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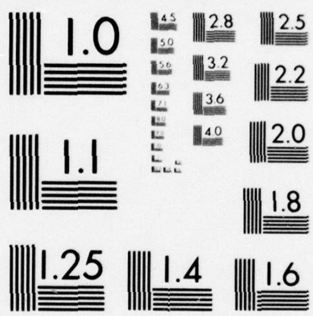

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F-18
COMPOSITE STRUCTURES DATA ANALYSIS

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Prepared by AIR-4111C3

15 September 1978

Naval Air Systems Command
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The F-18 Hornet is the first Navy aircraft to use composite structural materials extensively. It is the first aircraft to use certain combinations of graphite epoxy lamination techniques. The Navy and the DoD have a special interest in the impact on supportability of this aircraft as a result of the increased use of state-of-the-art advanced composite materials.

A listing of Navy aircraft which use or have used composite materials was developed, the ability of the Navy 3M system to collect and report useful data

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on composite repairs was analyzed and an F-18 composite structures risk analysis was conducted.

The study resulted in these recommendations:

(1) Historical 3M data should only be used to identify aircraft areas and structures which are potential problem areas.

(2) Work unit codes should be assigned to all composite structures and substructures. Work unit coding beyond the repairable assembly level will be required. Two new malfunction description code adjectives "water impregnation" and "disbonded" should be added to the coding system.

(3) Maintenance personnel should be thoroughly indoctrinated in the increased susceptibility to damage of composite structures.

(4) The feasibility of restructuring the 3M coding system to allow for coding of the cause, damage, and resulting symptom should be studied.

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EXECUTIVE SUMMARY

The F-18 Hornet is the first Navy aircraft to use composite structural materials extensively. It is the first aircraft to use certain combinations of graphite epoxy lamination techniques. The Navy and the Department of Defense have a special interest in the impact on supportability of this aircraft as a result of the increased use of state-of-the-art advanced composite materials. The purpose of this study was to:

- review the use of composite materials in aircraft in the U.S. Navy and U.S. Air Force inventory

- review the Naval Aviation Maintenance and Material Management (3M) system to determine if changes are needed to permit routine collection of maintenance data on composite materials

- collect and analyze such data as is available in the 3M system or other data sources, and

- develop an assessment of risks from the use of composite materials as supported by that analysis.

The study approach encompassed a review of current literature on developments in advanced composites and the tabulation of in-service Navy aircraft which utilize composite structures, interviews with Government and industry representatives for practical experience in utilizing automated maintenance data collection systems for analysis of composite materials, and the development of an initial data base to be used during later task efforts. The data base was then revised during repeated contacts with various agencies while investigating and verifying data during the study.

Initially, a thorough search of applicable literature was conducted in order to update the investigators' knowledge on developments in advanced composite applications. The result of the search was an understanding of the technical aspects of advanced fiber reinforced composite materials and theoretical failure modes. Additionally, a comprehensive listing of Navy aircraft which use or have used composite materials was developed.

The 3M system was reviewed with the specific objective of developing an assessment of the capability of the system for collecting and reporting useful data on maintenance impact problems associated with the use of composite structures. Several Navy and Air Force agencies were contacted in order to supplement the review with "real world" experience on the usefulness of data collection systems for this application. The result of this review was a recommendation for an expanded use of work unit codes and the addition of two malfunction description codes.

The 3M and Adjustment of Scheduled Maintenance through Analysis (ASMRA) systems were utilized to retrieve available data on composite structures. The data was analyzed with the objective of assessing areas of risk resulting from the use of composites on the F-18. The result of this analysis was the development of a listing of F-18 structures in rank order based on expected impact on maintenance resources.

The study resulted in the following conclusions:

- Historical 3M data on composite structures is extremely limited and data on graphite epoxy GR/EP structures is nearly nonexistent.

- Minor changes in work unit coding of repairable structures and the addition of at least two new malfunction description codes will be required to increase the usefulness of 3M data in the composites area.

- Damage caused during ground maintenance, servicing, and weapons loading, etc., will be the predominant cause of composite structures maintenance requirements.

- A major restructuring of the malfunction description coding system is required to make the coded data of optimum usefulness in describing the cause, damage and symptoms associated with repair actions.

The study findings lead to the following recommendations:

- Historical 3M data should only be used to identify aircraft areas and structures which are potential problem areas.

- Work unit codes should be assigned to all composite structures and substructures. Work unit coding beyond the repairable assembly level will be required. Two new malfunction description code adjectives "water impregnation" and "disbonded" should be added to the coding system.

- Maintenance personnel should be thoroughly indoctrinated on the increased susceptibility to damage of composite structures.

- The feasibility of restructuring the 3M coding system to allow for coding of the cause, damage, and resulting symptom should be studied.

CHAPTER 1

INTRODUCTION

1.1 Background

The aerospace industry uses the term composite or advanced composite in reference to a class of structural materials similar to automotive fiberglass. Actually, fiberglass is a composite material which combines glass fibers with a polymer (resin) substance. Advanced composites use special types of fibers and resins to form very strong materials which offer certain advantages over other aircraft structural materials. These concepts are more thoroughly discussed in the technical material attached as Appendix A.

The F-18 is a derivative of the YF-17 light weight fighter which was designed to provide improved operational capability primarily due to a significant increase in the aircraft thrust to weight ratio. The 8:1 class thrust/weight ratio of the F-18 was achieved partly through the increased use of composite structural materials. The F-18 Hornet will be the first Navy aircraft to utilize composite materials extensively. The Hornet is to replace the aging F-4 some of which use a composite rudder assembly which represents 0.1% of the aircraft weight. The other aircraft to be replaced by the Hornet is the A-7, which has no composite structural surfaces. The newest in-service Navy aircraft, the F-14, utilizes composite material horizontal stabilizers which amount to 0.4% of aircraft weight. By comparison the F-18 is to have graphite/epoxy vertical tail fins, horizontal tail structures, speed brake panel, fuselage central section, skins on the main wings and flaps, as well as landing gear and other doors, which represents 9.5% of total aircraft weight.

The Navy and the Department of Defense have a special interest in the impact on supportability of this aircraft as a result of this use of composite materials. Currently, the Project Manager for the F-18 aircraft is sponsoring numerous studies concerning reliability, maintainability and supportability of this weapon system. This report documents one of these studies.

1.2 Study Purpose

The purpose of this study was to review the use of composite materials in aircraft in the U.S. Navy and U.S. Air Force inventory; to review the Naval Aviation Maintenance and Material Management (3M) system to determine if changes are needed to permit routine collection of maintenance data on composite materials; to collect and analyze such data as is available in the 3M system or other data sources; and to develop an assessment of risks from the use of composite materials as supported by that data analysis.

1.3 Study Approach

The technical approach used in this study was directed toward assessing the capability of the 3M maintenance data collection system for collecting and reporting useful information on composite aircraft structures, and analysing currently available 3M and other data on composite and other aircraft structures in order to identify potential risks as they might apply to the F-18 aircraft. The approach established a technical documentation and personnel liaison data source/base which was used in an iterative looping fashion throughout the study.

The initial project activity involved an extensive literature search performed to update the project team's knowledge on technological developments in the composite materials field and to give the team an in-depth understanding of the various aerospace applications of these materials. This literature search was tailored to provide the investigators with a grasp of the chronological developments and applications of composites in the aerospace industry. The end result of this initial effort was a listing of composite materials by type of Navy aircraft currently in service. A by product of this search of the literature was an updated technical understanding of current composite materials production methods and theoretical failure modes.

The second major activity was the establishment of liaison between the investigators and various Navy and Air Force agencies expected to have experience and data sources concerning composite materials used in military aircraft. The primary data sources in this effort were the Navy intermediate and depot repair activities supporting the F-14 aircraft, the Naval Air Systems Command Library containing Maintenance Support Office Department (MSOD) reports, the Air Force component repair and depot activities providing support to the F-15 aircraft, and the Air Force Materials and Flight Dynamics Laboratories at Wright Patterson AFB, Ohio. During initial discussions, general data system and codes were covered as well as general composites failure experience. During this time period McDonnell Aircraft Company (MCAIR) was awarded a contract to do a somewhat parallel study on the maintenance data collection system (3M). Their purpose was to investigate the use of How Mal codes and to develop a new supplementary coding system involving fault isolation and detection. Liaison was established between this study group and the MCAIR "code development team". During discussions, preliminary findings were exchanged.

As anticipated, the investigation was handled as a building block process where data gathered from one source required complementary data collection and verification from other sources. For example, discussions with Air Force depot representatives on failure modes and repairs raised questions on data collection procedures which led to follow-on discussions with Navy depot repair and data analysis personnel. The central project activity involved numerous telephone interviews and follow-on data exchanges, visits to Navy and Air Force activities, and the review/analysis of 3M and Air Force provided reports.

The data retrieval/analysis portion of the study effort was individually documented by aircraft and is included in Appendix D. The following chapters document the detailed findings of the study.

CHAPTER 2

COMPOSITES MATERIALS USAGE ON NAVAL AIRCRAFT

2.1 Introduction

The purpose of this chapter is to review the evolution of composites usage and present a comprehensive listing of composite materials currently in use on Naval aircraft. Until recently composite materials usage on military aircraft was largely for purposes of research and data gathering. As will be shown, large scale Navy use of composite materials has been limited almost exclusively to the F-14 Tomcat. However, there are numerous other aircraft which have had composite structures installed which may provide a somewhat broader data base for use in later analysis tasks. In order to put this subject in perspective, the following paragraphs will briefly describe the chronology of using composite materials on military fighter aircraft similar to the F-18.

2.2 Early Composites Use

Written sources differ in their assessment of the time span of composite material usage in aircraft structures. Some sources mention that composites have been in use for over twenty five years while others say that composite materials technology has developed during the past decade. Both positions are correct depending on whether one is discussing composites in general or advanced composites as the later developments are called.

