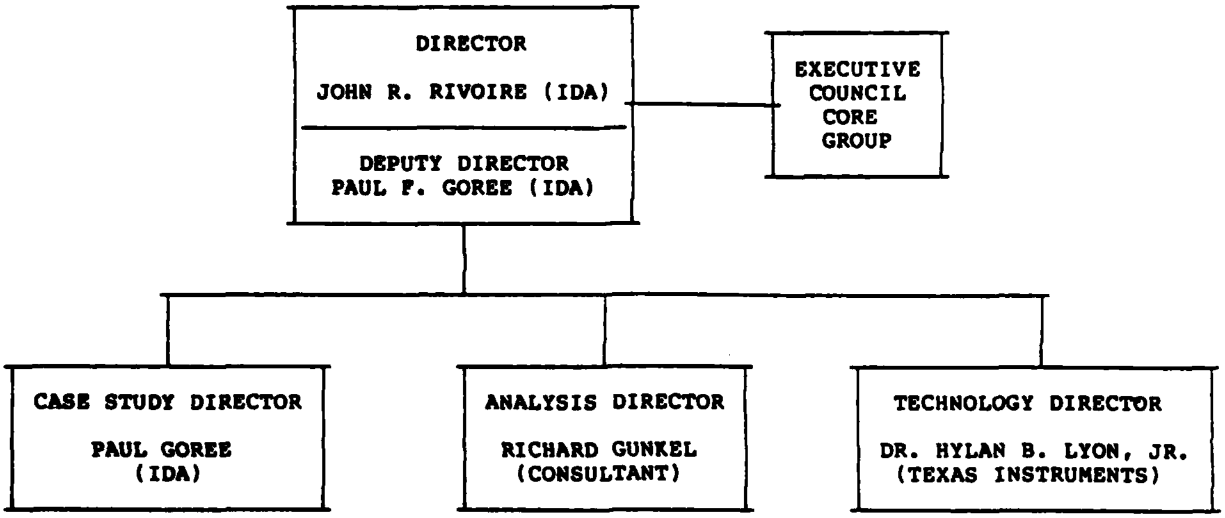

FIGURE P-1. Study Organization

this were existing documents, reports and study efforts such as the Militarily Critical Technologies List. To accomplish the technology studies, sixteen working groups were formed and the organization shown in Fig. P-2 was established.

This document records the activities and findings of the Technology Working Group for the specific technology as indicated in Fig. P-2. The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Without the detailed efforts, energies, patience and candidness of those intimately involved in the technologies studied, this technology study effort would not have been possible within the time and resources available.

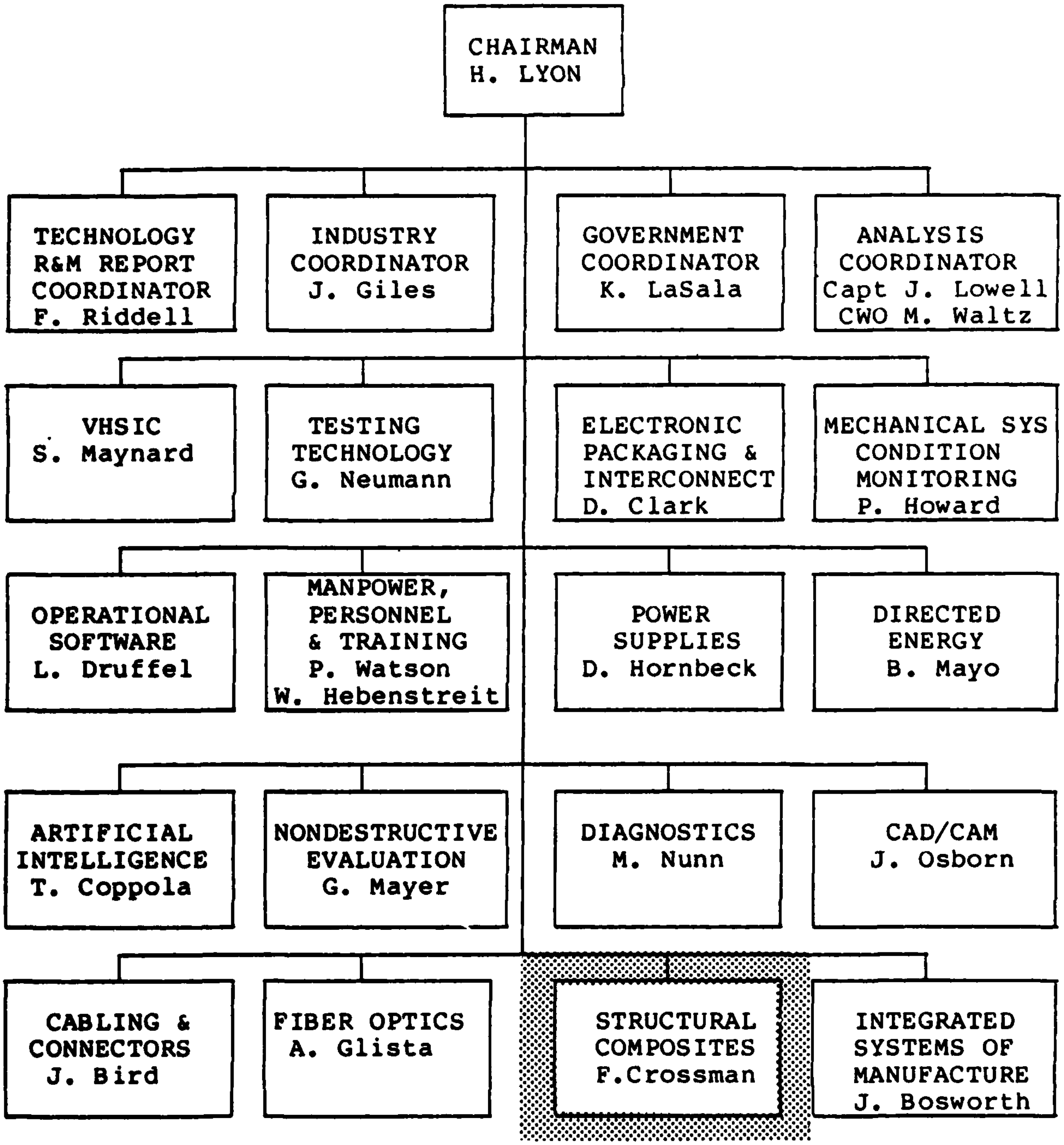

FIGURE P-2. Technology Study Organization

REPORT OF THE
STRUCTURAL COMPOSITES TECHNOLOGY
WORKING GROUP

FOR THE

OSD/IDA SPONSORED
RELIABILITY AND MAINTAINABILITY
STUDY

JUNE 10, 1983

ACKNOWLEDGEMENTS

The editor of this report would like to thank several key individuals who contributed significantly to the preparation of this document. First, my thanks go to Mr. Raymond Capiaux, Vice President of Research and Development, Lockheed Missiles and Space Co. Inc., who so kindly provided the financial support for my time and travel during the past three months of this study.

Second, my thanks go to Ms. Anthea DeVaughan of the IDA staff for her help in organizing this committee and in carrying out all of the detailed arrangements for our meetings.

Third, I would like to thank Mrs. Jeri Opalk and Mrs. Lisa Cuffe from the office staff of the Applied Mechanics Laboratory for their patience, speed, and good will as they prepared this report with its numerous revisions for publication.

Lastly, I must express my gratitude to all the participants in the meetings of the Composites Working Group: the official members; Joe Augl, John Fant, John Foltz, Ray Garrett, Bernard Halpin, Larry Kelly, Jim Labor, Roy Meade, Dan Mulville, Bryan Noton, Ken Reifsnider, Roy Rice, Larry Roderick, Bill Schweinberg, Dick Schapery, Joe Soderquist, Bob Stone, and Jerry Yanker; the alternates, Dennis O'Brien and Joe Schier and Tom Christian; and the presenters, Benson Dexter and Tom Condon.

This report represents the *combined effort of* all these people, because the information presented here covers such a broad range of our individual experiences. In our meetings this experience was discussed freely and the discussion and presentation of the critical issues and recommended actions in this report truly represent the considered opinion of the Working Group taken as a whole. My thanks to each of you for your time, effort, and professional manner in approaching this study.

Frank W. Crossman
Chairman,
Structural Composites
Technology Working Group

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EXECUTIVE SUMMARY

This report provides a documentation of the Reliability and Maintainability (R and M) issues associated with the incorporation of composites into advanced defense systems and the impact of composites technology on System Readiness. The degree to which the introduction or expanded application of composite technology can reduce the R and M costs is assessed, and R and E Technology Improvment Programs to further reduce the R and M costs associated with aerospace structure are identified.

This report has three major sections:

1. Section 1 describes the organization of the study.
2. Section 2 reviews the current and projected useage of composites and quantifies the R and M experience of composite structure.
3. Section 3 provides a detailed discussion of R and M issues related to design, damage tolerance, repair, inspection and NDE, and materials needs and presents a prioritized list of recommended actions which address improvements in structural R and M.

From a review of current composite technology programs and applications of composites in aerospace vehicles, the Composites Technology Working Group reached several conclusions with regard to future composites useage, R and M costs, critical technical needs, and recommended actions to meet those needs. These are summarized in the paragraphs which follow.

FUTURE USE AND LIFE CYCLE COST.

Composites will account for 40-70 percent of the structure of future aircraft, including helicopters, because their use provides greater performance and flexibility of design at a lower acquistion cost. Furthermore, the potential reduction in operational (e.g. fuel) and R and M costs associated with the application of composites places an even greater emphasis on reduction of acquistion cost to minimize the life cycle cost of the structure.

R and M COSTS OF COMPOSITES

It is difficult to compare the R and M cost savings associated with the use of composites vs. metals without a direct part-for-part substitution and a more detailed analysis and recording of the causes of maintenance actions. However, when composites have been directly substituted for metals in helicopter rotor blades, they have been found to reduce R and M costs by factors of 50-80 percent and increase mean time between repair actions by factors of 2-5 through alleviation of fatigue and corrosion problems.

The critical R and M cost item associated with the application of composites is their propensity for delamination and accumulation of sub-surface damage which is not always observable by visual inspection.

TECHNOLOGY NEEDS

Structural R and M costs associated with fatigue and corrosion are effectively minimized by use of composites, but the R and M effects of damage accumulation from impact and handling of composites are not well defined. Several technological improvements are needed to utilize the full potential of composites in reducing R and M costs. These needs have been categorized in the areas of design, damage tolerance, repair, inspection, and materials.

1. Design.

The detailed costs of structural R and M must be made available to the designer for tradeoffs of damage tolerant designs against strictly performance efficient designs. However, it is also necessary to provide monetary incentives for reduced R and M as well as for performance if these tradeoffs are to be conducted during the design process.

2. Damage Tolerance.

The impact of damage accumulation on the R and M of composite structure in not well defined by any unified analytical method akin to the damage tolerance analysis of metal structures. There is a need for tougher organic matrices to provide improved damage tolerance. Manufacturing concepts which provide some reinforcement through-the-thickness to mitigate the tendency for delamination are also required.

3. Repair.

Technology programs addressing the repair and maintenance of composite structure have concentrated on the peace-time environment. More emphasis on battle damage repair is needed. Furthermore, the training of personnel in the handling and repair of composite structure in depot and field must be expanded.

4. Inspection.

Inspection techniques for rapid scanning of large areas and automatic interpretation of scanned information are needed at the depot level. New and emerging methods of NDE should be investigated for their potential in providing a portable, large area scanning ability. Furthermore, structural designers must be made aware of the need to provide for ease of inspection during the design of the structure.

5. Materials.

In addition to the need for more damage tolerant materials described above, there is a need for new, long life, room-temperature storable adhesive bonding materials for field repair and for the development of matrix materials capable of withstanding a higher temperature operating environment. New classes of matrix materials including metals and ceramics must be evaluated for R and M as well as performance characteristics.

RECOMMENDED ACTIONS

The Composite Working Group Sub-committees on Design, Damage Tolerance, Repair, NDE, and Materials each developed a list of action plans for Improved R and M. In Section 3 the sub-committee reports summarizing the issues and recommended actions are presented.

During a discussion session of the entire Working Group, the individual recommendations were grouped into several categories according to the type of action. These categories were:

(1) DOD directive
(2) Policy changes
(3) System specific actions
(4) 6.3 and above technology programs
(5) 6.1/6.2 R and D programs

The recommended actions were then ranked in order of importance by Working Group members. The ranked actions are presented in Table 3.1 of this report according to category and referenced to detailed descriptions of each action within the sub-committee reports. A partial listing of this information is provided in Table E.1.

The Composites Working Group strongly endorses the recommendation of the Technology Steering Group Report to establish within DOD a year of emphasis on the extraction of detailed information from the maintenance data base of each major type of aerospace vehicle. Furthermore, a useful extraction of this data must include an engineering analysis of the causes of maintenance action. This study will require close coordination of the R and E and Logistics commands of each Service. The results of this study will provide crucial information to the Services for the initiation and direction of Technology Improvement programs such as those recommended in this report.

TABLE E.1
SUMMARY OF RECOMMENDED COMPOSITE R and M ACTIONS

CATEGORY	PRIORITY	ACTION
DOD DIR.	HIGHEST	Review present R and M data collection. Improve feedback of lessons learned. Develop Service-wide data handling, recovery, and interpretation procedures
POLICY	HIGHEST	Develop specifications with R and M requirements
POLICY	HIGH	Provide incentives for improved R and M in design
POLICY	HIGH	Train field and depot personnel in composite repair and maintenance
POLICY	MEDIUM	Require contractor validation of repair and durability
POLICY	LOWER	Improve procurement procedures for acquisition of SOA repair equip.
POLICY	LOWEST	Establish standard chemical nomenclature for organic matrices
SYSTEM	HIGHEST	Develop design guidelines for repair
SYSTEM	LOWER	Develop in-process and inspection specifications
6.3	HIGHEST	Design for damage tolerance and interchangeability
6.3	HIGH	Design for visual inspectability through improved damage tolerance assessment procedures
6.3	HIGH	Develop battle damage containment designs
6.3	MEDIUM	Develop procedures for rapid, battle damage-bolted repair

6.3	MEDIUM	Develop manufacturing methods for through-thickness reinforcement
6.3	MEDIUM	Develop portable, automated NDE methods for large composite struc.
6.3	LOWER	Quantify moisture effects on repair bond strength
6.3	LOWER	Evaluate bolted repair integrity
6.3	LOWER	Determine durability of bonded repair

6.1/6.2	HIGHEST	Develop tough organic matrices
6.1/6.2	HIGH	Develop rapid cure, long term storage adhesives for repair
6.1/6.2	HIGH	Support new and emerging NDE methods for composites
6.1/6.2	MEDIUM	Develop room temp. stored adhesives with hot, wet performance
6.1/6.2	MEDIUM	Develop portable NDE measure of bond strength in field
6.1/6.2	MEDIUM	Characterize new classes of metal ceramic matrix composites for processing and service R and M
6.1/6.2	LOWER	Develop means to measure moisture content in field prior to repair
6.1/6.2	LOWER	Develop NDE systems to assess quality of repaired structure
6.1/6.2	LOWER	Develop repair procedures for new organic, metal, and ceramic matrices
6.1/6.2	LOWER	Fully characterize newer organic systems for aging and durability
6.1/6.2	LOWEST	Improve understanding of toughness mechanisms in metal matrix comp.

SECTION 1

ORGANIZATION OF STUDY

1.1 STATEMENT OF WORK

The Structural Composites Working Group of the Technology Steering Committee was formed in February 1983 with the appointment of F. W. Crossman as Chairman of Working Group. On the basis of a briefing given by H. Lyon, Chairman of the New Technology Study, a Statement of Work (Fig. 1.1) for the Structural Composites was formulated. Emphasis was to be placed on the documentation of the R and M experience with composite structures and the means to assess the costs associated with structural R and M.

The Composites Working Group would proceed on the basis that a documentation of the performance advantages of composites vis a vis metal alloys was not the purpose of this study. Instead, the Working Group would concentrate on determining the level to which anticipated application of composites to the next generation weapons systems can bring about a payoff in system readiness through reduced R and M. The committee would also determine the existing barriers to improved R and M of composite structures by examining the specific issues listed in the statement of work.

1.2 COMMITTEE MAKEUP

Aspects of composite technology with potential impact on system R and M included:

1. Design and manufacturing tradeoffs
2. durability and damage tolerance
3. structural repair
4. inspection procedures and NDE
5. advanced matrix materials

Because of the breadth of technolgical issues related to Composites R and M, a Working Group membership with diverse experience was necessary to provide the information required to address the Statement of Work. Following positive responses to a letter of invitation sent out by Kenneth P. LaSala of IDA (see Appendix B), a Working Group of 19 people was formed (Fig. 1.2). The committee consisted of representatives from:

STATEMENT OF WORK

STRUCTURAL COMPOSITES

GOAL: TO IDENTIFY THE CHARACTERISTICS OF COMPOSITE MATERIALS WHICH CAN LEAD TO QUANTUM IMPROVEMENTS IN SYSTEM READINESS, RELIABILITY, AND MAINTAINABILITY.

SCOPE:

1. STRUCTURAL ADVANTAGES: THERMAL-MECHANICAL
2. NON-STRUCTURAL ADVANTAGES - ARMOR, ELECTRO-MAGNETIC
3. IDENTIFY BARRIERS TO APPLICATION OF COMPOSITE MATERIALS TO STRUCTURES WHERE THEIR USE PROVIDES AN R&M SYSTEM PAY-OFF

ISSUES:

1. LONG-TERM DURABILITY: FATIGUE, AGING, ENVIRONMENTAL DEGRADATION
2. REPAIRABILITY IN FIELD AND AT DEPOT
3. MATURITY OF DESIGN/MANUFACTURING METHODS (INCLUDING TESTING AND QUALITY CONTROL)
4. PREDICTION OF LIFE-CYCLE COSTS
5. IMPACT OF TECHNOLOGY ADVANCES IN NDE, CAD/CAM, ROBOTICS, TESTING, FIBER-OPTICS, ARTIFICIAL INTELLIGENCE, AND DIAGNOSTICS ON APPLICATION OF STRUCTURAL COMPOSITES

Figure 1.1

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STRUCTURAL COMPOSITE TECHNOLOGY WORKING GROUP

CHAIRMAN FRANK W. CROSSMAN - LOCKHEED/MSC

MEMBERS
JOSEPH A. AUGL - NSWC
JOHN A. FANT - GENERAL DYNAMICS/FW
JOHN FOLTZ - NSWC
RAMAN GARRETT - MCDONNELL AIRCRAFT/SL
BERNARD HALPIN - AMMRC
LARRY KELLY - AFWAL/FIBC3
JAMES LABOR - NORTHROP
L.E. ROY MEADE - LOCKHEED/GEORGIA
DANIEL R. MULVILLE - NAVAIR
BRYAN R. NOTON - BATTELLE COLUMBUS
KENNETH REIFSNIDER - VPI & SU
ROY RICE - NRL
G. LARRY RODERICK - AVRADCOM
WILLIAM SCHWEINBERG - WARNER ROBBINS/ALC
RICHARD A. SCHAPERY - TEXAS A&M
JOSEPH SODERQUIST - FAA
ROBERT STONE - LOCKHEED/CALIFORNIA
JERRY YANKER - AFALD/PTE

ALTERNATES
DENNIS O'BRIEN - LOCKHEED/GEORGIA
JOE SCHIER - MCDONNELL AIR/SL
TOM CHRISTIAN - WARNER ROBBINS/ALC

FIGURE 1.2

1. Air Force - 3
2. Navy - 3
3. Army - 2
4. university - 2
5. FAA - 1
6. industry - 7

1.3 SCHEDULE OF MEETINGS

Three meetings of the Working Group were held as shown in Fig. 1.3. The first meeting consisted of a series of informal briefings by various committee members on selected R and M issues associated with composites. These presentations provided background to the definition of composite application in future military systems and a listing of technology issues by each member of the committee.

At the second meeting following several briefings on the flight service experience of composite structures, sub-committees were formed to develop prioritized lists of issues and recommended actions pertinent to improved system R and M in each of several technology disciplines.

At the third meeting in June, the committee reviewed drafts of the Composite Technology final report and the Technology Study final report and completed a prioritized list of recommended actions.

1.4 PRESENTATIONS TO THE COMMITTEE

At the April meeting L. Kelly and D. Mulville briefed the committee on recent studies conducted by Air Force and Navy groups related to the repair, supportability, and safety of composite structures. At the May meeting, W. Schweinberg (Warner Robbins AFB/ALC), B.Dexter (NASA/Langley), and T. Condon (AVRADCOM) presented information to the committee on the flight service evaluation of composite durablity and R and M. A listing of these presentaions is given in Fig. 1.4, and a summary of each is given in Appendix A of this report.

COMPOSITES TECHNOLOGY
WORKING GROUP
SCHEDULE

	F	·	M	·	A	·	M	·	J	·
CHAIRMAN BRIEFED	▲									
WORKING GROUP FORMED			------▲							
FIRST MEETING				▲						
REPAIR TECHNOLOGY BRIEFING										
REVIEW OF AF NAVY STUDIES										
DEFINITION OF ISSUES										
TECH. PLANNING SUB-GROUPS										
SECOND MEETING						▲				
R&M IN SERVICE BRIEFINGS										
PRIORITIZATION OF TECH. PLANS										
CONCLUSIONS/RECOMMENDATIONS										
DRAFT FINAL REPORT										
THIRD MEETING								▲		
DEPENDENCY RELATIONSHIPS										
FINAL DRAFT OF REPORT										

Figure 1.3

PRESENTATIONS TO COMPOSITES R&M STUDY GROUP

LARRY KELLY - AIRFORCE ADVANCE COMPOSITES
AFWAL/FIBC SUPPORTABILITY WORKING GROUP REPORT MARCH 1983

DANIEL MULVILLE - NAVAIR COMPOSITE MATERIAL AND REPAIR STEERING
NAVAIR COMMITTEE INTERIM REPORT SEPT. 1982

DANIEL MULVILLE - JOINT SERVICES AIRCRAFT TECHNOLOGY
NAVAIR AND SAFETY REVIEW MAY 10-12 1983

H. BENSON DEXTER - FLIGHT SERVICE EXPERIENCE AND ENVIRONMENTAL
NASA/LANGLEY EFFECTS ON COMPOSITE AIRCRAFT MATERIALS

WILLIAM SCHWEINBERG - WARNER ROBBINS/ALC R&M ACTIVITY
WR/ALC

THOMAS E. CONDON - ADVANCED STRUCTURES CONCEPTS R&M/COST
AVRADCOM ASSESSMENTS

Figure 1.4

1.5 SUB-COMMITTEE STUDY GROUPS

Prior to the second meeting in May, each committee member prepared a table of Composite R and M Technology issues and a table of recommended programs to address these issues according to the format given below:

Table 1 format:

1. ISSUE
2. STATUS
3. POTENTIAL
4. GAPS
5. PAYOFF IN R AND M
6. PRIORITY LEVEL

Table 2 format:

1. RECOMMENDED ACTION
2. TARGET
3. GATEKEEPER
4. COST/TIME TO IMPLEMENT
5. IMPACT ON READINESS
6. PRIORITY

The working group was broken down into the five sub-committees shown in Fig. 1.5. These groups then examined each of the listings of issues and recommended actions prepared by individual members for its relevance to the technology discipline represented by each sub-committee.

Sub-committee reports were prepared and presented to the committee-as-a-whole which provided a priority judgement on specific recommended actions from the viewpoint of the specialist in that technological discipline. These sub-committee reports are found in Section 3 of this report. Each report provides the reader with an executive summary, a discussion of issues, and detailed recommended actions to address each issue.

STRUCTURAL COMPOSITE TECHNOLOGY STUDY

SUB-COMMITTEE ORGANIZATION

DESIGN AND COST	DAMAGE TOLERANCE	REPAIR TECHNOLOGY	NDE/ INSPECTION	ADVANCED MATERIALS AND PROCESSES
FANT	RODERICK	LABOR	HALPIN	AUGL
KELLY	SCHAPERY	MULVILLE	REIFSNIDER	FOLTZ
GARRETT	SODERQUIST	SIONE		RICE
MEADE		YANKER		
NOTON				
SCHWEINBERG				

Figure 1.5

SECTION 2

REVIEW OF COMPOSITES USAGE AND R AND M EXPERIENCE

2.1 INTRODUCTION

This section summarizes the information gathered by committee members which provides a status report on the current and projected usage of composites for aerospace structure and the limited amount of available data on the cost of R and M associated with composite vs. metal structure.

The discussion in this section places heavy emphasis on aircraft (including rotor-craft), since this has been the primary application of composites to military systems which are especially sensitive to R and M issues. Some discussion of applications to ship hulls and armored ground vehicles is also included. Maintenance issues associated with composites in space-craft and missiles were considered to be of secondary concern compared to the severity of the aircraft operating environment; and given the time limits placed on this study, they were not examined in any detail in this report.

The underlying theme of this section is that R and M improvements associated with the application of composites to structure will come about primarily by consideration of R and M issues during the initial design. Fig. 2.1.1 shows schematically the cost drivers for design of composite structures in the 1960's, 70's and 80's. During the 1960's composites were substituted for existing metal structure for performance improvements and to generate data on the durability of these systems. During the 1970's there was a increasing awareness that composites could not only provide a cost savings by weight reduction, but also produce a reduction in the cost of manufacturing. It was found that with a small loss of structural efficiency, low cost methods of manufacture could be employed to produce composite structure for a total acquisition cost less than that of a metal structure. In the early 1980's the concept of designing for reduced life cycle costs has been studied in a number of technology programs.

The full implementation of a design approach which trades off the costs associated with performance, manufacture, and R and M is hampered by the lack of data which quantify the cost of R and M at the structural component level. This issue and others associated with the further development of technology to improve the R and M of composite structure are introduced in this section.

Finally conclusions regarding the current state-of-the-art of composite technology and the potential for R and M improvements are presented in preparation for the presentation of recommended actions in the sub-committee reports of Section 3.

2.2 COMPOSITE APPLICATIONS TO AIRCRAFT

The use of advanced composites within the aerospace industry has expanded rapidly in recent years as confidence in their durability as well as performance advantages(high stiffness-and strength-to weight ratios) has become established. Fig. 2.2.1 shows that composites using Kevlar, boron, and graphite (or carbon) reinforcement have been utilized in a number of secondary structural components on Air Force aircraft and are being considered for primary structural applications on the ATF. Fig. 2.2.2 shows that most of the composite applications have been on small aircraft and helicopters. The relative useage of composites on aircraft structure ranges from 1 percent on the F-15, 10 percent on the F-18, 30 percent on the AV8B, to 70 percent on the Learfan (shown in Fig. 2.2.3).

The impetus for the steadily increasing use of composites in aircraft structure is described in Fig. 2.2.4. Corrosion has been a major maintenance problem for metal structure and only 25 percent of the problem can be avoided by preventive maintenance (Fig. 2.2.5). The remainder of the problem must be addressed by the substitution of materials which are not subject to corrosion such as the polymer matrix composites.

Fig. 2.2.6 and 2.2.7 illustrate that the advantages associated with a composite redesign of a F-111 Horizontal Stabilizer leading edge include:

1. 14 percent less weight
2. 12 percent less cost
3. one-eighth of the maintenance cost of the Al structure
4. 172 percent ROI

It should be emphasized that these design studies showed the POTENTIAL life cycle cost savings of composite structure. In the sections which follow the maintenance record of composite vs metal components will be compared to assess whether the projected costs savings are in fact realized.

