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FILAMENT-WOUND SPAR SHELL GRAPHITE/EPOXY FAN BLADES

by Sam Yao

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16. Abstract

This report presents the methodology for fabrication of wet filament wound spar shell fan blades. All principal structural elements were filament wound, assembled, formed, bonded and co-cured in a female mold. A pair of blades were fabricated as one integral unit and parted into two after curing.

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FOREWORD

This report presents the work accomplished by Fiber Science, Inc. during the period June 1974 to June 1975 on NASA Contract NAS 3-17822, "Filament-Wound Spar Shell Graphite/Epoxy Fan Blades." The work was administered by The National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio with Dr. T. T. Serafini, Project Manager.

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1.0 SUMMARY

Spar shell graphite/epoxy fan blades were designed and fabricated with wet impregnation filament winding technique/post-forming process. The blade airfoil shape and dimensions selected for fabrication conformed to NASA Drawing No. CR-502-118. The root attachment device consisted of a metallic-hub around which the spar and shell filaments were wound. The filament wound blade was designed to operate at a tip speed of 987 km/hr at 1.83 meter tip diameter. Both spar and shell consisted of Thornel 300 graphite fiber impregnated with an epoxy resin system. All principal structural elements were assembled, formed, bonded and co-cured in a female mold. A pair of blades were fabricated as one integral unit which were then separated.

A total of four blades were shipped to NASA for testing. Two of the blades were provided with Type 301 stainless steel leading edge shields.

2.0 INTRODUCTION

Advanced composites featuring high specific strength and modulus offer the potential for reducing fan blade weight and improving structural performance. The objective of this program was to establish the methodology for fabrication of filament-wound spar shell fan blades.

The program consisted of two technical tasks: Fabrication studies and fabrication of blades for spin testing, using Thornel 300 graphite fibers impregnated with epoxy resin system as the principal materials. The airfoil shape and dimensions for the fan blades, excluding the root attachment, conformed to NASA Drawing No. CR-502118. The blade was designed to operate at a tip speed of 987 km/hr at 1.83 meter tip diameter.

The fabrication process employed in this program is called "GeoForm".* The components were wet filament wound using geodesic winding patterns and subsequently post-formed into the desired shape prior to curing the resin. A unique application of this process in this program was to wind, assemble, form, and cure two blades as an integrated unit.

A total of four graphite/epoxy filament-wound spar

*Patent applied for by Fiber Science, Inc.

shell fan blades were delivered to NASA for testing. Two of the blades had no leading edge protection and two had Type 301 stainless steel leading edge protective caps.