Glass fiber reinforced plastic (GFRP), better known to the layman as "fiberglass" was the composite structural material which was used in several aircraft and missile applications between 1943 and 1963. The commercial development and production of glass fibers during the 1930's together with the invention of low pressure polymerizable polyester resine in 1939 made this possible. (See Appendix C for a definition of terms.) GFRP materials were first developed and designed for aircraft structures in 1943. The Vultee BT-15 had the first aircraft structures made of fiberglass. The first fiberglass radomes were produced for the WWII B-17 and B-29. The U.S. Air Force Wright Air Development Center was pioneering this early work which included the fabrication of reinforced plastic outer wing panels for the AT-6 airplane in 1946. Epoxy resins were invented in 1950 and this development overcame earlier problems with weather deterioration of the material.

The first production aircraft to use composite GFRP was the A-1E, for which Grumman Aircraft Corp produced fiberglass vertical tail structures. The A-1E used GFRP primarily to solve electronic radiation reflection problems in this special purpose aircraft. This occurred during the mid 1960s which was a milestone period for composite technology development. Boron fibers were developed during this period and this marked the beginning of the advanced filamentary composites

Boron fiber reinforcement offered a significant improvement in the strength of composite materials. Treatment of the chemical engineering and structural engineering aspects of composite materials is considered beyond the scope of this report. The following list of advantages of composites over conventional structure materials is offered merely to demonstrate the motivation which drove the developmental efforts in this area:

- Composites offered a potential for 50% reduction in weight for the same strength.
- Composites offered a 100% improvement in fatigue life characteristics over titanium which is the best of structural metal for fatigue resistance.
- Composite aircraft structures generally could be manufactured using a reduced number of individual parts which equated to lower tooling, fabrication and handling costs and also to improved reliability due to the reduced number of joints and discontinuities in the structure.
- Composites offered a significant improvement in corrosion resistance since the composite material is not susceptible to electrochemical corrosion.
- Composites offered a structural damping effect on vibration and noise transmission.
- Composites offered an elastic behaviour which made it uniquely less susceptible to battle damage and various types of material failure. For example, projectile impacts are localized to an area very slightly larger than the projectile itself. Projectile hits on metal typically result in cracks, bent and shredded metal which are vulnerable to further tearing due to air pressure and stress in flight. Impact damage to automobiles provides an example of this concept. Collision damage to metal auto parts typically results in a deformation of the metal which is proportional to the impact force. Collision damage to fiberglass auto parts typically gouges and cracks the material but the component flexes back to its original shape and is generally easier to repair rather than replace.
- Composites offered a potential for improved flight performance due to the smooth drag free surfaces.
- Composites offered less radar reflective surface. GFRP offered 50% decrease in radar energy reflection.

With the impressive list of advantages presented above, one may wonder why there wasn't a rush toward immediate large scale use of composites in aircraft structures. As with many technological innovations there were four factors which had to be dealt with. The first involved the cost of the new advanced composites. The costly fibers even when mixed with the less costly resin material (in the appropriate mix) were nearly $300 per pound in the late 1960s; by contrast structural aluminum cost was $10 per pound. Careful trade studies were required in order to justify the expensive composites. These studies were based primarily on weight savings factors and the fuel savings resulting from the lighter weight. The second factor was the unknown long term effects of the elements and stress on the composite materials. The third factor was that while conventional metal structures production procedures were well established, efficient cost effective techniques for production of composite aircraft structures needed to be worked out. The last factor was the problem of repairing composites under the conditions reasonably achievable in non-depot military repair facilities. This problem is of particular interest to the Navy because of the requirement for repairs aboard ship.

2.3 Research Projects

Numerous research projects were undertaken between the mid 1960s and 1970s in order to gather data on these unknowns. Several of the projects will be summarized in the paragraphs which follow.

A number of research projects involving commercial and transport aircraft, missiles and aerospace applications, propulsion system applications as well as VSTOL and fighter applications were sponsored by a variety of agencies. In addition graphite and other fibers such as quartz crystals were developed during the mid 1970s. For aircraft structures boron epoxy and graphite epoxy have demonstrated the optimum strength and flexibility characteristics and have therefore been the dominant materials used in aircraft applications. Additionally, as usage has increased the cost of these materials has decreased significantly and is projected to continue in this direction while the cost of conventional metals has been increasing. Boron and graphite epoxies had dropped from approximately \$300 per pound in 1968 to approximately \$100 per pound in 1974. By 1976 boron epoxy had remained at approximately \$100 per pound while graphite epoxy had dropped to \$45 per pound and is projected to be less than \$10 per pound in the 1980s.

During the 1960s at least ten flight test programs were performed on military jet fighter type aircraft. None of these were production/prototype development efforts, but were research projects to replace metal aircraft structures with composites for experimental purposes.

Boron epoxy center "wing box" sections were flight tested on a T-39 aircraft in order to accomplish relative weight studies and gather data on strain/fatigue. Aluminum skin sections of an F-111 horizontal stabilizer box were replaced with boron epoxy structures in order to demonstrate the effects of flutter on this material. The F-111 component was made of boron-epoxy skins, fiberglass spars and honeycomb core with a titanium root rib, pilot fitting, and tip rib. Load to failure tests were conducted to demonstrate strain relationships and compatibility of boron epoxy to titanium lamination. Flight test articles were installed on an F-111 and a one year test program began in March 1967. The test article demonstrated excellent serviceability and a weight savings of approximately 30 percent. Three test programs were conducted on F-100 wing skins over a two year period. Ground and flight testing data was gathered on strength, weight, flutter, aeroelasticity, stability/control and aerothermodynamics. Testing also demonstrated the effects of various flight loads on structural integrity in the composite wing design.

In 1965 an OV-10 was modified with a full seven foot center wing composite section which extended across the top of the fuselage. A weight savings of 40 percent was achieved utilizing composite upper fuel cell door in the wing skin, and adhesive bonded skin to spar tongue in groove joints. A glass filament wound wing was produced for a T-2B aircraft in 1969 to demonstrate advanced manufacturing methods. The low cost wing section exhibited a 40 percent weight savings while providing 165 percent of load requirement. The fabrication cost was competitive with production costs for metal structures.

The early 1970s were witness to continued feasibility demonstrations in the use of composite aircraft structures. Larger scale in-service testing programs were conducted on the F-111 and F-4 aircraft. Forty five F-4s were equipped with boron/epoxy rudders and accumulated some 51,000 flight hours. Data on these structures was collected and analyzed by the Air Force Flight Dynamics Laboratory at Wright Patterson Air Force Base. Twenty-two boron/epoxy wing trailing edge panels accumulated over 32,000 flight hours on F-111 aircraft. Additionally, 266 graphite/epoxy underwing fairing assemblies accumulated 44,700 flight hours on selected F-111s.

During the early to mid 1970s the Navy sponsored numerous evaluations of the less costly Graphite/Epoxy (GR/EP) composite materials. Fourteen S-3s were equipped with GR/EP spoilers, four F-4Js were equipped with GR/EP access doors, GR/EP landing gear doors were tested on nine F-14s, and five F-14s were fitted with GR/EP overwing fairings. These tests, coupled with the results of previous research projects, firmly established the feasibility of advanced composites for Navy aircraft. The Navy then desired to establish a sufficient data base to establish confidence in the long term service durability of composite aircraft structures.

2.4 Composites In Original Design

The test programs discussed this far were conducted by replacing structures originally designed using conventional metal materials with composite replacement assemblies. Sufficient favorable findings had been gathered by the time the F-14 and F-15 were being designed (at approximately the 1969/1970 time frame) to warrant conceptual design of composite structures for these aircraft. The tail structures of both of these aircraft were designed to be produced using boron/epoxy. By 1976, 5,000 flight hours had been accumulated on the F-15 empennage assembly when a decision was made to replace the conventional metal speed brake with one of composite material makeup.

Northrop Corporation invested in non metal structures technology beginning in 1966 in preparation for the "Light Weight Fighter" competition. While the General Dynamics F-16 utilized the costly boron/epoxy only in the stiffness critical horizontal stabilizer structure, the twin engine YF-17 was designed with more extensive use of graphite/epoxy. The original YF-17 was to have GR/EP wing leading edge extensions (LEX), trailing edge flaps, speed brake panel, vertical tail leading edges and rudders and various fuselage access and engine bay doors. The F-18, which has been developed for Navy aircraft carrier operations, weighs approximately 6,000 pounds more than its nominal prototype, the YF-17. To counter this, GR/EP use was expanded to include the leading edge flaps, wing skin panels and the vertical and horizontal stabilizers. When the YF-17 was originally conceptualized, GR/EP offered the optimum performance versus cost alternative for composite use. As the development of the F-18 evolved certain new lamination techniques were incorporated in GR/EP structures, and trade studies have resulted in the return to conventional metal for the LEX and engine bay doors.

2.5 Composites Usage

Figure 2-1 reflects the current composite structures and materials to be used on the F-18. Additionally, this figure also lists aircraft currently in the Navy inventory which utilize or have utilized composite structures. Figure 2-2 graphically portrays the extent of composites usage on the F-18. Figure 2-3 is a listing of other military aircraft which use or have used composite structures during test programs.

The literature review performed to develop the data presented in Figures 2-1and 2-3 has resulted in three findings which impact later study tasks. First, while some ten aircraft currently in the Navy inventory have used composite structures (during tests), not all of any one type of aircraft can be expected to still have the composite structure currently on the aircraft. The exception to this statement is the F-14, which uses a production composite horizontal stabilizer assembly. Second, the ideal procedure for accomplishment of the data collection and analysis would have been to collect data on graphite epoxy structures on existing Navy aircraft. Figure 2-1 shows that very little such data is available since GFRP and Boron Epoxy have been utilized predominantly. Third, it was concluded that a variety of Navy and Air Force agencies have been involved in the review of data related to composite structures. Contact was made with several of these agencies to gain a better perspective for this report.