2.3 NASA FLIGHT SERVICE EVALUATION STUDY

NASA has conducted a Flight Service Evaluation of a number of composite secondary structural components on commercial aircraft and has detailed the effects of long term exposure to flight and ground-based environmental conditions (App. A.4 and Fig. 2.3.1). The cumulative flight hours obtained on these components is presented in Fig. 2.3.2. These components and their metal equivalents have been subjected to detailed periodic inspections and maintenance. The causes of in-service damage have been tabulated (Figs. 2.3.3 and 2.3.4).

The repair record of a typical component, the B-737 spoiler, is shown in Fig. 2.3.5. The record shows a rather small improvement in the number of flight hours between repair for the composite version, but the total number of repair hours is greater. Reference to Fig. 2.3.3 and Fig. 2.3.6 shows that fully

78 percent of the damage and repair actions were associated with problems which could have been prevented by R and M considerations in the design of the component. For example, a fiber-glass insulation layer between the graphite and aluminum components could have prevented the corrosion which developed on the spoiler (Fig. 2.3.6).

In part, the inability of composites to demonstrate the projected improvement in R and M costs was related to the lack of knowledge at the design level of the difference in the service behavior between polymer and metal materials. The flight service evaluation program provided some of the experience base necessary for R and M decisions to be incorporated into the design. Fig 2.3.7 and 2.3.8 illustrate examples of in-service damage which are more severe in composites than in metals. The relative brittleness of composites has the advantage of providing damage tolerance to propagation of lightning induced cracking, but the degree of damage associated with ground handling can often be worse than that caused by flight conditions.

A summary of NASA results in flight service experience and environmental effects is provided in Appendix A.4.

In a related NASA sponsored study on the repair of composite structure for commercial transports (see Ref. 13), a detailed survey of airline damage experience was tabulated by damage type and component location. Aircraft damage and defects were found to have three basic causes -

(1) fatigue
(2) corrosion
(3) impact

The incidence of fatigue cracking was related to the age and history of the aircraft, while corrosion depended more on material and design factors. Impact occured to about the same degree on all aircraft.

Corrosion damage occurs primarily in the lower fuselage areas where water collects, while fatigue cracks are not limited to any specific area. Impact damage occurs principally in the lower fuselage area, flaps, and other areas subject to ground handling damage, especially in fuselage areas near cargo doors. Inboard flaps and inboard lower wing surfaces are subject to tire tread damage. Inflight damage due to hail and bird strikes is a less significant cause of damage and occurs primarily on the leading edges. The engine cowl door receives a high degree of damage due to its frequent removal for maintenance.

Of these three causes of damage to aircraft only the damage due to impact (or handling) is significant for composite components. Composite repair technology programs thus have placed a major emphasis on the detection and repair of impact damage to composites on commercial aircraft.

2.4 R AND M EXPERIENCE IN MILITARY AIRCRAFT

The usage of composites on fighter and tactical aircraft has risen rapidly in the last decade as illustrated for a series of McDonnell aircraft in Fig. 2.4.1. As was observed in the NASA flight service program, the earliest composite applications on the F-15 showed an mean time between maintenance actions (10000 hrs) which was not significantly different than that of the aluminum components (12000 hrs). However, these numbers are strongly affected by a speedbrake design which made it susceptible to damage during maintenance handling and which was subsequently redesigned with R and M in mind. If speedbrake actions are eliminated from consideration, the remaining composite components have twice the mean time between maintenance actions as the aluminum components. Furthermore, the causes for maintenance actions were not sufficiently detailed to attribute the cause of maintainance action to the composite portion of the component is question (for example, corrosion of an aluminum honeycomb core was a common maintenance action).

A similar experience base is presented for the General Dynamics F-16 aircraft in Figs. 2.4.3 and 2.4.5. There are certain composite components which show significant improvement in the mean time between maintenance actions compared to similar metal components; others, such as the horizontal stabilizer, show no improvement. Fig. 2.4.4 shows a breakdown of the causes of failure in the F-16. The delamination mode is unique to laminated composites and illustrates that designing for improved R and M requires a set of criteria specific to the material of construction.

Relatively little study has been made of the R and M costs associated with the application of composites to large transport aircraft. The Air Force Logistics Command is evaluating the use of graphite and Kevlar composites on the Lockheed C-141 leading edges and petal door (Fig.2.4.5). The size and thickness of the composite components are substantially greater than those on tactical and commercial aircraft structure. The petal door component (Fig. 2.4.6) is nearly the size of the entire Learfan aircraft (FIg. 2.2.3). While R and M cost reduction due to reduced corrosion is projected for these components, it is not known at this time whether there are any additional R and M considerations associated with the design of such large components.

In conjunction with the design of the C-141 petal door, analysis was made of the relative costs of acquisition, fuel, and operation and maintenance for large transport planes. The results of this analysis, presented in Fig. 2.4.7, illustrate that a projected 75 percent reduction in maintenance due to reduced corrosion leads to a 2 percent savings in life cycle costs. This illustrates that the major drivers for increased composite useage on aircraft will continue to be improved performance (with lower fuel cost) and reduced acquisition cost.

2.5 COMPOSITE DESIGN AND MANUFACTURING MATURITY

The degree of reduction in R and M costs associated with application of composites to aircraft structure is strongly influenced by the approach to the design. Figs. 2.5.1 and 2.5.2 show that the maximum performance and cost benefits come from a consideration of composites in the preliminary design phase and from an allowance for desizing of the aircraft due to the unique performance characteristics of composites. This preliminary design phase is also the stage at which R and M considerations must be introduced. The kinds of cost figures provided at the bottom of Fig. 2.5.2 are necessary for design tradeoffs.

Fig. 2.5.3 summarizes the historical approach to the manufacture of composite structure (oldest at top, newest at bottom). It illustrates that the structurally efficient honeycomb construction is being replaced by a less structurally efficient stiffened panel construction as ease of manufacture, inspection, and maintenance are influencing the design decisions to a greater extent. In large part these design decisions are now being made by teams of experts representing design, stress analysis, materials and process, quality assurance, and manufacturing--a sign that the design and manufacture of composite components is achieving a level of maturity comparable to that of metal technology.

2.6 ASSESSING R AND M COSTS

For R and M to be considered in the design of new aircraft, it is necessary to have a detailed breakdown of the existing causes of structural maintenance actions. Some of these data are available from a study conducted on Army helicopters (see Appendix A.6). Fig. 2.6.1 illustrates that most structural maintenance actions are on secondary rather than primary structure and that nearly half of these actions are associated with the mechanical fasteners. In addition to providing improved corrosion resistance, composites, by their manner a manufacture, also provide a large reduction in the number of mechanical fasteners, as indicated at the bottom of Fig. 2.6.1 for the L-1011 Composite Vertical Fin.

In conducting design tradeoffs it is important to consider different measures of R and M. For example Fig. 2.6.2 shows that the airframe accounts for 30 percent of the maintenance events, but only 5 percent of the maintenance cost of a typical Army helicopter. Comparison of these figures to those for large transport aircraft (Fig. 2.4.7) shows these numbers to be dependent on the specific system being designed. The sort of detailed breakdown in unscheduled maintenance events provided in Fig. 2.6.3 must be carried one step further in the identification of the causes of maintenance action.

2.7 R AND M EXPERIENCE WITH ROTOR BLADES

One of the most successful stories of improvements in R and M associated with composite application, is the substitution of composite for metal rotor blades on the H-46 Navy helicopter. Fig. 2.7.1 shows that the newly designed blade must be considered a "composite" of many different materials including metals, but the major factor in R and M improvement results from the reduction in fatigue cracking associated with the composite design. The new blade easily met all of the R and M objectives during the prototype and engineering verification phases (Fig. 2.7.2). The subsequent fleet experience through September 1982 shows a greater than ten fold improvement in mean time between failure and elimination of depot repair for this item (Fig. 2.7.3). A similar improvement was noted by a NASA evaluation of rotor blades in commercial use (Fig. 2.7.4).

2.8 DESIGNING FOR R AND M -THE ARMY BLACKHAWK

The Army (see Appendix A.6 and Fig. 2.8.1) has been conducting several studies aimed at definition of the critical R and M issues associated with specific helicopter components, assessing the ability of composite redesign to improve life cycle costs, and development of modular design concepts to reduce the time to repair battle damaged structure. Fig. 2.8.2 shows that the application of composites is not always cost effective (see transmission support data), and as noted earlier, the manufacturing costs dominate the life cycle cost for composites.

Fig. 2.8.3 illustrates several recommended design concepts which were established with improved R and M in mind. Implementation of these design changes results in a maintenance cost reduction of 40 percent with an increase in structural weight of 5.5 lbs. Fig. 2.8.4 shows that the estimated maintenance frequency is reduced by 50 percent and the flight maintenance cost is reduced by 40 percent with implementation of these design changes, while the average cost per repair actually increases due to elimination of nuisance type repairs.

Figs. 2.8.5 and 2.8.6 describe the concept of modular design of helicopter structure for large area damage repair. The costs of repair vs modular replacement are compared in Fig. 2.8.7. The costs of the replacement concept appear lower, but the cost of stocking and transport of the repair modules and the cost of transporting a depot repair team to the field were not factored into the analysis. The approach to R and M considerations in design and the conclusions reached by this study (Fig. 2.8.8) provide a framework for conducting the necessary tradeoffs between performance, manufacturing, and R and M costs in the design of new composite structures.

2.9 COMPOSITES FOR ARMORED GROUND VEHICLES

Composites have seen increasing use in aircraft because of the improved stiffness-and strength-to weight ratio of this class of material. In studies of armor conducted by both the Army and Marine Corps, composites have proven useful as protection against small arms fire (Figs. 2.9.1 and 2.9.2). For higher energy threats, steel or applique armor proves to be more effective. Thus the personnel carrier ground vehicles of less than 20 tons are most suitable for application of composites to provide a lighter vehicle with protection of crew equivalent to the current state-of-the-art.

A recent study sponsored by the National Research Council (Materials for Lightweight Military Combat Vehicles, NMAB Report 396, 1982) discusses the particularly severe operating environment of these vehicles. While substantial weight savings (Fig. 2.9.3) were projected, the study strongly recommended a much more detailed documentation of operating loads through improved data acquisition and analysis of field data. Without this information a realistic assessment of the R and M of such composite vehicles will not be possible.

2.10 INDUCED ENERGY IN ELECTRICAL COMPONENTS CAUSED BY LIGHTNING/EMI

The structural damage caused by lightning strike of graphite-epoxy structures has been relatively well studied in the past. However, the induced energy in wiring, avionics, and electrical equipment caused by swept strokes over a graphite-epoxy skin must be considered as well.

The structural skin and the internal electrical elements form two parallel paths for current transfer. Since graphite-epoxy has approximately 1000 times the resistivity of alumimum, more current will be carried by wiring, etc. below a graphite-epoxy skin than below an aluminum skin. This additional induced energy must be accounted for in establishing bonding, grounding, shielding, and redundancy requirements.

Several structural design approaches have been used to improve the current carrying capabilities of the composite skins. Aluminum screening with its fiberglass isolator provision to prevent corrosion, metal flame spray layers, and special metallized paints are examples of surface treatments that have been used.

2.11 CONCLUSIONS

The Structural Composites Working Group examined the potential usage of composites for aircraft, ships, and ground combat vehicles from the point of view of potential improvement in the R and M costs of the structure. These conclusions are presented in Figs. 2.10.1 to 2.10.3.

One of the benefits offered by composites is the enhanced survivability associated with the reduced radar signature of this materials. The committee did not examine this issue in any detail due to the level of classification attached to this topic. Suffice it to say that the survivability of systems provides another important driver for the expanded use of composite materials in the next generation defense systems.

Fig. 2.10.4 summarizes the results of the Committee's examination of composite technology and its ability to improve the R and M of aerospace systems. This section has documented the steady improvement in the R and M of composites as the technology has matured. It is evident from the most recent studies that a factor of 2 to 5 reduction in R and M costs can and has been attained when composites are designed with consideration of R and M in the initial design tradeoffs.

The existance of failure or damage modes specific to composites, such as delamination, have been pointed out in the discussion of light service evaluation programs. The issues of damage tolerance, repair methodology, inspection, and application of advanced materials or fabrication methods which provide higher toughness and use at higher temperatures were identified as topics which must be addressed if the R and M of structures is to experience the order of magnitude improvement which is its potential.

Some of the conclusions regarding this critical issues are presented in Figs. 2.10.5 to 2.10.7. This issues are addressed in more detail in the Section 3 sub-committee reports. These reports also provide a number of recommended actions which identify the agencies and costs of technology improvements needed to provide the order of magnitude improvment in structural R and M.

COMPOSITES DESIGN DRIVERS

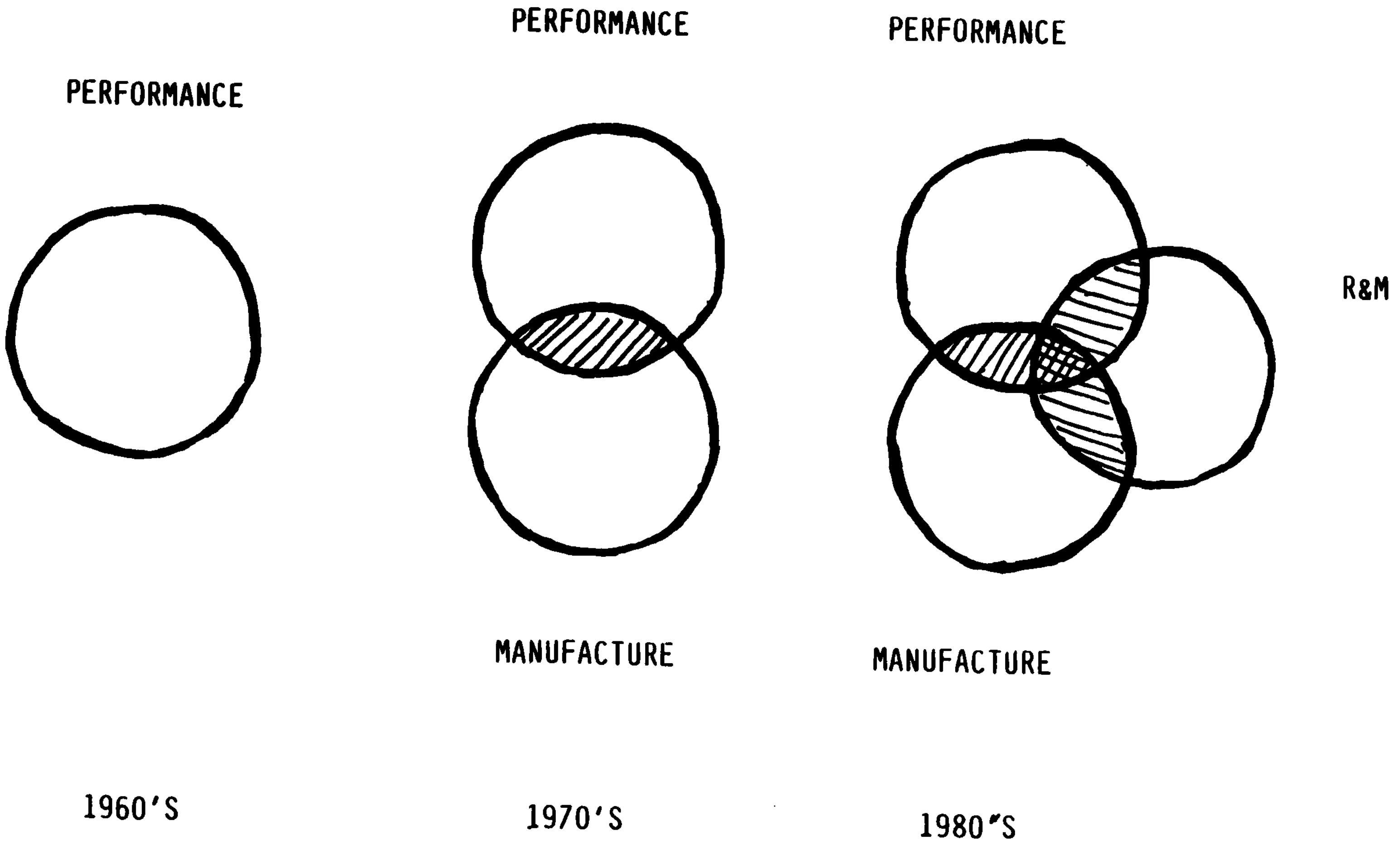


Figure 2.1.1

SUMMARY OF COMPOSITES UTILIZATION
USAF AIRCRAFT

CURRENT PRODUCTION	UTILIZATION	MATERIAL
F-16	• EMPENNAGE STRUCTURE • SPEED BRAKE	• BORON EPOXY/HONEYCOMB • GRAPHITE EPOXY HONEYCOMB
F-16	• EMPENNAGE STRUCTURE	• GRAPHITE EPOXY
F-111	• WING PIVOT DOUBLER • FAIRING	• BORON EPOXY • GRAPHITE EPOXY
PLANNED PRODUCTION		
B-1B	• FAIRINGS, FLAPS, SMC'S • VANES, WEAPONS BAY DOORS, ETC.	• GRAPHITE EPOXY
	• LONGERON DOUBLER	• BORON EPOXY
T-46	• SECONDARY STRUCTURE	• CHIEFLY KEVLAR
HH-60	• TAIL ROTOR BLADES • SECONDARY STRUCTURE	• GRAPHITE EPOXY • KEVLAR EPOXY
POTENTIAL		
C-17	• SECONDARY STRUCTURE; ELEVATORS	• KEVLAR EPOXY
	• RUDDERS, SPOILERS, WINGLETS	• GRAPHITE EPOXY
F-15E	• EMPENNAGE	• SAME AS F-15
F-16XL	• WING SKINS • VERTICAL	• BISMALEIMIDE/GRAPHITE • GRAPHITE EPOXY
F-20	• EMPENNAGE	• GRAPHITE EPOXY
FUTURE		
ATF	• WING/EMPENNAGE/FUSELAGE (CANDIDATES)	• UNKNOWN (SOME HIGH TEMP APPLICATIONS LIKELY)

Figure 2.2.1

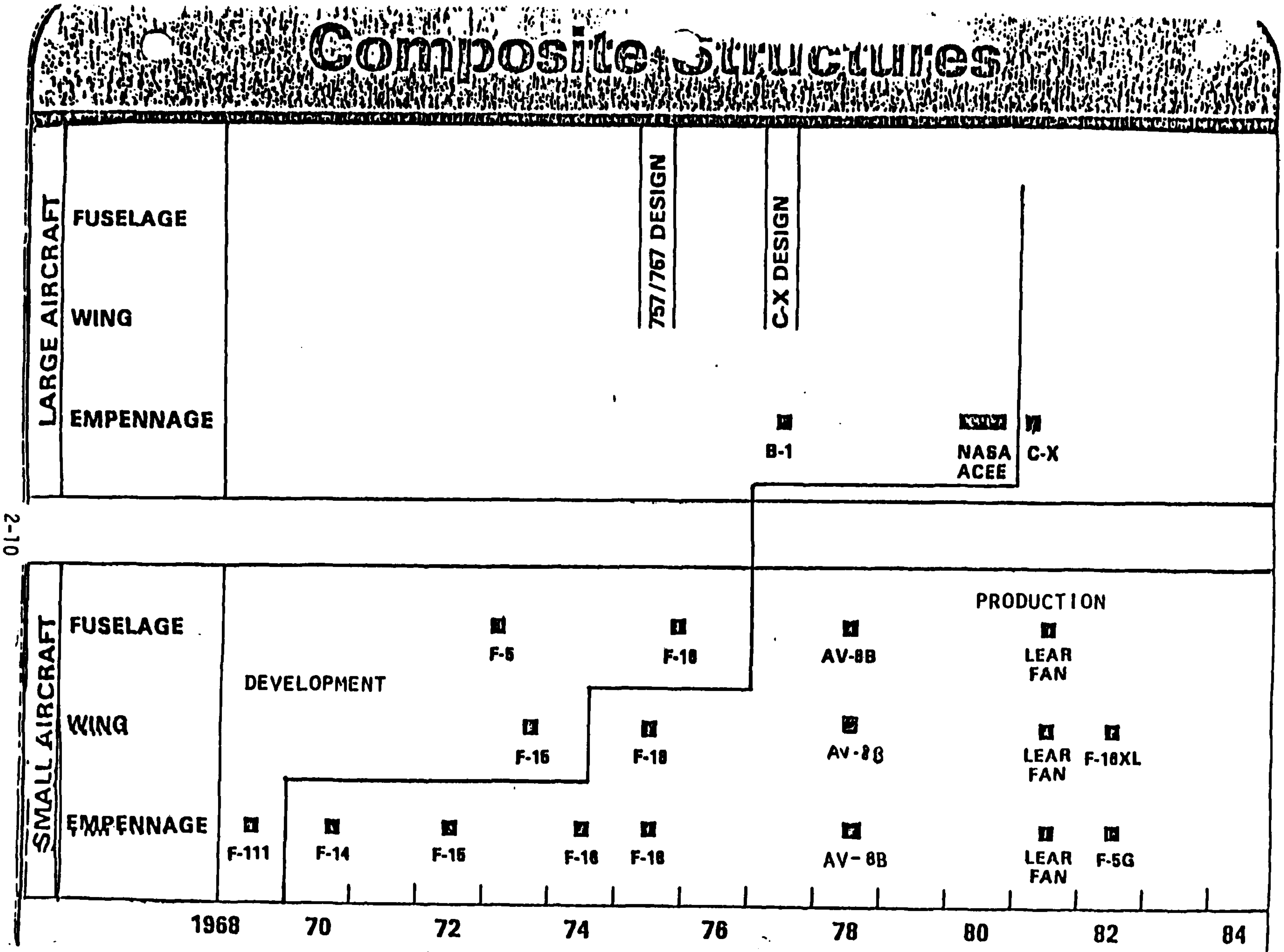

Composite Structures
LARGE AIRCRAFT
FUSELAGE
WING
EMPENNAGE
757/767 DESIGN
C-X DESIGN
B-1
NASA ACEE
C-X
SMALL AIRCRAFT
FUSELAGE
WING
EMPENNAGE
DEVELOPMENT
PRODUCTION
F-5
F-18
AV-8B
LEAR FAN
F-15
F-18
AV-8B
LEAR FAN
F-16XL
F-111
F-14
F-15
F-16
F-18
AV-8B
LEAR FAN
F-5G
1968
70
72
74
76
78
80
82
84

Figure 2.2.2

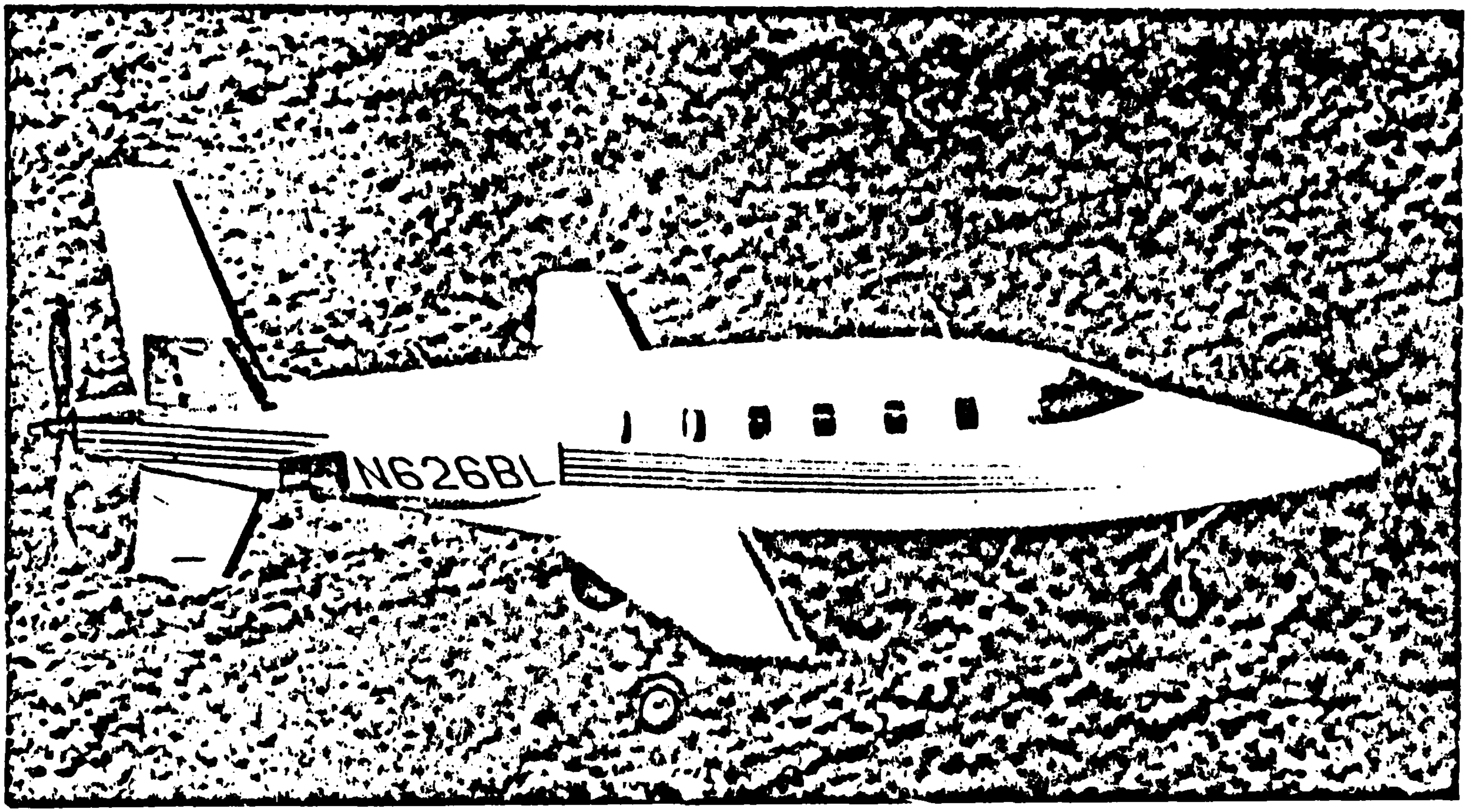


Figure 2.2.3

STRUCTURAL COMPOSITES IMPROVE MILITARY SYSTEMS

(ADVANCED (MACH 2.2) FIGHTERS)

PERFORMANCE IMPROVEMENTS RESULTING FROM REDUCED STRUCTURE WEIGHT FRACTION ENABLE

A. FEWER AIRCRAFT ARE NEEDED TO COUNTER A GIVEN THREAT

B. REDUCED PERSONNEL, TRAINING, FUEL, AMMUNITION, BASE RESOURCES

COMPOSITE STRUCTURES ELIMINATE CORROSION PROBLEMS THAT HAVE BEEN A MAJOR EXPENSE ITEM ON PREVIOUS SYSTEMS

COMPOSITE LAMINATES HAVE EXCELLENT DURABILITY (FATIGUE LIFE) AND EXTEND THE ALLOWABLE SERVICE LIFE OVER COMPARABLE STRENGTH-CRITICAL METAL STRUCTURE

SYSTEM READINESS, RELIABILITY, & MAINTENANCE ARE ENHANCED AT REDUCED LIFE CYCLE COSTS

Figure 2.2.4

HOW IMPORTANT IS RESISTANCE TO CORROSION?

