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COMPOSITES IN PRIMARY AIRFRAME STRUCTURES

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COMPOSITES IN PRIMARY AIRFRAME STRUCTURES

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ABSTRACT

This paper will provide an overview of new composite applications to primary structures at Sikorsky Aircraft. Sikorsky Aircraft currently manufactures over 13,000 composite airframe parts per month. These parts are used on the S-76, BLACK HAWK/SEAHAWK series, and CH-53 helicopters. This broad production base of composite experience has enabled Sikorsky to aggressively commit to new applications in primary airframe structures. The evolution from a first generation of lightly loaded composites to the second generation of high volume production advanced composite secondary structures through the new third generation of primary structures will be described. Discussions of current development and recent production applications will include the following programs.

Sikorsky Aircraft is currently under contract to the U.S. Army Applied Technology Laboratory (AVRADCOM), Fort Eustis, Virginia to conduct an Advanced Composite Airframe Program (ACAP). The goal of ACAP is to demonstrate the weight and cost saving potential of advanced composite materials when used to the maximum extent practical in a helicopter airframe. In addition, three other major pieces of composite primary structure have been developed for the BLACK HAWK and MH-53E helicopter which will also be discussed. These components include a composite rear fuselage for the BLACK HAWK, an external stores support system for the BLACK HAWK, and a fuel sponson for the MH-53E.

INTRODUCTION

Composite airframe structures have gone through three generations of evolution at Sikorsky Aircraft. In the first generation, fiberglass was used to fabricate lightly loaded parts and secondary structures. The feasibility of using molded construction to replace sheet metal details was clearly demonstrated.

In the second generation, advanced composite materials such as Kevlar® epoxy and graphite epoxy were introduced. These new materials had significantly higher strength to weight ratios than fiberglass, and as a result, nominal weight as well as cost savings were achieved. The production base for building composites was expanded, new manufacturing methods were developed, and new applications in primary airframe structures were introduced. Design configurations also began to exploit the unique characteristics of composites, and a philosophy of designing for the material was introduced as opposed to one in which materials were merely substituted for aluminum in sheet metal type structures.

The third generation is applying composites to primary airframe structures to achieve significant improvements in weight, cost, reliability, maintainability, crashworthiness, and survivability. At Sikorsky the development of this third generation of composite airframe structures is now reaching maturity, and entering into volume production.

FIRST GENERATION COMPOSITE AIRFRAMES

The first generation of composite airframe parts is exemplfied by the use of non-metallic materials on the Sikorsky CH-53A helicopter. Originally designed in 1961, the CH-53A uses approximately 409 pounds of composite materials in the airframe. Most of these parts were fabricated from fiberglass cloth. Figure 1 shows typical applications which include main rotor pylon covers, doors, miscellaneous fairings, and the entire cockpit canopy.

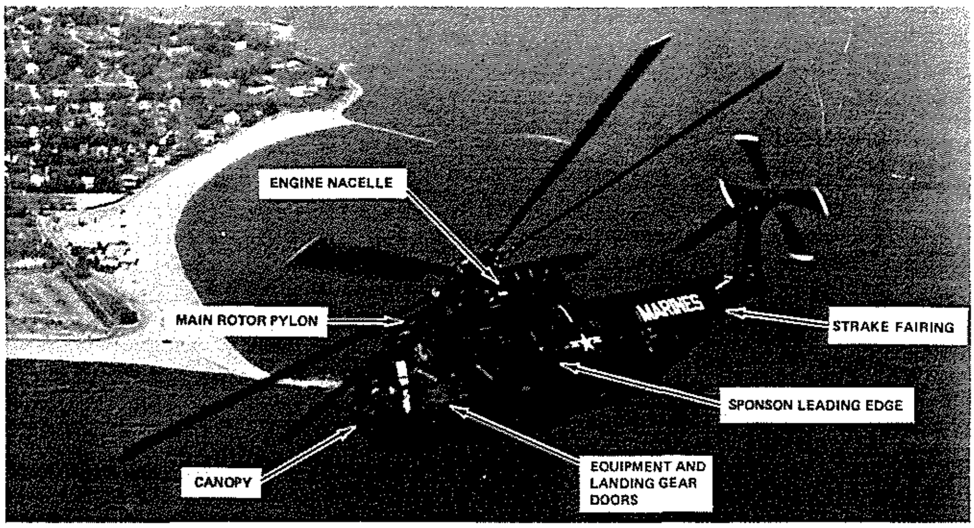

Figure 1. First Generation Composite Applications on the CH-53A.

The fiberglass was used in secondary structures containing complex shapes and contours. The ease of laying up fiberglass contrasted well against typical metal forming techniques such as drop hammer forming, stretch forming, or welding assemblies which required special skills and tooling. Since these parts were normally minimum gage metal structures, replacement with equivalent thickness fiberglass was weight efficient because of the fiberglass material's lower density.