Naval Aircraft Composite Component(s) Usage

AIRCRAFT	COMPOSITE COMPONENT	COMPOSITE MATERIAL
BT-16	Aft Fuselage	E Glass GFRP
AT-6	Wing	E Glass GFRP
*E-2	Vertical Stabilizer	S Glass GFRP
T-2	Tail Structure	S Glass GFRP
RA-5C	Leading Edge (Wing)	S Glass GFRP
OV-10A	Wing Surfaces	Boron Epoxy
*P-3	Tail Pod	S Glass GFRP
*F-5	Landing Gear Doors	Boron Epoxy
	Leading Edge Flaps	Graphite Epoxy
	Trailing Edge Flaps	Graphite Epoxy
	Horizontal Stabilizer	Boron Epoxy
*S-3	Spoilers	Graphie Epoxy
*F-14	Horizontal Stabilizer	Boron Epoxy
*A-4	Horizontal Stabilizer	Boron Epoxy
	Flaps	Boron Epoxy
*F-4J	Rudder,	Boron Epoxy,
	Access Doors	Graphite Epoxy
YF-17 (F-18 Prototype)	Wing Leading Edge Extensions	Graphite Epoxy
	Speed Brake Panel	Graphite Epoxy
	Vertical Tail Leading Edges	Graphite Epoxy
	Rudders	Graphite Epoxy

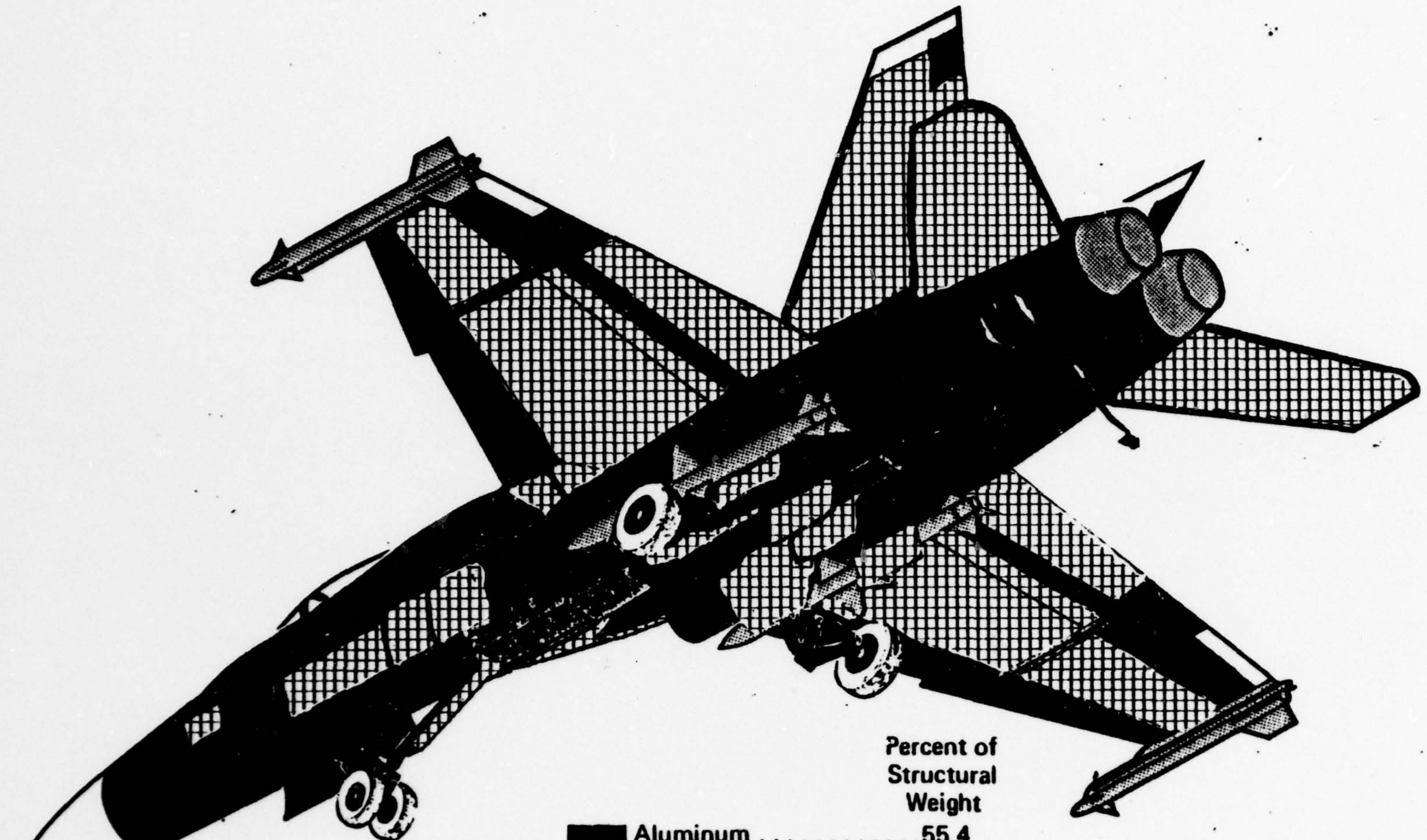
Figure 2-1

Fuselage/Engine Access Doors	Graphite Epoxy
Landing Gear Doors	Graphite Epoxy
Leading Edge Flaps	Graphite Epoxy
Trailing Edge Flaps	Graphite Epoxy
Horizontal Stabilizer	Graphite Epoxy
Cockpit Instrument Panel Cover	Kelvar Epoxy
Environmental Control System Ducts	Kelvar Epoxy

* denotes aircraft that are currently in the Navy inventory.

Figure 2-1 (Continued)

F-18 MATERIALS DISTRIBUTION



	Percent of Structural Weight
Aluminum	55.4
Steel	14.1
Titanium	8.4
Graphite/Epoxy	10.3
Other	11.8
	100.0

Figure 2-2

Other Military Composite Component(s) Usage

AIRCRAFT	COMPONENT	COMPOSITE MATERIAL
A-1E	Vertical Tail Sections	GFRP
T-39	Wing Box	Boron Epoxy
F-111	Horizontal Stabilizer Box	Boron Epoxy & GFRP
F-111	Air Flow Deflector Door	Boron Epoxy
F-100	Wing Skin	Boron Epoxy
FX	Wing Structure	Boron Epoxy
OV-10A	Wing	Glass Filament GFRP
F-15	Vertical & Horizontal Stabilizer	Boron Epoxy
F-15	Speed Brake	Boron Epoxy
F-16	Horizontal Stabilizer	Boron Epoxy
C-5A	Wing Slat	Boron Epoxy
C-141	Gear Pod Door	Boron Epoxy
C-130	Center Wing Box	Boron Epoxy

Figure 2-3

CHAPTER 3

ANALYSIS OF THE NAVAL AVIATION MAINTENANCE AND MATERIAL MANAGEMENT (3M) SYSTEM

3.1 Introduction

Chapter 2 provided a listing of aircraft from which to select candidates for analysis in this portion of the study. The data to be retrieved and analysed was to consist of data from the 3M System and from the Adjustment of Scheduled Maintenance Through Analysis (ASMRA) System. Prior to undertaking the data retrieval and analysis, a review of the data collection system itself was performed.

The Navy's maintenance data collection system is designated the Naval Aviation Maintenance and Material Management (3M) System. It was introduced on 2 January 1965, to provide for maintenance data collection, man-hour accounting and aircraft status reporting as a part of the Naval Aviation Maintenance Program (NAMP). The primary purpose of data collection and reporting is to ensure that basic data generated by maintenance/material personnel are documented into a system data base from which tailored reports can be produced for a variety of staff and management activities.

3.2 Information Sources

The literature review revealed that a number of agencies had collected various types of data on composite structures. The first event of this task was to contact several agencies to inquire into their use of the automated Maintenance Data Collection (MDC) systems. On-site interviews were conducted with engineering and analysis representatives from Naval Air Rework Facility (NAVAIREWORKFAC) Norfolk, Virginia, the depot repair facility for the F-14 (which has the composite horizontal stabilizer). On-site interviews were also held with F-15 maintenance personnel at Langley Air Force Base. Next, personnel from the Air Force F-15 Depot (Robins AFB, Georgia) were contacted concerning their use of maintenance data collection systems for performing analysis on the F-15 composite tail structure. Additionally, the Air Force Materials Laboratory at Wright Patterson AFB, Ohio was contacted in an inquiry about the use of maintenance data collection systems during their numerous studies of composite structures.

In all cases the personnel interviewed stated a general dissatisfaction with maintenance data collection systems (Navy 3M and Air Force 66-1) as they applied to composites studies. The primary objection stated was the lack of a detailed narrative on the nature and extent of the failure as well as the lack of detail on the corrective action. Navy personnel favored use of the Computerized Unsatisfactory Report Evaluation System (CURES) because it provided the desired narratives. Navy analysts also endorsed the Grumman Company's Reliability, Maintainability, Availability Support Action Program (RMSAP) for the same reason. With the RMSAP, Grumman personnel enter Navy Maintenance Action Form (MAF) data into the company's data system including the narratives of malfunction and repair.

3.3 Northrop Study

The Structures Division of the Air Force Flight Dynamics Laboratory (AFFDL) at Wright Patterson Air Force Base sponsored a Northrop Corporation study concerned with maintenance of advanced composite structures. One of the tasks of the study involved a historical survey and collection of available data using the Air Force maintenance data collection system. The automated data collection system proved less than completely satisfactory as reflected in their second quarterly progress report:

> "Maintenance data obtained from the AFM 66-1 system and from YF-17 flight test records --- do not provide the desired amount of detail concerning the severity of damage or the specific causes of the damage. To supplement the documented historical data, personal contacts have been made with knowledgeable personnel at the ---- (Air Force Depots)."

The objective of the Northrop study was to identify design parameters which will make composite structures less susceptible to ground handling damage. The study was to be conducted in three phases; retrieval and analysis of historical data on structures, damage assessments through laboratory experiments and simulations, and developments of design criteria. Task one of the Northrop study was therefore similar in some respects to this study.

AFFDL representatives reported that there were three primary weaknesses in the 66-1 MDS which limited its usefulness in composite structures analysis. First, the assignment of work unit codes (WUC) had not been carried out to a sufficient level of indenture. The engineers desired to identify failures to the substructural component such as a spar or composite-to-metal bond joint. The WUC codes are assigned only to complete repairable assemblies. Second, malfunction codes such as dented, cracked, or punctured did not provide data on the dimensions of the damage. The third problem concerned the organizational maintenance man's selection of malfunction codes. It appeared that maintenance technicians "favored" certain codes and used them repeatedly for various similar discrepancies rather than searching for the most applicable code in the work unit code manual.

