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## NAVY COMPOSITE MAINTENANCE AND REPAIR EXPERIENCE

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Abstract

The Navy has been a strong proponent of composites for aircraft structure. Fleet use of composites started with the F-14 in the early 1970's and has steadily increased. This experience base provides sufficient information to allow an evaluation of the maintenance performance of polymer composites in service.

This presentation will summarize the Navy's experience with maintenance of composite structure. The general types of damage experienced in the fleet as well as specific examples of composite damage to aircraft will be described. The impact of future designs on supportability is also discussed.

Introduction

The U.S. Navy has been a leader in the implementation of composites on weapons systems. The current fleet aircraft all have composite materials in the structure. The F-14 was the first aircraft to use a high performance composite material. The F/A-18 design dramatically increased the level of composites usage. The performance requirements of the AV-8B drove the design to composite materials. Finally, the V-22 represents the largest percentage of composite structure on any military aircraft. The Navy has fielded composite aircraft for approximately 20 years. This experience has provided an excellent database for the evaluation of the service performance of a number of material types and structural designs.

This paper will address the current state of composite supportability in the fleet. A general description of the types of problems experienced with composites will be provided followed by a summary of specific aircraft maintenance experience. Finally, the challenges which the fleet faces with support of emerging designs and issues that must be addressed to make them more supportable will be described. The information is drawn from a report on composites supportability recently completed by the Navy (1).

## Generic Composite Component Performance

The Navy's experience with fielded composite systems has been very positive. Carbon, glass and kevlar based composites have been used. The composite components have performed extremely well. It is important to emphasize that no composite component damage has ever been found to have caused an aircraft crash.

A number of the maintenance actions performed in the fleet have been documented in the 3M system. The term "3M" is an acronym for the Navy's Maintenance, Management and Materiel System as defined in OPNAV 4790.2E. The purpose of this system is to serve as a historical data base for all maintenance actions. Because of the volume of information that is stored in the system, it is a valuable tool for accessing and evaluating reliability and maintainability among other parameters. Data are entered into the system by squadron and IMA maintenance personnel. The depots do not currently input into the system. A VIDSMAF or Visual Information Display System/Maintenance Action Form is completed by maintenance personnel. Data are transcribed from this form to the 3M system. The system does have some deficiencies. Malfunction codes for structural components are based upon metallic aircraft and are therefore irrelevant for composites. Composites have a unique set of damage types or failure modes and repair dispositions which are not currently being addressed. This makes it difficult to interpret what the problem was and what disposition was taken.

The primary concern of fielded systems continues to be corrosion and fatigue of metal components. In the mid 1970's, the Navy and Air Force identified the potential for galvanic coupling between aluminum and graphite materials. Composite designs used since this time have attempted to minimize the galvanic corrosion through use of barrier plies and sealants. In general this has been successful. There have been composite driven corrosion problems which have occurred and caused considerable aircraft down-time. One recent example is the corrosion of aluminum substructure on the F/A-18 caused by a galvanic couple to a composite skin through a silver filled epoxy adhesive. The solution involved disassembly of the component, removal of the corroded metal, and reinstallation with a barrier adhesive. It is extremely important that the corrosion testing of all bi-material couples be investigated.

The Navy has had considerable experience with honeycomb structure. Honeycomb structure is ideally suited for stability critical components. The stiffness per unit weight of this structure is superior to that of any other concept. However, honeycomb structures negatively impact aircraft maintainability. For example, the largest single problem with the composite structures used on the F-14 was the degradation of the aluminum honeycomb core substructure on the horizontal stabilizer. The solution for this problem was the removal of the core and reinstallation of additional core material. Improved treated core material and adhesives coupled with enhanced manufacturing techniques greatly reduced the maintenance requirements of similar structure used on the F/A-18. There are still problems with honeycomb structure which are related to the damage intolerance of the structure. Fleet experience has shown that the structure is susceptible to handling damage. This fact was responsible for the elimination of honeycomb from current generation aircraft. Future applications of

honeycomb structure will be dependent on strong requirements for the specific properties that these structures provide.

