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Advanced Composite Structure Repair Guide

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This paper discusses the need for a standardized advanced composite structure repair guide and presents the status of a federal government-sponsored program which will result in the first edition of such a guide. The guide will be useful to the entire aerospace structures community and be to the repair area what the Advanced Composites Design Guide is to the design area. Some recent developments in the area of advanced composite structure repair, which will contribute much to the development of the repair guide, are presented.

Introduction

THE advantages of advanced composites as viable structural materials have been demonstrated by both structural development programs and application to hardware for actual production aircraft. All-composite wing construction has been used on the AV-8B, and composite wing skins, as well as several other composite components, are used on the F-18A, both of which are undergoing flight test programs. Composite spoilers have been flown on Boeing 737 aircraft for several years and composite ailerons and vertical fins have been designed for the L-1011. Ten prototype composite rudders have been fabricated for flight service on the DC-10, and flight testing is planned for a composite vertical stabilizer, floor beams, and other components. Composite components including major empennage assemblies and speed brakes are used on F-14, F-15, F-16, and F-18 aircraft. Missile and spacecraft designs and helicopter applications are also taking advantage of the unique properties of advanced composite materials.

As the structural use of advanced composites has increased, a commensurate need has developed for procedures to repair damage which occurs to these structures. The cost of structural repair represents a significant portion of the total operational and maintenance (O&M) cost for an aircraft. For more than two decades, these O&M costs have represented an increasing portion of the total cost of ownership, and, currently, far exceeds the cost of initial acquisition for an aircraft system.

Table 1 shows the results of a recent study by the Air Force Logistics Command on the life-cycle costs (LCC) of a specific transport. Approximately 83% of the dollars spent went for operation and maintenance of that aircraft. Figure 1 shows how that 83% of the LCC was spent; much of this went for maintenance and repair actions. Figure 2 shows a similar story for a helicopter.

It is now economically essential that O&M costs be minimized. One action that will considerably decrease the cost of ownership is to decrease the cost of structural maintenance and repair. Monetary savings can be realized only if economical procedures for maintenance and repair are developed and implemented.

Composite structures are susceptible to damage from the same sources which cause damage to metallic structure. Repairs for metallic structure have been developed over many years and have become more or less routine operations in many cases. The rapid increase in the use of advanced composites has created an immediate need for composite repair technology.

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Background

As a result of the various requirements for repair, considerable information has been developed related to advanced composite repair. It is contained in many varied places, some documented and some undocumented. The current need is to collect the wealth of existing information pertinent to advanced composite repair, critically evaluate it, identify gaps in the data, develop new information where needed, and reduce that information into a form which can be presented in a single, concise document.

As early as 1969, Air Force-funded research and development work addressed the problems of the repair of small-area damage to lightly loaded boron/epoxy structures.[1] More recently, repair techniques for small damaged areas have been developed for graphite/epoxy and hybrid composite structures, and field repairs for graphite/epoxy laminates have been developed using titanium alloy external patches and mechanical attachments.

Technical orders for several military aircraft now contain specific repair instructions for small damaged areas of composite structure, usually limited to nonstrength critical structure. Under a recently completed program, procedures were developed for the repair of large damaged areas, with 80-100% of the parent laminate strength restored by the repair.[2]

In addition to the documented repair information, there is also a body of knowledge based on actual repair experience which has not been documented. This experience exists as developed by manufacturers of aerospace hardware and by the military and civilian facilities responsible for the maintenance of the hardware. Table 2 lists some of the many sources of structure repair information.

Considerations

Production of the first edition of the Advanced Composites Structure Repair Guide required consideration of several factors.

1) Since this will be the first edition of the repair guide, it must be prepared with ease of maintaining and updating as considerations anticipating the future development of additional data.

2) Format and presentation must be compatible with Army, Navy, NASA, Air Force, and industry use factors since the guide is intended to be useful to all.

3) The contents of the guide must be generic and applicable to a wide variety of specific aircraft.

4) It must be written in an easily and quickly understood format and manner. Its use will be largely by nonengineer trained technicians and mechanics.

5) Since much of the most advanced composite repair latest information is not published, personal contact with leaders in the field is very important.