3.4 Use of Malfunction Description Codes

The use of "favorite codes" is also common in the Navy 3M system according to a McDonnell Aircraft Company (MCAIR) study. The MCAIR studied the use of "how malfunction" codes by Navy maintenance organizations. They found that while approximately 250 How Mal codes are available, the vast majority (over 90%) of all discrepancies are coded against only 46 of the codes.

The Navy 3M system originally offered over 900 How Mal codes. Many of the codes were very similar, which resulted in confusion at the organizational level and diluted data as similar discrepancies were reported under a variety of codes. Periodically, codes have been deleted and in some cases several discrepancy nomenclatures have been grouped into one numerical code. Currently some 250 How Mal codes remain in the 3M system, over 120 of which are authorized to be used on airframe, fuselage, landing gear, and flight control structures. Over 50 of these codes are applicable to composite material structures.

MCAIR representatives have stated that they intend to recommend further deletions and consolidation in order to streamline the use of the How Malfunction codes. During discussions with MCAIR, two informal recommendations were made concerning the work unit code manual and its listing of How Mal codes.

- The preface of the work unit code manual is generally used to explain the use of the various codes, i.e., work unit code, when discovered code, type maintenance code, support action code, and how malfunction code. Typically, the how malfunction code is divided into two categories - ordinary "how mal codes" and conditional "how mal codes". A clear distinction between the two categories should be provided in the explanations. Some WUC manuals currently in use don't make the distinction sufficiently clear. For example, the F-4 WUC Manual (NAVAIR 01-245FD-8) explains that the malfunction description code (How mal codes) are "used to describe equipment malfunction," while "conditional malfunction codes are those which describe a malfunction due to causes by battle damage, improper maintenance/handling, improper operation of associated equipment, etc." The F-14 WUC Manual (NAVAIR 01-F14AA-8) explains the malfunction description code but makes no mention of conditional malfunction codes. The following distinction was recommended: Non conditional malfunction description codes should reflect damage or symptoms during system/equipment operation where the resulting malfunction was caused by the work unit coded item itself or is unknown. Conditional malfunction descriptions should reflect the cause of a damaged/inoperative system which is attributable to some contributory factor. Examples of conditional malfunctions are: bird strikes, FOD, ground handling, over torqued, missing parts, moisture in the system, etc. This distinction is important in the case of composite materials which will become more obvious in later report sections.

- At least two new malfunction description code adjectives are required. One must describe damage caused by moisture penetration into composite structures. The only code in the current 3M system which could be used is 622-WET; however this is inadequate to describe the unique effects of moisture on certain composite materials. The recommended expansion to the code nomenclature is as follows: 622 - WET, accumulation of moisture, water impregnation, damage caused by moisture accumulation. The detailed explanation of the need for this code will be provided in a later section of this report. The second new malfunction description adjective should describe separation of bonded materials. The current code most closely related to this condition is delaminated which refers to the separation of sheets. Therefore the term disbonded was recommended to be added to the numerical coding of this category of damage. The code expansion will likely be: 846 - Delaminated, Disbonded, Separated.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.1 Introduction

This chapter documents the analysis of currently available 3M and other data on selected fighter aircraft structures. The overall objective of this analysis was to assess the risks from the use of composite materials in F-18 structural components. The original approach planned for this effort was to identify composite structures similar to F-18 components for which 3M data exists on aircraft currently in the Navy inventory. However, it was determined that, with the exception of the F-14 aircraft, the 3M system could not yield a significant amount of data on composite structures with a high degree of commonality (similar structure data) between the F-18 and in-service aircraft.

An alternate approach was developed as a result of this finding. Four aircraft were selected for a comparative analysis with a three fold risk assessment objective. The first objective was to develop a rank ordered listing of F-18 composite structures with respect to logistics resource requirements, the second, a determination of the relative risk pertaining to certain structures regardless of structural material, and the third to correlate the potential failure modes of the structures with the adequacy of malfunction description codes.

4.2 Selection of Aircraft for Comparative Analysis

The four Navy aircraft selected for comparative analysis were the F-14, F-4J, YF-17, and AV-8B. These aircraft were selected based on availability of data, type aircraft commonality with the F-18, and use of composite material. All aircraft selected had composite structures except the F-4J. This aircraft was included simply because it is one of the aircraft to be replaced by the F-18.

In addition to the 3M data on the four Navy aircraft, AFM 66-1 data was obtained from the Air Force on the F-111, F-104, A-37 and the A-7 which is the other aircraft to be replaced by the F-18. Structural component commonality between the Air Force A-7D and the Navy A-7E was considered sufficient to warrant use of the readily available Air Force data in lieu of performing a redundant data collection effort. The AFM 66-1 data was originally retrieved and tabulated for a Northrop Corporation study sponsored by the Air Force.

4.3 Data Compatibility and Constraints

Navy aircraft historical data was extracted from 3M Aviation Information Reports available in the NAVAIR technical library. The data, which is tabulated in Appendix D, was extracted primarily from MSOD reports A4104Z-01 and A2107, has been filtered since numerous conditional malfunction codes were screened from the failure history during preparation of these reports.

The AFM 66-1 data provided by the Air Force was also filtered but in a different way. In order to satisfy the objectives of the Northrop study specific malfunction codes were selected. "Only those 'How Malfunction Codes' pertaining to structurally related defects and damage criteria as applicable to maintenance performed both on-aircraft and off-aircraft were considered". Some of the codes used by the Air Force would fall into the conditional category in the Navy 3M system.

Consideration was given to the different data sources, somewhat different filtering criteria and different operating environments of the aircraft under consideration. Even with these constraints on the validity of a comparative analysis the investigators felt that a useful assessment of potential risks to the F-18 could be achieved.

4.4 Composite Material Failure Modes

Interviews conducted during the earlier phase of this study revealed that the majority of repairs to composite structures were required as a result of damage due to ground handling accidents rather than from material failure during flight operations. This problem is of sufficient magnitude that the Northrop Study had as its primary objective the development of design approaches to reduce damage to composite structures from ground handling.

The interviews also revealed that material failure resulting from moisture penetration through thin skin composite materials was significant and produced several types of reactions. For example, moisture which had penetrated composite skins and accumulated in aluminum honeycomb structures caused severe corrosive deterioration to the honeycomb. The Air Force now bans the use of this combination of structures (aluminum honeycomb/thin skin composite) as a result of their studies of the problem. In other instances the accumulated moisture has expanded during flight operations causing large ruptures in the composite skin material. Problems also resulting from moisture accumulation in honeycomb structures beneath composite skins have been the fluttering of flight surfaces due to the weight change and altered aerodynamic characteristics of the structures.

Air Force Flight Dynamics Laboratory engineers assured the investigators that design studies are underway to solve potential material failure problems in composite structures and that the primary risk area was that of ground handling caused damage. This problem poses a double threat in that thin laminant structures are extremely susceptible to handling damage and are therefore potential high consumers of maintenance manhours. Thick laminants present a different risk in that damage resulting from impact is usually most severe below the surface and not always easily detectable by surface damage.

As a result of the technical literature review and interviews the investigators formed the following conclusions:

- Three types of aircraft structures/surfaces will be most susceptible to damage whether they are conventional metal or composite material. These are doors, panels and surfaces located on lower portions of the aircraft in proximity to the majority of maintenance and aircraft servicing work, certain horizontal skin surfaces on top of the aircraft subject to dropped tool and damage resulting from walking or standing by maintenance personnel, and certain edge surfaces subject to bumping by maintenance stands or other ground operations equipment. Proportionally, composite structures will be higher in maintenance actions due to the greater susceptibility to ground handling damage.

- Aircraft control surfaces and doors/panels which are removable will reflect a relatively high number of maintenance actions due to damage caused on and off the aircraft.

4.5 Results of Data Analysis

Analysis of aircraft structures failure rates and maintenance manhours consumed during damage repair resulted in a tabulation of F-18 composite structures in order of expected maintenance impact. The rank ordered listing has been divided into relatively high, medium and low risk groupings for presentation in figure 4-1 below. Column A is the listing which resulted from this study's analysis of the 3M and 66-1 data. (See Appendix D.) Column B displays the rank ordering extracted from MCAIR maintainability block diagrams as of June 1977. Column C is the result of considering only YF-17 maintenance data.

EXPECTED F-18 MAINTENANCE IMPACT OF USE OF COMPOSITES

	A Consolidated Data	B MCAIR Data	C YF-17 Data
High	MLG Wheel Doors LEX Skin * Horiz Stabilizer Speed Brake Wing Skin	Horiz Stab Skin Outer Wing Skin Aileron Rudder Flap	LEX Skin * Speed Brake MLG Door Wing Skin Horiz Tail Skin
Medium	Vert Fin Skin Aileron Aft Wing Tip Flap Skin L/R NLG Door	Inner Wing Skin Speed Brake INBD MLG Door OUTBD MLG DOor L/R NLG Door	Flap Skin Vert Stab Skin Vert Stab LE MLG Strut Door Horiz Tail Act Door
Low	L/R MLG Door Vert Fin LE Rudder Vert Fin TE	LEX Skin * Vert Stab Skin Vert Stab LE Vert Stab TE	Aileron NLG Wheel Door Rudder Skin NLG Strut Door

* LEX included despite change to aluminum structure. See page 4-4 and Appendix D for the rationale.

Figure 4-1

The first objective of the data analysis was to develop a rank ordered listing of F-18 composite structures which is provided as column A of figure 4-1. Comparing columns A, B and C supports a MCAIR conclusion that the horizontal stabilizer skin and wing skin are high risk structures. MCAIR has predicted that the rudder will be a high risk structure; however, this structure did not demonstrate high failure/damage rates on Navy or Air Force aircraft surveyed. MCAIR's prediction placed the main landing gear doors in the medium risk category although they had experienced high failure rates on Air Force, Navy and YF-17 aircraft. The leading edge skin on the YF-17 is a GR/EP structure and has experienced at least twelve instances of damage. Even though the F-18 LEX will be an aluminum structure it is considered a high risk structure for two reasons. First it is highly susceptible to damage from ladders used for cockpit entry and second it presents an ideal step during maintenance work around the cockpit area. Such convenient surfaces are generally walked on regardless of no step placards.

The main landing gear doors are vulnerable to tire thrown FOD as well as ground damage due to close proximity to engine work and armament loading. Main landing gear doors have experienced sufficiently high damage rates on both Navy and Air Force aircraft surveyed to warrant placing this structure at the top of the high risk structures.