A significant proportion of the problems encountered with composite materials can be traced to the brittle nature of the resin used in the material. The 3501-6 resin system has been used on all of the epoxy based composite components installed on aircraft. The resin brittleness leads to cracking in the resin. This cracking occurs primarily when loads are applied in directions which cause fracture via resin dominant modes. The two common observations are microcracking which in extreme circumstances may progress through the thickness of the composite and delamination of the plies of the structure. The Navy's experience has shown that the damage that occurs can be introduced by many different mechanisms. Identification of damage in composites is difficult because of the fracture behavior of the material which is characterized by delaminations and cracks that are not visible on the surface. Internal stresses from processing, thermal cycling, poor manufacturing processes, and mishandling have all been found to cause defects in composite structures. Microcracking and delamination in composites can reduce strength and stiffness. In honeycomb structure, it provides a path for moisture intrusion into the core. Moisture has been found to cause dramatic weight increases in some commercial aircraft components which used kevlar composite-nomex honeycomb construction. It also causes corrosion in metallic cores. Since most of the cracking is internal, it is difficult to find with conventional inspection techniques.

Damage to composite components can be produced during initial assembly. The F/A-18, AV-8B and A-6 have all encountered fit-up problems upon assembly of skin structure to the substructure. One result has been delamination in the skin or substructure caused by out-of-plane bending and shear loading in the composites. These problems resulted from the basic design or by manufacturing procedures. The causes of the poor fit include location on fasteners in seal groove areas, failure to tool to all mating surfaces, tool wear, and material springback upon release from the tool. The short term solution has been to shim the structures to improve the fit. Future aircraft designs must improve tooling concepts and structural design to minimize this form of damage.

Handling damage has been observed on all aircraft. Usually, the damage is associated with the operation of aircraft in very restricted space. There has been a considerable amount of damage found on the F/A-18 horizontal stabilizers. Improvements in the aircraft materials and designs could reduce the amount and the severity of the damage incurred. One feature of handling damage is that it is so catastrophic that it is easy to find.

Other causes for component damage exist which although less destructive can lead to more difficult maintenance actions. The F/A-18 and the AV-8B both have a number of composite access doors. The frequent removal and reinstallation of fasteners in these doors eventually results in oversized holes and produces out-of-plane loads which have been found to cause delamination in the composite around the hole. Since the delamination occurs within the laminate, there is no visible indication of damage at the surface.

In addition, aircraft occasionally are impacted by runway debris which produces limited delamination in the composite components with little visible indication of damage. The strakes and gun pods on the

undercarriage of the AV-8B have experienced considerable surface and edge damage.

Finally, exposure to high temperatures has produced heat damage in composites. Composites are formulated to operate in moderate temperature environments (-65°F to 450°F). Exposure to temperatures in excess of the material thermal limit results in delamination, cracking, and blistering of the material. The exposure can occur due to improper prediction of component operating temperatures. For example, an engine access door on the AV-8B which was designed to function at 375°F actually was exposed to temperatures in excess of 650°F. This problem has been remedied by replacement of the composite component with a metal one. In normal aircraft application, the exposure can result from close proximity to other aircraft.

### Fleet Experience

#### F-14 Aircraft

Extensive corrosion has been experienced in the untreated 2024 honeycomb used in the stabilator. In general the corroded honeycomb core is removed and the covers are rebonded on a new sheet of machined honeycomb. The Navy is trying to qualify phosphoric acid anodized and primed honeycomb core and a new toughened assembly adhesive like FM 300 to replace MB 329. These design changes will improve corrosion resistance and moisture seal integrity respectively.

The Navy recently sponsored Grumman to develop and validate flush, step-lap-joint, boron/epoxy repair concepts to expand depot level repair concepts from 2 to 8 inch damage, a low cost, rapid and safe cold-wall autoclave repair method was demonstrated to localize the application of heat only to the damaged area.