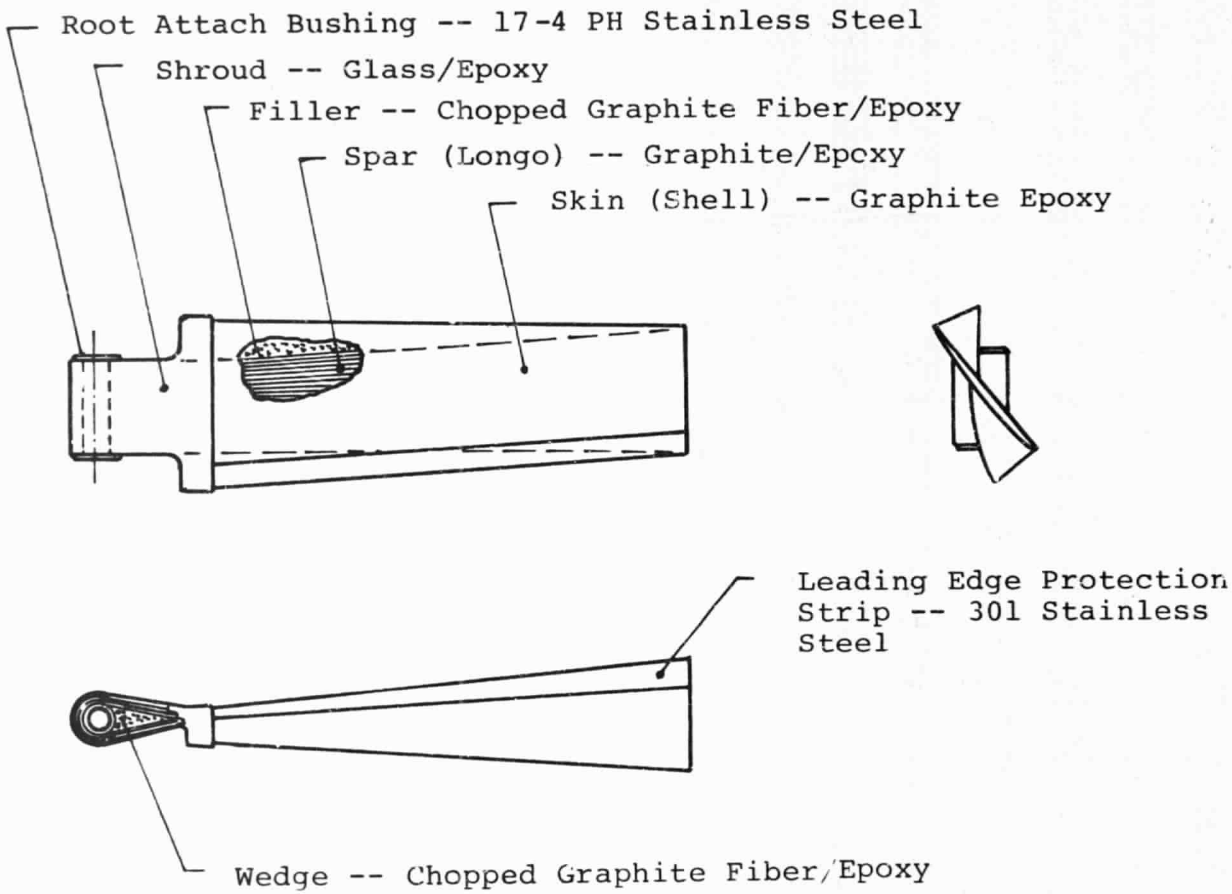

Figure 1. Blade Construction

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3.1 (Continued)

for stress concentration and to prevent local shear failure as a result of bearing loads on the attachment bushing. A metal bushing was incorporated at the root end clevis for wear resistance and to minimize bolt bending of the attachment bolt.

The cavities between the spar and skin shell was filled with chopped graphite fiber/epoxy to provide firm support of the thin shell skin.

A glass laminate shroud connected the end of the airfoil shell to the root end. This shroud provided a torsional link from the airfoil blade to the root end clevis. The shroud consisted of five plies of Style 1581 glass fabric impregnated with Applied Plastics APCO 2434/2340 epoxy resin system.

The leading edge of the blade was protected with a metal shield. This protective shield was made of 0.041/cm (.016 inch) thick, 1/4 hard, Type 301 stainless steel and was bonded on the recessed leading edge of the blade with B. F. Goodrich's A1177B epoxy adhesive. The protective surfaces were 2.54 cm (1 inch) wide on the upper surface and 3.81 cm (1-1/2 inches) wide on the lower surface and extending from the root to the very tip of the blade.

3.2 FABRICATION APPROACH

The fabrication approach was as follows:

3.2 (Continued)

1. Technique of wet impregnation filament winding was employed.
2. A set of two blades was manufactured as one integral unit at a time in order to speed up fabrication, minimize material waste and to simplify tooling.
3. Continuous filament winding was employed for the spar to ensure sound structural integrity.
4. Geodesic winding pattern was adopted for the skin.
5. All principal structural members, skin, spar, and root attach bushing, were assembled, formed, bonded, and cured together as an integral assembly to eliminate secondary bonding and dimensional tolerance (fit) problems.
6. A low cost inflatable thermoplastic bladder was utilized for winding the skin.

3.3 TOOLING

Major toolings required for this program were the blade forming mold, skin winding mandrel, spar winding fixture and filament winding machine.

The blade forming mold is shown in Figure 2. The mold was designed to produce a set of two blades with tip-to-tip arrangement and to make best use of the wet filament wound co-cured process. It is of high temperature,