The second objective of the analysis was to determine the relative risk to certain structures regardless of structural material. The key to this objective is susceptibility to incidents/accidents during ground operation. Structures which are low on the aircraft and in high traffic areas are more susceptible to this type of damage. The antithesis of this is the rudder assembly which experienced low incidence of damage on Navy and Air Force aircraft as well as the YF-17. Main landing gear doors and the edges of horizontal stabilizer structures on the other hand experienced high incidence of damage both to composite and non-composite assemblies.

The third objective was to correlate the potential failure modes of structures with the adequacy of malfunction descriptions. This objective could not be investigated by reference to standard 3M reports. The nature of this objective requires verification of the actual damage description on the Maintenance Action Forms (MAF) with the coded description. The investigators reasoned that this subject had been adequately covered during interviews to warrant conclusions in support of the Northrop report (see paragraph 3.3).

4.6 Ground Handling Risks Summary

Data analysis, interviews and documented sources resulted in the following findings concerning risks to the F-18 aircraft.

- Neither specific information on relative severity of damage to structures nor the cause of the damage can be expected from 3M analysis.

- Historical records on in-service aircraft are predominantly concerned with conventional metal structures and can be used only in a gross sense in predicting failures of the F-18 composite structures. Only failure areas can be predicted.

- Components located in high traffic areas or low on the aircraft are most vulnerable to damage during maintenance activity.

- Components which are removed from the aircraft present a higher risk than those which are not removed. Accidents and mishandling of removable panels and doors can be expected to result in damage particularly on edges and corners.

- Dents in the honeycomb structure of "No Step" structures can be expected from maintenance personnel walking on these surfaces.

- Damage from dropped tools and other maintenance equipment can be expected on their thin skin top surface structures.

- Damage to substructures of multilayer components can be expected to be more severe than surface damage indicates.

- Substructure damage can be expected to result from accumulated moisture unless specific remedies are designed into the structures.

4.7 Plan For F-18 Composite Data Collection

A requirement exists to identify what structures/materials are being damaged, the nature of the damage and the extent of the damage. To satisfy these requirements certain minimum changes in the present work unit coding philosophy and malfunction descriptions will be necessary.

4.7.1 Work Unit Codes

Currently work unit codes are assigned primarily to repairable assemblies and subassemblies. The F-14 rudder provides a convenient example of this. The rudder structure is coded (14311) and there are nine covers, fittings and links which are repairable subassemblies to the structure which are coded separately (14312 thru 1431B). If this rudder were a composite structure with full depth honeycomb inner structure and monolithic laminate skin then these two portions of the rudder structure would need to be coded (143111, 143112) to enable identification of the structure/material requiring expenditure of logistics resources. A more extensive system of indentured coding of composite structures will generally be required. This coding will need to extend into portions of repairable assemblies.

4.7.2 Malfunction Description Codes

The evolutionary development of the present list of some 250 malfunction description codes has resulted in a lack of any logical numbering sequence. A Navy sponsored study is currently being conducted by MCAIR which is expected to result in a further consolidation of code descriptions with a new total of approximately 140 codes. As previously mentioned two new adjectives applicable to composite structures are recommended. These two descriptive terms (water impregnation and disbonded) are considered the minimum required change to improve the description of the "nature of the damage". These terms and the rational supporting their use was discussed with the MCAIR study investigators.

There are three different kinds of codes lumped under the heading of malfunction description codes. They are: cause codes which are sometimes called conditional malfunction description codes, damage codes and malfunction codes. Composite structures rarely "malfunction". They are normally "damaged" due to some "cause". The problem is that only one code can be used. When the "damage code" is used the "cause" is unknown and vice versa. In either case the extent of the damage always remains an unknown quantity in the 3M system.

An infinitely more powerful coding system could be devised, utilizing two digits to describe the cause, two digits to describe any damage, and two digits to describe the resulting malfunction. However, development of such a coding system is considered beyond the scope of this study.

In order to improve the consistency of 3M data concerning composite structures only "damage" codes should be authorized in the applicable portions of the F-18 work unit code manaul. The following codes are recommended:

CODE	DAMAGE
780	Bent, buckled, collapsed, dented, distorted, twisted
050	Blistered, peeled, pitted
070	Broken, burst, cut, punctured, ruptured, torn sheared
020	Chaffed, stripped, worn, nicked, chipped
425	Scarred, scratched, burned, gouged
185	Corroded, contaminated, eroded, deteriorated
932	Does not engage, lock or unlock properly
846	Delaminated, disbonded, separated
374	Internal failure
622	Wet, water impregnation

In the strict sense code 622 is a cause code similar to 878 - weather damage but was included as an exception due to its unique applicability to composite structures.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of the study can be summarized in the following set of conclusions:

- Although some inservice Navy aircraft have or have had composite structures installed, very little useful data on composites is available in the 3M data files. Data on graphite/epoxy (GR/EP) materials is practically nonexistent.

- The 3M system is generally adequate to collect data on composite structures; however, certain minimum modifications to work unit coding policy and use of malfunction description code usage will be necessary to provide data which is useful for maintenance problem identification.

- Damage caused during ground maintenance, servicing, weapons loading, etc., will be the predominant cause of composite structures maintenance requirements.

- The lack of a detailed narrative of the cause, effect, and extent of damage to composites is a primary weakness in the 3M and other maintenance data collection systems.

- A restructuring of the present 3M malfunction description coding system could significantly improve the level of detail provided by the coded data without necessarily increasing the number of codes.

5.2 Recommendations

The following recommendations are made on the basis of the study findings:

- Historical 3M data on Navy inservice aircraft should be used with extreme caution when making predictions concerning GR/EP structures on the F-18 aircraft. The data should primarily identify aircraft areas and structures which are potential problem areas.

- NAVAIR should direct the individual work unit coding of each individual subassembly of composite structures in order to permit computer aided analysis of materials/design problems. Two new malfunction (damage) description codes should be added to the 3M system. The "How Mal" adjectives are: moisture penetration and disbonding. These adjectives should be integrated with other appropriately grouped terms under presently available codes.

- Damage susceptibility should receive increased emphasis during maintenance technician indoctrination and training.

- The feasibility of restructuring the 3M coding system should be studied with the objective of separating the cause, damage and symptom categories of "How Mal Codes". A five or six digit code is recommended where the first two digits describe the cause, the second two digits describe any physical damage, and the third digit(s) describe the resulting symptom.

APPENDIX A

COMPOSITE STRUCTURAL MATERIALS

The information presented in this appendix has been summarized from Warren E. Jamison's technical paper entitled "Chemical Bonding At The Polymer-Fiber Interface In Structural Composite Materials", dated April 1969. This material is furnished to provide the reader with an overview of the nature of composite materials with the intended objective of understanding some of the potential failure modes of these materials. Readers interested in a more in-depth discussion in the chemical aspects of bonding and recommendations for improvement in the mechanics of composite material bonding are referred to Mr. Jamison's full report.

Introduction

A fiber reinforced polymer composite is a material in which fibrous type reinforcing elements are imbedded in a compatible polymeric matrix to yield superior structural properties. Composites employing glass fibers in polymer matrices have been widely used with both continuous fibers (filament wound rocket motor cases and pressure vessels) and semi-continuous fibers (glass cloth reinforced boat hulls, automobile bodies and radomes). However, glass is an inferior reinforcing material for applications involving highly stressed components, and the maximum potential for such applications lies in relatively short, discontinous fibers of graphite, boron and quartz.

Polymer-Fiber Relationships

In order for a fiber composite to have high strenght, the fibers must carry a significant portioin of the load. The role that the matrix plays is to space the fibers and keep them from abrading each other, to act as a barrier against chemical attack by hostile environments, and to transfer and distribute the applied loads to the individual fibers. Even assuming a perfect interfacial bond, the properties of the ploymer and fibers must be matched in accordance with the quantity of fibers present in the matrix. The advantage of using thin fibers, as opposed to relatively thick reinforcing elements such as steel wire, lies in their extremely high strength, and their high surface to volume ratio which reduces the interfacial shear stress. Table I lists tensile strengths for various materials, showing that extremely fine fibers of crystalline solids can have strengths approaching the theoretical limit. This high strength can be attributed to near perfection in the crystal structure, rather than to the high dislocation density which adds strength to steel. A property of considerable importance in the application

TABLE I. Ultimate Tensile Strengths of Materials

Material	Condition	Diameter (in.x10 -3)	Tensile Strength (psi x 10 -3)	Ref.
Graphite	Fiber	0.3	400	5
Graphite	Whisker	0.04	3500	6
Boron	Fiber	4.0	500	5
S-glass	Fiber	0.4	500	5
Steel	Wire	3.0	500	5
Iron	Whisker	0.04	1900	6
Quartz	Fiber	-	1000	3
Polyamide	Fiber	-	120	3
Polyester	Fiber	-	100	3
Tungsten	Wire	0.21	391	7

of composite materials, and even greater significance to considerations of interfacial bonding is the modulus of elasticity, the stress required to produce unit elastic strain within the proportional range of the material. The influence of relative polymer-fiber elastic moduli on interfacial bonding will be discussed in detail later. In most design applications, it is desired to maximize both strength and elastic modulus while minimizing weight. Glass and quartz possess the necessary high strength, but are inferior to graphite and boron in terms of modulus.