#### F/A-18 Aircraft

A major concern is handling damage to thin skin (i.e., honeycomb sandwich) damage prone structures in areas susceptible to damage (i.e., flaps, rudders, landing gear doors and horizontal stabilizers). These structures appear to be more prone to damage than comparable metal designs. However, repair of these structures is greatly simplified compared to metal structures due to three factors: simple abrasive surface preparation in place of acid etch and chemical treatment required for metals, easy damage removal, and improved tailorability (e.g., tapered and scarfed patches and lighter materials) facilitate weight and balance requirements. The F-18 control surfaces are weight and balance critical by design. No mass was added forward of hinge points to provide counter-balance and narrow flutter margins exist.

Another major concern is with fastener hole wear and edge damage in access doors. The turtle back doors behind the cockpit and the thick monolithic wing access doors aft of the torque box experience this problem frequently. Damage is due to a frequent need for access, the over-torquing of fasteners during installation causing delamination, the failure to install grommets to aid in alignment and reduce hole wear and the necessity to pry off doors with sharp objects.

Thick monolithic structures like wing skins are infrequently damaged by handling abuse because they possess high levels of impact

resistance (energy levels to induce incipient damage) and are not located in damage prone areas. Damage prone areas are located low on the aircraft, near frequent maintenance areas and on the aircraft perimeter.

The second most frequent cause of damage is overheating of the component. Overheating originates from several sources, deck fires, hung ordinance, jet blast and malfunctioning heating blankets, controllers and operators. There is no technique available to rapidly assess overheat damage prior to disposition. Several repair scenarios have lead to overheat problems.

#### AV-8B Aircraft

The AV-8B has no honeycomb sandwich structure so the service experience differs somewhat from the F-18 composites. The AV-8B is also a VSTOL aircraft and has been subject to more frequent crash landings on a per aircraft basis than the F-18. Recent causes of crashes include engine out landings, night taxi off of established runways and a nose wheel steering problem, including collapse of the gear. Composite structures sustaining damage include: the nose cone and forward fuselage, severed outboard wings and tips, severed horizontal stabilizers and crushed strakes. These structures have been replaced or repaired using engineered splicing style repairs specifically developed for the damage area. A recent fan blade failure ruptured the fuel tank and sparked a fire which engulfed the wing and center fuselage.

In the past the aircraft has sustained numerous bird strike incidents especially when at MCAS Cherry Pt. Damage was sustained to the nose cone, and pressure bulkhead, engine air inlet and wing leading edge. Typical dispositions are remove and replace actions.

Due to design deficiencies the Auxiliary power unit (APU) exhaust door has sustained overheat damage and has been replaced with a titanium door. Similarly the epoxy strake fairings have sustained overheat damage and the inboard trailing edge flap have also experienced frequent overheat damage due to nozzle exhaust impingement. A titanium heat-shield/doubler has been added to the vulnerable areas. Similar to the F-18, the AV-8B has experienced hole wear and edge damage. Early Milson fastener designs resulted in rapid hole wear on removable panels. The AV-8B strakes and strake fairings have been prone to stone and handling damage due to their location on the aircraft.

The AV-8B has experienced frequent manufacturing defects in the form of included materials in the covers and delaminations resulting from cover to substructure mismatch in the wing and horizontal stabilizer during assembly. Assembly delaminations have also been noted over pylon support fittings, along seal grooves and around the front metallic hoist fittings. Several of these deficiencies are being corrected. Acoustic fatigue is a problem for some fuselage panels aft of the nozzles and buffet fatigue to fasteners along the trailing edge of the horizontal stabilizers. The frequency of impact induced damage is relatively low, likely due to the form of composite construction. Also repair procedures are predominantly bolted, quick and simple.

## V-22 Aircraft

The period of V-22 service experience has been brief. The bismaleimide engine access doors have experienced rapid hole wear and edge damage. Metal doubler strips are being added to reduce hole wear, but a more serious effort needs to be directed at redesign/material selection as corrective actions. Early in the program fan blade and fuel system failures resulted in fires in the IR suppressor causing damaged mixing ducts and overheat damage. Disposition of damaged components was by removal and replacement. Corrective actions included installing a new fuel drain vent and replacing the Torlon fan blade with a metallic blade. Composite components have also sustained handling damage in the form of delaminations and penetrations from impact with workstands and tools on engine access doors, flaperons and landing gear doors. Hole wear and receptacle problems have been reported for some quick disconnect fasteners. Part of the problem was due to over-torquing and part is due to a design deficiency. Alternative quick disconnect fasteners are being evaluated.