- NBS STUDY IN 1970's INDICATED COST OF CORROSION IN FEDERAL SECTOR WAS $8 BILLION/YEAR
- ONLY 25% COULD BE AVOIDED BY PREVENTION PRACTICE
- REMAINDER REQUIRES MATERIAL SUBSTITUTION

Figure 2.2.5

FIII HORIZONTAL STABILIIZER LEADING EDGE

COST ANALYSIS

- COMPOSITE L/E 12% LESS ACQUISITION COST THAN Al LIE
- COMPOSITE L/E 14% LIGHTER THAN AL L/E
- MAINTENANCE COST OF AL L/E WAS 200% OF ACQUISITION COST
- MAINTENANCE COST OF COMPOSITE L/E ESTIMATED AT 28% OF ACQUISITION COST
- ROI ((SAV. - IMPLE.) / IMPLE.)=172%

Figure 2.2.6

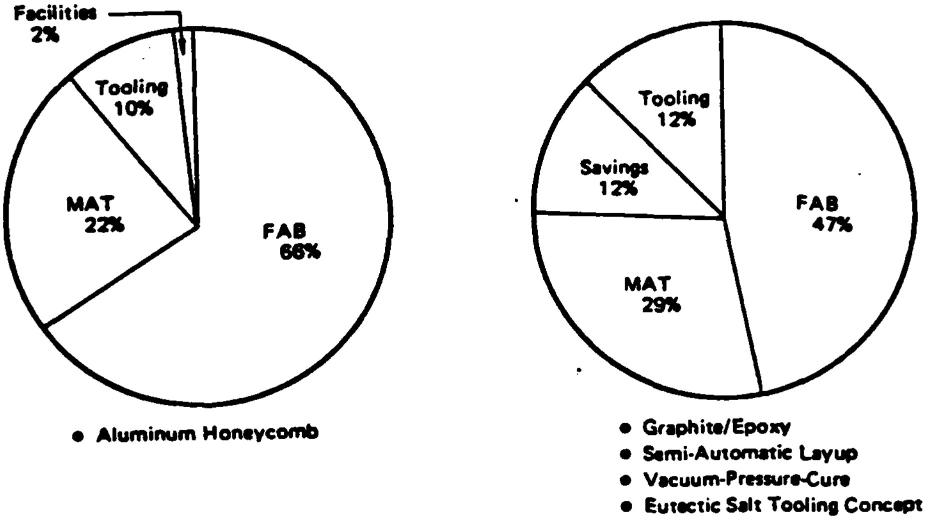


FIGURE E-9a: Acquisition cost comparison (based on cumulative average of 3 units).

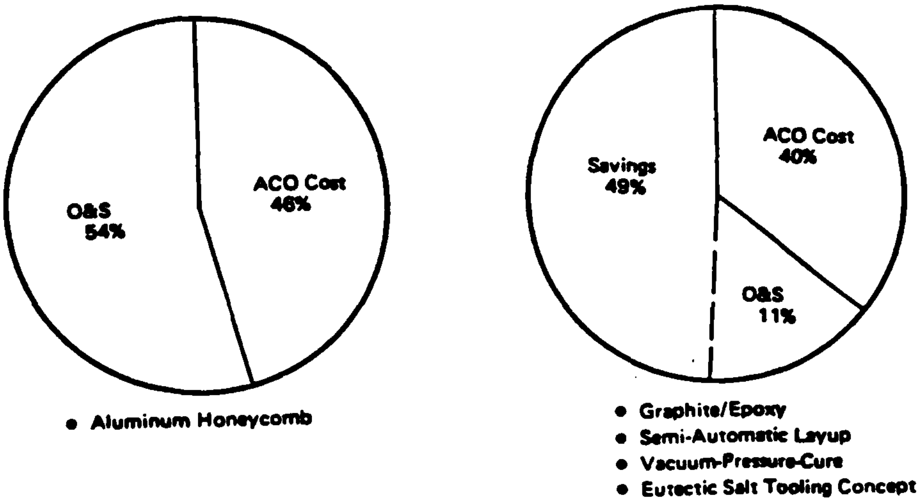


FIGURE E-9b: Life-cycle cost comparison (based on cumulative average of 3 units)

Figure 2.2.7

NASA SERVICE EXPERIENCE WITH COMPOSITE COMPONENTS ON AIRCRAFT

- FLIGHT SERVICE OF COMPOSITE COMPONENTS
  - TRANSPORT AIRCRAFT
  - HELICOPTERS
- ENVIRONMENTAL EFFECTS ON COMPOSITES
  - WORLDWIDE GROUND-BASED OUTDOOR EXPOSURE
  - FLIGHT EXPOSURE OF MATERIAL COUPONS
  - CONTROLLED LABORATORY EXPOSURE

Figure 2.3.1

NASA COMPOSITE STRUCTURES FLIGHT SERVICE SUMMARY

AIRCRAFT COMPONENT	TOTAL COMPONENTS	START OF FLIGHT SERVICE	CUMULATIVE FLIGHT HOURS	
			HIGH TIME AIRCRAFT	TOTAL COMPONENT
L-1011 FAIRING PANELS	18	JANUARY 1973	25 670	444 400
737 SPOILER	108	JULY 1973	26 200	1 830 390
C-130 CENTER WING BOX	2	OCTOBER 1974	6 250	12 310
DC-10 AFT PYLON SKIN	3	AUGUST 1975	21 450	60 500
DC-10 UPPER AFT RUDDER	13*	APRIL 1976	23 100	206 600
727 ELEVATOR	10	MARCH 1980	9 200	81 600
L-1011 AILERON	8	MARCH 1982	2 950	22 290
S-76 TAIL ROTORS AND HORIZONTAL STABILIZERS	14	FEBRUARY 1979	3 370	33 060
206L FAIRING, DOORS, AND VERTICAL FIN	144**	MARCH 1981	1 850	91 000
GRAND TOTAL	320			2 782 150

MARCH 1983

* 7 MORE RUDDERS TO BE INSTALLED

** 16 MORE COMPONENTS TO BE INSTALLED

B-737 SPOILER INSERVICE DAMAGE AND REPAIR

PROBLEM	NUMBER OF INCIDENTS	PERCENT OF TOTAL	CAUSE
BLISTER ABOVE CENTER HINGE FITTING	34	47	DESIGN
SPAR AND DOUBLER CORROSION	23	31	DESIGN/MFG.
MISCELLANEOUS CUTS AND DENTS	10	14	AIRLINE USE
TRAILING-EDGE DELAMINATION	6	8	ENVIRONMENT

Figure 2.3.3

NASA COMPOSITE COMPONENT INSPECTION AND MAINTENANCE RESULTS

COMPONENT	INSPECTION INTERVAL, months	INSPECTION METHODS	STATUS
L-1011 FAIRING PANELS	12	VISUAL	MINOR IMPACT DAMAGE, FIBER FRAYING AND HOLE ELONGATIONS
737 SPOILER	12	VISUAL ULTRASONIC	INFREQUENT MINOR DAMAGE REPAIRED AT BOEING
DC-10 AFT PYLON SKIN	12	VISUAL	ONE SKIN PANEL REMOVED DUE TO CORROSION
DC-10 UPPER AFT RUDDER	3, 12	VISUAL ULTRASONIC	MINOR RIB-TO-SKIN DISBOND ON TWO RUDDERS; MINOR LIGHTNING STRIKE ON THREE RUDDERS; GROUND HANDLING DAMAGE ON ONE RUDDER
727 ELEVATOR	13	VISUAL	MINOR LIGHTNING STRIKE ON TWO ELEVATORS; GROUND HANDLING DAMAGE ON TWO ELEVATORS

ESTIMATED REPAIR MANHOURS FOR B-737 PRODUCTION ALUMINUM AND GRAPHITE/EPOXY SPOILERS

-8.75 YEARS SERVICE-

SPOILER TYPE	TOTAL COMPONENT* FLIGHT HOURS	NUMBER OF SPOILERS REMOVED FOR REPAIR	TOTAL REPAIR** MAN-HOURS	FLIGHT HOURS PER MAN-HOUR OF REPAIR
PRODUCTION ALUMINUM	1,200,000	49	1000	1200
GRAPHITE/EPOXY REINFORCED ALUMINUM	1,830,000	73	1390	1317

*BASED ON 108 SPOILERS OF EACH TYPE

**DOES NOT INCLUDE MINOR REPAIRS ON COMPONENTS INSTALLED ON THE AIRCRAFT

Figure 2.3.5

CORROSION OF BOEING 737 GRAPHITE/EPOXY SPOILERS

PHASE 1

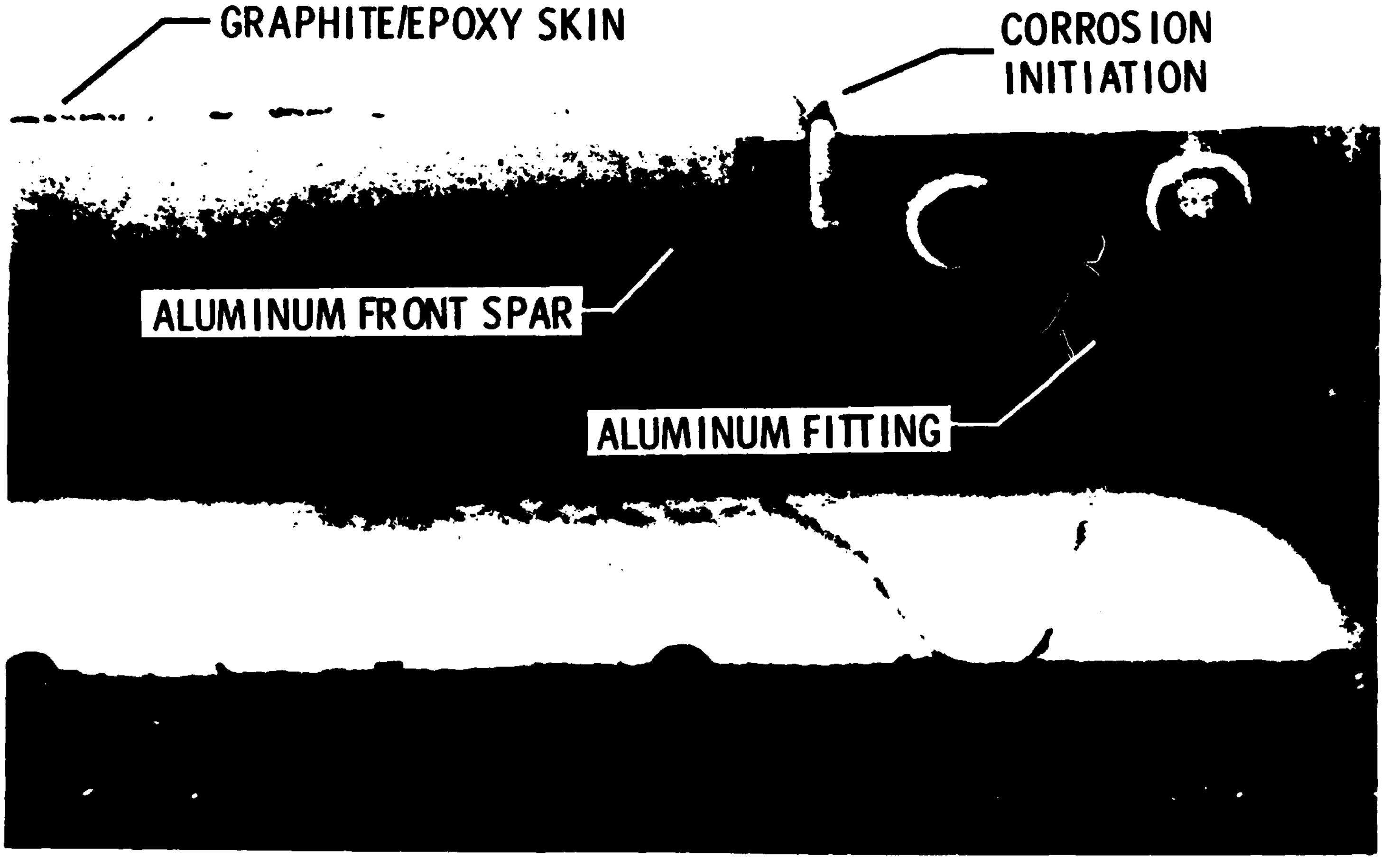
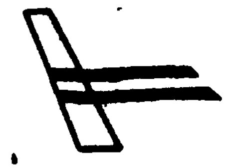


Figure 2.3.6

DC-10 COMPOSITE RUDDER
LIGHTNING DAMAGE



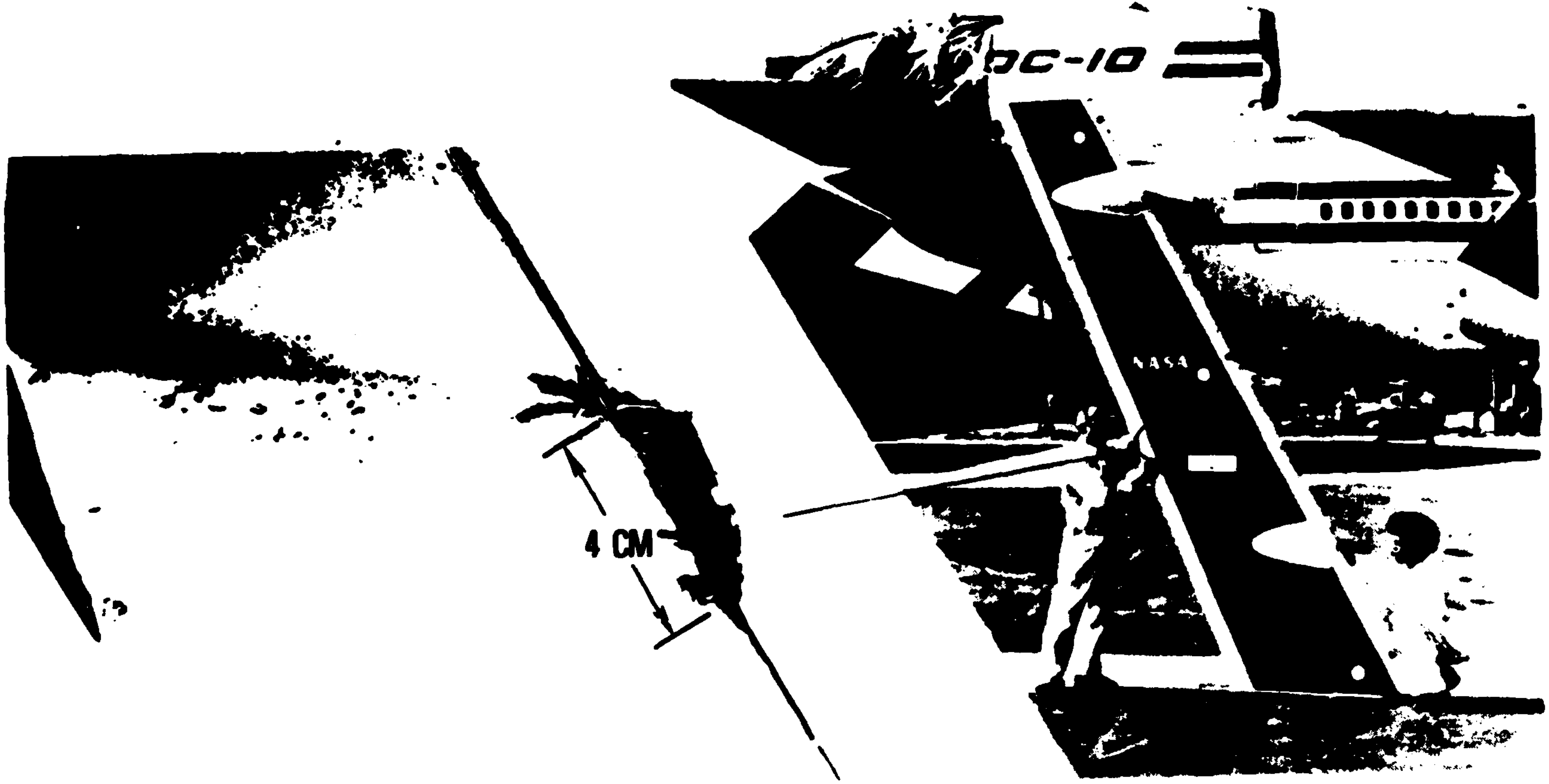


Figure 2.3.7


B-727 GRAPHITE/EPOXY ELEVATOR
GROUND HANDLING DAMAGE
TRAILING EDGE FRACTURE

Figure 2.3.8

MCAIR BORON & CARBON EPOXY

	F-15	F-18	AV-8B
% (WEIGHT)	1	10	28
POUNDS	231	1074	1371

663 DIFFERENT PARTS

91 ASSEMBLIES

RANGE - 2 OZ. RIB TO 260 LB. WING SKIN

FIGURE 2.4.1

OPERATIONAL EXPERIENCE

BASED ON: 782 F-15 EAGLES
640,000 FLIGHT HOURS

MEAN TIME BETWEEN MAINTENANCE ACTIONS
(PER COMPONENT)

RANGE	2260 FOR SPEEDBRAKE
	71430 FOR STABILATOR TORQUE BOX
AVERAGE	>10,000 OVERALL
	24,000 WITHOUT SPEEDBRAKE

COMPARABLE ALUMINUM COMPONENTS
12,000 AVERAGE

Figure 2.4.2

INSERVICE COMPARISON OF COMPOSITE
TO NON-COMPOSITE AIRCRAFT STRUCTURES
(MAY + OCT 82)
TAF BASES

GRAPHITE		ALUMINUM	
PART	MFTBF	PART	MFTBF
HORIZONTAL STABILIZER	4,796	LEADING EDGE FLAP	19,782
RUDDER, ASSY	10,550	FLAPERON ASSY	5,966
LEADING EDGE, VERTICAL STABILIZER	13,188	VENTRAL FIN	3,652

*TAF BASES - HILL, NELLIS, HAHN, KUSAN
TOTAL FLIGHT HOURS = 52,752 HRS. F-16

Figure 2.4.3

JANUARY 1981 - NOVEMBER 1982

PART	NUMBER OF FAILURES	HOW MALFUNCTIONED	MFTBF
SKINS - VERT. STABILIZER	2	DELAMINATED	41,630
LEADING EDGE - VERT. STAB.	4	BENT/BUCKLED	10,407
RUDDER, ASSY OF	11	DELAMINATED	3,784
SKINS - HORIZ. STABILIZER	5	BENT/BUCKLED	33,303
TRAILING EDGE - HORIZ. STAB.	8	BENT/BROKEN	10,407
HORIZ. STABILIZER, ASSY OF	37	BENT/BUCKLED	2,250

TOTAL NUMBER OF FLIGHT HOURS: 41,630 HOURS F-16

Figure 2.4.4

LOGISTICS COMMAND TECHNOLOGY

WARNER ROBBINS/ALC

C141 LEADING EDGES

- NINE AIRCRAFT FLYING WITH GRAPHITE/EPOXY LEADING EDGES

C141 PETAL DOOR

- GRAPHITE/KEVLAR HYBRID OUTER SKINS TO BE INSTALLED BY WR/ALC
- 30% ACQUISITION COST SAVINGS
- EXPECTED R&M COST SAVINGS DUE TO REDUCED CORROSION

Figure 2.4.5

C-141 Petal Door

COMPOSITE REPLACEMENT OUTER COVER

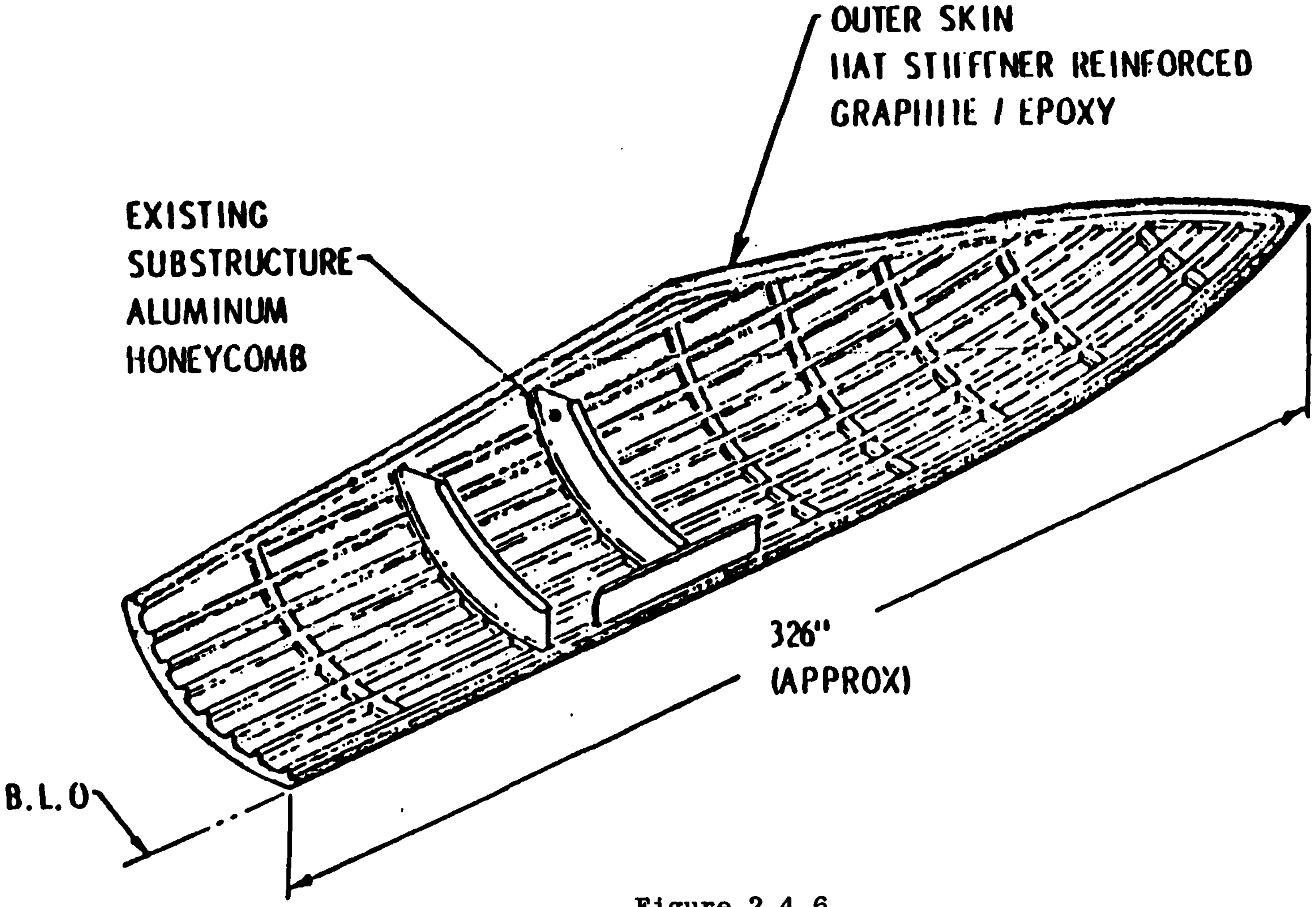


Figure 2.4.6

Lockheed

CONCLUSION

APPLICATION OF COMPOSITES TO LARGE AIR TRANSPORTS SAVES PRIMARILY

- ACQUISITION COSTS (THROUGH REDUCED FABRICATION COSTS)
- FUEL COSTS (THROUGH REDUCED WEIGHT)

CONSIDER COSTS FOR:

ACQUISITION	35%
FUEL	35%
OPERATION AND MAINTENANCE	30%
TOTAL LIFE CYCLE COST:	100%

CREW	50%
MAINTENANCE	50%
TOTAL O&M	100%

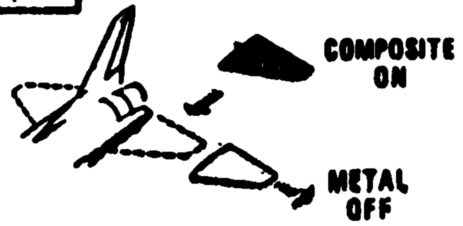
STRUCTURE	18%
OTHER	82%
TOTAL MAINTENANCE	100%

REDUCTION OF STRUCTURAL MAINTENANCE TO 25% OF CURRENT COST SAVES 2% OF LIFE CYCLE COSTS

Figure 2.4.7

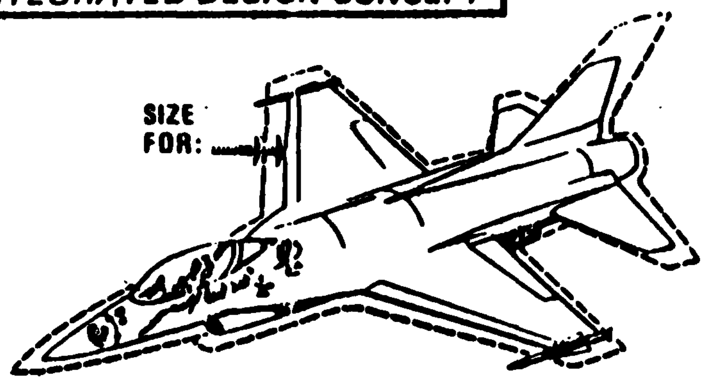
THE FULL BENEFIT – INTEGRATE COMPOSITES INTO TOTAL DESIGN

PAST APPROACH



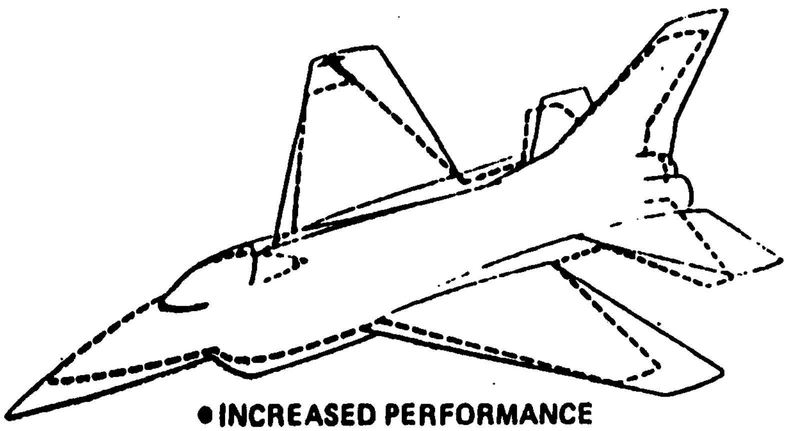
- "METAL REPLACEMENT" CONCEPT RESTRICTS THE COMPOSITES TO METAL REQUIREMENTS AND SIZE
- NO "FULL COMMITTMENT" TO COMPOSITES

INTEGRATED DESIGN CONCEPT

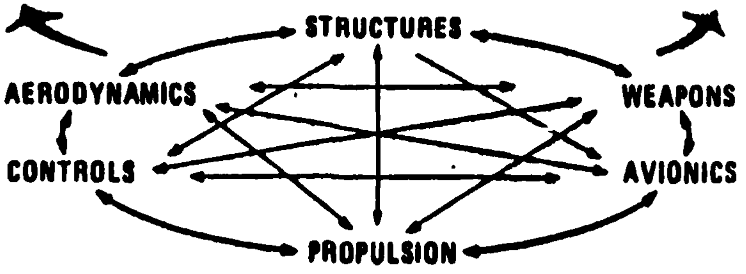


- EQUAL PERFORMANCE AND LESS COST

– OR –



- INCREASED PERFORMANCE FOR SAME WEIGHT



✔ MAX SYSTEM SYNERGISM

Figure 2.5.1

MCAIR COMPOSITE STRUCTURES DATA

REDUCED AIRCRAFT WEIGHT

- F-15: 1.5% COMPOSITES (231#) ~ 160# WEIGHT SAVINGS
- F-18: 10% COMPOSITES (1074#) ~ 500# WEIGHT SAVINGS
- AV-8B: 28% COMPOSITES (1371#) ~ 600# WEIGHT SAVINGS