The required relationships between properties of the fibers and the polymer matrix are best seen through specific examples. If a perfect interfacial bond is assumed, and the fibers are oriented in the direction of the applied load, the following analysis results: An applied load will produce a certain strain in the composite. If the fibers and polymer have the same elastic modulus, the strain will produce equal stress in both materials, regardless of the quantity of fibers present. As the load is increased, the stress will increase equally until the ultimate strength of the polymer is reached. At this point, the matrix will fail and the entire load will be applied to the fibers in the region of the matrix failure. This places the fibers under unsupportably high stresses and thus the composite strength is not substantially greater than the strength of the polymer matrix. To utilize the maximum potential strength of the fibers, the fiber modulus must be considerably higher than the polymer modulus. In this situation, the polymer matrix acts to transfer the load uniformly between the fibers via a shear stress at the fiber-polymer interface. The fibers thus carry the major portion in the polymer is well below its ultimate strength. The fibers must occupy a minimum critical volume of the composite; otherwise the composite strength will be less than that of the polymer. Therefore repairs to broken/deteriorated composites will not fully replace the original strength. In all likelihood there will be an area between the original composite and the main repair bulk that is deficient in fibers, i.e. primarily polymer. Consider a polymer containing only a few fibers of extremely high modulus. Under an applied load, the strain of the "composite" will be essentially that dictated by the polymer modulus. That is, the fibers will be strained to extremely high stresses and will fail either by fracture of the fiber or by shear of the interface. The fibers thus add nothing to the strength of the composite and act as holes which reduce the effective area of the polymer. Thus, for maximum effectiveness the fibers must have a modulus considerably higher than that of the polymer and must occupy a significant portion of the composite in order to carry the load without imposing excessive stresses on the bulk polymer of the interface. Under an applied load the fibers will strain a small amount and the polymer will deform to distribute the stresses evenly.

In addition to the basic aspects of chemical bonding, factors which influence the properties of the interface are listed below:

1. Residual contamination on the fibers - Contaminants which are not removed prior to blending of the polymer resin and the fibers may act to creat regions of poor adhesion, voids and bubbles, or they may dissolve in or react with the polymer to alter the polymer properties in the region of the interface. In the chemical sense, they may act as inhibitors, initiators,

catalysts or terminators; thus affecting polymer structure and composition, particularly when the matrix is a copolymer. Contamination of composite repair material (during storage and use) may add to this problem.

2. Residual stresses - Even without external applied loads, the interface will be subjected to shear stresses caused by shrinkage of the polymer during polymerization and differential thermal expansion. If the polymer-fiber adhesive bonds are established prior to polymer gelation, as will usually be the case, subsequent shrinkage of the polymer on curing will establish compressive stresses on the fibers and will place the interface under a shear stress. If the loads applied during use act to strain the fibers in tension, the residual stresses will be additive to the service stresses and will reduce the useful strength of the composite. If the polymer is cured at a high temperature, the subsequent contraction on cooling will place the fibers in compression due to the ten-fold difference in thermal expansion coefficients between polymer and fiber materials. The resultant shear stresses at the interface will be additive to the stresses induced by shrinkage.

3. Permeation of the polymer - All polymers are permeable to various vapors to some extent. Solvents, coatings and other liquids applied to the cured composite, and even atmospheric vapors may diffuse through the polymer. Since the interface exists at a higher chemical potential than the bulk polymer, the vapors will accumulate in this region. They can react detrimentally with the fibers, cause localized swelling or otherwise modify the interfacial state. Atmospheric moisture, absorbed while the aircraft is on the ground, will freeze at altitude. The expansion may cause gradual deterioration of bonding.

4. Incomplete penetration of polymer resin into fiber bundles - Generally, to expedite manufacture of components, fibers are spun and woven into a cloth which is then molded with the polymer resin. Unless precautions are taken, the resin may not completely infiltrate the fiber bundles comprising each strand of the cloth, thus leaving voids and reducing the effectiveness of the reinforcement. This must be considered in the conduct of repairs. This problem has been substantially reduced by precoating the cloth or yarn prior to lay up of the cloth mats and by molding under high pressures. However, the precoating can raise additional problems of polymer homogeniety, absorption of impurities, etc. Since the quantity of polymer in the precoat is much less than that in the matrix, the precoat will be affected to a greater extent by soluable and reactive impurities remaining on the fibers. The use of a precoat, however, provides a means of optimizing the interface properties, since the polymer in the precoat need not have the same composition or properties as the matrix polymer.

Adhesion

Adhesion between a polymer and an inorganic solid surface can be effected by a number of different mechanisms. Epoxy-graphite composites have demonstrated exceptional strength. The composites are usually formed by precoating graphite fiber mats with a resin and subsequently polymerizing the mass with additional resin after the mats are properly positioned in a mold. The precoating should serve two functions in forming the adhesive bonds.

First, graphite has a layered crystal structure and absorbs water from the atmosphere quite readily between the layers. The epoxy precoat can react with this water to form a glycol which can then be hydrogen bonded to the remaining water absorbed in the graphite. Secondly, the precoating enhances the orientation of the polymer molecules for optimum bonding.

The ability of graphite to absorb water has been a problem in the application of polymers that are sensitive to water. Since it appears that hydrogen bonding may predominate in the adhesion of polymers to graphite, this absorption capability can be used advantageously. It is possible to remove much of the water through vacuum or thermal processing, and to intercalate other polar species between the graphite layers.

APPENDIX B
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APPENDIX C

GLOSSARY OF TERMS

Plastic: (1)	Capable of being molded or shaped
(2)	Any of the nonmetallic compounds synthetically produced, usually from organic compounds by polymerization, which can be molded into various forms and hardned, or formed into pliable sheets or films for commercial use.
Polymer:	Synthetic substance consisting of giant molecules formed from smaller molecules of the same substance.
Polymerzation:	The process of joining two or more like molecules to form a more complex molecule whose molecular weight is a multiple of the original and whose physical properties are different.
Epoxy:	A compound in which an oxygen atom is joined to two carbon atoms in a chain to form a bridge. A resin, containing epoxy groups, that polymerizes spontaneously when mixed with a diphenol, forming a strong, hard, resistant adhesive.
Diphenol:	A chemical compound $(C_6H_5)2$, the molecule of which consists of two chemically combined phenyl groups.
Phenyl:	Basis of Phenol
Phenol:	White crystaline compound (C_6H_5OH) produced from coal tar or by hydrobysis of chlorobenyene, and used to make explosives, synthetic resins, etc. It is a strong corrosive poison with a characteristic odor. Diluted it becomes carbolic acid.
Fiber Glass:	Fine spun filaments of glass made into yarn that is woven into textiles, — molded and pressed into plastic material.
Composite:	To put together (Fibers & Polymer)

1 Websters New World Dictionary, Second College Edition (New York: William Collins and World Publishing Company, 1974).

APPENDIX D

DETAILED DATA REPORTS

- Analysis of Maintenance Data Pertinent to F-18 Composite Structures (F-4J, F-14A, YF-17)
- Analysis of Maintenance Data Pertinent to AV-8B Composite Structures

Analysis of Maintenance Data Pertinent

to

F-18 Composite Structures

Enclosure (1)

INTRODUCTION

The purpose of this report is to provide an assessment of data related to maintenance parameters of composite and metal components of the following weapon systems:

F-4J

F-14A

YF-17

The analysis of data will be used to perform a comparison study for the F-18.

The approach to presenting the data and its analysis for this report is as follows:

- Identification of composite structures for the F-18
- Comparative data (3M) analysis of the F-4J, F-14A and YF-17
- Narrative Analysis

The data presented in this report was obtained from ASMRA and MSO reports of the applicable weapon systems.

AV-8B data was analyzed in a separate report because of the incompatibility of the data base used for this analysis.

The following table depicts the distribution of composite and "other" type structure materials for the F-18. The table does not address all structural areas, but shows all composite structures and a representative sampling of non-composite areas that are subject to a high degree of maintenance requirements.

F-18 COMPOSITE STRUCTURES

ITEM	MATERIAL
Speedbrake Faces	Composite
Horiz. Stab. Actr. Door	Composite
Vertical Stab. Skins	Composite
Rudder	Composite
Horiz. Stab. Skins	Composite
Horiz. Stab. Root Rib Extensions	Composite
Inner Wing Skins	Composite
Inner Wing Spars	Other
Outer Wing Torque Box Skins	Other
T.E. Flap Lower Surface	Composite
LEX Skins	Other
Aileron Skins	Other
Center Fuselage Doors (dorsal)	Composite
NLG Door Skins	Composite
MLG Door Skins	Composite
Equipment Access Doors	Composite

TABLE 1

COMPARATIVE DATA (3M) ANALYSIS OF THE F-4J, F-14A and YF-17

The data in the following tables was extracted from MSO and ASMRA reports depicting 3M data with respect to individual components and historical maintenance data. This effort was accomplished to assess the impact of maintenance requirements on components that are comparable to those depicted in Table 1.

This data is contained in the following tables:

	MSO Report A2142-01	MSO Report A2107	ASMRA
• F-4J	Table 2	Table 4	Table 6
• F-14A	Table 3	Table 5	Table 7
• YF-17	N/A	N/A	Table 8

There are no structural components made of composite material in the F-4J. In the F-14A, only the Horiz. Stab. Control Surfaces is manufactured from composites. On the other hand, a significant number of YF-17 structural composites as shown in paragraph 4 in the narrative, are composites.

COMPARATIVE DATA

Weapon System: F-4J		Reporting Period: JAN 75 – JUN 75, Flight Hours: 43,325			Reporting Period: JUL 75 – DEC 75, Flight Hours: 41,027			Reporting Period: JAN 76 – JUN 76, Flight Hours: 37,130			Reporting Period: JAN 75 – JUN 76 (AVERAGE), Flight Hours: 121,482		
WUC	Nomenclature	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH
14610	SPEEDBRAKE ASSEMBLY	6.16	1.18	.027	7.09	1.66	.028	7.78	1.78	.025	7.01	1.54	.027
1119B	STABILATOR ACTUATOR ACCESS DOOR	*	*	*	*	*	*	.45	0	.001	.45	0	.001
1118220	VERTICAL FIN SKIN	*	*	*	*	*	*	*	*	*	*	*	*
1118250	VERTICAL FIN LEADING EDGE	*	*	*	*	*	*	*	*	*	*	*	*
14414	RUDDER STRUCTURE	1.20	.23	.005	.56	.02	.005	.86	.11	.007	.87	.12	.006
14317	STABILATOR SKIN	6.53	1.13	.049	4.02	.83	.033	4.39	.62	.034	4.98	.86	.039
14212	AILERON STRUCTURE	2.61	.18	.014	2.83	.37	.021	3.10	.46	.022	2.85	.34	.019
11232	AFT WING TIP	1.98	.25	.005	1.15	.29	.004	1.45	.35	.004	1.52	.30	.004
13327	AFT NOSE LANDING GEAR DOOR	2.10	.58	.005	2.34	.17	.005	2.56	.43	.008	2.33	.39	.006
13328	FORWARD NOSE LANDING GEAR DOOR	1.96	.30	.007	2.29	.22	.011	1.99	.19	.005	2.29	.24	.008
3234	GEAR STRUT DOOR (MLG)	2.52	.48	.013	2.83	.46	.028	4.31	.70	.036	3.22	.55	.026
13235	OUTBOARD MLG DOOR	4.29	.51	.020	5.07	.51	.023	5.79	.67	.029	5.05	.56	.024
13236	INBOARD MLG DOOR	3.62	.92	.020	3.34	.58	.014	4.63	.65	.017	3.86	.72	.017