Table 1 Life-cycle cost by phase

Life-cylce phases	15-yr total cost (in millions) 1976 dollars	Total 1976 dollars, %
R & D	3.221	0.04
Procurement/ production	1257.358	17.00
Operations and support	6134.742	82.95
Total	7395.321	100.00

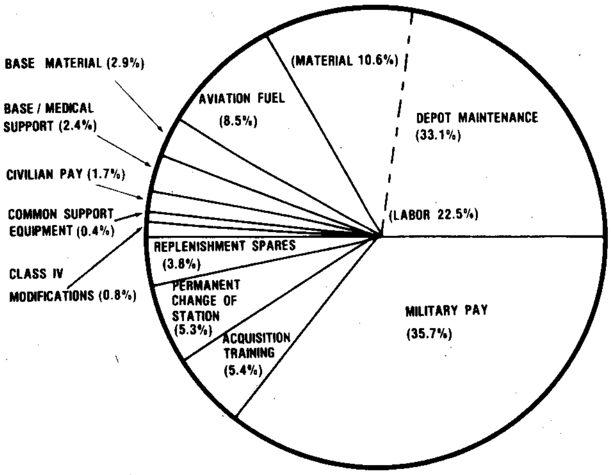

Fig. 1 Operation and maintenance costs by category.

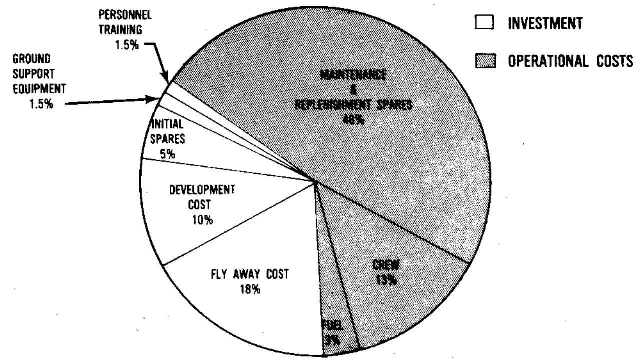

Fig. 2 Typical life-cycle cost breakdown for a military helicopter.

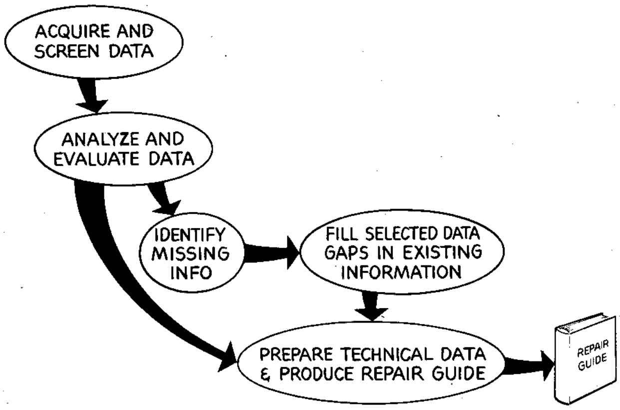

Fig. 3 Program flow chart.

Program Progress

The work plan to prepare the guide is divided into three phases, with publication scheduled for March 1982.

Phase I - Acquisition and evaluation of existing data.

Phase II - Development of data to fill selected gaps.

Phase III - Publication of the repair guide.

The program flow chart shown in Fig. 3 illustrates the conduct of the program, which is nearing completion of phase II.

In addition to phase divisions, the program also investigates advance composite structure repair in the categories of fixed-wing aircraft, helicopters, and space and missile systems. At this point the status in each category is as follows.

Helicopters

With the exception of rotor blades, relatively small amounts of advanced composites have been used in helicopters. Almost all advanced composite use on helicopters is on new helicopters which have not been used enough to have incurred damage requiring repair development. Graphite/epoxy is used in limited structural applications on the Sikorsky UTTAS (UH-60), the Sikorsky S-76, the Hughes AAH (AH-64), the Vertol CH-47, the Vertol 234, and the Bell Models 222 and 214ST. As use time is accrued, damage incurred, and repairs implemented, the amount of repair data for advanced composites on helicopters will increase.[3]

Space and Missile Systems

Space and missile systems are experiencing an increase in the use of graphite/epoxy and other advanced composites for critical structural applications. Repair of advanced composites on space systems requires consideration of many factors not associated with aircraft repair. Maintaining aerodynamically smooth surfaces is not a requirement of space system repair. However, the repair materials and processes must be noncontaminating with low outgassing and survive space environmental conditions including radiation, high vacuum, and wide-temperature excursions. Often the maintenance of electrical continuity and the isolation of conductive components are important.

Three categories of space systems employing advanced composites are 1) orbital satellites and planetary probes, 2) the Space Shuttle Orbiter and 3) large space structures. Composite structures on orbital satellites and planetary probes are generally stiff, low-weight, intricate, complex, thin-walled, high-cost, low-production quantity items which are easily damaged. Because of these attributes, the repair of this type structure is delicate and highly specialized to meet strict specifications.

The Space Shuttle advanced composite structure repair may be similar to aircraft repair with the added consideration of wide-temperature excursions. Repairs to composite beams on large space structures will include considerations of satellite component repair plus possible requirements for repairs to be made in orbit.