ACQUISITION COSTS - COMPOSITES INCORPORATED

- AFTER INITIAL DESIGN - GREATER COST THAN METAL STRUCTURE
- DURING INITIAL DESIGN, SAME A/C SIZE - SAME COST THAN METAL STRUCTURE
- INITIAL DESIGN, SMALLER A/C SIZE - LESS COST THAN METAL STRUCTURE

REDUCED LIFE CYCLE AND MAINTENANCE COSTS

- 100# SAVED (FIGHTER) = 2 GAL/FLT-HR = $\$10\overline{M}$ FOR 1000 A/C
- 1000 FT^2 (NO CORROSION) = .5 M/HR/FLT-HR = $\$50\overline{M}$ FOR 1000 A/C

Figure 2.5.2

DESIGN/MANUFACTURING MATURITY

FULL-DEPTH HONEYCOMB - F-15 & F-18 EMPENNAGE

THICK, HIGH-LOADED MONOLITHIC SKINS - F-18 & AV-8B WINGS

CO-CURED, INTEGRALLY STIFFENED FUSELAGE PANEL - AV-8B

INTEGRATED SPARS & SKINS - AV-8B STABILATOR

Figure 2.5.3

TABLE 1. PERCENTAGE BREAKDOWN OF AIRFRAME UNSCHEDULED MAINTENANCE FOR TWO CURRENT-INVENTORY ARMY HELICOPTERS

	UH-1	CH-47
UNSCHEDULED MAINTENANCE EVENTS/ 1,000 FLIGHT-HOURS	242.4	536.1
AIRFRAME PERCENT OF TOTAL AIRCRAFT	31.4	37.3
PERCENT OF AIRFRAME		
SECONDARY STRUCTURE	84.7	80.8
PRIMARY STRUCTURE	15.3	19.2
PERCENT OF PRIMARY STRUCTURE		
SKIN	41.6	54.2
STRUCTURE	58.4	45.8
RIVETS/HARDWARE PERCENT OF TOTAL	50.0	38.3

COMPOSITES REDUCE THE NUMBER OF FASTENERS
(84% OF 40,000 FASTENERS ON L1011 VERTICAL FIN)

Figure 2.6.1

AIRFRAME SERVICE EXPERIENCE

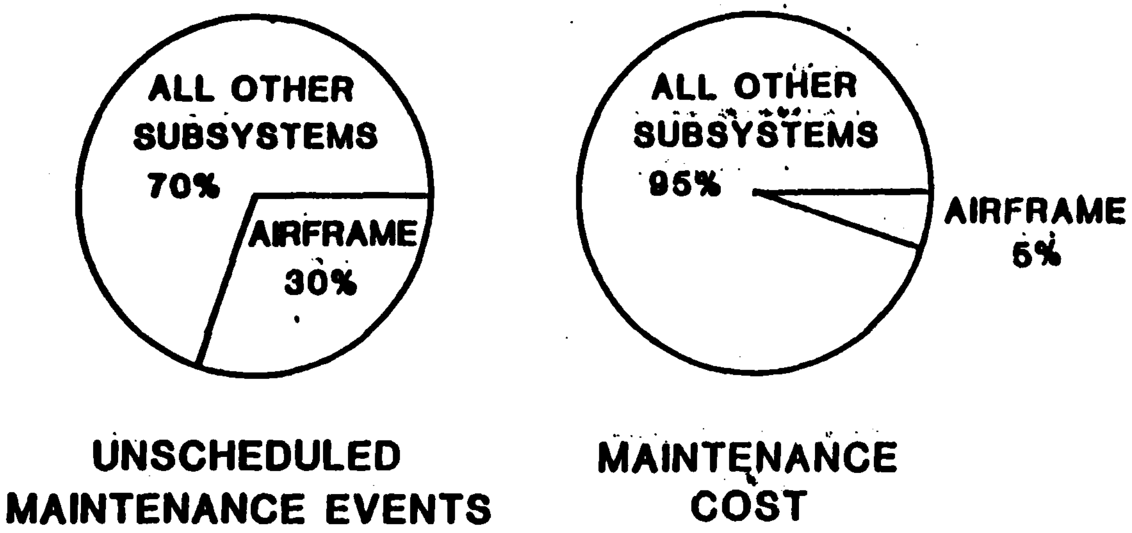


Figure 2.6.2

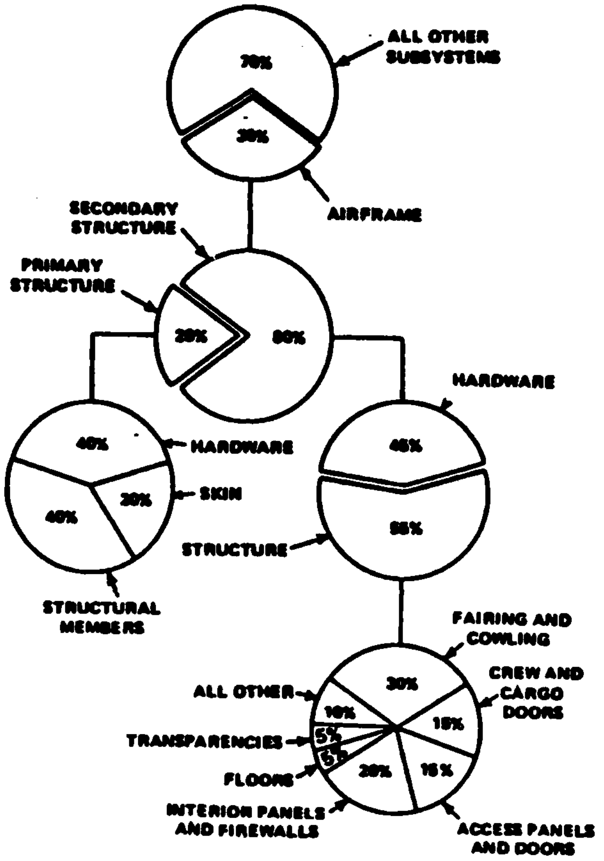
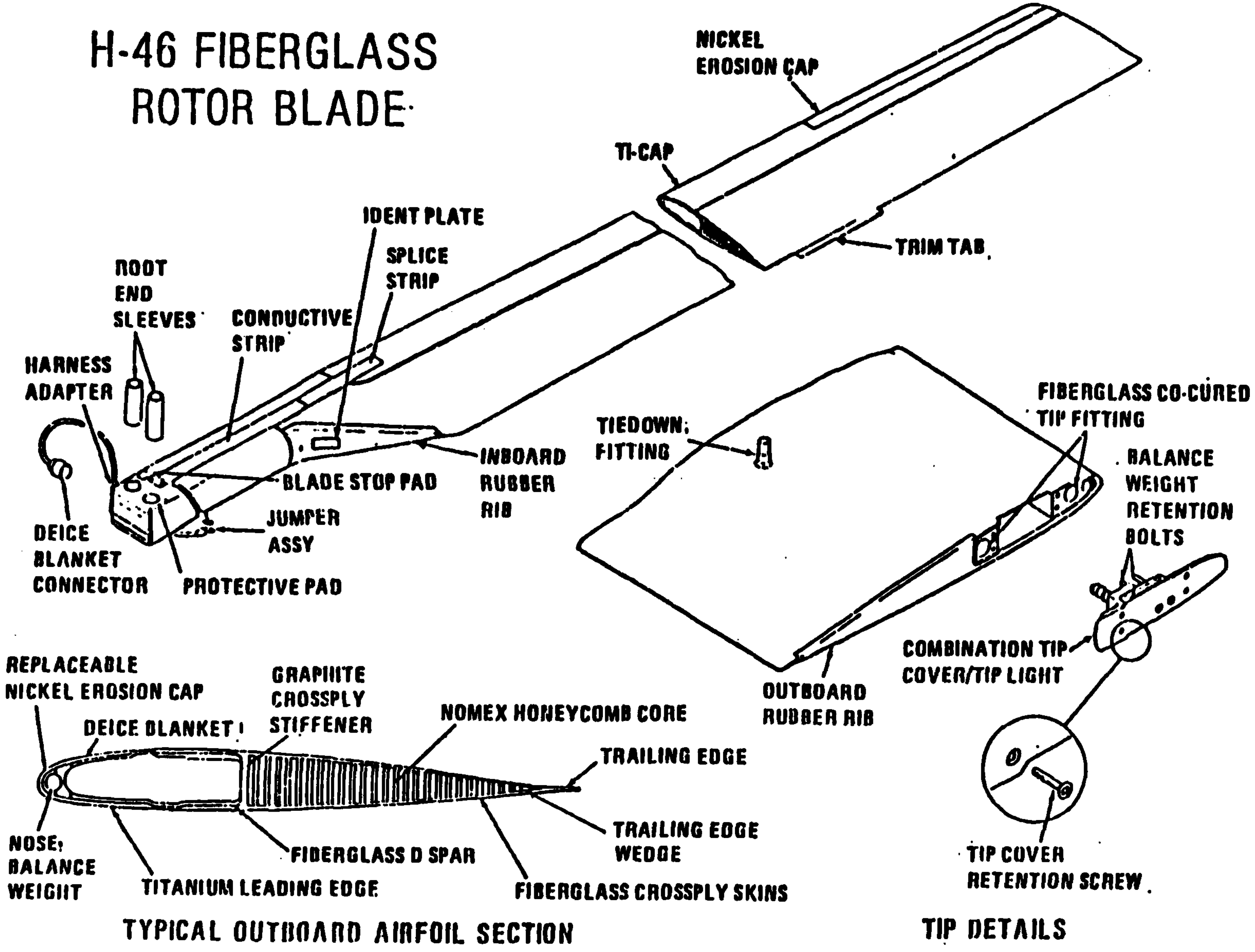


Figure 1. Representative Distribution of Unscheduled Maintenance Events for Current-Inventory Helicopters

Figure 2.6.3



TYPICAL OUTBOARD AIRFOIL SECTION

TIP DETAILS

Figure 2.7.1

Figure 1

H-46 FIBERGLASS ROTOR BLADES

	METAL BLADES	OBJECTIVES	R&M DEMO
MBFHBMA *	56	56	548
MBFHBRD *	464	2500	NO REMOVALS
MBFH3F *	280	280	666

* MEAN BLADE FLIGHT HOURS BETWEEN MAINTENANCE ACTIONS

* MEAN BLADE FLIGHT HOURS BETWEEN REMOVAL TO DEPOT

* MEAN BLADE FLIGHT HOURS BETWEEN FAILURE

Figure 2.7.2

H-46 FIBERGLASS ROTOR BLADES

	METAL BLADES	R&M DEMO	CUMULATIVE FLEET EXPERIENCE THROUGH 9/30/83	FLEET EXPERIENCE 6/79 - 5/80
TOTAL BLADE FLIGHT HOURS	---	18,000	506,800	64,000
MTBF *	280	666	>3,000	3,368
MTBR FOR DEPOT REPAIR	464	NONE	NONE	NONE
MAINTENANCE MANHOURS PER FLIGHT HOUR	0.96	---	0.13	---

* MEAN TIME BETWEEN FAILURE IS DEFINED AS UNSCHEDULED MAINTENANCE REGARDLESS OF EXTENT OR CAUSE EXCEPT FOR GROSS EXTERNAL CAUSES SUCH AS:

- BURNED UP IN FIRE
- HIT BY FORKLIFT
- DROPPED FROM TOP OF HELICOPTER
- TRACKING NOT CAUSES BY BLADE

Figure 2.7.3

BELL HELICOPTER EXPERIENCE

VH1	METAL BLADE	1562 FAILURES/10^6 FLIGHT HOURS
MOD 412	COMPOSITE BLADE	343 FAILURES/10^6 FLIGHT HOURS

Figure 2.7.4

UH-60A BLACK HAWK HELICOPTER ADVANCED COMPOSITE STRUCTURE REAR FUSELAGE R&M SUPPORT PROGRAM

PROGRAM OBJECTIVES

- DEFINE & RECOMMEND A COST-EFFECTIVE SET OF R&M DESIGN OPTIONS FOR THE COMPOSITE REAR FUSELAGE
  - DAMAGE TOLERANCE
  - DAMAGE MITIGATION
- DEVELOP REPAIR CONCEPTS
  - FIELD REPAIR
  - MODULAR DESIGN
- DEVELOP PRELIMINARY SERVICEABILITY CRITERIA
  - REPAIR
  - INSPECTION

SUMMARY OF ADVANCED DESIGN CONCEPTS R&M/COST ASSESSMENTS

STRUCTURE/EVALUATION FACTOR	COMPOSITE CONCEPT I	COMPOSITE CONCEPT II	METAL BASELINE
COCKPIT CANOPY			
WEIGHT (LBS.)	47	35	49
S/V*	+	+	BASE
MANUFACTURING COST	$4,600	$5,100	$5,200
LIFE-CYCLE COST DELTA**	-$3,232	-$2,620	---
STABILATOR			
WEIGHT (LBS.)	62	56	68
S/V	+	+	BASE
MANUFACTURING COST	$5,800	$6,600	$47,000
LIFE-CYCLE COST DELTA	-$4,040	-$3,620	---
REAR FUSELAGE			
WEIGHT (LBS.)	380	359	422
S/V	+	-	BASE
MANUFACTURING COST	$29,000	$55,000	$47,000
LIFE-CYCLE COST DELTA	-$19,356	+$12,248	---
TRANSMISSION SUPPORT			
WEIGHT (LBS.)	88	83	110
S/V	SAME	+	BASE
MANUFACTURING COST	$18,000	$19,500	$16,500
LIFE-CYCLE COST DELTA	+$ 1,490	+$ 3,010	---

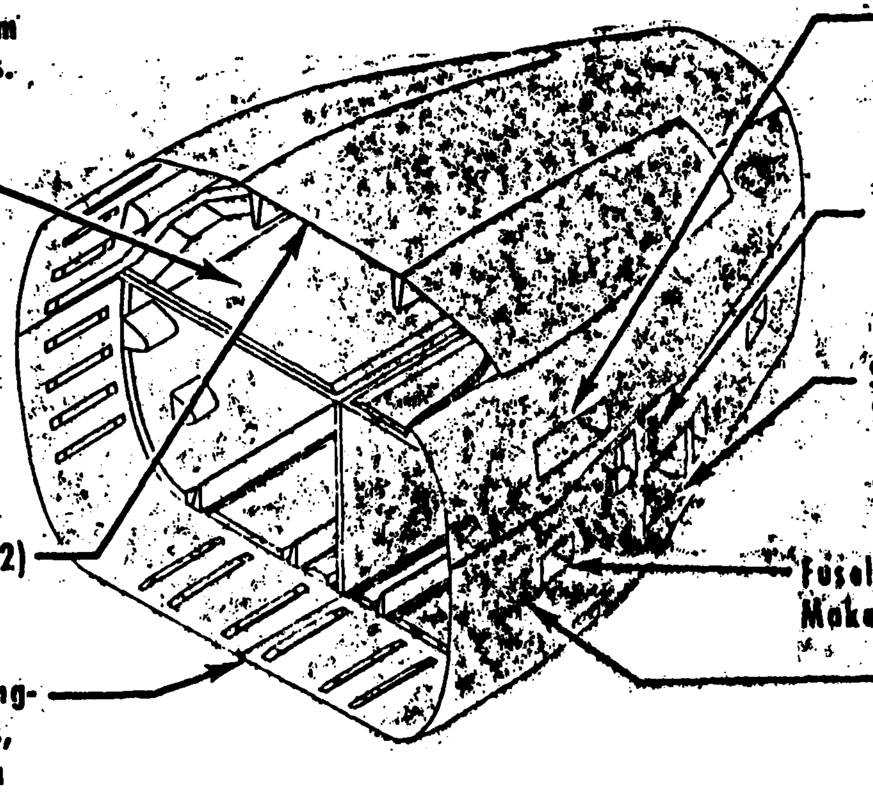
* SURVIVABILITY/VULNERABILITY RATING VERSUS BASELINE (+ = BETTER; - = POORER)

** ESTIMATED LIFE-CYCLE COST REDUCTION (-) OR INCREASE (+) RELATIVE TO BASELINE, PER AIRCRAFT

- COMPOSITES ARE NOT ALWAYS COST EFFECTIVE
- MANUFACTURING COSTS DOMINATE LIFE CYCLE COSTS FOR COMPOSITE STRUCTURE

Figure 2.8.2

KEY R&M DESIGN RECOMMENDATIONS



Fuel Cell Covers-Make From Nomex and 6 Plies E-Glass. Add Bonded Metal Grommets. (1)

Baggage Compartment Aft Bulkhead-Make From 4 Plies E-Glass, 4 Plies Woven Graphite. (2)

Underside Skin and Framing-Make from 6 Plies E-Glass, 8 Plies Woven Graphite in Cap Strips. (3)

Structure Surrounding Upper Fuselage Step-Increase to 7 Plies Kevlar. (4)

Ground Cable Receptacle-Add Plastic Grommet and Ground Jumper. (6)

Structure Surrounding Pressure Refueling Access Door-Make from Nomex and 8 Plies E-Glass. (5)

Fuselage Step Enclosures-Make from 6 Plies E-Glass. (4)

Structure Surrounding 2 Lower Fuselage Steps-Make from Nomex and 8 Plies E-Glass. (4)

---

(1) Improved tolerance to stowed baggage, dropped tools and parts, fastener damage.

(2) Improved tolerance to stowed baggage impact.

(3) Improved tolerance to impact with terrain objects.

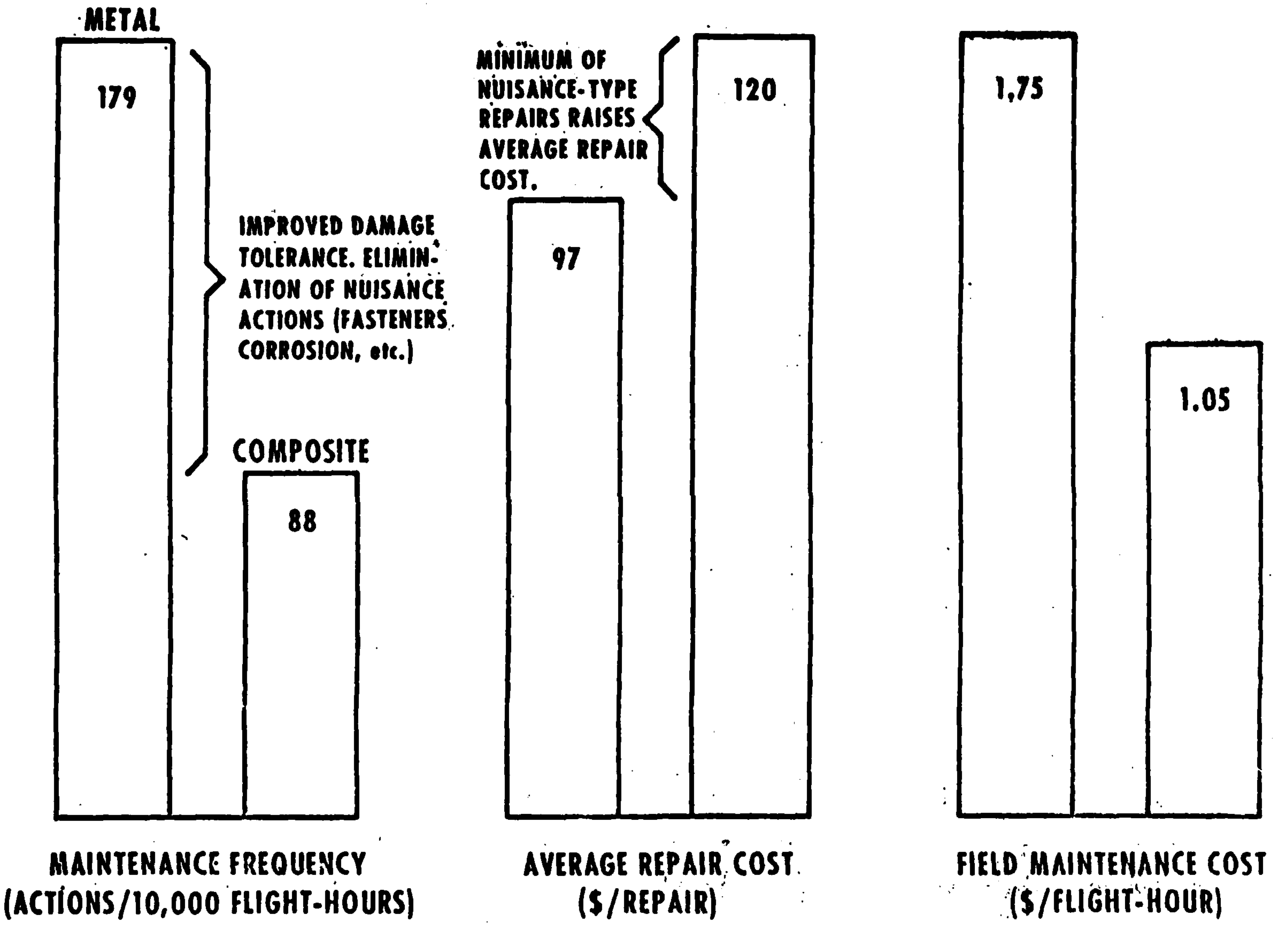
(4) Improved tolerance to boot impact.

(5) Improved tolerance to refueling nozzle impact.

(6) Improved tolerance to overstress due to cable snagging.

Figure 2 8.3

COMPOSITE VS. METAL ESTIMATED R&M COSTS



UH-60A BLACK HAWK HELICOPTER ADVANCED COMPOSITE STRUCTURE REAR FUSELAGE R&M SUPPORT PROGRAM

PROPOSED MODULAR DESIGN CONCEPT HIGHLIGHTS (LARGE AREA DAMAGE REPAIR)

- COMPOSITE REAR FUSELAGE SECTIONED INTO MODULES
- FIELD REPLACEABLE
- SIZED FOR ECONOMICAL DISCARD.
- REPLACEMENT ACCOMPLISHED VIA :
  - STANDARD SHEET METAL TECHNIQUES
  - AVERAGE SKILLS
  - COMMON HAND TOOLS / BULK MATERIALS
- QUALITY VERIFIABLE VIA VISUAL INSPECTION
- SMALL WEIGHT / COST PENALTY

Figure 2.8.5

MODULAR DESIGN CONCEPT

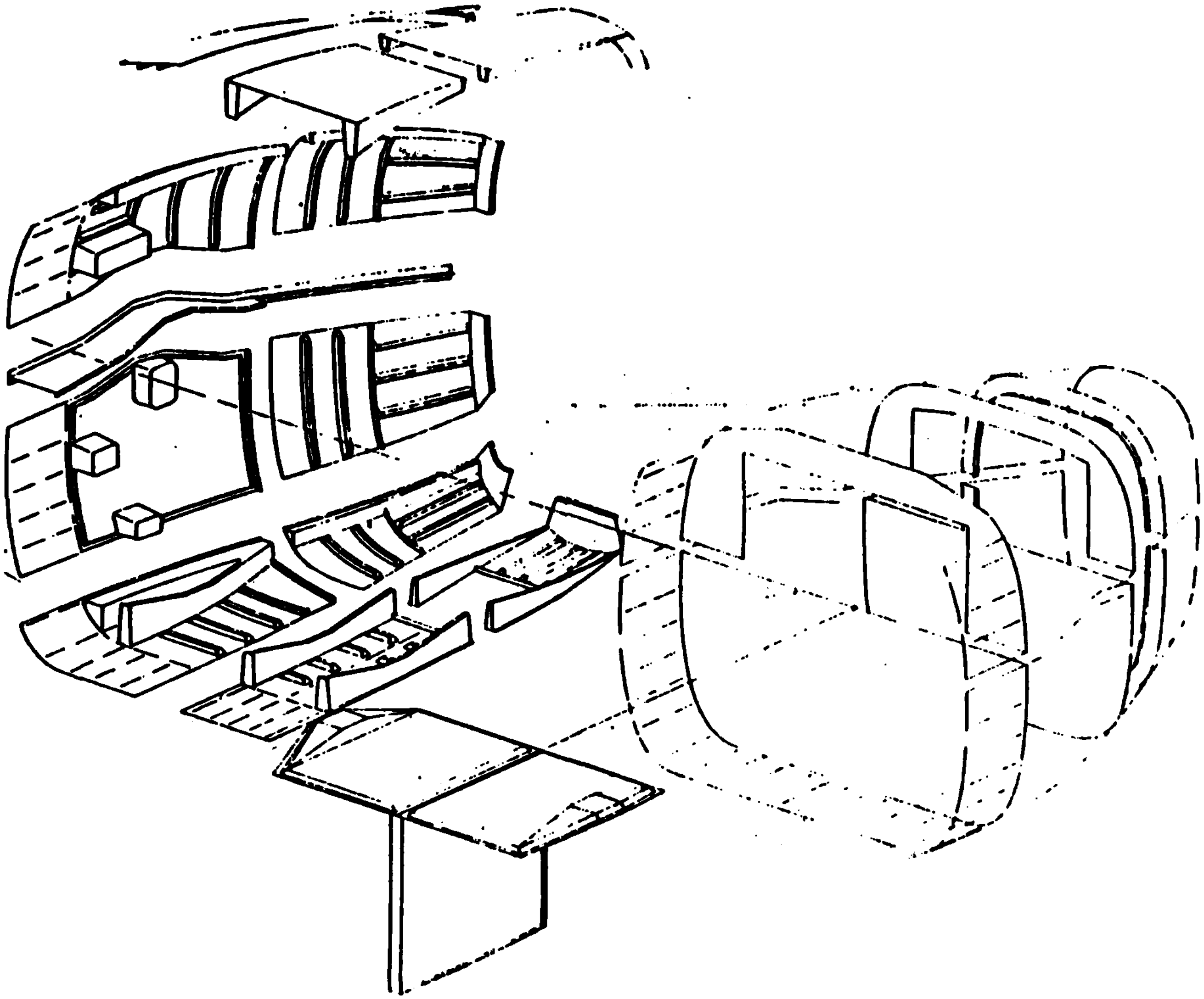


Figure 2.8.6

TABLE 3. ESTIMATED COSTS OF CUSTOM-ENGINEERED REPAIRS AND MODULE REPLACEMENT FOR REPAIR OF LARGE AREA STRUCTURAL DAMAGE.

	LABOR	MATERIALS	TOTAL	
CUSTOM-ENGINEERED METAL REPAIR	$4,985	$15	$5,000	PLUS THE COST OF DISPATCHING A REPAIR TEAM FROM THE DEPOT OR TRANSPORTING THE AIRCRAFT TO THE DEPOT.
CUSTOM-ENGINEERED COMPOSITE REPAIR	$2,925	$155	$3,080	
MODULE REPLACEMENT	$450	$1,935	$2,385	PLUS THE COST OF STOCKING MODULES AND TRANSPORTING THEM TO THE FIELD.