Fairings such as ramp strakes, were simple two-ply laminates with extra reinforcing plys added along the edges where they fasten to the airframe. Landing gear and equipment doors were honeycomb sandwich construction. Complex parts such as the engine nacelles used pre-molded ribs and frames which were bonded to molded fiberglass skins. The entire cockpit canopy was also fabricated from fiberglass on the CH-53A.

The simplification achieved by going to molded construction proved to be so attractive that Sikorsky has used composite materials in similar application on all subsequent production aircraft. Service experience on these composite parts has been excellent and no service problems have been reported after twenty years of operation.

CH-53A Canopy

The CH-53A fiberglass canopy is shown in Figure 2. In the early 1960's this was an extremely daring departure from conventional fabrication techniques.

The entire outside surface of the canopy was molded as a one piece continuous skin. Rebates for the windshield were molded in, as were the jambs for the equipment bay doors and the crew jettison windows. The internal structure was very much akin to that used on sheet metal designs except for the material. Several hundred canopies were manufactured using this design even though extensive labor was required for bonding preparation and fit ups. Therefore, in an effort to reduce assembly time, in-line design changes were introduced to integrate many of the separate structural details directly into the skin. Using foam cores and removeable mandrels, many of the detail parts were co-cured in place resulting in a substantial saving of man-hours. Thus, the trend for design simplification through reduced parts count was initiated.

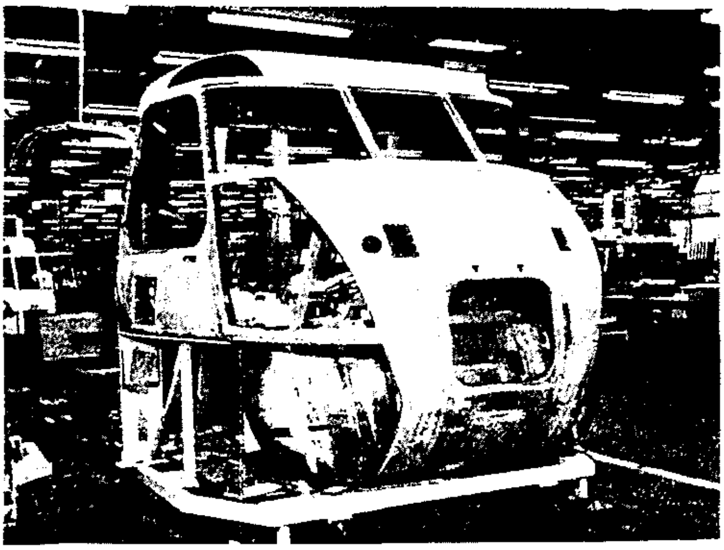

Figure 2. CH-53A Fiberglass Canopy

SECOND GENERATION COMPOSITE AIRFRAMES

The second generation of composite airframes is exemplified by the composite usage on the S-76, BLACK HAWK, and CH-53E helicopters. Figure 3 shows the wide range of components fabricated from composite material used on these helicopters. Production rates up to 13,000 parts per month have been achieved. On the S-76 there are 798 composite parts weighing 370 pounds; on the BLACK HAWK there are 944 composite parts weighing 568 pounds, and on the CH-53E there 824 composite parts weighing 887 pounds.

Composite applications on the S-76 and BLACK HAWK have expanded to include virtually all of the secondary structures on the aircraft including crew doors, main rotor pylons and even the cargo floors on the BLACK HAWK. Extensive use of co-curing has been made. Cockpit canopies on the BLACK HAWK and S-76 are now made using a skin-skeleton construction. Using this technique the entire inner skeleton structure is made in one mold as a single piece which is then subsequently bonded directly into the skin. Thus, the entire canopy structure is composed of only two major pieces; a skin and a skeleton. Most of the composite airframe parts on these helicopters are made from Kevlar epoxy. However, graphite epoxy is also used as a local reinforcement material. In an effort to provide superior environmental resistance, 350°F curing epoxy resin systems are used.