* DENOTES "NO DATA AVAILABLE" DUE TO MSO POLICY TO "EXCLUDE FROM THIS REPORT ALL WORK CODE ENTRIES FOR WHICH 12 OR LESS MAINTENANCE ACTIONS HAVE BEEN REPORTED

TABLE 2

SOURCE: MSO Report A2142-01

COMPARATIVE DATA

Weapon System: F-14A		Reporting Period: JAN 75 – JUN 75, Flight Hours: 9,178			Reporting Period: JUL 75 – DEC 75, Flight Hours: 14,532			Reporting Period: JAN 76 – JUN 76, Flight Hours: 16,995			Reporting Period: JAN 75 – JUN 76 (AVERAGE), Flight Hours: 40,705		
WUC	Nomenclature	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH
14710	SPEED/DIVE BRAKE CONTROL SURFACE	*	*	*	1.38	.62	.014	.88	.41	.009	1.13	.52	.012
11336	STAB. ACTR. ACCESS PANEL	*	*	*	*	*	*	*	*	*	*	*	*
11510	VERTICAL STABILIZER STRUCTURE	3.27	.43	.043	4.27	2.00	.046	4.18	1.82	.057	3.91	1.42	.049
11513	FIN LEADING EDGE	*	*	*	.96	.28	.008	*	*	*	.96	.28	.008
14311	RUDDER	1.74	.43	.015	2.06	.76	.023	1.65	.59	.018	1.82	.59	.019
* 14411	HORIZONTAL STAB. composite CONTROL SURFACES	11.44	4.69	.064	7.91	2.75	.069	8.06	5.12	.097	9.14	4.19	.076
11414	WING FIXED LEADING EDGE	*	*	*	*	*	*	.82	.18	.005	.82	.18	.005
11412	WING TIP ASSEMBLY	3.05	.76	.031	2.20	.34	.012	3.88	.47	.044	3.04	.52	.029
13411	NLG FORWARD DOOR	1.42	.33	.010	1.45	.41	.005	*	*	*	1.44	.37	.008
13413	NLG AFT DOORS	2.51	.98	.009	*	*	*	*	*	*	2.51	.98	.009
13211	MLG INBOARD DOOR	*	*	*	1.51	.48	.002	.88	.41	.003	1.20	.44	.002
13212	MLG OUTBOARD DOOR	*	*	*	2.06	.28	.029	1.24	.65	.007	1.65	.46	.018
13213	MLG AFT DOOR	1.96	.44	.030	1.31	.07	.015	3.35	.71	.146	2.21	.41	.064

*DENOTES "NO DATA AVAILABLE" DUE TO MSO POLICY TO "EXCLUDE FROM THIS REPORT ALL WORK CODE ENTRIES FOR WHICH 12 OR LESS MAINTENANCE ACTIONS HAVE BEEN REPORTED."

TABLE 3

SOURCE: MSO Report A2142-01

COMPARATIVE DATA

Weapon System: F-4J		Reporting Period: JAN 75-DEC 75		Reporting Period: JUL 75-JUN 76	
WUC	Nomenclature	Average Failures Per Month	Total Failures Per Year	Average Failures Per Month	Total Failures Per Year
14610	SPEEDBRAKE ASSEMBLY	11	131	12	145
1119B	STAB. ACTR. ACCESS DOOR	0	2	-	-
1118220	VERTICAL FIN SKIN	1	7	0	4
1118250	VERTICAL FIN LEADING EDGE	1	7	0	4
14414	RUDDER STRUCTURE	1	11	0	5
14317	STABILATOR SKIN	7	85	5	57
14212	AILERON STRUCTURE	2	24	3	34
11232	AFT WING TIP	2	28	3	32
13327	AFT NLG DOOR	3	37	2	29
13328	FORWARD NLG DOOR	2	27	2	23
13234	GEAR STRUT DOOR (MLG)	7	84	8	91
13235	OUTBOARD MLG DOOR	5	56	6	74
13236	INBOARD MLG DOOR	7	83	6	72

TABLE 4 SOURCE: MSO Report A2107

COMPARATIVE DATA

Weapon System: F-14A		Reporting Period: JAN 75-DEC 75		Reporting Period: JUL 75-JUN 76	
WUC	Nomenclature	Average Failures Per Month	Total Failures Per Year	Average Failures Per Month	Total Failures Per Year
14710	SPEED/DIVE BRAKE CONTROL SURF	0	2	1	10
1133G	STAB. ACTR. ACCESS PANEL	0	3	0	2
11510	VERTICAL STAB. STRUCTURE	3	34	5	60
11513	FIN LEADING EDGE	0	7	1	7
14311	RUDDER	1	16	2	22
14411	HORIZ. STAB. CONTROL SURF.	6	69	9	111
11414	WING FIXED LEADING EDGE	0	4	0	4
11412	WING TIP ASSEMBLY	1	15	1	13
13411	NLG FORWARD DOOR	1	12	2	23
13413	NLG AFT DOORS	1	10	0	2
13211	MLG INBOARD DOOR	1	11	1	14
13212	MLG OUTBOARD DOOR	1	14	2	23
13213	MLG AFT DOOR	1	14	3	30

TABLE 5 SOURCE: MSO Report A2107

Weapon System: F-4J		Reporting Period: JAN 76 - OCT 76 Flight Hours: 64,312		
WUC	Nomenclature	O-Level MA	I-Level MA	Verified Failures
14610	SPEEDBRAKE ASSEMBLY	469	4	367
1119B	STAB. ACTR. ACCESS DOOR	34	0	17
1118220	VERTICAL FIN SKIN	153	0	147
1118250	VERTICAL FIN LEADING EDGE	16	0	16
14414	RUDDER STRUCTURE	55	0	48
14317	STABILATOR SKIN	321	3	226
14212	AILERON STRUCTURE	147	5	96
11232	AFT WING TIP	160	4	60
13327	AFT NLG DOOR	162	4	133
13328	FORWARD NLG DOOR	127	2	115
13234	GEAR STRUT DOOR (MLG)	273	31	235
13235	OUTBOARD MLG DOOR	390	29	279
13236	INBOARD MLG DOOR	297	24	224

TABLE 6 SOURCE: ASMRA

Weapon System: F-14A		Reporting Period: JAN 76 - OCT 76 Flight Hours: 31,051		
WUC	Nomenclature	O-Level MA	I-Level MA	Verified Failures
14710	SPEED/DIVE BRAKE CONTROL SURF.	11	0	6
1133G	STAB. ACTR. ACCESS PANEL	22	0	16
11510	VERTICAL STAB. STRUCTURE	105	0	88
11513	FIN LEADING EDGE	26	1	23
14311	RUDDER	50	1	28
14411	HORIZ. STAB. CONTROL SURF.	291	3	262
11414	WING FIXED LEADING EDGE	20	0	16
11412	WING TIP ASSEMBLY	165	5	139
13411	NLG FORWARD DOOR	51	1	39
13413	NLG AFT DOORS	15	0	9
13211	MLG INBOARD DOOR	29	0	22
13212	MLG OUTBOARD DOOR	45	2	43
13213	MLG AFT DOOR	96	15	66

TABLE 7 SOURCE: ASMRA

COMPARATIVE DATA

Weapon System: YF-17		Reporting Period: JUN 74-JAN 77 Flight Hours: 426			Reporting Period: Flight Hours:			Reporting Period: Flight Hours:			Reporting Period: Flight Hours:		
WUC	Nomenclature	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH
14LAO	SPEEDBRAKE SKIN	16.4	11.7	.034									
11ELG	HORIZONTAL TAIL ACTR. DOOR	2.3	2.3	.004									
11LAA	VERTICAL STAB. SKIN	4.7	4.7	.005									
11LAC	VERTICAL STAB. LEADING EDGE	4.7	2.3	.005									
14EAA	RUDDER SKIN	0	0	0									
14CAA	HORIZONTAL TAIL SKIN	9.4	7.0	.008									
11JAA	WING SKIN	16.4	0	.020									
14HAA	FLAP SKIN	7.0	0	.011									
11GAB	LEX SKIN	28.2	28.2	.031									
14AAA	AILERON SKIN	2.3	2.3	.004									
[illegible]	NLG STRUT DOOR	0	0	0									
[illegible]	NLG WHEEL DOOR	2.3	2.3	.004									
11CLX	MLG WHEEL DOOR	14.1	14.1	.035									
11CLY	MLG STRUT DOOR	2.3	2.3	.005									

TABLE 8

SOURCE: ASMRA

NARRATIVE ANALYSIS

1. This section contains an assessment of the data presented in the previous tables. Discussion will initially be divided into sections pertaining to each weapon system's comparative data. Finally, an assessment will be made comparing these findings with respect to the F-18.