Repair concepts are currently under development for 24 regions of the V-22 aircraft where new materials and unique forms of construction are being applied.

### Future Navy Aircraft Needs

The fleet's experiences with support of composite components provide useful insight into improvements that could be made on future aircraft. The quality of the fabricated composite components has a significant impact on fleet readiness. Surprisingly, manufacturing quality of composites has declined as the technology has matured. Quality affects all aspects of process sensitive composites manufacturing. The fabrication of high quality components will improve supportability and fleet readiness.

The design complexity of the aircraft also impacts supportability. Since the repair concepts used are dependent on the structural design, the support of the system becomes more difficult as complexity increases. For example, there are a number of stiffener configurations that can be used in a given structure. Not only can different shapes be used, but also different size stiffeners with modified angles or radii can be incorporated. This places a great logistics burden on the fleet since this myriad of substructural components must be held in stock. Obviously, in many cases the use of specially designed substructure is required in order to meet weight requirements and operational goals. The fact that selection of multiple types of structural designs will negatively affect the Navy's ability to effectively field these systems must be taken into consideration during the system design phase.

Another characteristic of composite design which has impacted supportability has been the assembly processes used in production. The machining process used to mate composite skins to the component substructure must be performed with hard tools which determine the location of the substructure and fasteners in a repeatable process.

Currently the fastener hole locations can vary. The result of this is the skin and substructure become specific to a particular component. Only a limited number of composite components have been made interchangeable. Major component replacement has to be performed with the existing substructure and the original tooling at the manufacturer's facility. Less complex structure can be replaced at the component level at depot installations. This is a logistics burden on the fleet since replacement parts must be purchased and stocked. Also, the replacement parts must be matched to the existing structure, drilled and trimmed. This costly process occurs because of the custom nature of these structural components. The time associated with purchase, acquisition, and preparation of the part is down-time for the aircraft. An effort to produce fully interchangeable parts must be initiated as part of the acquisition program.

Another aspect of supportability addresses the accessibility of structure for repair procedures employed to restore structural integrity. Ideally, repair actions should be performed in an eight hour time period. However, most repair actions take considerably longer. The principal difficulty encountered in performance of repair actions has been in gaining access to the damaged zone. In most cases, repairs must be performed with single side access from the component surface. Inspection of the inside of the component to determine substructure damage is difficult. Completion of the repair process is also hindered because back side sealing or support plate alignment is difficult. As repair designs are driven to flush outer mold line requirements, this problem will increase in importance. Future designs must allow adequate access to the internal structure of components which are expected to require repair actions.


There is a considerable amount of effort being directed towards the development and demonstration of new repair concepts. Most of the work has focused on conventional repair concepts aimed at the restoration of structural integrity to damaged components. Emerging and future Navy aircraft will incorporate low observables (LO) technology in both the materials and the designs used. Based on fleet experience, it is extremely likely that this LO structure will be damaged in service. The repair action required to restore performance may have to restore strength or signature or both. In order for the Navy to take full advantage of the unique capabilities that these structures afford, more effort must be directed towards the establishment of a maintenance system capable of supporting these aircraft.

Finally, the majority of development work performed on field repair of composite structures has concentrated on small, relatively simple damage. A limited number of components have had large, complex damages which have had to be shipped to depots for engineered repairs. This process is time consuming and labor intensive. Although sufficient for peacetime operations, the process of depot repair would not be practical for fast turnaround during wartime scenarios. There is a movement towards field level repair of larger damage sizes through the depot engineering disposition (DED) process at North Island. The need exists for a dedicated program to address the support required for battle damage repair processes.

## References

1. T. M. Donnellan, Navy Council on Materials and Structures Report on Composites Supportability, NADC Report 91083-60 Aug 1991.



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