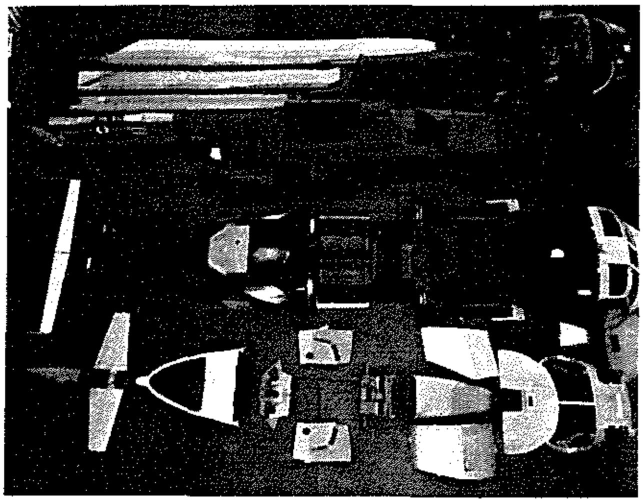

Figure 3. Composite Components used in Production on the CH-53E, BLACK HAWK and S-76

Development of composite rotor blades was also underway during this time period. The main spars on the BLACK HAWK and S-76 tail rotor blades are made entirely *from graphite epoxy. The airfoil coverings* on both main and tail blades are likewise made from composite material. Graphite epoxy main rotor blades were also developed and flight tested on the Navy H-3 helicopter. Thus, at the same time composite materials were being applied to the airframe in secondary structures, they were also being applied to primary structures in the rotor system.

S-76 STABILIZER

The S-76 stabilizer was the first primary airframe structure made from advanced composite material certified by the FAA for a commerical aircraft. Figure 4 shows the basic construction used in the S-76 stabilizer. Kevlar skins with graphite epoxy caps and honeycomb core are used to build upper and lower halves which are subsequently bonded together along the core mid plane. Aluminum honeycomb core is used in the main box spar while Nomex® honeycomb is used in the leading and trailing edges.

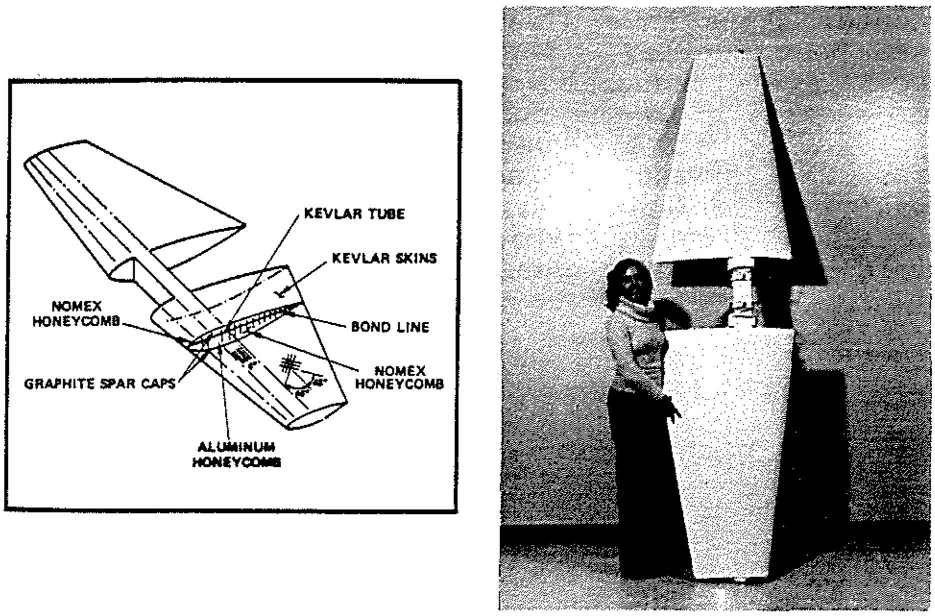

Figure 4. S-76 Stabilizer

Certification of this structure included static, fatigue, and environmental-temperature-wet qualification testing. Bond integrity quality control is achieved by conducting proof load tests of complete assemblies.

An in-service recall program is also being performed to monitor the effects of environment on structural strength and stiffness. Periodically, stabilizers are brought back from the field for examination and structural testing. The objective of this testing is to evaluate and determine the degradation in strength due to environmental exposure. So far, the recall program has substantiated the methodologies used to predict moisture absorption and strength reduction, and in fact has shown them to be somewhat conservative.

R&D PROGRAMS

As production methods were being develo improved for secondary structures, a number of i ant Research and Development Programs were also conducted which were to prove of immense benf adapting composite materials to primary struct Under Army and NASA funding, the use of Kevla graphite epoxy materials was investigated for fus skins and frames. Kevlar was found to be extre efficient when used in tension field applicati The post buckled strength of Kevlar was many t greater then the load at which the panels initia buckled. This research was very important since he copter skins have always been designed to operate the post buckled mode, and therefore to save weigh composite structures would likewise have to be capab of operating in the post buckled mode. Weight savi potentials of 25% were demonstrated by designing fabricating, and testing fuselage type structures mad with Kevlar skin and graphite epoxy stringers and frames. Figure 5 shows typical subcomponents that were fabricated as part of these development programs.