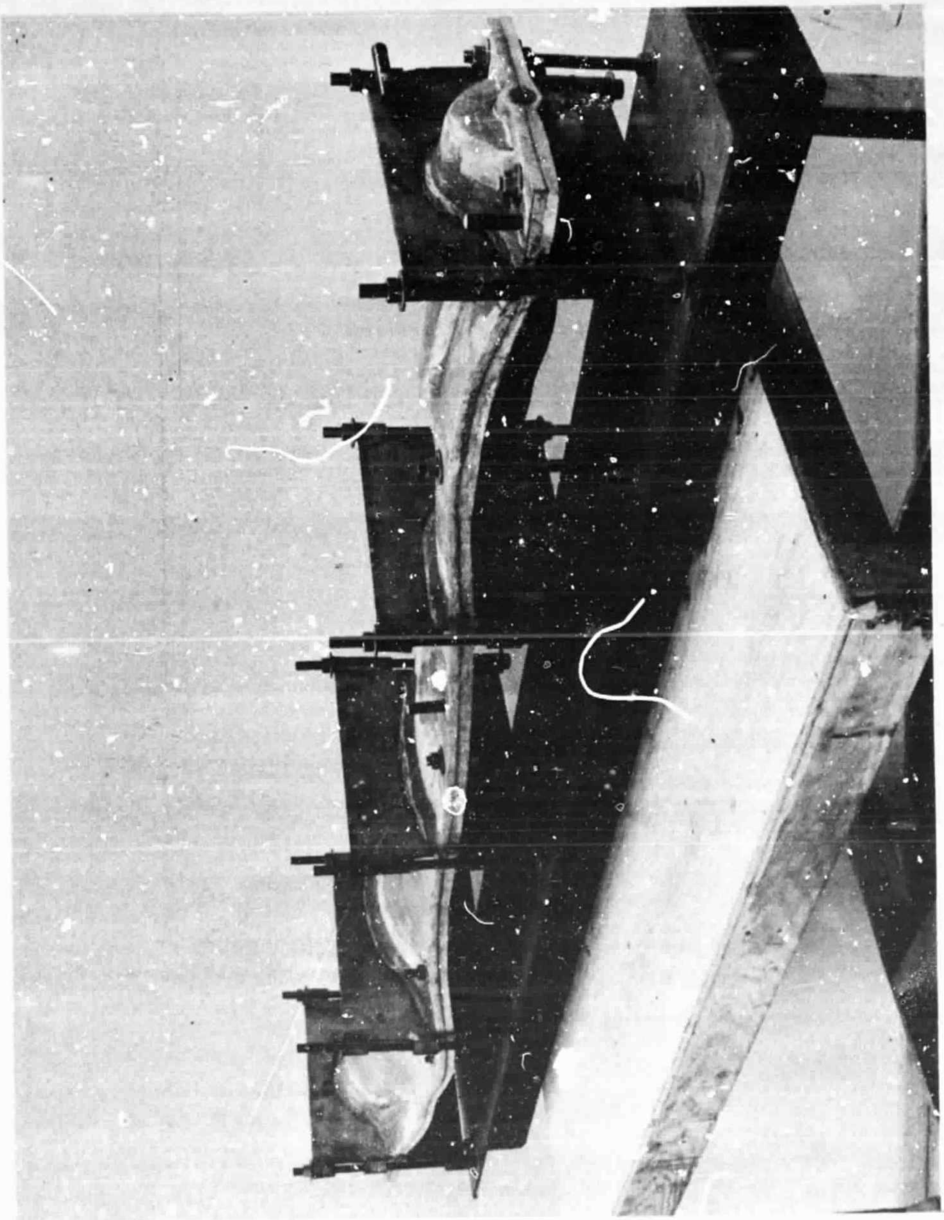

Figure 2. Mold Assembly

3.3 (Continued)

1.27 cm thick, fiberglass construction. The parting line of the mold lies on the leading/trailing edge of the blade. The mold is suspended with steel threaded rods on a steel mold base. This type of mold support allows uniform heating as well as freedom for thermal expansion and contraction. The fiberglass mold proper was also reinforced with steel clamp-plates.

The skin winding mandrel was designed for winding under internal air pressure. Application of external pressure would collapse the wound assembly into the desired shape.

The spar winding fixture consisted of a piece of rectangular steel tubing with a spindle fastened at the middle. A root attachment bushing was secured at each end of the fixture. The fixture was designed to wind longos to desired lengths with uniform fiber tension.

3.4 FABRICATION DEVELOPMENT

Five major areas of fabrication process were developed in this program.

1. Skin Bladder. Several plastic films had been employed as bladder materials. Fiber-Resin Corporation's FR7035 epoxy film adhesive was found satisfactory in the winding application and compatible to the fabrication process.

3.4 (Continued)

2. Spar Longo. Because of the highly twisted blade configuration, the fiber length in the spar varies across the chord. Variable fiber lengths required in this spar were obtained by introducing a variable height spacer to the longo fixture. Spreading of longo into desired shape was accomplished by loosely tieing small bundles of fiber.

3. Pressurization and Forming. Forming of skin contour was accomplished satisfactorily by applying hydraulic pressure using chopped graphite fiber/epoxy. The use of chopped graphite fiber/epoxy also accomplished the filling of cavities between the skin and spar near the root end. Pinching of leading and trailing edges of the blade skin was eliminated by proper alignment of the wound assembly in the mold.

4. Leading/Trailing Edge Definition. Since both the leading and trailing edges have very small radii, the one-piece skin was required to have a sharp fold. Leading/trailing edge was difficult to form from a single circuit helical pattern skin. Multi-circuit helical pattern skins were found preferable because of the tight weave.

5. Leading Edge Protection. Nickel plating and metal spraying over the leading edge area were tried and found unsatisfactory due to

3.4 (Continued)

poor adhesion. Forming a stainless steel cap and bonding it on the leading edge of the blade was found to be superior.