For missile applications, retention of high-stiffness, high-strength, low-weight, and high-temperature capability are requirements for repaired components. In some cases, selection of repair materials is limited by nuclear vulnerability and hardening requirements and radar observability considerations. Repaired components on missiles must also withstand long-term storage environments.[4]

Fixed-Wing Aircraft

The largest use of advanced composite structure on aircraft has been on fixed-wing aircraft. As a result, most work relating to advanced composite structure repairs has been done for fixed-wing aircraft. Under Ref. 1, repair procedures were developed and verified by testing. Only adhesive-bonded repairs were considered due to bearing allowable limitations. Two repair configurations, a scarf inclusion, and an external patch were developed. A portable repair kit was developed to provide vacuum pressure and heat in an integral rubber blanket.

Between 1974 and 1976, repair procedures were developed for lightly loaded graphite/epoxy sandwich structure,

Table 2 Repair information sources

TITLE	CONTRACT NO.	SPONSOR OR DOCUMENT	CORPORATE SOURCE	REMARKS
(1) LARGE AREA COMPOSITE STRUCTURE REPAIR	F33615-76-C-3017	AFFDL-TR-79-3040	NORTHROP	FINAL REPORT OF PROGRAM WHICH DEVELOPED PROCEDURES FOR REPAIR OF LARGE DAMAGED AREAS
(2) LARGE AREA COMPOSITE STRUCTURE REPAIR	F33615-76-C-3017	AFFDL-TR-77-5, 77-121 78-83	NORTHROP	LARGE AREA REPAIRS TO GR/EP & HYBRID STRUCTURES INTERIM REPORTS
(3) REPAIR TECHNOLOGY FOR BORON/EPOXY COMPOSITES	F33615-69-C-1498	AFML-TR-71-270	GRUMMAN	FLUSH (SCARF) & EXTERNAL PATCHES USING TITANIUM FOIL FOR BORON EPOXY PARENTS (BONDED)
(4) REPAIR PROCEDURES FOR ADVANCED COMPOSITE STRUCTURES	F33615-74-C-5133	AFFDL-TR-76-57 VOL I VOL II	GENERAL DYNAMICS/ FORT WORTH	METALLIC, PRECURED, & CURED-IN-PLACE REPAIR PROCEDURES OUTLINED FOR SMALL AREA REPAIRS – BONDED, AERODYNAMICALLY SMOOTH – BONDED & BOLTED JOINTS, SUBSTRUCTURE
(5) DIGEST OF REPAIR * PROCEDURES FOR ADVANCED COMPOSITES		INTERNAL DOCUMENT (WSDS 75-10)	NORTHROP	REPAIR PROCEDURES FOR COMPOSITE MATERIALS
(6) ADHESIVE BONDED AEROSPACE STRUCTURES STANDARDIZED REPAIR HANDBOOK	F33615-73 C-5171	AFML-TR-77-206 AFFDL-TR-77-139	BOEING	EXCELLENT EXAMPLE OF ORGANIZATION OF A GUIDE FOR REPAIR OF BASICALLY METAL-TO-METAL BONDS
(7) S-3A GRAPHITE/EPOXY SPOILER FABRICATION OF TEN SHIPSETS & DAMAGE REPAIR STUDY	N62269-74-C-0428	NADS-76234-30	VOUGHT	GOOD EXAMPLE OF A REPAIR PROCEDURE OUTLINE GEARED TO A SPECIFIC COMPONENT
(8) PROCEEDINGS OF THE COMPOSITE MATERIAL MAINTENANCE/REPAIR WORKSHOP		NAVAL AIR SYSTEMS COMMAND		NUMEROUS INDUSTRY & GOVERNMENT PERSONNEL PRESENTED PAPERS ON VARIOUS ASPECTS OF COMPOSITE REPAIR
(9) FIELD REPAIR OF COMPOSITE STRUCTURES		NADC	MCDONNELL	MECHANICALLY FASTENED Ti PATCHES 3/16 & 0.5 INCH – THREE HOLE SIZES = 1, 2-1/2, 4" FAILURES AT OR ABOVE 4000 μIN/IN
(10) REPAIR OF BONDED PRIMARY STRUCTURES		AFFDL-TR-78-79	BOEING	DESCRIBES REPAIR METHODS FOR ADHESIVE BONDED METALLIC PRIMARY STRUCTURES
(11) LOW COST AIRCRAFT STRUCTURAL REPAIR AND MAINTENANCE STUDY	F33615-74-C-3101	AFFDL-TR-76-63	ROCKWELL	DEVELOPMENT OF COST EFFECTIVE REPAIRS TO REDUCE LIFE CYCLE COSTS
(12) ADVANCED STRUCTURAL REPAIR FOR LOWER COST	F33615-78-C-3208	AFFDL	ROCKWELL	APPLICATION OF ADVANCED TECHNOLOGY, INCLUDING COMPOSITES, TO CHRONIC STRUCTURAL MAINTENANCE ITEMS
(13) DAMAGE REPAIR TECHNOLOGY FOR COMPOSITE MATERIALS	NASA GRANT NO. 1304	NASA	UNIV OF DELAWARE	DEVELOPMENT OF ANALYTICAL TECHNIQUES FOR DETERMINING STRENGTH OF SCARF JOINTS WITH AND WITHOUT DOUBLERS
(14) COMBAT DAMAGE TOLERANCE & REPAIR OF AIRCRAFT STRUCTURES		AGARD REPORT NO. 667		USER PERSPECTIVE ON REPAIRS ARISING BECAUSE OF COMBAT. GIVEN BY THREE AUTHORS
(15) PRIMARY ADHESIVELY BONDED STRUCTURE TECHNOLOGY PHASE II – DETAIL DESIGN	F33615-75-C-3016	AFFDL	DOUGLAS	DESIGN OF ADHESIVELY BONDED JOINTS
(16) DETERMINATION OF MOISTURE CONTENT IN COMPOSITES BY DIELECTRIC MEASUREMENTS	F33615-78-C-3216	AFFDL	LOCKHEED	PROGRAM TO DEVELOP METHODS FOR MEASURING MOISTURE IN LAMINATES
(17) SPACE SHUTTLE PAYLOAD DOORS		NASA	ROCKWELL	REPAIR INFORMATION FOR SANDWICH PANELS AND SPLINTERING AT HOLES IN FRAMES
(18) STRUCTURAL REPAIR ORGANIZATIONAL & INTERMEDIATE		USAF	MCDONNELL	REPAIR MANUAL FOR F-15 HONEYCOMB & COMPOSITE PARTS
(19) STRUCTURAL REPAIR		NAVY	GENERAL DYNAMICS	REPAIR MANUAL FOR F-16 INCLUDES SMALL STANDARD REPAIRS FOR COMPOSITES