MODULAR DESIGN GIVES R&M COST SAVINGS

Figure 2.8.7

UH-60A BLACK HAWK HELICOPTER
ADVANCED COMPOSITE STRUCTURE
REAR FUSELAGE R&M SUPPORT PROGRAM

MAJOR CONCLUSIONS

- R&M ENHANCED VIA SELECTED DESIGN OPTIONS
- ESTIMATED FIELD MAINTENANCE COST 40% LOWER THAN METAL
- MODULAR DESIGN IS FEASIBLE AND COST EFFECTIVE
  - FOR PEACETIME
  - FOR COMBAT

TABLE IV-5 Armor Weight Reduction for LVTP-7

Protection	Materials	% Weight Reduction
Equal to Existing Aluminum Vehicle*	GRP** + KRP*** and Steel/GRP + KRP	33
Increased Projection (1) Defeat 14.5-mm Steel Core AP	Alumina/GRP + KRP	15
(2) Defeat 14.5-mm Tungsten Carbide Core AP	Steel/Alumina/GRP + KRP (Spaced System)	0

*Partial protection against 12.7-mm AP
**GRP = glass-reinforced plastic
***KRP = Kevlar-reinforced plastic

Figure 2.9.1

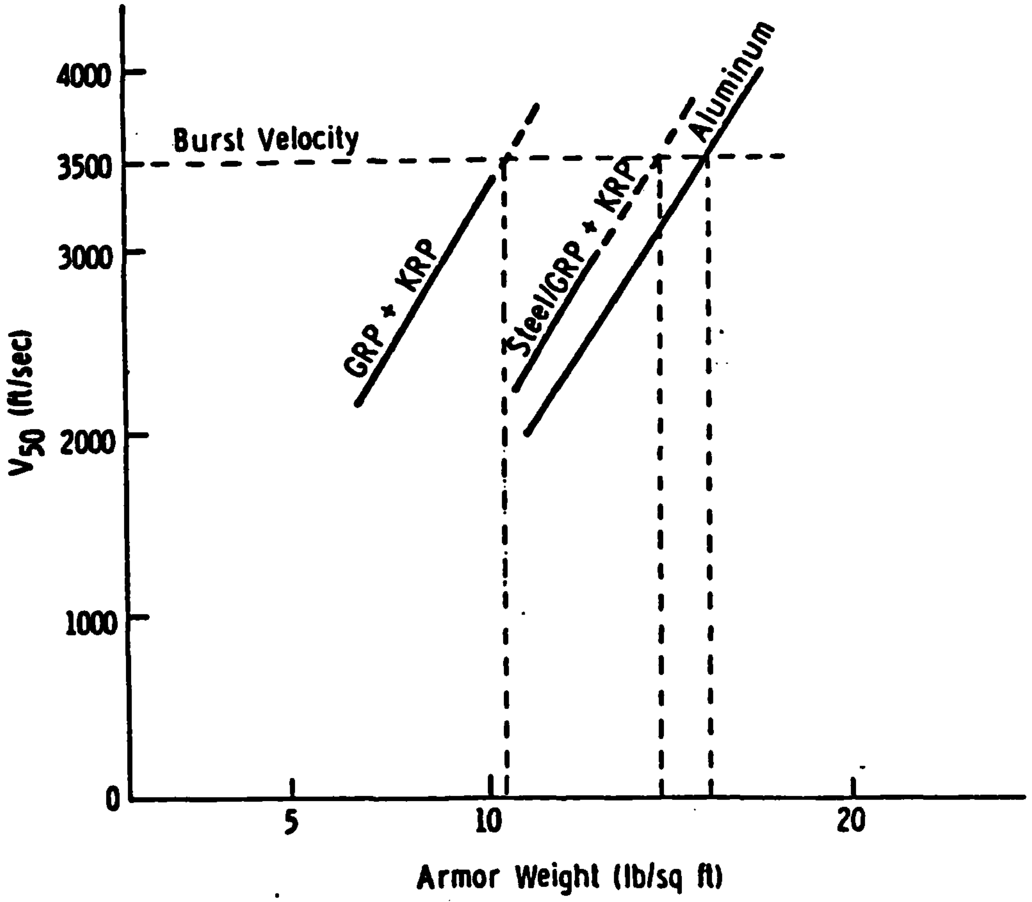


FIGURE IV-5: V_{50} ballistic limit velocities for vehicle hull materials 207-grain fragment-simulating projectile, 0° obliquity

Figure 2.9.2

TABLE IV-7: Weight Savings Possible on a Vehicle of M2 Size

Component	Current Wt (lb)	Potential Wt Savings (lb)	Most Attractive New Material	Critical Properties	Predicted Probability of Success
Hull plate	7642	1900-2300 (25-30%)	gr/gl/ar/ pe or ep	durability, fatigue fracture	excellent
Hull Assy	5472	1100-1350 (20-25%)			
Bolt-on Armor	3224	950-1150 (30-35%)	st/gl/ar/ pe or ep	ballistic resistance	excellent
Turret	1995	200-300 (10-15%)	gl/ar/pe or ep, st/gl/ar/ pe or ep	ballistic resistance	good
			SiC/Al		fair
Track Shoes	4616	800-1000	Al	toughness, fatigue, corrosivity	excellent
Torsion Bars	742	300-350	gr/gl ep or pe	fatigue	good
Road Wheels	1599	150-200	chopped gl/pe	environmental durability, fatigue	good

TOTAL: 5400-6650, or 13-16% of vehicle air-drop weight

gr = graphite fiber
gl = glass fiber
ar = aramid fiber
st = steel cladding
pe = polyester matrix
ep = epoxy matrix

Figure 2.9.3

ADVANCED V/STOL AIRCRAFT

BENEFITS ASSOCIATED WITH COMPOSITES

- REDUCED WEIGHT, 25% LESS THAN CURRENT COMPOSITE STRUCTURE, 50-60% USAGE
- APPLICATION OF NEW HIGH TEMPERATURE COMPOSITE & METAL-MATRIX MATERIALS EXTENDS OPERATING TEMPERATURE RANGE
- REDUCED AIRCRAFT SIGNATURE (RADAR, IR)
- IMPROVED FATIGUE LIFE/DAMAGE TOLERANCE
- REDUCED CORROSION MAINTENANCE
- IMPROVED SURVIVABILITY & CRASHWORTHINESS
- REDUCED COST USING ADVANCED FABRICATION METHODS

Figure 2.10.1

ADVANCED SHIP STRUCTURES

BENEFITS ASSOCIATED WITH COMPOSITES

- NON-MAGNETIC PROPERTIES FOR MINE-SWEEPER SHIP HULLS
- REDUCED WEIGHT TOPSIDE STRUCTURES
- REDUCED SIGNATURE/SONAR APPLICATIONS
- REDUCED CORROSION MAINTENANCE
- IMPROVED FATIGUE LIFE/DYNAMIC LOAD RESPONSE
- REDUCED COST USING ADVANCED FABRICATION METHODS

Figure 2.10.2

ADVANCED ARMORED FIGHTING VEHICLES

BENEFITS ASSOCIATED WITH COMPOSITES

- IMPROVED ARMOR FOR SMALL ARMS FIRE PROTECTION
- 25-30% WEIGHT REDUCTION IN HULL
- 10-15% WEIGHT REDUCTION IN TURRET ASSY
- 30-35% WEIGHT REDUCTION IN BOLT-ON ARMOR PLATE
- 13-16% WEIGHT REDUCTION IN AIR DROP WEIGHT
- REDUCED RADAR SIGNATURE
- REDUCED COST OVER ALUMINUM STRUCTURES IF AUTOMATED FABRICATION METHODS EMPLOYED
- INCREASED READINESS THROUGH DOWNSIZING AND REDUCED FLY WEIGHT

Figure 2.10.3

STATEMENT OF WORK REVISITED

CONCLUSIONS

COMPOSITES WILL ACCOUNT FOR 40-50% OF STRUCTURAL WEIGHT OF ALL FUTURE AIRCRAFT BECAUSE OF THE FOLLOWING ADVANTAGES:

- STIFFNESS-AND STRENGTH-TO-WEIGHT RATIO
- RAS/RAM CONSIDERATIONS
- ARMOR USE
- ACQUISITION COST REDUCTION
- R&M COST REDUCTION
  - CORROSION RESISTANCE
  - FATIGUE RESISTANCE
  - FACTOR OF 2 TO 5 REDUCTION IN STRUCTURAL MAINTENANCE BY PROPER DESIGN

Figure 2.10.4

DURABILITY/DAMAGE TOLERANCE

- FATIGUE LIFE IS PREDICTABLE
- COMPOSITES ARE STATIC STRENGTH CRITICAL
    - FATIGUE NOT LIKELY
- CURRENT NDE WILL CATCH MANUFACTURING DEFECTS THAT COULD GROW
- MAINTENANCE ACTIONS WILL BE RESULT OF DESIGN DEFECTS OR DAMAGE

Figure 2.10.5

BARRIERS TO APPLICATION OF COMPOSITES FOR IMPROVED R&M

- TRAINING OF R&M PERSONNEL & ADEQUETE SUPPORT FACILITIES & EQUIPMENT
- INSPECTION METHODS, DAMAGE ASSESSMENT, FAILURE ANALYSIS & REPAIR METHODS FOR FIELD & DEPOT LEVELS
- ADVANCED DESIGN METHODS WHICH INCLUDE DAMAGE TOLERANCE & R&M AS DRIVERS
- TECHNOLOGY DEVELOPMENT IN:
  - AUTOMATED MANUFACTURING/QC
  - LARGE SCALE NDE/DAMAGE ASSESSMENT
  - IMPROVED MATERIALS METHODS FOR REPAIR
  - ANALYTICAL METHODS FOR LIFE PREDICTION, CERTIFICATION & FAILURE ANALYSIS

Figure 2.10.6

ADVANCED STRUCTURES MAINTENANCE CONCEPTS

NDI LIMITATIONS AND CONSTRAINTS

- LACK OF INFORMATION ON INFLUENCE OF DEFECT ON STRUCTURAL INTEGRITY - UNCERTAIN WHAT NEEDS TO BE MEASURED
- FLAW DETECTION SENSITIVITY AND RESOLUTION IMPROVEMENT NOT NECESSARY
- INTERPRETATION OF NDI RESULTS DIFFICULT AND AMBIGUOUS BECAUSE OF LACK OF REFERENCE STANDARDS
- NDI METHODS NOT SUFFICIENTLY DEVELOPED FOR FIELD USE
- NEED TO UPGRADE ULTRASONIC AND RADIOGRAPHIC METHODS NOW IN USE (REF SRI RPT NO. TR-79-24)
- RADIOGRAPHIC METHOD LIMITED TO DEPOT LEVEL

Figure 2.10.7

SECTION 3

SUB-COMMITTEE REPORTS AND RECOMMENDED ACTIONS FOR COMPOSITE R&M

SECTION 3.0 SUMMARY OF RECOMMENDED ACTIONS

The Composite Working Group Sub-committees on Design, Damage Tolerance, Repair, NDE, and Materials each developed a list of detailed action plans for Improved R&M. In this section the sub-committee reports summarizing the issues and recommended actions are presented. During a discussion session of the entire Working Group, the individual recommendations were grouped into several categories according to the type of action. These categories were:

(1) DOD directive
(2) Policy changes
(3) System specific actions
(4) 6.3 and above technology programs
(5) 6.1/6.2 R&D programs

The recommended actions were then ranked in order of importance by Working Group members.

The ranked actions are presented in Table 3.1 according to category and referenced to detailed descriptions of the actions in each of the sub-committee reports.Some of the actions are referenced to more than one location in the sub-committee reports.

TABLE 3.1

RANKING OF RECOMMENDED COMPOSITE R&M ACTIONS

CATEGORY	WEIGHTED RANK(1-10)	PRIORITY	REFERENCES	ACTION
DOD DIR.	1	HIGHEST	D1.1,R9, N6	Review present R&M data collection. Improve feedback of lessons learned. Develop Service-wide data handling, recovery, and interpretation procedures
POLICY	2.8	HIGHEST	D1.2	Develop specifications with R&M requirements
POLICY	3.7	HIGH	D2,M1.2	Provide incentives for improved R&M in design
POLICY	4.8	HIGH	R5.2,R8, N8	Train field and depot personnel in composite repair and maintenance
POLICY	7.2	MEDIUM	R6.2	Require contractor validation of repair and durability
POLICY	8.5	LOWER	R10	Improve procurement procedures for acquisition of SOA repair equip.
POLICY	10	LOWEST	N1	Establish standard chemical nomenclature for organic matrices
SYSTEM	1	HIGHEST	R2	Develop design guidelines for repair
SYSTEM	10	LOWER	N2,M3	Develop in-process and inspection specifications
6.3	2.2	HIGHEST	D3	Design for damage tolerance and interchangeability
6.3	3.2	HIGH	D4,T3	Design for visual inspectability through improved damage tolerance assessment procedures

6.3	4.1	HIGH	T2	Develop battle damage containment designs
6.3	5.2	MEDIUM	R1.2	Develop procedures for rapid, battle damage-bolted repair
6.3	5.7	MEDIUM	M1.2	Develop manufacturing methods for through-thickness reinforcement
6.3	6.7	MEDIUM	N4	Develop portable, automated NDE methods for large composite struc.
6.3	7.6	LOWER	R3.1	Quantify moisture effects on repair bond strength
6.3	7.7	LOWER	R5.1	Evaluate bolted repair integrity
6.3	7.7	LOWER	R6.1	Determine durability of bonded repair

6.1/6.2	2.5	HIGHEST	T1,M1.1	Develop tough organic matrices
6.1/6.2	2.8	HIGH	R1.1	Develop rapid cure, long term storage adhesives for repair
6.1/6.2	3.7	HIGH	N5	Support new and emerging NDE methods for composites
6.1/6.2	4.0	MEDIUM	R7,M4	Develop room temp. stored adhesives with hot, wet performance
6.1/6.2	4.3	MEDIUM	N3	Develop portable NDE measure of bond strength in field
6.1/6.2	4.6	MEDIUM	M6	Characterize new classes of metal ceramic matrix composites for processing and service R&M
6.1/6.2	6.4	LOWER	R3.2	Develop means to measure moisture content in field prior to repair
6.1/6.2	6.5	LOWER	N7	Develop NDE systems to assess quality of repaired structure
6.1/6.2	7.5	LOWER	R4,M5.2	Develop repair procedures for new organic, metal, and ceramic matrices
6.1/6.2	7.5	LOWER	M2	Fully characterize newer organic systems for aging and durability
6.1/6.2	8.2	LOWEST	M5.1	Improve understanding of toughness mechanisms in metal matrix comp.

3.1 DESIGN SUB-COMMITTEE REPORT

3.1.1 Executive Summary

The quantification of the R&M performance of composite structures through maintenance record data was considered to be of first priority, in order to more clearly identify the effort required to repair composite structures for a given damage type. This quantification would also define the payoff, in man hours, dollars, and fleet readiness, for all aspects of R&M. This quantification, lacking in the past, will permit an assessment of the relative importance of R&M as compared to weight savings or performance improvement for vehicle design trade off studies.

The transformation of the composites R&M data into system specification requirement, the second priority item, was viewed by the group as the only workable mechanism to have R&M requirements considered in vehicle initial design as a trade off with performance, weight savings, and other design parameters. The maintenence record data would be used to establish R&M specification requirements; further, the type of inservice repair requirements will provide visibility for establishing satisfactory analysis or test approaches designed to verify the meeting of specification requirements. Contractors will consider R&M aspects when it is introduced as a design requirement with quantifiable levels in system requirements to be traded with other design/performance requirements. Such considerations by the contractor should carry the same incentives as do the performance considerations.

The third priority item, development of survivability/damage tolerant design approaches, was identified to support improved R&M performance of composite structures. Techniques to improve the translaminar strength of laminated composite materials was a main consideration; however, lightning and ballistic damage was also included in this group. Several approaches, such as stitching, 3 dimentional braiding, and micro fiber reinforcement, have been demonstrated to provide improvement. However, suitable analysis approaches to support these techniques are not available, especially in the area of proven damage containment under a variety of loading and environmental conditions.

The fourth priority item is that composite designs should require on visual inspection for flight readiness. Visible damage of realistic sizes should not result in catastrophic failure during an identifiable limited quantity of flights.

3.1.2 Discussion of Issues

1. Improve present field and depot maintanence data collection systems to develop an adequate data collection system that provides feedback of maintenance records for composite structures and lessons learned.

The issue is that explicit R&M requirements or need for improvements can not presently be defined because there is currently no adequate mechanism or pipeline by which the service behavior of different types of structural materials and construction approaches can be determined or directly applied in establishing the reliability and maintenance requirements in specifications for future systems. This lack of service information for use at the conceptual and preliminary design level is preventing proper emphasis on composite structures R&M where improvement is needed or desired. Having this data available during a new system conceptual definition phase is the only way to a major impact on the eventual life cycle costs of a system. The data shall be developed into a specification or procurement document that can clearly quantify or weigh R&M factors for trade offs against performance criteria. In addition, methods and procedures to fully test, evaluate and verify the R&M factors of the design must be developed and included in the specifications.

The amount of data to be stored and analyzed requires a computerized data bank which can be tapped to provide operations and maintenance hours/costs for all types of structural repairs. Such a data bank would facilitate the training of designers and provide the necessary back up information to better market the need for good supportability practices such as standardization, ease of removal,good accessability and interchangeability. The data bank would also support the Government contractor teams for follow up, find and fix function recommended by the Defense Science Board. In addition, the availability of this data would help establish an incentive procurement approach that is based on establishing specifications for readiness goals.

2. Give R&M greater emphasis in the procurement process (monetary incentives for R&M)

Weapon system contractors should be clearly told the relative importance of better R&M features in their products. The current practices emphasize performance that is somewhat controlled by weight. The emphasis on R&M should be included in the Work Statement of RFP's, as well as in RFP evaluation criteria with similar incentives to the contractor as provided for performance. Optimization for minumum weight, without adequate regard for R&M, results in reduced readiness. Explicit quantified R&M requirements should be included in the system specification. Factors to be addressed are: repair concept definition, specific repair development (including battle damage), and adoption of design features to enhance supportability and toughen structure to maintenance and service damage. Representatives of the manpower, personnel training, and logistics community must accept primary responsibility for readiness advocacy at service and DoD program reviews.

3. Any new airframe design or major modification to present airframes must give considerable more emphasis to damage tolerance of composites, survivability and interchangeability of major structural components.

Based on present trends, it can be assumed that the next new aircraft will have considerable amounts of composite structure. That structure must be considerably more damage tolerant than some early composite designs or maintenance actions will become unreasonable. The designs are going to have to allow some levels of delamination and visible damage with assurity that such damage will not progress to failure short of ultimate design load. In addition, the designs (dependent upon aircraft mission) should allow some levels of battle damage without progressing to failure short of limit load.

With the ever increasing competition for the defense dollar and the escalating costs of new aircraft, itis doubtful that the quantities of new airframes will match past or present procurements. As such, every airframe becomes a precious asset which must be as battle damage survivable as possible if sortie rates are to be kept at acceptable levels. Once the structure is damaged, the designs should allow rapid BDR (less than 24 hours)in a austere environment, and not repairable (within 24 hours) allow for easy removal of major structure (flight control surfaces, stabalizers, wing panels, etc.) for use on less damaged aircraft.

For damage tolerance, designers should consider/incorporate:

1. Judicious use of honeycomb core
2. Large strength margins
3. Positive/Mechanical attachment of stiffeners to skin (stitching)
4. Softer bond lines at stiffener to skin bond (± 45° Plies)
5. Modular construction for ease of maintenance
6. Crack arrestment features
7. Laminate through-the-thickness reinforcements

For survivability and rapid battle damage repair, designers should consider/incorporate:

1. Judicious use of honeycomb core
2. More consistent contours (fewer compound contours)
3. Access to both sides of part
4. Reasonable design margins
5. Part interchangeability

For Interchangeability, Designers should consider/incorporate:

1. Jig drilled holes for all major structure
2. Bolted-in major fittings and hinges
3. Reversibility (L to R) where possible (Vertical Stabilizer, Horizontal Stabilizer, Aileron, Flap, Trailing Edges, Etc.)
4. Limit use of Taperlock fasteners
5. Standardization in fastener style, diameter and grip as much as possible.

4. New composite designs should be R&M designed to only require visual inspection in liew of more involved/costly NDI techiniques.

Designs should be such that damage or flaws which are not visible are not critical enough to lead to failure short of ultimate load. Designs should also be such that visible damage or realistic limits (based on threat i.e. 23 mm, 50 cal, xx square inches, .xx deep, etc. and zone of part) should not result in failure short of limit load in an identified number of flight hours.

3.1.3 DESIGN ISSUES/RECOMMENDATIONS FOR COMPOSITE R & M

ISSUE: 1.	No explicit definition or quantification of R & M requirements by procuring agencies
STATUS:	Current data collection systems are inadequate and incomplete. No current pipeline for field service information to specification writers exists. Relative R & M costs of different material systems are vague.
POTENTIAL:	Adequate data for supportability design decisions.
GAPS:	Lack of adequate data reporting. Lack of emphasis on R & M life cycle costs.
PAYOFF:	Improved readiness and reduced R & M costs.
PRIORITY LEVEL:	High
REFERENCED PLAN TO FILL GAP:	D1.1 and D1.2 (Next page)

RECOMMENDATION: D1.1 Review present data collection systems and develop an adequate data collection system that provides feedback on lessons learned.

TARGET: All new systems and major mods or retrofits

GATEKEEPER: DOD operating commands to identify and quantify need; Maintenance to implement and feedback data to ASD.

COST/TIME TO IMPLEMENT: High: $1M/yr for 2 yrs

IMPACT ON READINESS: Would highlight present system problems and could be implemented as soon as responsibility is assigned.

Would influence future aircraft design decisions to include R & M by 1986.

PRIORITY: High

RECOMMENDATION: D1.2 Develop specifications with R & M requirements and verification techniques.

TARGET: All new systems and major mods (ECP's)

GATEKEEPER: Independent review team designated by OSD

COST/TIME TO IMPLEMENT: Low; continuing effort

IMPACT ON READINESS: Provide early R & M evaluation mechanism for advanced structures

PRIORITY: High

ISSUE: 2. Design for R & M

STATUS: In current design criteria/ philosophy performance consistantly outweighs R & M

POTENTIAL: More maintainable and damage tolerant design

GAPS: Lack of emphasis on R & M

PAYOFF: Readiness inmprovment and higher sortie rates.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: D2

RECOMMENDATION: D2. Give R & M greater emphasis in the procurement process and provide monetary incentives for improved R & M in designs.

TARGET: All new systems and major mods (ECP's).

GATEKEEPER: ASD/NAVAIR/AVSCOM

COST/TIME TO IMPLEMENT: High; $1M/yr for 3 years

IMPACT ON READINESS: Potential for billions of dollars in corrosion and fatigue related savings over the life of a major weapons system.

PRIORITY: High

AD-A137 331 STRUCTURAL COMPOSITES TECHNOLOGY WORKING GROUP REPORT 2/2
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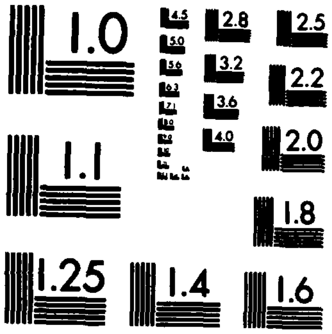

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ISSUE: 3. Survivability/ Damage Tolerant Design

STATUS: Delaminations ore a significant in-service failure mode. These delaminations are caused by handling, low energy impact, or ballistic impact

POTENTIAL: Minimize delamination failures and reduce the number of inspections for damage

GAPS: Inadequate practical design approaches at realistic costs

PAYOFF: Reduced R & M costs thorugh improved design

PRIORITY: High

REFERENCED PLAN TO FILL GAP: D3

RECOMMENDATION: D3. Design structure for damage tolerance, survivability, and interchangeability

TARGET: Design criteria specific to each system

GATEKEEPER: ASD/NAVAIR/AVSCOM with support from R & D community

COST/TIME TO IMPLEMENT: High; $2M/yr for 5 years

IMPACT ON READINESS: Improved BDR capability and sortie generation through reduced downtime.

PRIORITY: High

ISSUE: 4.	Design for Visual Inspectability
STATUS:	Present designs require specialized equipment and trained personnel for inspectability
POTENTIAL:	More damage tolerant design
GAPS:	Damage tolerant designs should require primarily visual inspection methods to be used at the depot and field level
PAYOFF:	Greatly reduced manpower and equipment costs. Increased readiness.
PRIORITY LEVEL:	High
REFERENCE PLAN TO FILL GAP:	D4

RECOMMENDATION:	D4. Develop design criteria/ philosophy which will allow non visual damage to carry ultimate load and visual damage of an identified size to carry limit load.
TARGET:	All new systems.
GATEKEEPER:	ASD/NAVAIR/NAVSEA/AVSCOM
COST/TIME TO IMPLEMENT:	High; $1.7M/yr for 3 years
IMPACT ON READINESS:	Significant improvement in inspectability and greatly increased readiness.
PRIORITY:	High

3.2 DAMAGE TOLERANCE SUB-COMMITTEE REPORT

3.2.1 Executive Summary

DoD composite aircraft structure must be damage tolerant. Damage tolerant design increases surviveability, safety, and aircraft availablity, while reducing maintence costs. For damage tolerant design, material development, structural design, and manufacturing efforts must be intergrated. Material systems must be developed to resist low-energy impact and lend themselves to damage containment structural concepts. To this end, effective damage tolerance criteria must be developed for both material and structural design.

3.2.2 Discussion of Issues

1. Material Design

The minimum interlaminar fracture toughness of composite laminates should be increased by an order of magnitude to approximately 10#/in . To this end, laminates need to be examined as a fiber/matrix system. To optimize these systems, resin/fiber/particle interactions have to be quantified. For system improvements high-glass transition temperature matrices with high fracture toughness (without modulus reduction) need to be developed. Also material design flexibility needs to be established through considerations such as development of high-strain, multi-diameter fibers. Moreover, three dimensional fiber concepts, such as stitching, should be integrated into material systems designs.

2. Damage Containment

Programs are needed to address damage containment in large composite structures. To this end, practical methods to integrate damage arrestors into design concepts need to be explored. Alternative methods which take advantage of the design freedom offered by composite materials should be studied, and may include use of buffer strips, external panel reinforcements, stitching, adhesive bonding and mechanical fasteners. To support these advances, analytical methods must be concurrently developed. The damage tolerance should be demonstrated with programs simular to the PABST program (mid. 70's) which addressed full-scale bonded structure. All damage containment methods should stress economical design concepts.

3. Design Criteria

For both damaged and undamaged composite structures, damage tolerance criteria based on the physics of the fracture processes need to be developed. The complex failure process of current and new systems must be understood. To this end, critical failure modes and interactions must be defined and reflected in practical analytical methods. An effort should be made to expand the current programs to develop damage tolerant requirements for advanced composite structure.

3.2.3 DAMAGE TOLERANCE ISSUES/RECOMMENDATIONS FOR COMPOSITE R & M

ISSUE: 1.	Material Design
STATUS:	Poor impact resistance of laminated composites currently requires frequent and detailed inspections and repairs and reduces the maximum allowable in-plane design strains well below the ultimate capability of the reinforcing fibers.
POTENTIAL:	Higher impact resistance will lower the inspection and repair requirements and allow increased operational strain levels.
GAPS:	Material development is needed
PAYOFF:	Tough composites which are not prone to delamination could eliminate 75 percent of field level repairs and provide higher payload performance.
PRIORITY LEVEL:	High
REFERENCE PLAN TO FILL GAP:	T1

RECOMMENDATION:	T1. Development of tough organic matrix composites
TARGET:	Aircraft
GATEKEEPER:	DOD/NASA 6.1/6.2 Funding
COST/TIME TO IMPLEMENT:	High; $2M/yr for 7 years
IMPACT ON READINESS:	Provide a 75 percent reduction in field maintenance.
PRIORITY:	High

ISSUE: 2. Damage Containment Designs

STATUS: Rapid fracture to failure may occur due to severe battle damage. Slow damage growth is not always a precursor to failure.

POTENTIAL: Hybrid composite structure can potentially withstand 23 mm ballistic damage over a high percentage of the airframe and not lose required structural integrity.