Figure 5. Kevlar/Graphite Fuselage Subcomponents

Techniques for designing critical joints such as main transmission attachment mounts were also developed under Army NASA Research and Development Contracts. Figure 6 shows a transmission support structure that was built entirely from graphite epoxy material. In this design transmission attachment loads are introduced directly into graphite epoxy beams by transmission load links. This program showed that major attachments could be accomplished in composites by simply building up the laminate thickness in lieu of having to resort to complex machine fittings as used on metal structures. Weight savings of 23% were demonstrated.

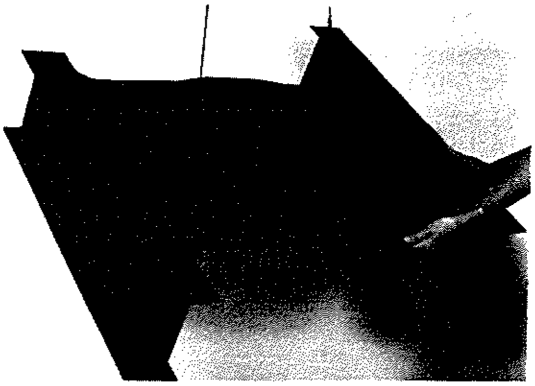

Figure 6. All-Graphite Transmission Support Structure

Additional data on joints, material allowables, and post-buckling strength design curves were also developed under Sikorsky IR&D programs. Thus, Sikorsky was well postured to develop a third generation of primary composite airframe structures in the 1980 time frame.

THIRD GENERATION-PRIMARY STRUCTURES

Two major development programs marked Sikorsky's entry into the third generation of composite airframe structures. The BLACK HAWK Composite Rear Fuselage Program showed that composites could be applied to primary structures in a cost effective manner. The Army's Advanced Composite Airframe Program (ACAP) went even further by demonstrating that major weight and cost savings could be achieved when composites are applied to the maximum extent practical in a helicopter fuselage. The technology demonstrated by these two landmark programs was quickly exploited by Sikorsky on the MH-53E Sponson, and the external stores support system for the BLACK HAWK aircraft. Both of these components are slated for production. Highlights of each of these programs are discussed below.

COMPOSITE REAR FUSELAGE

The major thrust of this Manufacturing Methods and Technology Program was to develop and demonstrate cost saving manufacturing methods for building composite airframe structures. The UH-60A BLACK HAWK rear fuselage was selected as a candidate component because of its inherent complexity and labor intensive construction. On the BLACK HAWK helicopter the rear fuselage serves as a transition structure between the cabin section and the tailcone. As a result, it has compound curvature and is loaded under a variety of conditions. It also contains two fuel tanks. Of necessity, the metal construction used in this structure was fairly complex and offered a good potential for cost reduction.

The composite rear fuselage shown in Figure 7 weighs approximately 400 pounds and is predominantly of Kevlar and graphite epoxy material. Noteworthy design features include a modular construction with integrally stiffened cocured skins, a foam fuel tank support structure, and a corrugated graphite epoxy fuel pressure bulkhead.

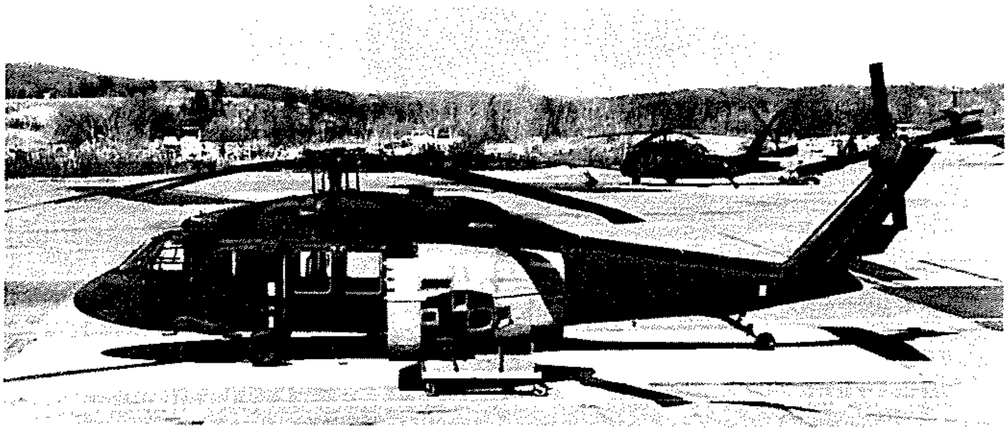

Figure 7. BLACK HAWK Composite Rear Fuselage

A co-cured, stiffened skin was selected because of load path compatibility with adjacent structures and superior weight savings potential compared to sandwich construction. The upper assembly is built in three sections, separated by titanium engine deck skins as shown in Figure 8.