complex structural elements, and for some highly loaded structures typical of those found in a wing or fuselage.[5] Both flush patches and tapered external patches were used, the latter made of either titanium foil or graphite.

In 1977 and 1978, bolted titanium external patches were developed for field repair of laminates up to 1/2 in. thick.[6] Laminates used were typical of AV-8B and F-18A wing skins. Damage up to 4 in. in diameter was considered.

The study of Ref. 2 concentrated on the development of repair procedures for use at military depot level facilities where relatively highly skilled personnel and adequate facilities and equipment are available. Both monolithic and honeycomb sandwich construction were considered. Several variations of an essentially flush repair using a scarf joint were used to make repairs with access from one side only, for partial thickness repairs, and for use with honeycomb sandwich construction. As part of this program, five large panels (approximately 20×60 in. test section) were repaired and subjected to static tests. Each of these panels represented a different repair problem. In addition, an in-service damaged aircraft speed-brake with graphite/epoxy skins was repaired and proof loaded to verify the adequacy of the repair.[7]

Observations

1) Approximately 200 titles have been found that are related to damage effects, damage assessment, joints, repairs, repair needs, or repair evaluation, and have been reviewed.

2) Repair means different things to different people. As the pressures of circumstance increase, the criteria for acceptability decrease.

3) The use of bonded repairs for honeycomb sandwich structure is well-documented and established.[8]

4) Bonded primary structure has been thoroughly investigated and documented showing structural efficiency and durability are improved as compared to riveted structure. Bonded structure has come of age.[9]

5) For primary structure repair requiring high strength and durability as used in depot repair, the bonded repair is now widely preferred by many researchers. These repairs were made on various material and structural types and used various patch materials. In common is a bonded joint of some kind and a successful repair.[2,5,10]

6) For combat damage repair, where minimum downtime for repair becomes more important, the bonded repair is preferred by many service people for its simplicity and quickness. This has been demonstrated by several researchers involved in battle damage repair work.[11]

7) The potential for resins and adhesive systems for special-purpose applications such as rapid curing, ambient curing, or underwater curing is either a present reality or very hopeful for the near future.

8) Bonded advanced composite patches and reinforcements have been successfully used to repair metal structure.[12]

9) Epoxy resins have been used in the construction industry for reinforced concrete repair.

10) A practical method of measuring the moisture content of an unknown laminate is needed. There is a limited amount of work being conducted in this area.[7]

11) A truly practical method of repair quality verification is lacking. The conventional methods being used give rather limited information and are generally expensive, both in dollars and know-how.[7]

Concluding Remarks

There is considerable information, documented and undocumented, on the repair of advanced composite structure. Techniques have been developed which permit repairs restoring between 80% and 100% of the parent laminate ultimate allowable.

The present use and the anticipated near-term increase in the use of advanced composite structure makes the publication of a repair guide timely. It is intended that the first edition of the advanced composite structure repair guide will be beneficial to all.

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