GAPS: The technology for design of hybrid structures for battle damage survivablity is lacking in analysis tools and experimental data.

PAYOFF: A significant increase in survivability and aircraft and ground vehicle personnel carrier availability is anticipated.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: T2

RECOMMENDATION: T2. Develop battle damage containment design methodology

TARGET: Aircraft, armored personnel carriers

GATEKEEPER: DOD/NASA 6.2/6.3 Funding

COST/TIME TO IMPLEMENT: High; $1.4M/yr for 7 years

IMPACT ON READINESS: Increase the survivablity of aircraft in combat by 25 percent; in peace-time by 1-2 percent.

PRIORITY: High

ISSUE: 3. Design Criteria for Damage Tolerance

STATUS: Criteria for damage tolerant designs are based primarily on extensive point design tests

POTENTIAL: Generic and more accurate criteria, including analytical procedures are needed to allow higher operating strain levels at a fixed level of performance and R & M factors.

GAPS: Damage assessment criteria are needed which minimize the testing and inspection requirements.

PAYOFF: Increased aircraft availablity, payloads and reduced maintenance costs

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: T3

RECOMMENDATION: T3. Develop more accurate design criteria and analysis methods for damage tolerance which reduces the degree of testing and inspection required for certification.

TARGET: Aircraft

GATEKEEPER: DOD/NASA 6.1/6.2 Funding

COST/TIME TO IMPLEMENT: High; \$1.5M/yr for 10 years

IMPACT ON READINESS: Reduce field maintenance of structure by 25 percent.

PRIORITY: High

3.3 REPAIR SUB-COMMITTEE REPORT

3.3.1 Executive Summary

A major issue in R&M of composites is repair. The first need is for designs which incorporate such factors as repairability , damage tolerance, and inspectability as design criteria along with cost and performance. For this purpose, data is needed on current maintenance actions on composite structures; and further effort is needed to collect this data. Another issue is training of depot and field level prsonnel in composite repair. The above items are recurring activities which must be continued and maintained by the military organizations.

The improvement of composite repair capabilities requires that attention be given to several key technical issues. These include several items for which there are on-going programs including bonded repair quality (moisture effects, storability, durability, containment, equipment limitations), and bolted repair quality(hole clearances, fasteners). Two new issues which have yet to be fully addressed are battle damage repair and repairs of new composite systems such as metal matrix-, thermoplastic-, and high temperature organic-composites. The implementation of programs to resolve these issues will result in a major improvement in R&M with reduced maintenance costs. and down-time and increased operational readiness.

3.3.2 Discussion of Issues

1. Rapid Battle Damage Repair Procedures

Repairs to battle damage under austere combat conditions requires repairs that can be made faster, with less supporting facilities and equipment, and by personnel working in protective clothing. Criteria for repairs are less severe, however, since normally only a limited service is necessary for a few missions or a flight to a rear area repair station. Because of these different requirements from peacetime repairs, different procedures will be applicable, and such procedures do not currently exist for composite structure.

2. Develop Design Guidelines

The choices of the kinds of repairs to be made are currently left to the responsible individual with little or no guidance to assist in the choices. Data generally does not exist to define the requirements a repair must meet, e.g., required strength, stiffness, durability, smoothness, etc. In some cases a cosmetic repair to smooth and reseal an area may be acceptable, with much less time and cost involved than if a full strength-restoring structural repair is made. Except for standardized repairs for small damage areas, each large repair on strength-critical structure must be designed by a structures engineer. Many of the design procedures currently used for fastener patterns or the geometry of a bonded joint are complex and require use of computer programs. In many cases, these programs, the computers, or the trained design personnel are not available. Even when they are available, considerable time delay is required to make a design before the repair can be started. Development of design charts, standardized configurations, and known strength values would greatly simplify the design of repairs and reduce the time and cost involved.

3. Effect of Absorbed Moisture

It is necessary to determine how much absorbed moisture can be tolerated before its affect on bonded repairs becomes unacceptable. The tolerable amount will vary with a number of parameters including structural type, configuration of the repair, part thickness, kinds of materials, repair cure cycle and properties required in the finished repair. Much of the moisture behavior can be predicted by existing analytical procedures, but the effects on the strength of bonded repairs must be determined largely by testing on small scale specimens and final verification on relatively large scale, realistic specimens. Three specific conditions need to be addressed;

1. Effect of moisture which, when heated, blows skins off of honeycomb sandwich structure,

2. Effect of moisture in causing porosity in adhesive bond lines which in turn causes a reduced bond strength, and,

3. The effect of moisture within the composite being repaired, which can expand and cause further damage in the form of blisters or delaminations when the part is heated to mare a repair.

It is currently not possible to determine how much moisture has been absorbed by a composite part that is to be repaired. The amount of drying needed before heat can safely be applied to make a bonded repair depends on the amount of moisture. Currently, somewhat arbitrary drying times (up to many days) are used when absorbed moisture is suspected, and this frequently delays repairs, increases down time and cost of repair . Development of a method to measure moisture should be possible using microwave, capacitance, resistance or other techniques.

4. Repair of New Composite Systems

The introduction of new composites into advanced technology aircraft will provide increased temperature range and damage tolerance. Development of repair techniques is essential to the successful use of these new systems, and needs to be initiated at an early stage of the materials development to ensure readiness of the materials for production use in 1990.

Repairs on composite structures have been adapted to the requirements of graphite/epoxy material. New systems such as polyimides, thermoplastic composites, and metal matrix composites introduce new requirements and an extended range of operating temperatures which the repair must withstand. Bonded repairs which meet these requirements must be processed using significantly different procedures and more stringent processing conditions.

5. Hole Quality for Bolted Repairs

Additional programs and increased training is required to insure that bolted repair quality is adequate for restoration of component strength and storage life. The critical processing factor is drilling of fastener holes, and the effects of hole clearances and exit-side damage need to be determined.
The major variable affecting the strength and service life restoration achieved by a bolted repair is quality of the fastener hole. Excessive hole clearances and exit-side damage can significantly effect structural characteristics of the repair. In many cases lack of access will require that holes will be drilled without back-up which increases the probability of damage to the composite.

6. Bonded Repair Durability

A need exists for generic and part-specific programs to evaluate bonded field and depot level repair durability under combined environmental/load cycles representative of the component service life; and to assess the effects on repair durability of processing limitations typically encountered in the field.

Bonded repairs will be used extensively for structural repairs of highly loaded primary structures because of the capability for restoration of higher strength levels than other repairs. In many cases, the adhesive will be cured and the composite part and potch treatedunder less than optimum field conditions. The durability of the bond must be adequate for the remaining life of the component, and the effects of the repair fabrication limitations must be evaluated.

7. Storage of Bonded Repair Materials

The most structurally efficient repair concepts are bonded repairs which eliminate and thus theoretically provide a greater restoration of design strength then bolted repairs. For many highly loaded primary composite structures, bonded repairs may be essential for the restoration of design strength, and the ability to accomplish bonded repair in field situations may be essential. The lack of room-temperature storable adhesives which meet structural criteria of both hot wet durability and toughness (peel) is a major drawback to the use of composites in these critical applications.

The need exists for DoD sponsored programs to develop adhesives providing the necessary combination of properties for a bonded field repair. Current programs have made progress towards this goal, but further efforts are needed. This would provide immediate benefit to aircraft now being introduced into service, and would make the use of composite more feasible for new weapon systems.

To facilitate relatively quick repairs in field locations such as forward air bases and aboard aircraft carriers, or under battle damage conditions, new adhesives are needed. Storage for up to at least 12 months at room temperature is necessary to ensure availability when needed under existing logistics systems. Materials currently available do not have sufficient strength at elevated service temperatures for use on high performance aircraft.

8. Training of Maintenence Personnel

A very limited number of maintenance personnel working on composites have extensive experience with the materials and the special procedures and precautions needed for bonded and bolted composite repairs. This is particularly true for field level facilities, since training programs in composite are at a preliminary stage of development at best.

The need exists for the DoD to expand and institute where required: (1) familiarization training to acquaint depot and field personnel with composites and (2) specific training on procedures for various components. This would be a relatively low cost activity with immediate and long-term benefits in lower maintenance costs, improved structured integrity, and extended service life of the repaired components.

9. Documentation of Repairs

Existing maintenance data recovery systems do not provide quality information on repair actions (such a number of repairs, causes of damage, extent and location of damage, repair costs, time between maintenance actions, etc). A need exists for data which can be used with confidence to assess maintainability of existing structures, and provide input for trade-offs of maintainability of new designs with respect to weight, manufacturing cost, stress level and other factors.

This documentation would provide long-term benefits in future composite designs with improved reliability and maintainability and in more effective repairs at lower cost.

10. Equipment Limitations

Repair of composites requires specialized equipment, particularly for depot-level repairs not used in conventional metal repairs, such as autoclaves, ovens, zone heaters, special drills, etc. These equipment needs must be evaluated early in the design and acquisition of composite parts on new aircraft. The specific action required is for the services to define these requirements as part of the preliminary design activities. At moderate cost, this would provide higher quality structural repairs at reduced cost with reduced down times.

3.3.3 REPAIR ISSUES/RECOMMENDATIONS FOR COMPOSITE R & M

ISSUE: 1. Battle damage repair

STATUS: Limited capability exists for rapid battle damage repair for composite structures.

POTENTIAL: New materials and procedures applicable to austere conditions.

GAPS: Rapid cure bonded repair techniques and procedures for bolted repair.

PAYOFF: Increased operational readiness under combat conditions

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: R1.1,1.2 (See next page)

RECOMMENDATION: R1.1 Develop rapid-cure adhesives with a minimum 1 year storage and with a strength capablity to 220 deg F and above

TARGET: Aircraft

GATEKEEPER: AFWAL/AMMRC/NAVAIR 6.2 and 6.3 Funding

COST/TIME TO IMPLEMENT: Medium; for 3-5 years

IMPACT ON READINESS: Permits repair at field level and under battle conditions for reduced downtime and increased operational readiness for less cost of repairing.

PRIORITY: High

RECOMMENDATION: R1.2 Procedures to be developed for rapid bolted repair of battle damage under combat conditions.

TARGET: Aircraft and armored ground vehicles

GATEKEEPER: AFWAL/AVSCOM/NAVAIR 6.3 Funds

COST/TIME TO IMPLEMENT: Medium; for 3-5 years

IMPACT ON READINESS: Increased operational readiness under combat conditions with more aircraft being repaired in less time

PRIORITY: High

ISSUE: 2.	Design guidelines for repair
STATUS:	Very little criteria exist to specify when to repair and to choose among possible materials, methods and configurations. Many designs for repairs require complex computer analysis for sound placement of bolts and bonded joint strengths
POTENTIAL:	Easy-to-use information in chart form for field use
GAPS:	Need for a repair handbook for each system.
PAYOFF:	Faster evaluation of damage and selection of repair method reduces downtime and total repair costs.
PRIORITY LEVEL:	High
REFERENCE PLAN TO FILL GAP:	R2

RECOMMENDATION:	R2. Develop design guidelines for repair to determine appropriate kinds of repair for types of damage in typical kinds of structure. Define materials, configurations, sizes, etc., for quick reference in handbook form.
TARGET:	Aircraft
GATEKEEPER:	AFWAL/AVSCOM/NAVAIR
COST/TIME TO IMPLEMENT:	Medium; for 2-4 years
IMPACT ON READINESS:	Reduce repair time and cost.
PRIORITY:	High

ISSUE: 3. Effects of moisture and surface contaminants on bonded repairs

STATUS: Moisture causes blown skins on sandwich structures, porosity which decreases strength os adhesive bonds, and a potential for delamination of the parent material during heat-up.

POTENTIAL: Lower temperature curing adhesive, ctriteria for acceptable amounts of moisture, methods to measure moisture content of the structure to be repaired.

GAPS: Quantification of the effect of moisture and contaminants on bond strength.

PAYOFF: Less damage to structure being repaired and less time for necessary drying would reduce cost of repairs and downtime.

PRIORITY LEVEL: Medium

REFERENCE PLAN TO FILL GAP: R3.1,3.2 (See next page)

RECOMMENDATION: R3.1 Determine the quantitative effect of absorbed moisture and surface contaminants on the strength of bonded repairs

TARGET: Aircraft

GATEKEEPER: AFWAL/NAVAIR/AMMRC 6.2 and 6.3 Funds

COST/TIME TO IMPLEMENT: Medium; for 2-3 years

IMPACT ON READINESS: Reduce repair costs and reducing drying time currently used and obtain better quality and more dependable repairs with less potential damage to repaired structure.

PRIORITY: Medium

RECOMMENDATION: R3.2 develop a method to measure the amount of absorbed water in a structure to be repaired.

TARGET: Aircraft

GATEKEEPER: AFOSR/ONR/ARO 6.1 Funding

COST/TIME TO IMPLEMENT: Medium; for 2-4 years

IMPACT ON READINESS: Reduce time used to dry structure and obtain more reliable repairs.

PRIORITY: Medium

ISSUE: 4. Repair methods for "new" composite materials

STATUS: Repair methods do not exist for materials such as metal-matrix, polyimides, thermoplastics, etc.

POTENTIAL: Probable future use of new materials must have repairablilty considered early in their selection.

GAPS: Include repair technology in early evaluation of advanced materials

PAYOFF: Capability to repair new material to minimize scrap and replacement costs and increase operational readiness.

PRIORITY LEVEL: Medium

REFERENCE PLAN TO FILL GAP: R4

RECOMMENDATION: R4. Develop procedures including materials and processes and configuration for the repair of metal-, polyimide-, and thermoplastic-matrix composites

TARGET: Future systems

GATEKEEPER: AFWAL/NAVAIR/AVSCOM 6.1 and 6.2 Funding

COST/TIME TO IMPLEMENT: Medium; 3-5 years for each material

IMPACT ON READINESS: Capability to maintain structures made with new materials in future weapon systems.

PRIORITY: Medium

ISSUE: 5. Hole quality for bolted joints.

STATUS: The quality of the fastener hole is the major processing factor in determining the effectiveness of a bolted repair. Field limitations and lack of back-side access make hole clearances and hit-side damage the major concerns.

POTENTIAL: Bolted repair procedures adapted to field level capabilities which have been verified as restoring component strength and service life.
Depot and field level personnel trained in the proper techniques for drilling composite holes with hand tools and no back-side access.

GAPS: Evaluations of bolted repair strength and training of personnel in drilling techniques.

PAYOFF: Improved R & M through validation of bolted repair procedures suited for both depot and field level use; and through improved personnel skills to effect these repairs.

PRIORITY LEVEL: Medium

REFERENCE PLAN
TO FILL GAP: R5.1,5.2 (See next page)

RECOMMENDATION: R5.1 Evaluation of bolted field repairs

TARGET: Current aircraft inluding F-18 and AV8-B

GATEKEEPER: AFWAL 6.3 Funding

COST/TIME TO IMPLEMENT: Medium; for 2-3 years

IMPACT ON READINESS: Improved short term readiness of existing aircraft

PRIORITY: Medium

RECOMMENDATION: R5.2 Provide specialized training to ensure field and depot personnel are familiar the the special drilling and countersinking requirements of composites.

TARGET: Current Aircraft

GATEKEEPER: ALC's

COST/TIME TO IMPLEMENT: Low; for continuing life of system

IMPACT ON READINESS: Impact on performance and reliabilty after repair

PRIORITY: Medium

ISSUE: 6. Bonded repair durability

STATUS: The effects of field repair facility limits (low pressure cure, field level surface treatments) on repair durability has not been sufficiently studied. The use of bonded repairs on highly loaded structures makes this an essential need, since the repair quality is dependent upon an organic resin and interface known to be environmentally sensitive.

POTENTIAL: Bonded repair techniques and procedures (both field and depot level) whose long-term durability has been validated for use in primary structure repair.

GAPS: Verification of bonded repair durability through testing.

PAYOFF: Improved R & M through capability to use bonded repairs on primary structure with confidence that the service life of the component has been restored. This will increase the ratio of repairable to non-repairable damage incidences.

PRIORITY LEVEL: Medium

REFERENCE PLAN TO FILL GAP: R6.1,6.2 (See next page)

RECOMMENDATION:	R6.1 Provide for in-house and contractual programs to evaluate the bonded field repair durability
TARGET:	Current aircraft including F-16, F-18, and AV8-B
GATEKEEPER:	NAVAIR/AVSCOM/AFWAL 6.2 and 6.3 Funding
COST/TIME TO IMPLEMENT:	Medium; for 2-3 years per system
IMPACT ON READINESS:	Improved confidence in the performance after repair
PRIORITY:	Medium

RECOMMENDATION:	R6.2 Establish the requirement that contractors validate repair durability for specific composite structure prior to aircraft delivery.
TARGET:	Future systems
GATEKEEPER:	DOD procurement organizations
COST/TIME TO IMPLEMENT:	Medium; for 2-3 years per system
IMPACT ON READINESS:	Undegraded performance following repair
PRIORITY:	Medium

ISSUE: 7. Storage of bonded repair materials

STATUS: Currently available adhesive which meet both hot, wet durablity requirements and peel strengths are film adhesives with limited room temperature storablity. Currently available two-part adhesives do not meet both standard criteria.

POTENTIAL: Room-temperature storable two-part adhesives which meet structural and environmental criteria for bonded repairs.

GAPS: Lack of such an adhesive.

PAYOFF: Improved R & M to composites due to te ability to perform more efficient structural repairs at field level facilities.Reduced costs through elimination of freezer storage of materials.

PRIORITY LEVEL: Medium

REFERENCE PLAN TO FILL GAP: R7

RECOMMENDATION: R7. Provide for technology studies to investigate new adhesive systems which provide room temperature stability and high hot-wet properties

TARGET: All systems

GATEKEEPER: NAVAIR/AFWAL/AVSCOM 6.2 Funding

COST/TIME TO IMPLEMENT: Medium; for 2-3 years

IMPACT ON READINESS: Reduction in inventory costs.

PRIORITY: Medium

ISSUE: 8. Training of maintenance personnel

STATUS: A very limited number of maintenance personnel working on or around composite structures have had any experience with the material, its susceptability to handling damage, and its required repair procedures.

POTENTIAL: Highly trained maintenance personnel who understand composites, how they can be damaged, and who can apply high quality repairs

GAPS: Requirement for continuous training of new personnel and broadening the training program currently in force at the depot level.

PAYOFF: Familiarization training and repair training for maintenance personnel would result in fewer damaged parts, higher quality repairs and fewer parts scrapped due to "learning experiences" during repair.

This should translate into reduced downtime and lower maintenance costs.

PRIORITY LEVEL: Medium

REFERENCE PLAN TO FILL GAP: R8

RECOMMENDATION: R8. *Training of maintenance personnel for familiarization* with composite materials during handling and specific training in repair procedures

TARGET: Current aircraft

GATEKEEPER: ALC's

COST/TIME TO IMPLEMENT: Low; for 2-3 years then continuing for new personnel

IMPACT ON READINESS: Reduce damage to components during inspection and handling. Increase confidence in durabilty of repair.

PRIORITY: Medium

ISSUE: 9. Documentation of repairs

STATUS: Existing maintenance data systems do not provide quality information on repair actions (e.g. number of repairs, causes of damage, extent of and location of damage, MMH to repair, cost of materials, etc.) which can confidently be used to assess supportability of current structures or to develop supportability design requirements for new composite structures

POTENTIAL: Intelligent and informed decision making when determining repair concepts or making design tradeoffs for future composite structures.

GAPS: Action at ALC's to require detailed repair and maintenance records.

PAYOFF: Vastly improved future designs which are maintainable at lower cost in materials, manhours, and needed support equipment and which result in higher readiness of the system.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: R9

RECOMMENDATION: R9. Documentation of repair procedures by development of an improved data base containing more detailed information than current practice indicates.

TARGET: All systems

GATEKEEPER: Service logistics support

COST/TIME TO IMPLEMENT: High; for 5-7 years

IMPACT ON READINESS: Long term improvement in R & M associated with improved damage tolerant design

PRIORITY: High

ISSUE: 10. Equipment limitation (e.g. cure or dry out ovens, drills, more refined zone heater blankets, etc.)

STATUS: Some of the current field and depot level equipment for effecting repairs is not adequate or upgrades to new equipment to do the job better have not taken place.

POTENTIAL: reduced repair time and higher quality repairs.

GAPS: Slow procurement procedures

PAYOFF: Reduced maintenance costs and less downtime.

PRIORITY LEVEL: Low

REFERENCE PLAN TO FILL GAP: R10

RECOMMENDATION: R10. Develop better definition of procurement procedures and justification to maintain state-of-the-art reapir equipment.

TARGET: All systems at depot level

GATEKEEPER: Procuring agencies (e.g. AFLC/AFSC)

COST/TIME TO IMPLEMENT: Medium; for 2-3 years

IMPACT ON READINESS: Some improved confidence in the performance of repaired component

PRIORITY: Low

3.4 NDE SUB-COMMITTEE REPORT

3.4.1 Executive Summary

This section of the report deals specifically with non-destructive techniques related to composite materials with an emphasis on their potential impact on reliability and maintainability. The proposed programs are divided into areas related to incoming material inspection and acceptance, in-process inspection and control, in-service inspection and post-repair inspection and evaluation. Other issues which are raised include developing of standard nomenclature for composite materials and establishing of training procedures for NDI personnel. The highest priority programs are these related to development of equipment and techniques for inspecting composite materials. The programs are geared to depend on explanations relating to physical or mechanical reality. In the past NDI has been used to outline anomalies without being aware of their importance to the life of the system being inspected when that system is constricted of composite materials. In that regard the most important efforts are seen as those attempting to determine the quality of bonds both in as-fabricated components and after components have been repaired.

In other parts of this report evidence is presented which strongly suggests that the inherent durability, reliability and damage tolerance of composite materials are superior, sometimes greatly superior, to other engineering materials commonly used in various defense systems. If this inherent potential is to be fully exploited and the R&M benefits fully realized, it is essential that users be able to characterize the mechanical and physical condition of composite materials by nondestructive tests. Prior efforts in this field have laid a firm foundation and defined some clear directions for continuing work. This section deals with those aspects of such work that are important to our overall goal of identifying opportunities for major advances in the R&M of defense systems, systems which can partly or totally utilize composite materials in the present case.

Some parts of any complex mechanical system, will inevitably be less reliable than others. Earlier in this report we mentioned that a recent study revealed that in the weapons systems studied 20 percent of the line replaceable units were accounting for 70-80 percent of the actual replacements. What is the cause of the lower reliability of such parts? Are they more severly stressed, less well constructed, improperly designed? How can the problem, whatever it is, be eliminated? The answers to these questions, and other closely related ones, ultimately control the R&M of a component.

Most of the information needed to answer those questions must come from experimental information, and most of that information must come from nondestructive tests. Our ability to evaluate the reliability of a component without destroying it rests entirely on the precision and sophistication of available NDE techniques and the related interpretive philosophies. For composite materials (and for other materials in many cases) it is not sufficient to have NDE techniques that are only sentinels of internal micro events, although such techniques play an important "warning" role. It is essential to have techniques and interpretive concepts that can be used to predict the remaining strength and life of composite components, i.e., techniques and concepts that are directly related to the mechanical response and physical properties of the materials in such a way that they can be interpreted in terms of subsequent behavior. Such techniques can be and are being developed. But much work is needed to bring classical, emerging and new NDE techniques and concepts to the full support of R&M objectives.

This section will address those needs under four categories which concern the nature of composite materials as-received, as-processed, in-service and after repair. Recommendation for programs which will insure the proper support of NDE for the exploration of the excellent R&M capability of composite materials are made.

3.4.2 Discussion of Issues

1. As received Materials Inspection

A major concern among the DoD user community has been the lack of a code which describer ends composite materials in the manner in which metallic alloys are described. Until recently it was not possible to successfully "pull-apart" a proprietary resin formulation and decipher its component parts. Advances in analytical techniques such as Fourier Transform Infra Red (FTIR) and high pressure liquid Chromatography (HPLC) have made it possible to fingerprint and determine the composition of organic materials. It will be necessary to standardize these techniques to make them practical for performing uniform acceptance tests. With these tools in hand it becomes feasible to establish a standard nomenclature for the organic based composite materials. The code should be worked out between the standardization functions of the services in concert with the materials research laboratories.

2. In process Inspection of Organic Materials

The control of fabrication using organic materials is especially critical given the batch nature of the processes involved. A number of nondestructive techniques have emerged which appear to have promise for use in closed loop control systems. Dielectometry and thermography can be used to monitor curing processes especially in components having varying thickness. Other techniques such as acoustic emission and holography have the potential to monitor structures for latent defects which may escape traditional inspection techniques and will show up later in the life cycle as premature failures. This overall thrust will be embedded in programs dedicated to processing manufacturing science, and the R&M community should emphasize the benefit of utilizing more predictable materials on reliability costs.

3. Inspection of Bonded Joints

Another R&M opportunity which is associated with composite materials has to do with the fact that many composite structures are bonded together. There is an opportunity to reduce the failure of such bonds by developing NDE techniques which can detect weak bonds before they cause structural malfunction. Such a program would support the development of techniques which could indicate the actual strength of bonded joints rather than the simple continuity of the joints as present techniques do. This program would be of considerable value to repair activities since bonded patches present a special challenge to evaluation procedures. This is an immediate payback item that would significantly reduce or eliminate failures in the area that is most critical to the R&M of composite materials.

4. Improved Inspection Techniques Equipment

One of the best and most general opportunities to reduce the overall cost of NDE of composite materials is associated with the need for a program to develop inspection techniques and equipment that can be used to facilitate the actual practice of inspection. In service inspections (single lifetime inspections associated with damage tolerance designs, battle damage inspections, handling damage inspections, etc.) are presently conducted, for the most part, by labor intensive techniques such as hand-held ultrasonic transducers and coin-tap schemes. A program which would have an immediate significant impact on R&M

inspection costs is the development of equipment and techniques which are more automated, mechanized and portable so that the personnel and time needed for inspection could be reduced substantially. In appropriate cases such systems could be adapted to the specific geometries and contours peculiar to a given component or aircraft. The large-area capabilities of such a system would also improve the capability of operators to detect non-visible damage (such as low velocity impact damage) in highly loaded composite primary structures where damage propagation could occur. It is estimated that this program would reduce the cost of NDE of composite systems by about 20 percent. A 6.3 (generic) and 6.4 (part specific) support activity is recommended.

5. Inspection of Composite In-Service

In order to fully exploit the superior durability, inherent reliability and damage tolerance of composite material components, further development of new and especially emerging NDE techniques is needed. Most NDE methods currently applied to composite materials were developed for metallic structures and are primarily concerned with the detection of the presence (shape and size in some cases) of individual flaws. One of the reasons for the distinctly superior long-term performance and reliability of composite materials is the fact that those materials rarely form a single dominant flaw. Instead, damage development is complex and generally widely distributed. Also, such things as the presence of water or other fluids which may diffuse into composite materials may be impertant and should be detectable by NDE. Other factors such as small changes in stiffness and small loss of mass due to ultraviolet exposure, etc. may be of some importance to performance. Finally, the quality and integrity of bonded joints, which are common in these materials, is an object of NDE inspection. Several new and emerging NDE techniques such as vibro thermography, stiffness monitoring and neutron radiography (there are others) show promise for the specialized NDE of composite materials. It is recommended that support be provided (probably at the 6.1 or 6.2 level) for programs which are directed at the further development of NDE concepts and methods which are more directly related to the performance and reliability characteristics peculiar to composite materials.