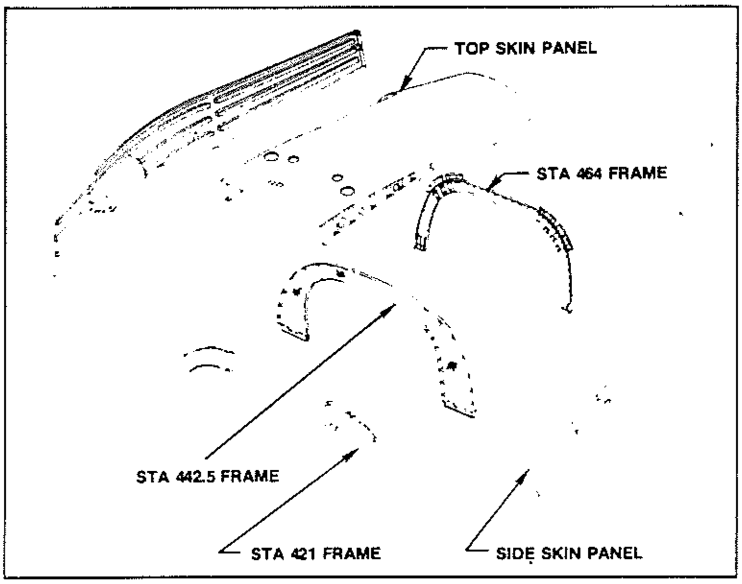

Figure 8. Composite Rear Fuselage Upper Assembly

The lower structure consist of left and right hand skin panels with bulkheads and decks for the fuel tanks as shown in Figure 9. Only one intermediate frame is required to stabilize the longitudinal skin stiffeners.

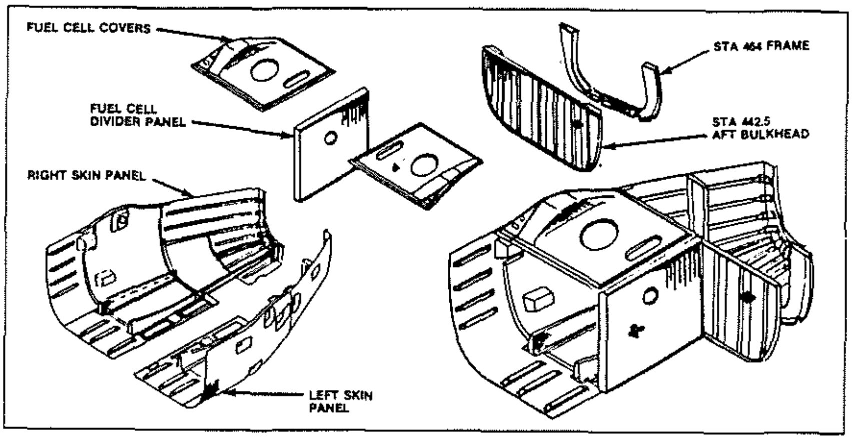

Figure 9. Composite Rear Fuselage Lower Assemblies

It should be noted that there is a significant amount of retained metal structure in the composite rear fuselage. Some of the internal bulkheads and frames at the forward portion of the composite rear fuselage were part of the cabin crash attentuation structure, and their replacement with a composite design would have required development testing which was beyond the scope of this program. Also, the metal fire walls and foam used to support the fuel tanks is common to both designs which left approximately 200 pounds of composite material in the structure to form the basis for achieving weight and cost saving objectives. Thus, in order to achieve a 10% overall weight saving, the saving for the portion of structure redesigned to be composite had to be 17%.

Figure 10 shows typical construction and design features used in the skin panels. The lower skin panel illustrated is the most complex part of the composite rear fuselage. The basic shell is Kevlar stiffened with co-cured graphite longerons and stringers. Beams, step wells, fuel scupper, and tail cone attach fittings are all co-cured in place. An external view of the skin is presented in Figure 11.