2. F-4J Analysis

Upon review of Tables 2, 4 and 6, the components are ranked as follows (ranked from highest degree of maintenance requirements to the lowest):

1. Stabilator Skin
2. Outboard MLG Door
3. Inboard MLG Door
4. Gear Strut Door (MLG)
5. Aft NLG Door
6. Aft Wing Tip
7. Aileron Structure
8. Forward NLG Door
9. Vertical Fin Skin
10. Speedbrake Assembly (Skin)
11. Rudder Structure
12. Vertical Fin Leading Edge
13. Stab. Actr. Access Door

3. F-14A Analysis

Upon review of Tables 3, 5 and 7, the components are ranked as follows (ranked from highest degree of maintenance requirements to the lowest):

1. Horiz. Stab. Control Surfaces - Composite
2. Vertical Stabilizer Structure
3. MLG Aft Door
4. Wing Tip Assembly

5. MLG Outboard Door
6. Rudder
7. NLG Forward Door
8. MLG Inboard Door
9. NLG Aft Doors
10. Fin Leading Edge
11. Wing Fixed Leading Edge
12. Speed/Dive Brake Control Surf.
13. Stab. Actr. Access Panel

4. YF-17 Analysis

Upon review of Table 8, the components are ranked as follows (ranked from highest degree of maintenance requirements to the lowest):

1.	LEX Skin	- Composite
2.	Speedbrake Skin	- Composite
3.	MLG Wheel Door	- Composite
4.	Wing Skin	
5.	Horiz. Tail Skin	
6.	Flap Skin	- Composite
7.	Vertical Stab. Skin	
8.	Vertical Stab. Leading Edge	- Composite
9.	MLG Strut Door	- Composite
10.	Horiz. Tail Actr. Door	
	Aileron Skin	- Composite
	NLG Wheel Door	- Composite
11.	Rudder Skin	- Composite
	NLG Strut Door	- Composite

5. F-18 Analysis

MCAIR predicts the following ranking of maintenance requirements of components shown in Table 1:

ITEM		0-LEVEL MTBUMA
1.	Horiz. Stab. Skin	94.3
2.	Outer Wing Skin	125.0
3.	Aileron	174.0
4.	Rudder	243.0
5.	T.E. Flap	266.5
6.	Inner Wing Skin	480.3
7.	Speedbrake Assy	651.0
8.	Inboard MLG Door	1019.4
	Outboard MLG Door	1019.4
9.	Left NLG Door	2150.5
	Right NLG Door	2150.5
10.	LEX Skin	2252.3
11.	Vert. Stab. Skin	3436.4
12.	Vert. Stab. L.E.	5154.6
13.	Vert. Stab. T.E.	5882.4

(SOURCE: MCAIR Maintainability Block Diagrams - 22 June 1976)

The rankings are based upon all of the data included in Tables 2 through 8.

1. MLG Wheel Doors
2. LEX Skin
3. Horiz. Stabilizer
4. Speed Brake
5. Wing Skin
6. Vert. Fin Skin
7. Aileron
8. Aft Wing Tip
9. Flap Skin
10. L/R NLG Door
11. L/R MLG Door
12. Vert. Fin LE
13. Rudder Assy
14. Vert. Fin TE

Analysis of Maintenance Data
Pertinent to
AV-8B Composite Structures

Enclosure (2)

INTRODUCTION

The purpose of this report is to provide an assessment of data related to maintenance parameters of composite and metal components of the following weapon system:

AV-8A

The analysis of data will be used to perform a comparison study for the AV-8B.

The approach to presenting the data and its analysis for this report is as follows:

- Identification of composite structures for the AV-8B
- Comparative data (3M) analysis of the AV-8A
- Narrative Analysis

The data presented in this report was obtained from ASMRA and MSO reports of the AV-8A.

The F-18 analysis was accomplished in another report, due to the incompatibility of the data base used for this analysis.

The following table depicts the distribution of composite and "other" type structure materials for the AV-8B. The table does not address all structural areas, but shows all composite structures and a representative sampling of non-composite areas that are subject to a high degree of maintenance requirements.

AV-8B COMPOSITE STRUCTURES

ITEM	MATERIAL
Airbrake Skin	Other
Pitch Control Panel	Other
Fin Skin	Other
Rudder	Other
Tail Plane Skin	Other
Tail Plane Rib	Other
Main Plane Skin	Composite
Main Plane Spar	Composite
Flap Skin	Composite
Flap Ribs	Composite
Flap Spar	Composite
Aileron Spar	Composite
Aileron Skin	Composite
Outrigger Gear Fairing	Composite
Wing Tip (aft structure)	Composite
Nose Undercarriage Doors	Other
Main Undercarriage Doors	Other

TABLE 1

COMPARATIVE DATA (3M) ANALYSIS OF THE AV-8A

The data in the following tables was extracted from MSO reports depicting 3M data with respect to individual components and historical maintenance data. This effort was accomplished to assess the impact of maintenance requirements on components that are comparable to those depicted in Table 1.

This data is contained in the following tables:

MSO REPORT A2142-01	MSO REPORT A2107	ASMRA
Table 2	Table 3	Table 4

COMPARATIVE DATA

Weapon System: AV-8A		Reporting Period: JAN 75 – JUN 75 Flight Hours: 7,217			Reporting Period: JUL 75 – DEC 75 Flight Hours: 14,532			Reporting Period: JAN 76 – JUN 76 Flight Hours: 16,995			Reporting Period: JAN 75 – JUN 76 (AVERAGE) Flight Hours: 40,705		
WUC	Nomenclature	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH	Total MA Per 1000 FH	O-Level Repair Failures Per 1000 FH	Unsched. MMH/FH
11426	PITCH REACTION CONTROL PANEL	*	*	*	*	*	*	*	*	*	*	*	*
11615	FIN SKIN	2.08	.69	.003	2.21	.15	.004	*	*	*	2.14	.42	.004
14214	RUDDER SKIN	*	*	*	*	*	*	*	*	*	*	*	*
14315	TAIL PLANE RIB	*	*	*	*	*	*	*	*	*	*	*	*
14316	TAIL PLANE SKIN	3.46	.97	.010	*	*	*	*	*	*	3.46	.97	.010
11513	MAIN PLANE SKIN	3.88	.28	.004	*	*	*	*	*	*	3.88	.28	.004
14511	WING FLAP SPAR	*	*	*	*	*	*	*	*	*	*	*	*
14512	WING FLAP RIBS	*	*	*	*	*	*	*	*	*	*	*	*
14514	WING FLAP SKIN	*	*	*	*	*	*	*	*	*	*	*	*
14111	AILERON SPAR	*	*	*	*	*	*	*	*	*	*	*	*
14117	AILERON SKIN	*	*	*	*	*	*	*	*	*	*	*	*
13352	OUTRIGGER LEG LOWER FAIRING	*	*	*	2.79	1.91	.010	4.59	2.15	.021	3.69	2.03	.016
11514	MAIN PLANE TIP	*	*	*	2.06	.88	.021	1.86	.72	.041	1.96	.30	.031
13251	NOSE UNDERCARRIAGE DOOR	2.22	.28	.004	*	*	*	*	*	*	2.22	.28	.004
13252	NOSE UNDERCARRIAGE LEG DOOR	*	*	*	*	*	*	*	*	*	*	*	*
13151	MAIN UNDERCARRIAGE DOOR	*	*	*	*	*	*	*	*	*	*	*	*
13153	MAIN UNDERCARRIAGE LEG DOOR	*	*	*	*	*	*	2.87	1.58	.010	2.87	1.58	.010

* DENOTES "NO DATA AVAILABLE". DUE TO MSO POLICY TO "EXCLUDE FROM THIS REPORT ALL WORK CODE ENTRIES FOR WHICH 12 OR LESS MAINTENANCE ACTIONS HAVE BEEN REPORTED."

TABLE 2

SOURCE: MSO REPORT A2142-01

COMPARATIVE DATA

Weapon System: AV-8A		Reporting Period: JAN 75-DEC 75		Reporting Period: JUL 75-JUN 76	
WUC	Nomenclature	Average Failures Per Month	Total Failures Per Year	Average Failures Per Month	Total Failures Per Year
11426	PITCH REACTION CONTROL PANEL	-	-	-	-
11615	FIN SKIN	1	6	0	4
14214	RUDDER SKIN	0	1	0	1
14315	TAIL PLANE RIB	0	1	-	-
14316	TAIL PLANE SKIN	1	9	0	4
11513	MAIN PLANE SKIN	0	4	0	1
14511	WING FLAP SPAR	-	-	0	1
14512	WING FLAP RIBS	0	2	0	2
14514	WING FLAP SKIN	0	1	0	1
14111	AILERON SPAR	-	-	-	-
14117	AILERON SKIN	-	-	-	-
13352	OUTRIGGER LEG LOWER FAIRING	2	24	3	30
11514	MAIN PLANE TIP	1	9	1	14
13251	NOSE UNDERCARRIAGE DOOR	0	5	0	4
13252	NOSE UNDERCARRIAGE LEG DOOR	1	7	0	3
13151	MAIN UNDERCARRIAGE DOOR	1	14	2	18
13158	MAIN UNDERCARRIAGE LEG DOOR	1	9	2	19

TABLE 3

COMPARATIVE DATA

Weapon System: AV-8A		Reporting Period: JAN 76 - OCT 76 Flight Hours: 11,255		
WUC	Nomenclature	O-Level MA	I-Level MA	Verified Failures
11426	PITCH REACTION CONTROL PANEL	1	0	1
11615	FIN SKIN	1	0	1
14214	RUDDER SKIN	1	1	1
14315	TAIL PLANE RIB	0	0	0
14316	TAIL PLANE SKIN	22	0	19
11513	MAIN PLANE SKIN	35	0	21
14511	WING FLAP SPAR	1	0	1
14512	WING FLAP RIBS	0	0	0
14514	WING FLAP SKIN	21	0	10
14111	AILERON SPAR	0	0	0
14117	AILERON SKIN	4	0	1
13352	OUTRIGGER LEG LOWER FAIRING	47	2	27
11514	MAIN PLANE TIP	19	2	9
13251	NOSE UNDERCARRIAGE DOOR	6	2	5
13252	NOSE UNDERCARRAIGE LEG DOOR	0	0	0
13151	MAIN UNDERCARRAIGE DOOR	18	0	17
13158	MAIN UNDERCARRAIGE LEG DOOR	42	0	23

TABLE 4

NARRATIVE ANALYSIS

This section contains as assessment of the data presented in the previous tables.

- AV-8A -

Upon review of Tables 2, 3 and 4 the components are ranked as follows (ranked from highest degree of maintenance requirements to the lowest):

1. Outrigger Leg Lower Fairing
2. Main Undercarriage Leg Door
3. Tail Plane Skin
4. Main Plane Skin
5. Main Undercarriage Door
6. Main Plane Tip
7. Nose Undercarriage Door
8. Wing Flap Skin
   Fin Skin
9. Nose Undercarriage Leg Door
10. Rudder Skin
11. Wing Flap Ribs
    Aileron Skin
12. Wing Flap Spar
13. Pitch Reaction Control Panel
    Tail Plane Rib
14. Aileron Spar