3.5 FABRICATION

The blade skin and spar were all fabricated by wet impregnation filament winding technique/post forming process developed at Fiber Science, Inc. The skin was wound over a cylindrical air inflatable mandrel covered by a one-piece film adhesive (Figure 3). The mandrel was then removed. The backing strip of film adhesive was removed prior to the installation of the spar longos.

The spar (longo) was wound over two root attachment bushings located on a fixture (Figure 4). Variable height spacers were employed to obtain the required fiber lengths. A 0.0025 cm (.001 inch) thick glass laminate was inserted in between the longos to serve as a carrier at the end of the winding. The fibers were loosely tied on the carrier in their respective paths. A pair of yokes were then attached to the bushings on the wound assembly. A precase wedge made of chopped glass/epoxy was installed next to the attachment bushing to provide a smooth transition for the longos. Chopped graphite fiber/epoxy filling materials were spread on the longos where required. This whole assembly was inserted inside the skin winding.

The wound spar/skin assembly was placed on the lower

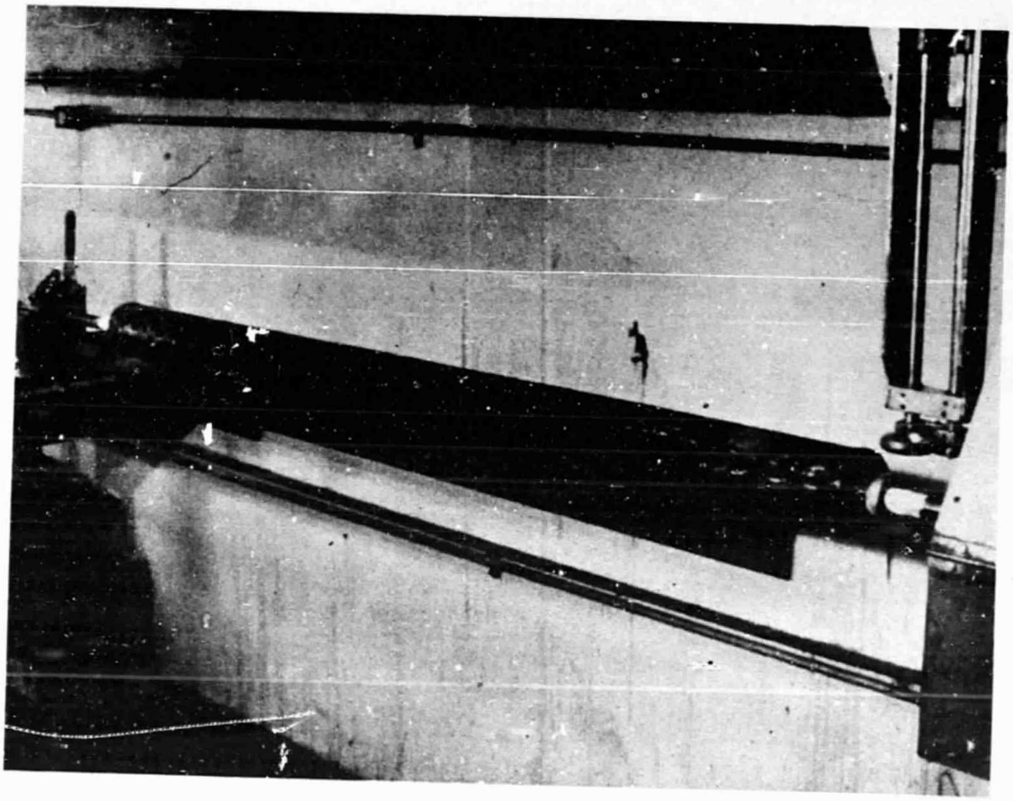

Figure 3. Skin Winding

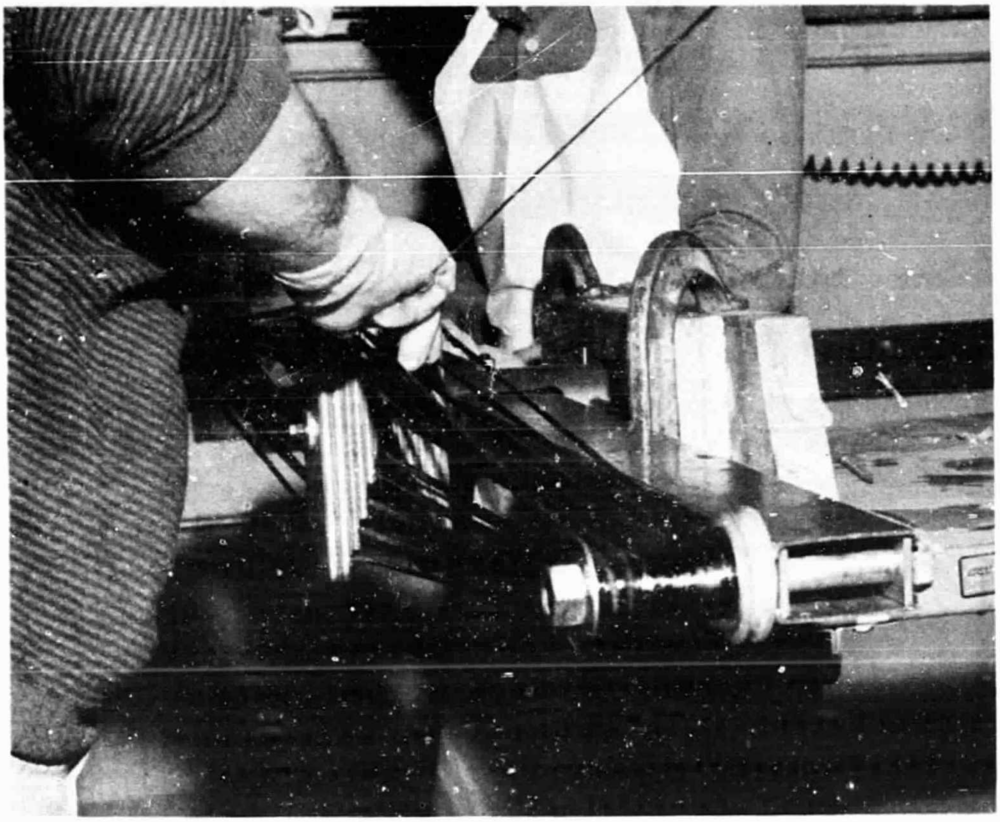

Figure 4. Longo Winding

3.5 (Continued)

mold half (Figure 5). The attachment bushing was aligned in the recess on the mold and held in place by securing the yoke on the mold. The skin winding was then flattened and aligned with the leading/trailing edge to the mold. Rubber pinch blocks were installed at both ends of the skin at the root end area before closing the mold. The wound assembly in the female mold was gelled 4 hours at $327^{o}K$ and cured 2 hours at $355^{o}K$ and followed 2 hours at $394^{o}K$. The cured assembly is shown in Figure 6.

The glass/epoxy shroud was laminated to the root ends of the cured assembly (see Figure 7). The stainless steel leading edge shield bonded onto the trimmed blade (see Figure 8) using B. F. Goodrich A1177B adhesive.