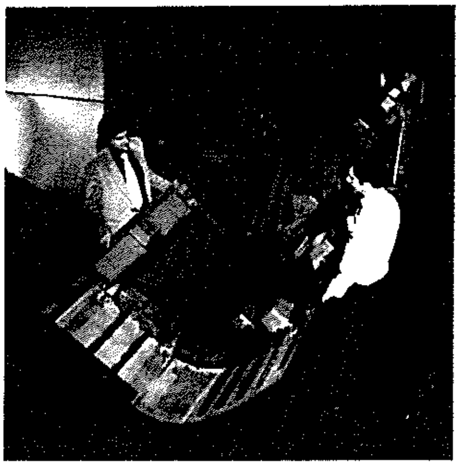

Figure 10. Lower Fuselage Skin, Internal View

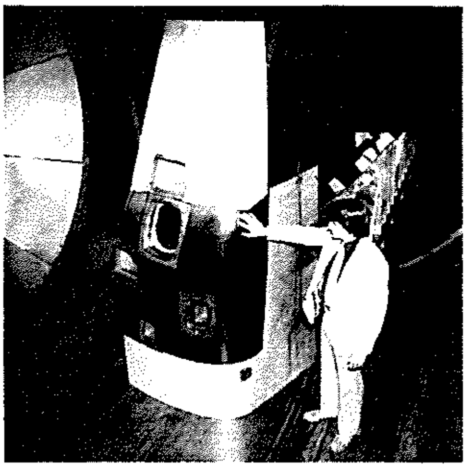

Figure 11. Lower Fuselage Skin, External View

Fuel tank loads are transmitted to the basic shell structure through molded foam blocks. This design eliminated the need for any support structure. A photograph of the aft pressure bulkhead of the composite rear fuselage fuel cell compartment is shown in Figure 12. This design was selected over a sandwich construction because of its 25% lower weight.

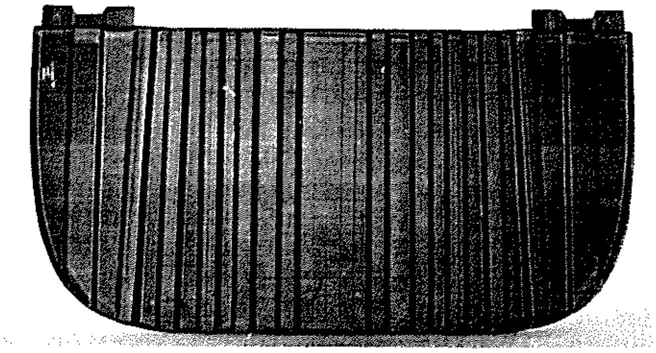

Figure 12. Corrugated Graphite Bulkhead

Full scale static tests have been successfully completed which demonstrated that the composite rear fuselage had sufficient strength to withstand critical design limit and ultimate loads. Figure 13 shows skin buckles as limit load was applied during the test. These buckles were not permanent and came out when the load was removed.

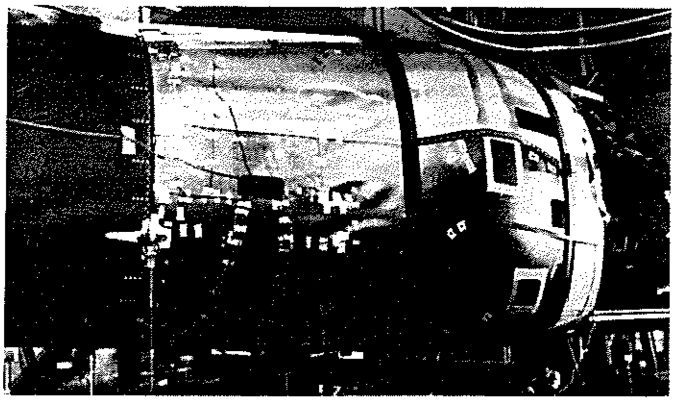

Figure 13. Static Test of Composite Rear Fuselage

Manufacturing costs for the composite rear fuselage were tracked during fabrication. Labor actuals were then used to fine tune detail production estimates. At equivalent points in production, the composite rear fuselage is estimated to cost over 30% less then the metal rear fuselage. This savings is attributed to a significant reduction in detail parts and fasteners for the portion of the structure redesigned to composite.

ACAP

The Sikorsky ACAP helicopter has a composite airframe designed to stringent military requirements, and is more than 20% lighter and 20% lower in cost than its metal baseline airframe. The program is being conducted in two phases. The first phase which is complete, consisted of detail design, manufacturing planning, tool design, and subcomponent testing. The second phase was started in October 1982, and covers fabrication of three airframes which will be subjected to a thorough ground and flight test program.

In addition to weight and cost saving goals, the airframe also had to comply with stringent military requirements. To accomplish this novel design concepts were required.

The ACAP helicopter, designated the S-75, is shown in Figure 14. Gross weight is 8470 pounds, and there is a cabin space for six fully equipped troops and baggage. The dynamic system including engines, rotors, transmissions, and flight controls was taken from the commerical S-76.

Figure 14. Sikorsky ACAP Helicopter

The entire wetted area of ACAP was designed with composite material. However, during detail design of the airframe it was found that certain materials were more suitable for particular types of structure then other materials. Accordingly, all of the common composite material forms including Kevlar, graphite and fiberglass were used.

Kevlar was used for lightly loaded structures such as the canopy, doors, cowlings, and some fuselage skins. Where load intensity was higher, such as the regions adjacent to the main transmission and landing gear attachements, hybrid Kevlar-graphite and all-graphite skins were used. The tailcone was made from graphite epoxy primarily for stiffness purposes.