6. Data handling, Recovery, Interpretation

Another opportunity to reduce the cost of R&M through the use of composite materials and to increase the readiness of such components is associated with data handling, recovery and interpretation. Several aspects of this situation are especially important for composite materials. Presently the practice of generating maintenance action reports (AFM66-1) and related information is insufficient for the general purpose of assessing the continuing serviceability of composite structures. Moreover, the way in which such maintenance and repair information is retrieved, reported and made available to others is not consistant or specific enough to be of full use to other personnel with simular concerns. This situation presents a major opportunity to contribute to the R&M of composite parts while cutting costs and greatly upgrading the technical capabilities of the maintenance community. This can be done by a program aimed at the development of thorough, specific and service-wide procedures for the generation and reporting of maintenance and repair data for composite components. An especially important part of such a program should be the development of computerized data collection, analysis and interpretation of NDE results. Artificial intelligence techniques should be carefully scrutinized for the possibility of developing "expert systems" that could greatly reduce the need for highly specialized training of maintenance personnel for the purpose of NDE interpretation for composite materials. This program would have immediate payback and would ultimately reduce the need for spare parts. It is likely that a 6.3 or 6.4 program is appropriate.

7. Inspection of Repairs

Another important NDE matter which plays a critical role in the R&M of composite materials is the inspection of repairs. It is inevitable that repairs of some members of any large fleet of parts (composite or otherwise) will be required during service, due to service related damage, damage induced by handling or service, battle damage, etc. Such repairs can generally not be mechanically tested to establish their quality and integrity. Programs are needed to develop NDE systems and methods which can be specifically used to evaluate repaired composite components such as bonded patches, bolted patches, and rebonded structural sections. There is a special need for systems that generate information that is directly related to the actual strength and reliability of the repairs. For that reason, the recommended program should have a 6.1 and 6.2 component. However, it is also possible to approach this problem with a particular single type of repair peculiar to certain situations in mind, so that 6.3 activity may be warranted. The reliability, readiness and cost avoidance to be gained from such a program can be measured by the fact that such a capability would bring the reliability of the repaired part back to essentially the as-manufactured level-the ultimate objective of any repair operation. This program is an essential part of the opportunity to exploit the inherent R&M of composite components.

8. Education and Training

Education and training is essential in any technical program. For the objectives of R&M of composite material components, the problem to be addressed is especially urgent. Education and training, from university programs to field training, is presently fragmented and does not address the special properties and requirements of composite materials. As a consequence of this fact, much opportunity for improved reliability and maintainability is lost. For example, many of the maintenance and repair actions presently required by composite components are associated with damage induced by handling (or mishandling) during other maintenance activities. There is an urgent need for support of development of consistent and systematic educational programs in all institutions; including universities, concerned with R&M of composite materials.

3.4.3 NDE ISSUES/RECOMMENDATIONS FOR COMPOSITE R & M

ISSUE: 1.	Non-standard nomenclature and acceptance standards for composite materials.
STATUS:	Composite materials, especially organic composite materials, are subject to a wide variety of proprietary designations. Inspection techniques such as Fourier transform infra-red spectroscopy and high pressure liquid chromatography are available to characterize incoming materials to base constituents.
POTENTIAL:	With a "standard" code to classify organic based composite materials and the tools available to verify the standard compositions, the confusion existing because of proprietary designations will be greatly reduced. Designers will benefit by being able to specify a class of material rather than a specific proprietary system.
GAPS:	Lack of uniform designations of composite materials.
PAYOFF:	Inventories of material will be cut back. Commonality of systems will improve R & M because the support tail for composite items will be dramatically reduced. Greater confidence in materials will result from common acceptance procedures.
PRIORITY LEVEL:	Medium
REFERENCE PLAN TO FILL GAP:	N1

RECOMMENDATION:	N1. Establishment of a standard nomenclature for organic based composite materials
TARGET:	All military systems using composites
GATEKEEPER:	DOD/Service Standardization activities Army 6.3 Funding
COST/TIME TO IMPLEMENT:	High; $1M/yr for 10 years
IMPACT ON READINESS:	During the design phase materials can be specified without relying on proprietary restrictions. Inventories can be reduced to generic items necessary for repair.
PRIORITY:	Medium

ISSUE: 2. Control and verification of processing of composite materials

STATUS: At every stage of manufacture, organic based composite structures are fabricated in batch processes

POTENTIAL: Adaptation of NDE inspection techniques such as thermography, holography, acoustic emission in conjunction with closed loop control of organic processing will provide a means of controlling process conditions to accommodate batch-to-batch variation.

GAPS: Lack of application of existing techniques

PAYOFF: More predictable composite components will allow for better material inventory criteria and reduced R & M costs

PRIORITY LEVEL: Low

REFERENCE PLAN TO FILL GAP: N2

RECOMMENDATION: N2. Development of in-process control and inspection techniques applied to composite manufacture.

TARGET: All military systems using composite materials

GATEKEEPER: DOD/Service Material Labs 6.2 Funding

COST/TIME TO IMPLEMENT: High; $10M/yr for 10 years

IMPACT ON READINESS: More uniform and predictable structural response. Longer mean time between repair and reduction of materiel inventory to repairs

PRIORITY: Low

ISSUE: 3. Inspection of bonded joints

STATUS: The integrity and strength of adhesive bonds cannot be directly established.

POTENTIAL: Test techniques that can detect weak bonds and establish the strength of bonds could reduce the possibility of structural failure and prevent the ignition of fuel vapor during lightning strike.

GAPS: Lack of bond strength NDE techniques

PAYOFF: Reduced retrofit and maintenance cost. Reduced down time, reduced fastener cost, and associated maintenance costs.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: N3

RECOMMENDATION: N3. Develop a portable NDE system to detect weak bonds

TARGET: All systems

GATEKEEPER: AFWAL/NAVAIR/AMMRC 6.2 Funds

COST/TIME TO IMPLEMENT: Medium; $1M/yr for 3 years

IMPACT ON READINESS: Method is especially important in eliminating the opening of gaps in wet wing configurations which can act as spark gaps during lightning strike.

PRIORITY: High

ISSUE: 4. Improved inspection techniques and equipment

STATUS: Present techniques for testing in-service components are slow, labor intensive and not easily applied.

POTENTIAL: Mechanized and automated portable devices could greatly reduce the personnel and time required to inspect composite components

GAPS: Need to develop such NDE equipment

PAYOFF: Reduced downtime and inspection costs, increased inspector proficiency and efficiency, and 20 percent overall reduction in inspection costs.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: N4

RECOMMENDATION: N4. Develop composite component inspection techniques and equipment that is more automated and portable

TARGET: AV8B, F-18, F-15, F-16, UH-60, AH-64, JVX, LHX

GATEKEEPER: AFWAL/NAVAIR/AVSCOM 6.2 and 6.3 Funding

COST/TIME TO IMPLEMENT: Medium; $1M/yr for 4 years

IMPACT ON READINESS: Reduced downtime and inspection costs, increased inspector proficiency, overall cost reduction for inspection in the long term.

PRIORITY: Medium

ISSUE: 5.	Inspection methods for composite materials in service
STATUS:	Most inspection of in-service composite components is currently done using methods and concepts developed for metal structures. Determination of continuing reliability and readiness is difficult. Information is difficult to interprete.
POTENTIAL:	Research and development activities, especially in new NDE areas which presently show promise for composite material interrogation such as thermography, stiffness monitoring and neutron radiography could provide NDE information that is more directly related to the performance and reliablilty characteristics peculiar to fiber reinforced composites.
GAPS:	Verification of the effects of defects detected by these methods on the structural response is not complete.
PAYOFF:	Cost avoidance by malfunction reduction through better interpretation of NDE data. More accurate assessement of reliability and readiness.
PRIORITY LEVEL:	Medium
REFERENCE PLAN TO FILL GAP:	N5

RECOMMENDATION:	N5. Support R and D of new and emerging methods for in-service inspection of composite materials
TARGET:	All systems
GATEKEEPER:	AFWAL/NAVAIR/AMMRC
COST/TIME TO IMPLEMENT:	Medium; $1M/yr for 3 years
IMPACT ON READINESS:	Cost avoidance by malfunction reduction through better interpretation of NDE data and more accurate assessment of reliability and readiness in the long term.
PRIORITY:	Medium

ISSUE: 6. Data handling, recovery, and interpretation

STATUS: Maintenance action reports(AFM 66-1) and other information are not sufficient to assess continuing serviceability of composite structures. The present system for retrieving, handling, accessing and interpreting such information is not service-wide consistant or adequate.

POTENTIAL: Thorough and specific data development and reporting precedures for composite materials could provide valuable details for reliability and maintainability decisions, for readiness assessment and for feedback to designers. Computerized collection, analysis and interpretation of NDE could provide wide access and "expert" assistance to data interpretation.

GAPS: More application of computerized system for data reduction and AI interpretation is needed

PAYOFF: Cost avoidance by workforce reduction. Less highly trained operators required. Operational readiness increased, spare parts reduced.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: N6

RECOMMENDATION: N6. Develop service-wide data handling, recovery, and interpretation systems and procedures

TARGET: All systems

GATEKEEPER: ALC's

COST/TIME TO IMPLEMENT: Medium; $1M/yr for 2 yrs

IMPACT ON READINESS: Cost avoidance by workforce reductions, reduced need for high level training, increased operational readiness, and reduced need for spare parts. Short term impact.

PRIORITY: High

ISSUE: 7. Inspection of repairs

STATUS: Existing NDE methods do not indicate repair bond strength or other data that can be used to clearly assess the quality of the repair.

POTENTIAL: NDE methods which indicate information related to the performance of bondlines, patches and other repairs could provide direct reliability and readiness interpretations. Methods which assist in the specific repair operation such as rapid and accurate hole size and shape determination would greatly enhance repair operations.

GAPS: Repair technology programs have not emphasized the NDE and subsequent testing of bond integrity.

PAYOFF: Reliablity, readiness and cost avoidance of field level and depot level repair quality and structural integrity.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: N7

RECOMMENDATION: N7. Develop NDI systems and techniques which can be used to establish the quality of repaired composite components.

TARGET: Aircraft and ground vehicles

GATEKEEPER: AFWAL/NAVAIR/AMMRC

COST/TIME TO IMPLEMENT: Medium; $1M/yr for 3 yrs

IMPACT ON READINESS: Reliability, readiness and cost avoidance by verification of field level and depot level repair quality and structural integrity.

PRIORITY: High

ISSUE: 8. Education and training

STATUS: Education and training activities which specifically address R & M are sparse and not systematically applied

POTENTIAL: A systematic approach to the development of educational and training programs which address R & M, especially as it relates to composite materials, could provide essential support for R & M, especially in the context of maintenance-induced damage avoidance.

GAPS: Lack of systematic E and T program.

PAYOFF: Overall improvement in R & M efficiency and awareness, reduction in damage due to mishandling during other maintenance operations.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: N8

RECOMMENDATION: N8. Support of educational and training programs

TARGET: All systems

GATEKEEPER: DOD/services

COST/TIME TO IMPLEMENT: High; $1M/yr for 10 yrs

IMPACT ON READINESS: Provides critical support for maintenance of advanced composite components and minimizes problems with mishandling during inspection and maintenance

PRIORITY: High

3.5 MATERIALS SUB-COMMITTEE REPORT

3.5.1 Executive Summary

3.5.1 Executive Summary

Composite aircraft structures for military application must not only be damage tolerant but also repairable under field and depot level conditions. The new BMI and other polyimide composites that are presently being introduced for aircraft structural use are being considered for higher temperature use than the current epoxy composites. At the same time, these new resins are quite brittle and little is known about their damage tolerance. Characterization of these new resins and composites with respect to their mechanical properties as well as their processibility is essential.

Another very important area of investigation is the establishment of field and depot level repair procedures to minimize the effect of moisture which causes weak porous bond lines. For other advanced composites such as metal matrix and ceramic composites no repair technology exists to date. The priorities for technology programs related to materials issues are (in decreasing order of importance):

1. damage tolerance
2. composite matrix characterization
3. processing techniques
4. adhesives for field repair
5. metal and ceramic matrix composites

3.5.2 Discussion of Issues

1. DAMAGE TOLERANCE

Organic matrix composites have demonstrated many desirable structural properties (light weight, fatique resistance, structural integrity etc.) yet damage tolerance remains a problem. Fracture toughness in composites is not well understood because the methodology used in metal fracture toughness is not quite applicable to composites. Improvement of damage tolerance is therefore a high priority item since it is expected that it would lead to a reduction in repair and maintenance cost.

2. COMPOSITE AND MATRIX CHARACTERIZATION AND PREDICTABILITY

New bismaleimide, polyimide and thermoplastic resins are presently developed by industry. Some are ready to be used in production. However, there are not enough material property data available that would allow a reliable predictive analysis with respect to aging under service conditions. Also some of the new BMI resins are even more brittle than the presently used epoxy systems. Their use, however, is desirable in cases where higher temperatures performance is required. In some cases they may be used to replace Titanium. A program for a composite and matrix characterization will allow an accelerated use of these materials and give a better understanding of future repairs and maintenance problems.

3. PROCESSING SCIENCE

A number of physical and chemical techniques are available that can aid the processing techniques with newly introduced resins and adhesives. Some of the methods are based on the rheological, dielectric, spectroscopic and chromatographic behavior of these materials. It is expected that a combined use of these techniques will lead to a better control in processing, and , therefore to a reduction in repairs and maintenance cost.

4. NEW ADHESIVES FOR COMPOSITE FIELD REPAIR

Field repair has presently many problems of which shelf life of adhesives at ambient temperature and void formation, caused by moisture diffusion out of the composite into the adhesive, are perhaps the most severe. A program for tailoring adhesive properties, with longer shelf life and with the added capability of chemically quenching the moisture diffusing into the adhesive, would be of great benefit since it would reduce considerably the possibility of high void (low strength) repair patches. Long room temperature shelf life of adhesives eliminates the necessity of refrigeration in the field. Thermoplastic adhesives should also be taken into consideration for this purpose.

5. METAL-MATRIX COMPOSITES

Metal matrix composites are now being developed for a wide variety of applications, including aircraft, missiles, space hardware, antennas, and underwater weaponry. The ductility of this class of materials is low and in many instances constitutes a limiting factor in systems use. Increased fracture toughness would allow low cost composites such as silicon carbide/aluminum to penetrate the aircraft market. Few metal composites articles are in production and the science of field repair of structures is completely undeveloped. Addressing this technology area is an urgent requirement.

6. CERAMIC MATRIX COMPOSITES

Ceramic matrix composites have recently greatly expanded beyond previous limited materials/applications of SiO_2 -SiO_2 for re-entry antenna windows Availability of the new fine diameter Japanese SiC fibers and the potential for other types of fibers, e.g. BN, B_4C , Si_3N_4, from similar polymeric pyrolisis have been a major factor. The field experience and hence the extent of understanding is very limited, but spectacular results have attracted great attention. Most noteworthy is the attainment of toughness approaching that of structural metals and polymeric based composites with an all ceramic composite combined with the attendant implications of ceramic capabilities, eg. high temperature, hardness, corrosion-, erosion-, resistance, with much greater than normal ceramic reliability. However, this field is in a very early stage of development, and lacking in detailed understanding of basic mechanisms, processing capabilities, costs, etc. The field is complicated, but enhanced by possibilities of expanding carbon-carbon composite useage, especially for oxidation resistant applications since there can be both competition on as well as a merging of such carbon-carbon work with the studier of more conventional composites. Another potential application opportunity is the concept of hybrid polymer-ceramic matrix composites.

3.5.3 MATERIALS ISSUES/RECOMMENDATIONS FOR COMPOSITE R & M

ISSUE: 1. Damage tolerance of organic matrix composites.

STATUS: Is currently a major cost factor in structural maintenance.

POTENTIAL: More damage resistant structures will reduce maintenance and repair costs and increase system readiness.

GAPS: Fracture toughness of composites is not well understood and much more difficult to treat theoretically than isotropic materials. More experimental and theoretical studies are are required.

PAYOFF: Improved reliability of structural components.

PRIORITY LEVEL: High

REFERENCE PLAN TO FILL GAP: M1.1,1.2 (See next page)

RECOMMENDATION: M1.1 Develop organic matrices for improved fracture toughness and damage tolerance by support of theoretical and experimental programs to understand the fracture phenomenon and interaction of failure mechanisms.

TARGET: Aircraft structure, rocket motor chambers.

GATEKEEPER: ARPA/ONR/NAVAIR/AFML/AMMRC 6.1 and 6.2 Funding

COST/TIME TO IMPLEMENT: High; 10 man-yr for 3 years

IMPACT ON READINESS: Decreased inspection and repair costs for aircraft, missiles, and ship hulls.

PRIORITY: High

RECOMMENDATION: M1.2 Develop manufacturing methods for organic matrix composites which provide for the through-thickness fiber reinforcement of the laminate

TARGET: ATF and VSTOL

GATEKEEPER: AFWAL/ML,NAVAIR 6.2, 6.3, and 7.8 Funding

COST/TIME TO IMPLEMENT: High; 5 man-yr for 2 yrs (6.2) and
10 man-yrs for 3 yrs (6.3/7.8)

IMPACT ON READINESS: Potential to eliminate 75 percent of all structural composite field repairs. Eliminate hot,wet testing costs during acquistion of system.

PRIORITY: High

ISSUE: 2. Composite organic matrix characterization and predictability.

STATUS: Thermoplastics and new BMI and toughened resins are being developed which need extensive characterization if they are to be considered for future systems.

POTENTIAL: Provide improved performance at higher temperatures and improved R & M through damage tolerant designs and manufacturing techniques

GAPS: Lack of material data for predictive analysis of structural durability and environmental aging. Tooling and processing procedures will be different from the current epoxy resins.

PAYOFF: Performance improvements and cost savings through the elimination of titanium components

PRIORITY LEVEL: Medium

REFERENCE PLAN TO FILL GAP: M2

RECOMMENDATION: M2. Characterize the composite mechanical properties and aging behavior of candidate matrices including BMI, PMR, Larc 160, PEEK

TARGET: Aircraft, missiles

GATEKEEPER: ARPA/ONR/NAVAIR/DOD LABS/INDUSTRY
6.1 and 6.2 Funding

COST/TIME TO IMPLEMENT: Medium; 5 man-yrs for each material

IMPACT ON READINESS: Reduce the uncertainty regarding the long-term durability of emerging materials before they are introduced into new systems.

PRIORITY: Medium

ISSUE: 3. Processing science of organic matrix composites

STATUS: A number of physical and chemical techniques are available for processing characterization including rheological, dielectric, chromatographic and spectroscopic methods.

POTENTIAL: Greater consistency in composite production due to improved control of processing

GAPS: Lack of knowledge of the optimal processing conditions for the newer classes of organic matrices.

PAYOFF: Decreased rejection during manufacturing and better definition of repair procedures

PRIORITY LEVEL: Low

REFERENCE PLAN TO FILL GAP: M3

RECOMMENDATION: M3. Improve reliability of manufactured product through improved process control.

TARGET: Aircraft

GATEKEEPER: ARPA/NAVAIR/AFML 6.2 and 6.3 Funding

COST/TIME TO IMPLEMENT: Medium; 4 man-yr per material

IMPACT ON READINESS: Reduction of manufacturing costs.

PRIORITY: Low

ISSUE: 4.	New adhesives for bonded field repair
STATUS:	Field repair has many problems of which the most important are the shelf life of the adhesive at ambient storage conditions and void formation during the cure.
POTENTIAL:	Provide simpler repair procedures and improved quality of repairs
GAPS:	Current shelf life of adhesives used in bonded repair is short and many require refrigeration. Moisture in the component to be repaired diffuses into the adhesive during cure and creates voids in the bond line.
PAYOFF:	Improve the quality and strength of bonded repairs.
PRIORITY LEVEL:	Medium
REFERENCE PLAN TO FILL GAP:	M4

RECOMMENDATION:	M4. Develop longer shelf life adhesives for field repair of composites.
TARGET:	Aircraft
GATEKEEPER:	NAVAIR/AFML/AMMRC 6.2 and 6.3 Funding
COST/TIME TO IMPLEMENT:	Medium; 4 man-yrs
IMPACT ON READINESS:	Reduced inventory costs at depot.
PRIORITY:	Medium

ISSUE: 5. Damage tolerance and field repair of metal matrix composites.

STATUS: Metal matrix composites are now in advanced development for missiles, antennas, and torpedoes

POTENTIAL: MMC's are expected to be used by 1995 in aircraft/missile systems

GAPS: The subject of field repair of MMC structure has received no attention. The basic mechanism controlling damage tolerance is not understood and limits the use of these materials.

PAYOFF: Enhanced design flexibility associated with the availablity of a new class of structural materials

PRIORITY LEVEL: Medium

REFERENCE PLAN
TO FILL GAP: M5.1,M5.2 (See next page)

RECOMMENDATION:	M5.1 Develop basic understanding of toughness mechanisms in metal matrix composites
TARGET:	Aircraft, helicopters, antennas
GATEKEEPER:	ARPA/ONR
COST/TIME TO IMPLEMENT:	Medium; for 5 years
IMPACT ON READINESS:	Use of MMC's now limited by low toughness.
PRIORITY:	Medium

RECOMMENDATION:	M5.2 Develop repair methodology for MMC's by cataloguing permissible damage for various structures, inspection techniques for damage detection, and field repair procedures.
TARGET:	Aeropace systems
GATEKEEPER:	DOD labs 6.2 Funding
COST/TIME TO IMPLEMENT:	High; for 5 years
IMPACT ON READINESS:	Provides R & M technolgy and cost information for consideration of MMC's in design of future systems.
PRIORITY:	Medium

ISSUE: 6. Ceramic matrix composite development.

STATUS: Ceramic matrix composites (eg. SiO2-SiO2) have had limited application in re-entry antenna windows, but a new class of ceramic matrix composites reinforced by graphite and SiC fibers are beginning to appear.

POTENTIAL: Performance and reliability improvements can be expected. Very high potential for key environmental extremes, especially at high temperatures. Excellent survivability and RAS/RAM characteristics.

GAPS: Inadequate understanding of mechanical behavior, processing relationships, strength-toughness tradeoffs, long term stability at high temperatures, and the oxidation inhibition of carbon-carbon systems.

PAYOFF: Potentially large impact on engine performance and weight savings. Reduced radar signature of engine.

PRIORITY LEVEL: Low

REFERENCE PLAN TO FILL GAP: M6

RECOMMENDATION: M6. Investigate the application of oxidation inhibited carbon-carbon and ceramic matrix composites to future systems by characterization of the mechanical properties and processing procedures for each candidate material system

TARGET: Rear engine applications. RAM applications

GATEKEEPER: ARPA/ONR/AFOSR/AMMRC/AFWAL
6.1 and 6.2 Funding

COST/TIME TO IMPLEMENT: Medium; for 5 years for each material

IMPACT ON READINESS: Primarily performance improvement impact and improved RAS/RAM characteristics

PRIORITY: Low

Section 4

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APPENDIX A SUMMARIES OF PRESENTATIONS TO THE STUDY GROUP

A.1 Air Force Advanced Composite Supportability Working Group Document, March 1983

A.2 Navy Composite Material and Repair Steering Committee Interim Report, Sept. 1982

A.3 Joint Services Aircraft Technology and Safety Review, May 1983

A.4 Flight Service Experience and Environmental Effects on Composite Aircraft Materials

A.5 Air Force Logistics Command R&M Studies

A.6 AVRADCOM Advanced Structures Concepts and R&M Cost Assessments

Executive Summary of the Air Force

Advanced Composites Supportability Working Group Document

In anticipation of an expansion of advanced composite applications within the Air Force, HQ USAF/LEY in August 1981 requested AFLC, with assistance from AFSC, to address the area of composites supportability; that is maintenance, repair, and inspection; and define the major areas for improving the current Air Force posture so that the transition to the expected increase in future applications could be made in an orderly manner.

In response to the HQ USAF direction, an Advanced Composite Supportability Working Group (ACSWG) was formed comprised of representatives from the using support training, design development, acquisition, and research agencies, as well as, the Air Staff. The ACSWG activities spanned approximately a 13 month period following an initial charter meeting in January 1982. The ACSWG conducted detailed reviews of the F-15, F-16 field and depot experiences including visits and firsthand contact with field and depot maintenance personnel, and the specific contractors for the F-15 and F-16 components.

The ACSWG found the service experience with advanced composites to generally be good with the attitude expressed by field and depot personnel toward maintenance and support extremely positive. Incidents of in-service damage were encountered on thin composite skinned honeycomb structure and recommendations were developed for improving the maintenance and repair of this type of composite construction and for supportability design improvements in general.

A significant result of ACSWG activities was the identification of R&D initiatives required to solve current supportability problems and to enhance composites supportability of emerging and future systems. The final report contains a prioritized listing of these R&D initiatives. The group considered dry out procedures for both honeycomb core and composite laminate to be a first order task of the R&D community.

Personnel training at all levels was judged to be imperative to prepare for the increase in composite usage. The ACSWG concluded that the benefits of expanded training would have immediate return and recommended a combined initiative amongst the ALC's to promote uniformity in training and reduce the costs of such training.

The ACSWG found all ALC's planning for or in process of developing facilities for composites. It was recommended that a lead ALC be designated for developing techniques, training equipment needs etc. and then transferring this capability efficiently to other ALC's as required.

The concern for nonvisible impact damage and its effect on structural integrity, inspection and maintenance is high. The working group believed that this source of damage should be given highest attention in the development of damage tolerance design criteria.

Battle damage tolerance and battle damage repair were found to be topics requiring immediate attention both in terms of defining hardening requirements for new systems and repair program development.

In-service inspections and the requirement to some day have to conduct 100% inspection of large surfaces was judged to be the impetus to develop fast, automated inspection techniques for field and depot use.

The working group found general concensus for the requirement to address supportability early in systems development with clearly defined goals/objectives and specific data requirements being incorporated in the contractual documents. Among the factors to be addressed were: Defined repair concepts, specific repair development, an adoption of design features to enhance supportability and toughen the structure to maintenance and service damage. The group recommended early and frequent supportability reviews to be held in conjunction with the Logistics Support Assessment and Preliminary Design Reviews. The purpose of these reviews to insure that durable design features and maintenance considerations are being incorporated.

1.0 SUMMARY

The Steering Committee for Composite Material Repair and Composite Nondestructive Inspection was established at the request, Reference (a), of the Assistant Commander for Logistic/Fleet Support (AIR-04). This action resulted from concern for the Navy's capability to support weapon systems in production and under development which utilize composite materials in structural/non-structural components.

Reference (a) required the committee to: assess the requirements for support of the weapons system; contrast these with the existing or planned capabilities; identify the limitations; and state the actions required to alleviate the current or anticipated limitations.

The Steering Committee has reviewed the elements considered critical in determining the readiness of the Navy to maintain aircraft making extensive use of composite materials. This capability is particularly relevant to the F-18 and the AV-8B which have 9.5% and 26.0% respectively of their structural weight in composites. Emphasis in this report has been given to the F-18 because of its earlier deployment.

It is emphasized that this report sets forth the situation at a particular stage, or point in time, of a rapidly changing evolutionary process. For this reason, final and conclusive opinions would have debatable credence. Therefore, the report presents the facts and status as they are known and recommends courses of action, where appropriate, to insure the Navy's readiness to maintain the aircraft.

> **In summary, it is the judgement of the committee that the Navy will be capable of performing the approved composite repairs upon deployment. Inherent in this judgement is the requirement that continued reviews will track the critical elements for conformance to established schedules and that action will be taken on the recommendations presented in this report.**

A summary of the critical elements considered and the findings are presented on the following three pages.