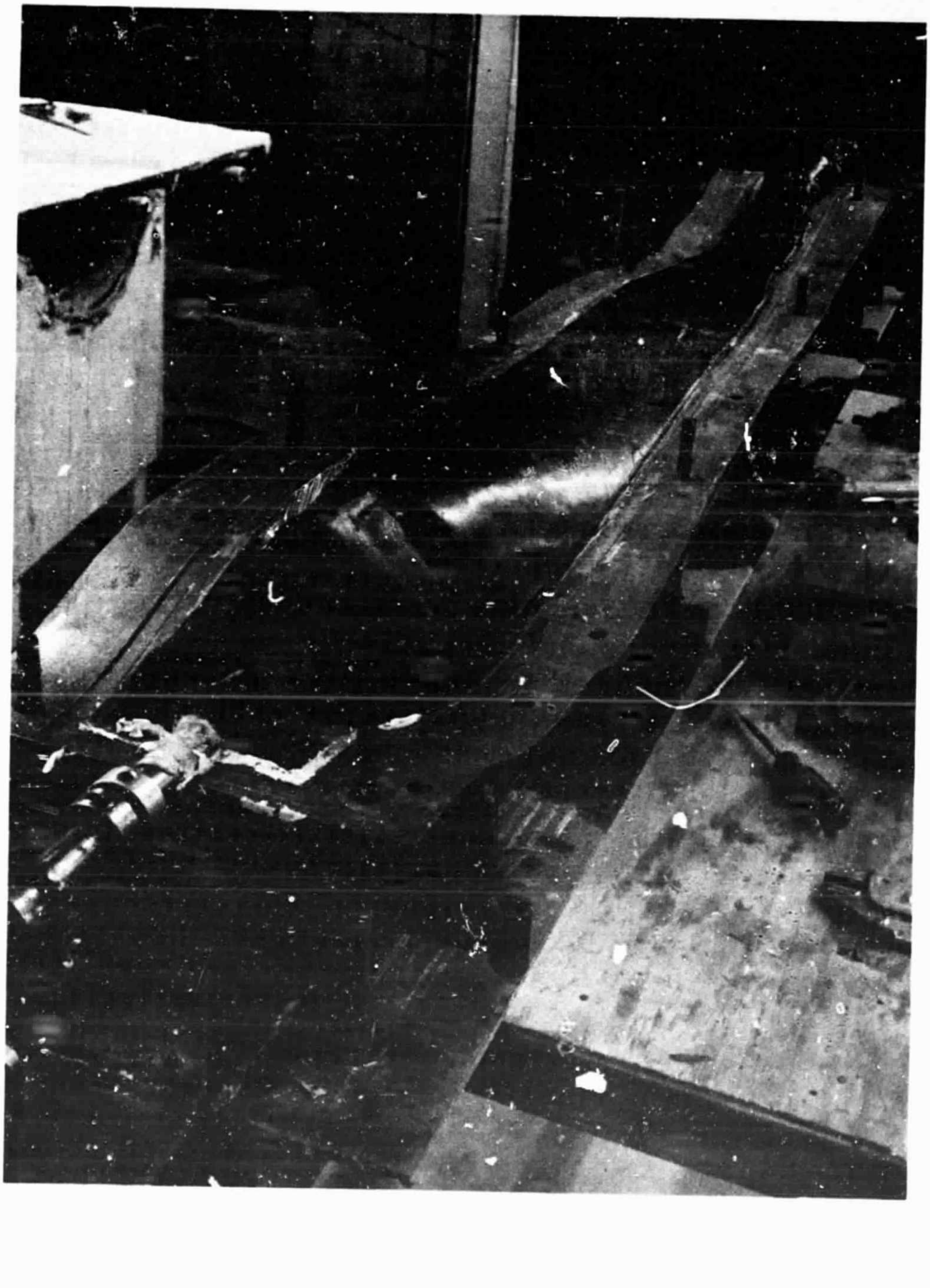

Figure 5. Forming Blade on Mold

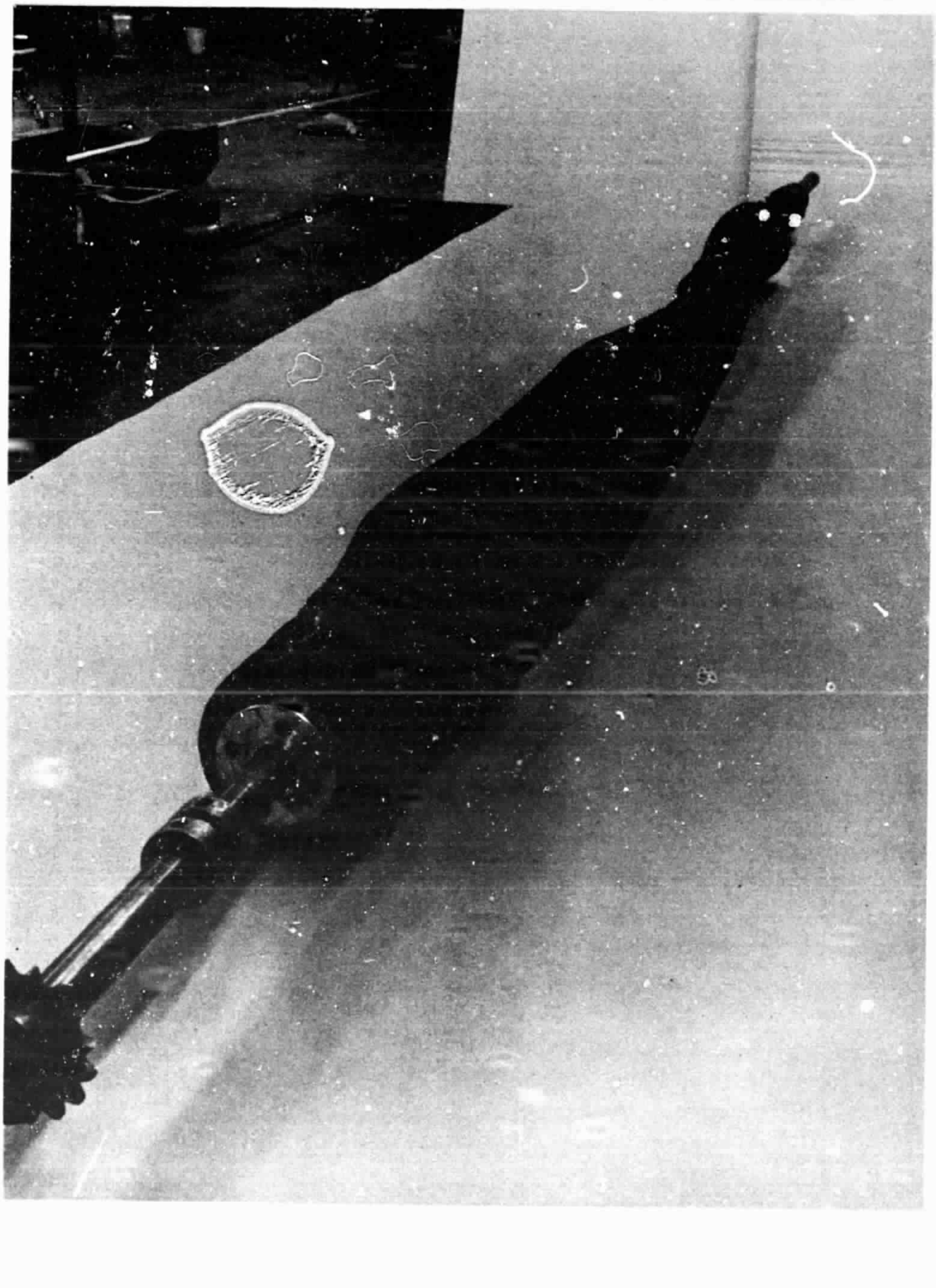

Figure 6. Cured Assembly

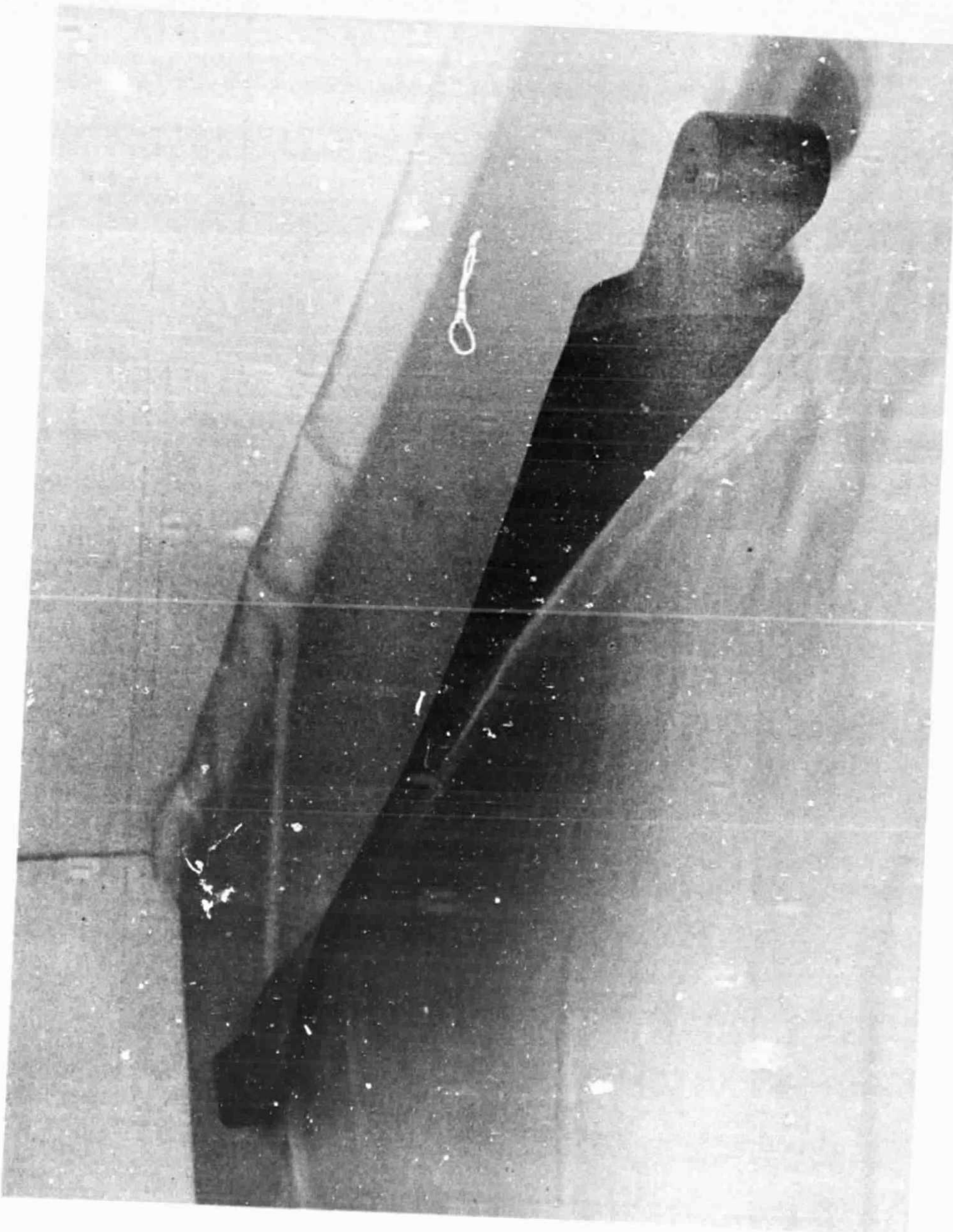

Figure 7. Uncut Assembly

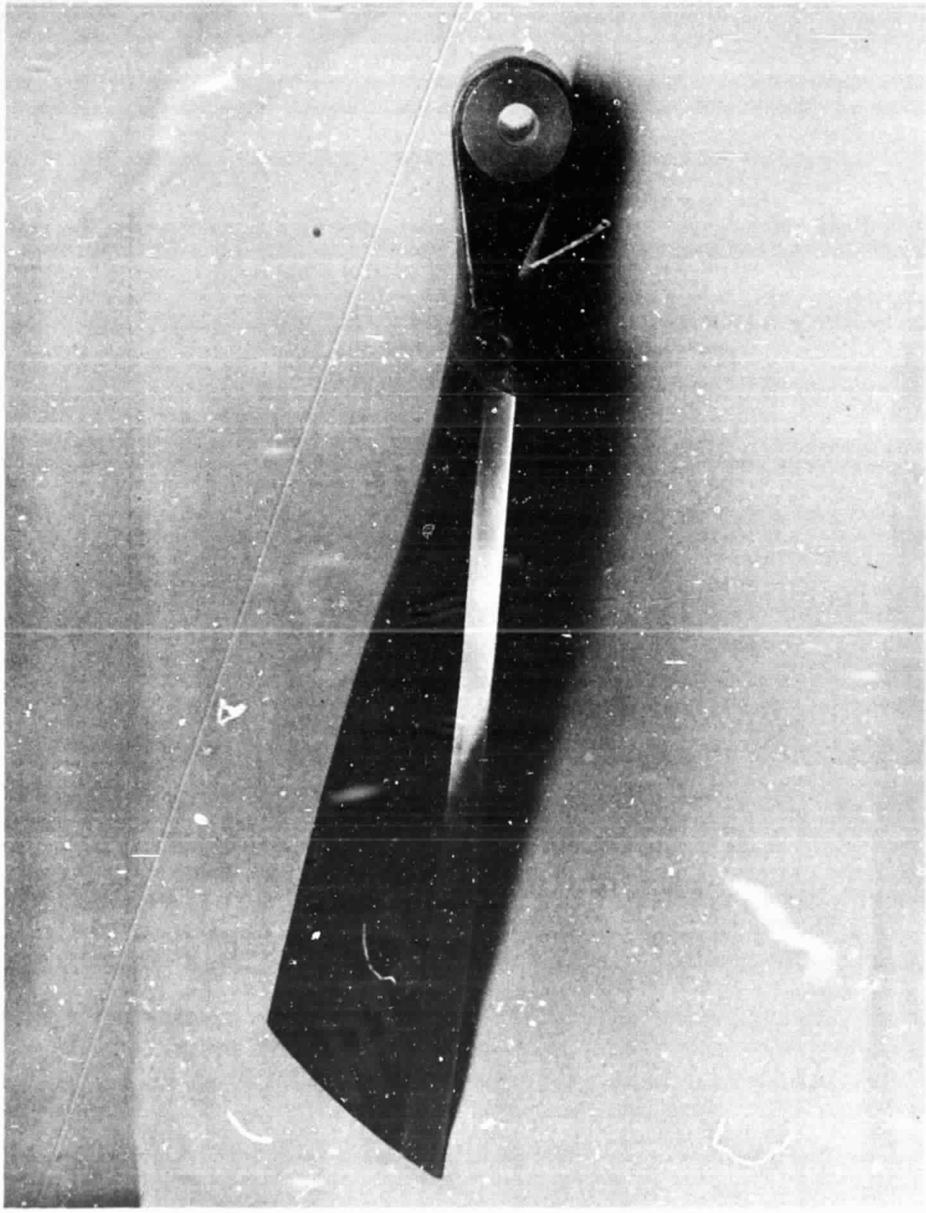

Figure 8. Complete Blade

4.0 RESULTS

A total of four blades (two sets) fabricated from graphite/epoxy by the filament winding post-forming (GeoForm) process were successfully fabricated and shipped to NASA for testing. Two of the blades had no leading edge protection and two had Type 301 stainless steel leading edge protection shields.

5.0 CONCLUSIONS

It is concluded that the spar shell graphite/epoxy fan blades can be successfully fabricated by employing wet impregnation filament winding techniques and subsequently forming into the desired shape in a configurated mold prior to curing the resin.

The fabrication process also demonstrated that all principal structural members, skin, spar and root attachment bushing could be assembled, formed, bonded and cured together in one integral unit to eliminate secondary bondings and dimensional fit problems. A set of two blades could be manufactured simultaneously. Thornel 300 graphite impregnated with an epoxy resin system has been proven to have sound structural integrity as indicated by NASA test results of the blade specimen. Graphite/epoxy blades have yielded a significant (4 [illegible]) weight saving as compared to the metal blade.