Overall the ACAP airframe is 70% composite material. The remainder is made up of parts that are not practical to change to composite material. This includes transparencies, miscellaneous bracketry, door latch mechanisms, hardware, fasteners, and fire decks.

To establish a cost effective design, producibility was considered as a primary factor in the development of airframe breaks and sizing of major components and assemblies. Although preliminary design studies showed that in order to meet the program cost goals it was essential to minimize the number of parts and fasteners, past experience at Sikorsky indicated that there are practical limitations to the size of components when tool complexity, accessibility and turn around time is considered. Furthermore, the larger the part is, the more difficult it becomes to vacuum bag and the greater the risk of losing a part.

The main landing gear bulkheads shown in Figure 15 illustrate how major structural components can be simplified through composite design. These bulkheads are of one piece graphite construction. Concentrated loads from the landing gear are introduced through built up pads on the graphite. The cleanliness of the design is self-evident as can be seen in Figure 16. Whereas a metal equivalent bulkhead would consist of machined forgings riveted to a built-up sheet metal structure, the composite design requires only local reinforcement in the form of additional graphite plies at loading points. Heavy splices are eliminated as is the lead time normally associated with procuring forgings. Major cost and weight savings are achieved throughout the airframe by integrating hard points directly into the structure with graphite build-ups in a manner similar to that used on the landing gear bulkhead.

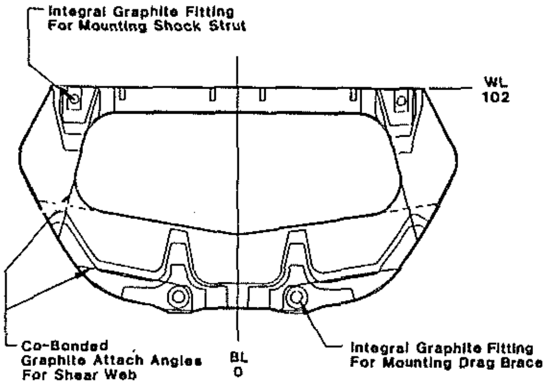

Figure 15. Main Landing Gear Bulkhead Design Features

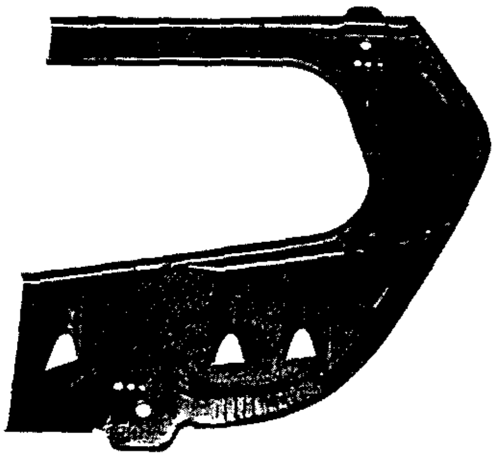

Figure 16. Main Landing Gear Bulkhead Test Component

MH-53E COMPOSITE SPONSON

The MH-53E fuel sponson slated for production deliveries in 1984 is the largest cocured graphite epoxy primary structure of its type in the world. Each externally attached sponson carries approximately 11,000 pounds of fuel and is designed for a wide range of flight, ground and crash conditions. The sponson weighs about 600 pounds and is approximately 12 feet long, 5 feet wide, and 6 feet high. This very large structure was originally designed as a sheet metal assembly. It was redesigned as a graphite epoxy part due to the superior cost advantages of cocured composite construction.

A view of the sponson with the outboard skin panels removed is shown in Figure 17. Basically the cocured part is manufactured as a graphite epoxy sandwich shell. The forward and aft closure bulkheads together with the inboard top and bottom panels are laid up as separate pre-plied details which are then loaded into a large steel mold to be cocured into a one piece assembly. This unique method of assembly was made possible through the use of pre-plied corner assemblies which splice the segments together. Two outboard skin panels and a center bulkhead, all made of graphite epoxy construction, make up the rest of the sponson. These three components are subsequently mechanically fastened to the shell with screws. Excellent quality of these components was demonstrated on the prototype sponsons.