Maintenance Plans - The Maintenance Plan/Logistic Support Analyses (MP/LSA's) for the F-18 were approved in May 1982 and are now undergoing revision. Due to inadequacies or incompleteness of the plans and the relatively short time remaining until the aircraft (F-18/AV-8B) are introduced into the Fleet, continuing attention must be given to insuring that adequate repair procedures, listings of peculiar support equipment, materials, training requirements and inputs for technical publications are provided for all levels of maintenance. Responsibility for this action in the case of the F-18 resides with the Naval Engineering Support Office at North Island. For the AV-8B, the responsibility resides with the Naval Air Systems Command, AIR-410. Representatives of the respective organizations believe that scheduled milestones relative to all essential aspects of the plans are being met.

Technical Manuals - The F-18 contractor has progressively defined and prepared Organizational ("O") and Intermediate ("I"), and Depot ("D") level composite repair procedures for incorporation into the structural repair technical manuals. Initial technical manuals have been received by the Navy for approval based on the contractor's validation.

The manuals have been reviewed at various stages by the Naval Air Systems Command (NAVAIRSYSCOM), Naval Air Technical Service Facility (NAVAIR-TECHSERVFAC), Fleet Personnel, and engineering personnel at the Naval Air Rework Facility at North Island and to a limited extent by the Naval Air Development Center. The manuals are not complete at this time. Additional detailed information and procedures are continuing to be prepared by McDonnell Douglas (MCAIR) for inclusion in the manuals. It is essential that continued monitoring of this work be performed to insure the timeliness and quality of the additions and modifications. The Navy, Air-410, will continuously approve and order "O" and "I" level repair manuals as changes occur in 1982. The completion date for this milestone as shown in Appendix D is January 1983. NAVAIRTECHSERVFAC has responsibility for the scheduling of reviews and adherence to the established milestone.

Materials for Repairs - Capability for repairs, both bolted and bonded, will be available within the limitations established by the repair manuals. There are, however, clear requirements for successful completion of research and development work now in progress to optimize materials and processes for bonded repairs and to validate the use of a more readily formable and machinable alloy than the titanium alloy currently considered for bolted repairs.

Pending the availability of approved adhesives without limited storage requirements, NAVAIRSYSCOM should initiate an interim supply procedure similar to that established for handling the refrigerated adhesives for the F-14 aircraft.

Nondestructive Inspection (NDI) - In general, the types of defects and/or damage found in composite material can be detected by the available techniques and equipment. However, current Fleet equipment is manually operated and will require excessive aircraft down time in order to perform required large area composite inspections. Consequently, there is a need to develop an automated system for large area inspections which will greatly facilitate the inspection process and reduce the number of maintenance man hours required.

Facilities - Site Activation Surveys have been completed for the USS Constellation, Independence, Ranger and Kennedy. The composite repair facilities have been planned by the Naval Air Engineering Center (NAVAIRENGCEN) in conjunction with the Naval Sea Systems Command (NAVSEASYSCOM). Special attention has been given to contamination control, safety, and health factors. Procurement and planned installation of equipment for the USS Constellation is progressing on schedule.

The Naval Air Rework Facilities (NAVAIREWORKFACs) at Cherry Point and North Island, San Diego, respectively, have requested military construction (MILCON) support for their AV-8B and F/A-18A composite components facilities. The Cherry Point MILCON facility will be required by FY-87, whereas the San Diego facility is scheduled for completion by late 1984. Prior to completion of the facilities, repair of major damage based on a capability assessment will be accomplished either by the contractor or the NAVAIREWORKFAC through the use of F-14 and F-18 composite repair kits in conjunction with existing support equipment.

Composite Material and Repair Steering Committee
Recommended Action Items

Specific actions were generated as the result of the work of the Composite Material Repair and Composite Nondestructive Inspection Steering Committee and are presented in the following paragraphs. The items should be reviewed by the cognizant NAVAIR codes in the context of the Steering Committees report and appropriate implementing actions taken.

While certain of the listed items are being monitored and have been given some attention they were identified here as areas which require continued monitoring and expeditious implementation.

Maintenance Plans.

Continued Contractor/Navy monitoring to insure that simple generic repairs, whether of the bolt-on-patch or the bonded type are validated. (AIR-410* AIR-411).

Manuals.

Task the Composite Structures and Materials personnel from the Naval Air Development Center to participate in the on-going reviews of the structural repair manuals. (AIR-410*, AIR-311, AIR-530, NAVIRTECHSERFAC).

Materials for Repairs.

Establish an interim stand-by supply procedure for refrigerated adhesives pending the availability of non-refrigerated adhesives with longer storage life. (AIR-410* AIR-411, Naval Aviation Supply Office).

Accelerate the following: (1) Development of a non-autoclave processing method. (2) Develop criteria for moisture content limitation guideline/procedures for field and depot level repairs. (AIR-311* AIR-530, AIR-411, NAVAIRDEVCEN).

Accelerate test and verification of repair procedures using ambient temperature storeable resins and adhesives to permit organizational repairs without requirement for refrigerated material. (AIR-311*, AIR-530, NAVAIRDEVCEN).

Establish design data for selection of the optimum metallic material from bolt-on patches from viewpoint of strength/compatability and machinability (AIR-311* AIR-530).

Nondestructive Inspection (NDI).

Initiate the development of a procedure for large area nondestructive inspection of composite structures and equipment. (AIR-522*, AIR-410).

Expedite the development of ultrasonic inspection standards for composites structures. (AIR-552).

Expedite the development of an effective ultrasonic transducer/equipment specification. (AIR-552, NAVAIRDEVCEN).

Training.

Incorporate generic composite repair training in the present structural mechanics A school at Memphis.

Update and expand training programs at NAVAIREWORKFACS as new procedures, materials, and field experience dictate (AIR-412).

*Recommended Coordinator

OFFICE OF THE SECRETARY OF DEFENSE

WASHINGTON, D.C. 20301

22 MAR 1983

MEMORANDUM FOR DISTRIBUTION

SUBJECT: Joint Services Aircraft Technology and Safety Review

This is to provide information on the Joint Services Aircraft Technology Review to be held on May 10-12, 1983, at Wright-Patterson AFB, Ohio. In a joint memorandum of 27 August 1982 to the Assistant Secretaries of the Military Departments, Mr. James N. Juliana, Principal Deputy Assistant Secretary of Defense (Manpower, Reserve Affairs, and Logistics) and Dr. Edith W. Martin, Deputy Under Secretary of Defense for Research and Engineering (Research and Advanced Technology), established a tri-Service Joint Topical Review on Aircraft Technology and Safety. The purpose of this review is to provide an opportunity for cognizant technical and safety personnel from each of the Services to review on-going and planned technology base programs and identify safety related issues on such topics as cockpit design, mishap analysis tools, damage tolerance, maintenance, advanced flight controls, advanced structures, and expanded envelope capability. It will also provide an opportunity for identifying program omissions and gaps presently known or anticipated. Methods of enhancing inter-Service and interdisciplinary coordination and cooperation will be discussed also.

A working group, composed of members from each of the Services, FAA, and NASA, and co-chaired by the undersigned, developed the scope and structure of a detailed agenda for the topical review. The three day agenda consists of the first day of presentations and panel discussions on aviation safety; the second day devoted to presentations and panel discussions on aircraft technology programs, and a third day for the administrative wrap-up of the working group.

The panels will be composed of members from each of the participating agencies, with the chairman designated by the working group. A list of issues developed by the working group is attached with selected presenters and panel chairmen and members, including addresses and phone numbers, indicated. Each of the addressees has been advised by their respective working group members that they have been selected to participate.

Each panel will meet at the call of the Chairman and at a mutually agreed upon place (effort should be made to minimize the overall travel required), to address the following:

- What are the current problems or issues?
- What current programs do we have that address these problems and issues (includes all three Services, FAA and NASA)?
- Are the problems being adequately addressed? If not, why not?
- Are there any remaining gaps? What are we planning to do about them? What is the impact of not filling the gaps?

Each panel will have one hour in the afternoon of the meeting, as indicated, to present their findings. It is suggested that a spokesman be selected to present a thirty minute summary of the panel findings and use the remaining thirty minutes for discussion.

Each panel is requested to submit a point paper summarizing the panel findings to the co-chairmen of the working group no later than 3 May 1983: If you have any questions, please call either co-chairman, Stuart Nelson, Director of Safety Policy, OASD (MRA&L), Autovon 225-0110, or Raymond Siewert, Director, Military Systems Technology, OUSDRE, Autovon 227-7922.

Stuart Nelson

Stuart Nelson
Acting Deputy Secretary of Defense
(Equal Opportunity and Safety Policy)

Raymond F. Siewert

Raymond F. Siewert
Director
Military Systems Technology

FLIGHT SERVICE EXPERIENCE AND ENVIRONMENTAL EFFECTS ON COMPOSITE AIRCRAFT MATERIALS

H. BENSON DEXTER
NASA LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

OSD/IDA R&M STUDY
COMPOSITE TECHNOLOGY STUDY GROUP
MAY 5, 1983

SUMMARY OF RESULTS

FLIGHT SERVICE EXPERIENCE

- ONLY MINOR IN-SERVICE DAMAGE EXPERIENCED WITH OVER 300 COMPOSITE COMPONENTS DURING 9 YEARS AND 2.8 MILLION FLIGHT HOURS.
- STRENGTH REDUCTION OF GRAPHITE/EPOXY REINFORCED ALUMINUM SPOILERS IS A FUNCTION OF DESIGN RELATED CORROSION.
- ROOM TEMPERATURE CURE EPOXIES ARE CURRENTLY BEING USED FOR MOST FIELD REPAIRS.

OUTDOOR ENVIRONMENTAL EFFECTS

- MOISTURE ABSORPTION RANGED FROM 0.5 TO 2.5 PERCENT FOR SIX COMPOSITE MATERIAL SYSTEMS EXPOSED AT SIX WORLDWIDE LOCATIONS.
- UNPAINTED SHORT BEAM SHEAR SPECIMENS INCURRED UP TO 15 PERCENT ROOM TEMPERATURE STRENGTH REDUCTION AFTER 7 YEARS EXPOSURE.
- SURFACE DEGRADATION DUE TO ULTRAVIOLET RADIATION WAS EXPERIENCED WITH UNPAINTED COMPOSITE SPECIMENS.

LABORATORY ENVIRONMENTAL EFFECTS

- STRENGTH REDUCTION AS A FUNCTION OF MOISTURE ABSORPTION AND TEMPERATURE WAS DETERMINED.
- 5 YEARS CONTINUOUS EXPOSURE TO AIRCRAFT FLUIDS DEGRADED THE SHEAR STRENGTH OF GRAPHITE/EPOXY UP TO 40 PERCENT.
- ULTRAVIOLET DEGRADATION WAS CONTROLLED BY AIRCRAFT PAINT.

USAF DEPOT AND FIELD EXPERIENCE WITH COMPOSITE REPAIR

BRIEFERS SUMMARY
BILL SCHWEINBERG WR-ALC/MMTRC
ROBINS AFB GA (912) 926-2656

MOST OF THE AIR FORCES EXPERIENCE WITH COMPOSITE REPAIR HAS BEEN ON THE F-15 DUE TO IT'S LONGER TIME IN SERVICE. THERE ARE NUMEROUS PROBLEMS WITH COMPOSITE REPAIR WHICH WERE DISCUSSED IN DETAIL DURING THE BRIEFING, THE MAJOR PROBLEMS OR CONCERNS ARE:

1. MOISTURE IN THE LAMINATE & CORE WHICH REQUIRES LENTHY DRYING TIMES BEFORE REPAIR. THERE IS NO EASY WAY TO DETERMINE MOISTURE CONTENT OR ACTUAL DRYING TIME REQUIRED.

2. NO TOP SACRIFICIAL OR SCRIM PLY WHICH ALLOWS ALMOST ANY IMPACT TO REQUIRE REPAIR OF THE COMPOSITE. NO REAL ROOM FOR COSMETIC DAMAGE.

3. HIGH STRAIN RATE DESIGN WITH HONEYCOMB REQUIRES BONDED REPAIRS, NO BOLTED REPAIRS.

4. DESIGN TECHNIQUE OF INTEGRALLY BONDED TITANIUM FITTINGS & ATTACHMENTS MAKES REPAIR FOR ATTACHMENT PROBLEMS VERY DIFFICULT.

5. NO PROTECTIVE EDGE TREATMENT.

6. REPAIR MATERIAL AVAILABILITY AT FIELD LEVEL IS VERY INADEQUATE DO TO LARGE QUANTITIES MATERIAL IS SUPPLIED IN AND LIMITED SHELF LIFE. ?

MANY OF THE COMPOSITE MAINTENANCE PROBLEMS WITH THE F-15 ARE NOT REALLY THE FAULT OF THE COMPOSITE MATERIAL AS SUCH BUT ARE DUE TO A POORLY MAINTAINABLE DESIGN AND INAPPROPRIATE USAGE OF COMPOSITES WHICH APPEARS TO HAVE GENERATED FROM A PERFORMANCE FIRST CONCEPT AND A RELIANCE (IN PART) ON COMPOSITE TO MAINTAIN THAT PERFORMANCE EDGE. THE F-15 COMPOSITE DESIGNS COULD HAVE EASILY BEEN MUCH MORE MAINTAINABLE IF R&M CONSIDERATIONS WERE GIVEN JUST CONSIDERATION. IN ADDITION, THE SUPPORTABILITY PHILOSOPHY APPARENTLY USED BE THE F-15 SPO HAS CAUSED SIGNIFICANT REPAIR PROBLEMS AT DEPOT LEVEL; FOR EXAMPLE, NO TOOLING WAS PROVIDED NOR WERE THE DEPOT REPAIR MANUALS ADEQUATELY DEVELOPED. BY COMPARISON THE F-16 SPO PROVIDED A FULL COMPLETE SET OF AIRCRAFT TOOLING ALONG WITH DETAILED REPAIR MANUALS.

THE F-15 AND ITS COMPOSITES IS IN MANY WAYS LIKE THE C-141 WITH BONDED HONEYCOMB IN THE EARLY 60'S. BONDED HONEYCOMB CONSTRUCTION WAS THEN THE NEW TECHNOLOGY THAT OFFERED THE DEFINITE IMPROVEMENT IN PERFORMANCE AND PAYLOAD

AND IT WAS USED EXTENSIVELY IN THE AIRCRAFT. SOME OF THE DESIGNS AND AREAS OF USAGE WORKED FINE, BUT OTHERS WERE A TOTAL FLOP. OVER THE YEARS THERE HAVE BEEN TREMENDOUS STRIDES IN ADHESIVE BONDING DESIGN, PROCESSING AND MATERIALS WHICH HAVE HELPED CONSIDERABLY IN INCREASING THE DURABILITY OF BONDED HONEYCOMB AND WHERE THE IMPROVEMENTS ARE STILL NOT ENOUGH WE ARE TRYING DIFFERENT APPROACHES INCLUDING COMPOSITES. COMPOSITE CONSTRUCTION OFFERS TREMENDOUS POTENTIAL BUT IT MUST BE USED INTELLIGENTLY WITH R&M GIVEN REAL CONSIDERATION.

Appendix A.6

Advanced Structures Concepts R&M/Cost Assessments

Thomas N. Cook
Senior R&M Engineer
Sikorsky Aircraft Division
United Technologies Corporation

Thomas E. Condon
Aerospace Engineer
Applied Technology Laboratory
U.S. Army Research and Technology Laboratories (AVRADCOM)

PRESENTED AT THE 36TH ANNUAL FORUM
OF THE
AMERICAN HELICOPTER SOCIETY
WASHINGTON, D.C.
MAY 1980

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Appendix A.6

Preprint
No. 4

Impact of Operational Issues on Design of Advanced Composite Structures for Army Helicopters

Thomas L. House
Chief, Reliability & Maintainability Technical Area
and
Thomas E. Condon
Aerospace Engineer
Applied Technology Laboratory
US Army Research and Technology Laboratories (AVRADCOM)
Fort Eustis, Virginia

Abstract

A review of Army helicopter service experience vividly demonstrates that operationally induced failures are the dominant cause of structures maintenance requirements. Furthermore, many of these induced events will most likely exist regardless of the materials or design approaches selected for future helicopters. Recognition of this situation dictates that careful consideration be given to the general damage tolerance and repair requirements and limitations of proposed advanced (composite) structures. This paper reviews the Army's helicopter operational service history regarding structures externally induced damage and relates this knowledge to design considerations for future composite concepts. The potential problem of environmental effects on structures repairs is discussed along with the interrelationship of design/materials selection and logistic support. Finally, a review of an ATL ongoing R&D program to more fully assess the reliability, maintainability, and operational and support cost characteristics of candidate helicopter advanced structures concepts is provided.

Introduction

Generally speaking, most efforts to date regarding composite structures have been directed toward the assessment of overall structural performance/efficiency (fatigue life, strength-to-weight ratios, etc,); only a superficial consideration of R&M has existed. If composite structures are to be seriously considered for application to Army aircraft, a thorough R&M assessment is required. The Applied Technology Laboratory of the US Army Aviation Research Development and Acquisition Command's Research and Technology Laboratories (AVRADCOM) has recently initiated such an effort. This program is centering on operational aircraft experience and will also consider the rather limited operational data available for composite structures. Many areas of concern have been identified which strongly indicate that R&M consideration may have a major effect on decisions regarding application of composite structures concepts. The purpose of this paper is to review the potential benefits available from composite structures and then discuss those issues which must ultimately be considered in establishing realistic design criteria and related operational concepts. The interrelationship of operational damage, repair limitation, and overall aircraft operational effectiveness and maintenance support costs will be discussed, along with how each of these issues might affect design requirements.

Overview of Issues

The objectives of R&M improvements and evaluation of same within the Army have changed significantly in the last few years. Specifically, during the late 60's and early 70's, a rather high, continuous flying hour program (often over 70 flying hours per month per aircraft) was in evidence, and operations and maintenance support costs were major items of concern. Subsequent to the operations in Southeast Asia, however, the Army has implemented a very restrictive flying hour program (generally less than 20 hours per month per aircraft) which results in major changes in cost analyses. Specifically, even very small R&M improvements were often found to be cost beneficial during the high flying hour periods; however, many major cost reduction proposals cannot pass a strict cost effectiveness test during the very low peacetime flying hour periods. In addition to the above, the issue of "affordability" is now a major management concern. Many cost effective concepts must now be rejected simply due to the nonavailability of procurement funds. The above facts point to the importance of conducting strict total cost analyses prior to accepting application of new technology concepts. Certainly, advanced composite structure falls into the category of "new technology";

Presented at the AHS/NASA-Ames Conference on Helicopter Structures Technology, November 16-18, 1977.

Appendix A.6

Advanced Structures Concepts R&M/Cost Assessments

Thomas N. Cook
Senior R&M Engineer
Sikorsky Aircraft Division
United Technologies Corporation
Stratford, Connecticut 06602

Thomas E. Condon
Aerospace Engineer
Applied Technology Laboratory
U.S. Army Research and Technology Laboratories (AVRADCOM)
Fort Eustis, Virginia 23604

Abstract

Under two contracts with the U.S. Army's Applied Technology Laboratory at Fort Eustis, Virginia, Sikorsky Aircraft investigated the R&M and life-cycle cost potential of advanced composite airframe structures for Army helicopters and developed concepts for repair of these structures in the Army field environment. Surveys were made of in-service experience with helicopter airframe structures. Reliability and maintainability factors in composite structures design were identified and defined. Laboratory testing was conducted to assess the damage tolerance and field repairability of several composites in both monolithic and sandwich form. A method was developed to assess and rank the R&M and life-cycle cost potential of advanced structures designs. Detailed R&M analyses were conducted for an advanced composite rear fuselage for the UH-60A BLACK HAWK helicopter. Modular design was shown to be a feasible and highly cost-effective approach to the repair of major structural damage.

Introduction

The field of advanced composite materials has witnessed remarkable growth over the last few years. Until recently, applications of composite materials to aircraft were almost exclusively in the nature of fiberglass fairings and minor secondary structures. While fiberglass and secondary structural uses still predominate aircraft applications, advanced composite materials are now being used in a variety of new areas, including the design of primary structure and major dynamic components. Development work with advanced composites is expanding enormously, and airframes constructured entirely from these new materials are now receiving serious study.

Advanced composites offer a number of attractions to the aircraft designer. They combine high strength with low weight and they are adaptable to a variety of manufacturing processes. Because they lend themselves to monolithic types of construction, composites eliminate many assembly details, reduce complexity and lower manufacturing costs. In many areas, composites have greater damage tolerance and are more survivable against combat damage than metals.

An aspect of advanced composites design receiving increased attention within the Army is that of reliability and maintainability (R&M) and its associated life-cycle costs. In October 1977, the U.S. Army's Applied Technology Laboratory (ATL) at Fort Eustis, Virginia awarded a contract[1] to Sikorsky Aircraft to investigate the R&M and life-cycle cost implications of advanced composite structures for Army helicopters. In August 1979, ATL awarded a second contract[2] to Sikorsky to develop field maintenance concepts for advanced composite airframes. This paper discusses the results and conclusions of these two programs.

Service Experience With Airframe Structures

An investigation was conducted to assess the R&M experience of airframe structures in service. The investigation included a review of published data on current-inventory Army helicopters and visits to two Army helicopter depots.

Current-Inventory Army Helicopters

Published maintenance data[3] for the airframe systems of the UH-1 and CH-47 helicopters disclose remarkable similarities as shown in Table 1. The frequency of unscheduled maintenance is of course greater for the much larger airframe of the CH-47, but the breakdown of maintenance by elements of the airframe is nearly identical. A representative distribution of unscheduled maintenance events based on a composite of the service experience with these two aircraft is shown in Figure 1.

The airframe produces a substantial share of the unscheduled maintenance events on current-inventory Army helicopters. Of the total number of unscheduled maintenance actions on the airframe, roughly 20% involve primary structure, 80% secondary structure. For both primary and secondary

INSPECTION AND REPAIR OF ADVANCED COMPOSITE AIRFRAME STRUCTURES FOR HELICOPTERS

Thomas E. Condon
Aerospace Engineer
Applied Technology Laboratory
U.S. Army Research and Technology Laboratories (AVRADCOM)

Thomas N. Cook
Senior R&M Engineer
Sikorsky Aircraft Division
United Technologies Corporation

Abstract

A program was conducted to develop and demonstrate techniques for the inspection and repair of advanced composite airframe structures in the Army aircraft field environment. The study was based on advanced structures designs and design concepts incorporated in Sikorsky Aircraft's candidate for the Advanced Composite Airframe Program (ACAP), the BLACK HAWK Helicopter Composite Rear Fuselage (CRF), and the BLACK HAWK Helicopter External Stores Support System (ESSS).

Ten methods of nondestructive inspection having potential applications to advanced composite airframe structures were evaluated. Tests were conducted to assess the structural effects and visual inspectability of large subsurface flaws in primary composite structures.

Field repair methods were developed for primary airframe structures. Test panels were fabricated and ballistically damaged. The damaged test panels were repaired and statically tested to failure. The strength of the repaired panels was compared to the strength of undamaged panels, and the quality and feasibility of the repairs were evaluated.

A demonstration of modular airframe repair was conducted using a tool proofing model of the BLACK HAWK CRF. The strength of the repair joints was verified through static testing. R&M guidelines were established for the design of advanced composite airframes.

Introduction

Advanced composite materials are finding widespread application in the construction of Army helicopters. Used for many years in the fabrication of secondary structures, composites are now being used extensively in the construction of rotor system dynamic components and in some primary structural applications. The use of advanced composites as the primary material for the construction of helicopter airframes is now being aggressively pursued in a variety of Army-sponsored development programs. The ACAP, the BLACK HAWK CRF, and the BLACK HAWK ESSS are three of the major programs currently underway in the Army (Figures 1, 2 and 3). The all-graphite sponsons for the Navy MH-53E helicopter are among the largest composite structures to go into production (Figure 4).

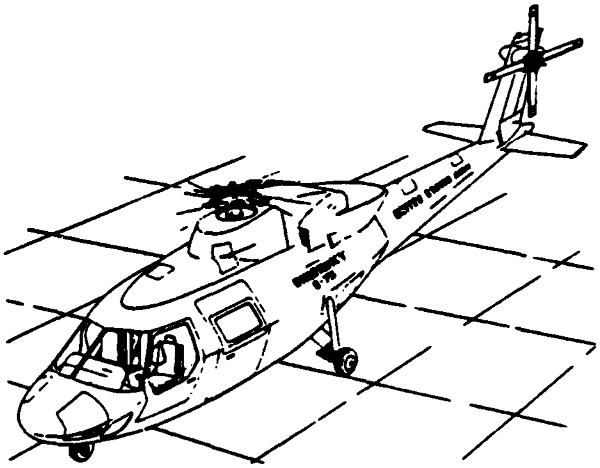

Figure 1. The Sikorsky Aircraft Candidate for the Army's Advanced Composite Airframe Program (ACAP)

In concert with programs aimed at developing the design and manufacturing technology for advanced composite airframes, the Army is exploring other important issues associated with the introduction of this new technology. Reliability and maintainability and their effect on life cycle costs are among these issues.

The program discussed in this paper is the third in a series of ATL programs investigating the R&M of advanced composite airframe structures (References 1, 2, and 3). It carries the concept studies of the previous programs into the realm of hardware development and demonstration. Its principal objective was to develop and demonstrate techniques for inspection and repair of these structures in the Army aircraft field environment.

IDA
INSTITUTE FOR
DEFENSE ANALYSES

SCIENCE AND TECHNOLOGY DIVISION
1801 N. Beauregard Street, Alexandria, Virginia 22311 • Telephone (703) 845-2000

16 March 1983

Mr. Joseph Soderquist
AWS-102
Federal Aviation Administration
800 Independence Avenue, SW
Washington, DC 20591

SUBJECT: DoD Study Entitled Steps Toward Improving the Materiel Readiness Posture of the DoD

Dear Mr. Soderquist:

The DoD has made a long-term commitment to enhance the availability of defense weapon systems in both peace and wartime environments and to do so as economically as possible. The total effort required to meet this commitment is large and a number of related efforts are under way. The product of the subject effort, managed for OSD by the Institute for Defense Analyses (IDA), will be a set of high-payoff actions designed to attain quantum improvements in the reliability and maintainability of future weapon systems (see Attachment A). These actions will focus on two key areas: the innovative use of advancing technology, and initiatives in program management and structure. Specific strategies for implementation will be developed. Finally, an overall strategy designed to achieve quantum improvements in R&M will be developed.

The technology studied in this effort will be selected according to the criteria shown in Attachment B. One of the more significant technological areas that has been highlighted for in-depth analysis is that of composites. In accordance with the interest in this technology, a work group has been established under the chairmanship of Dr. Frank Crossman, Lockheed Missiles & Space Co. You have been recommended as a well qualified member of the composites work group. Your extensive background in this area will be vital to help ensure study success and, ultimately, study concept implementation. In this endeavor, participation by you and your company is encouraged.

The statement of work for the Composites Technology Work Group is enclosed as Attachment C.

To provide more information on the objectives of the overall study and the extent of your participation, you are invited to contact Dr. Frank Crossman at (415) 858-4034, Dr. Hy Lyon at (703) 892-9333, or me at (202) 692-1748, who are the points of contact for the composites aspect of this study.

Sincerely,

Ken La Sala/(amd)

Kenneth P. LaSala
Government Resources Coordinator
New Technology Working Group
OSD-IDA R&M Study

KPL:amd
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Attachments:
- A) OUSDRE Letter/DoD Task Order
- B) Technology Selection Criteria
- C) Composites Technology Statement of Work

cc: Mr. John Rivoire, IDA
Dr. Hy Lyon
Dr. Frank Crossman