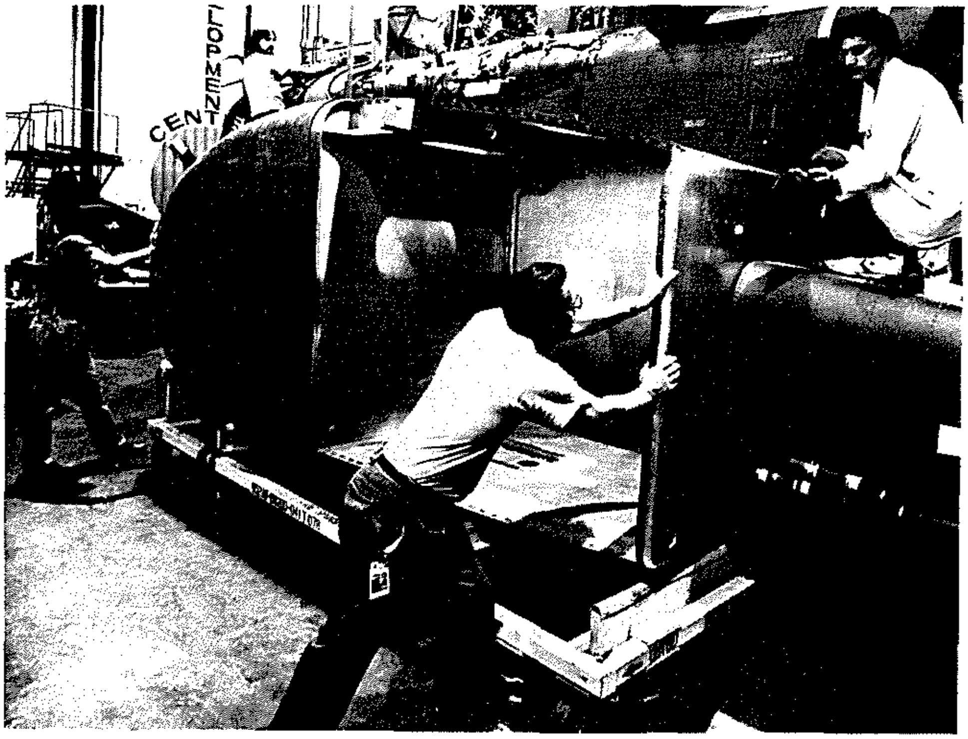

Figure 17. MH-53E Graphite Fuel Sponson

BLACK HAWK EXTERNAL STORES SUPPORT SYSTEM

The external stores support system for the BLACK HAWK helicopter is designed to support auxiliary fuel tanks and/or weapon pylons. This structure was designed from the outset with graphite epoxy in order to meet rigid stiffness requirements. In addition, operational requirements called for a rapid field conversion capability for the UH-60A further necessitating a light-weight composite design. The major elements shown in Figure 18 consists of the support beams and two graphite epoxy filament wound struts.

Figure 18. BLACK HAWK External Stores Support System

The support beams are two-cell rectangular cross section box beams made up of solid graphite laminates. Internal ribs are located at the tip. The structural integrity of the graphite structure was verified by static and fatigue tests of the actual hardware. The graphite box beam structure is shown in Figure 19.

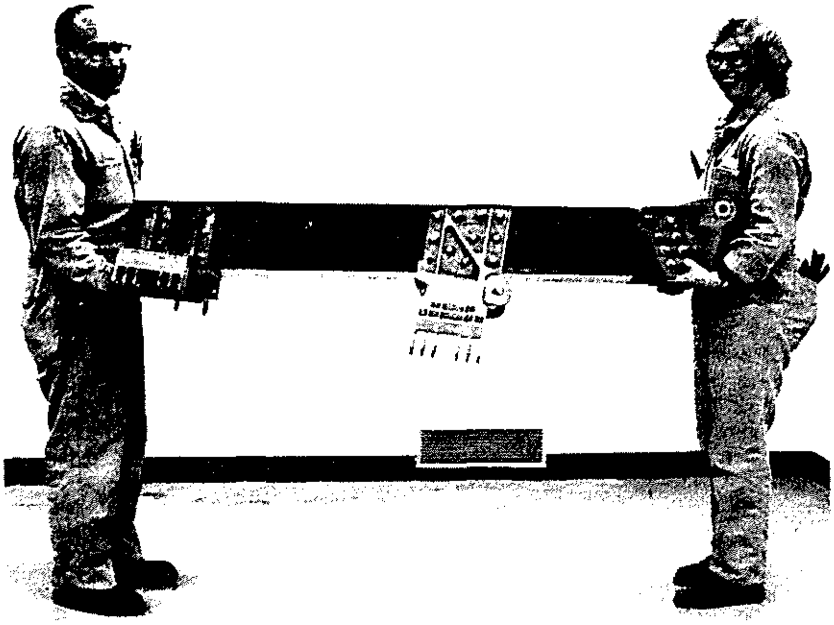

Figure 19. Graphite Box Beam Structure

CONCLUSION

Extensive research and development, plus years of manufacturing experience has firmly established a technology base to design and build primary composite airframe structures that are significantly lighter and lower in cost than metal structures. The maturity of this new generation of composites is evident by production commitments such as MH-53E sponson and the BLACK HAWK external stores support system.