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Fabrication and Quality Assurance Processes for Superhybrid Composite Fan Blades

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FABRICATION AND QUALITY ASSURANCE PROCESSES FOR SUPERHYBRID COMPOSITE FAN BLADES

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ABSTRACT

An investigation was conducted to evaluate the feasibility of fabricating full-scale fan blades from superhybrid composites (SHC) for use in large, commercial gas turbine engines. The type of blade construction selected was a metal-spar/SHC-shell configuration, in which the outer shell was adhesively bonded to a short, internal, titanium spar. This report describes various aspects of blade fabrication, inspection, and quality assurance procedures developed in the investigation. Conclusions from this investigation indicate that the SHC concept is feasible for the fabrication of prototype, full-scale, metal-spar/SHC-shell fan blades that have good structural properties and meet dimensional requirements.

1.0 INTRODUCTION

The superhybrid composite (SHC) concept provides one means for efficiently utilizing advanced composite materials in selected aerospace applications. The SHC concept combines the best characteristics of fiber/resin-matrix, fiber/metal-matrix composites, and high-strength metallic foils in an integrated adhesively-bonded structure. One SHC laminate consists of a core of boron/aluminum and graphite/epoxy plies sandwiched between outer plies of high strength titanium foils. All of the components are adhesively-bonded to each other. The result is a composite structure with the following characteristics: (1) density comparable to fiberglass/resin composites, (2) impact resistance approaching that of titanium on a specific impact basis, (3) moisture and erosion resistance comparable to titanium, (4) longitudinal strength comparable to advanced fiber/resin composites, (5) transverse flexural strength comparable to titanium yield strength, and (6) a bending and torsional stiffness comparable to boron/aluminum composites.

The feasibility of making SHC laminates and the exploratory evaluation of physical and mechanical properties is described in references 1 and 2. Further evaluation of SHC properties, including effects of thermal fatigue, is described in reference 3. The ballistic impact resistance of cantiliver, double-wedge shaped (blade simulation) SHC specimens was evaluated as described in reference 4.

Based on the promising data obtained in the above programs, an investigation was conducted to evaluate the feasibility of using the SHC concept for the design and fabrication of full-scale spar/shell fan blades for commercial aircraft turbofan engines. Details of this investigation, including results of foreign object impact testing, are described in references 5 and 6. The objective of this report is to provide a summary description of the blade fabrication, inspection, and quality assurance procedures developed as a major part of the investigation.

2.0 BLADE CONFIGURATIONS

A commercial jet engine CF6-type fan blade was selected to demonstrate the feasibility of the SHC concept. The CF6 blade configuration met design requirements necessary to demonstrate the SHC concept for the fabrication of large fan blades and to assess benefits associated with weight and foreign object damage (FOD) resistance. Some advantages of the selected blade configuration are: (1) the configuration is representative of other large fan blades used in high-bypass turbine engines, (2) the CF6 aerodynamic design was used in other comparable composite fan blade programs supported by the Department of Defense and NASA, (3) titanium CF6 blades were available for low-cost fabrication of the spars, and (4) an existing test facility and fixtures were compatible with the CF6 blade.

The CF6 titanium blade is shown in figure 1. There are 38 blades in a CF6 rotor assembly. The blade has a length of 30 inches, a tip chord of 9.8 inches, and a root chord of 6.5 inches. Blade weight is 11.0 pounds. The titanium CF6 blade weight represents the baseline weight used for comparison with the SHC blades constructed in the program. The airfoil geometry used for the SHC blades was the same as for the titanium CF6 blade with the mid-span shroud removed.

Two basic blade configurations were evaluated. Both designs used metallic titanium spars with conventional CF6 dovetails (root attachment). The titanium CF6 blades were machined to provide spars for construction of the SHC blade specimens. The first design, designated as "TiCore", had a spar that was internal to the blade shell, as shown schematically in figure 2. The second design, designated as "TiCom", had the titanium spar shaped to provide spar material at the leading-edge concave side of the blade where it could dissipate local impact forces from foreign objects. Schematics of the TiCom configuration are shown in figure 3.

Two different spar sizes were analytically evaluated for the TiCom and TiCore blades. The two spar sizes represent the extremes of the range of practical spar sizes. The small spar is limited by leading-edge FOD protection requirements in the outer blade airfoil. The large spar is limited by weight payoff aspects over the all-titanium CF6 blade. The weight benefits of the TiCore small spar/shell designs compared to the titanium CF6 blade could be substantial (about 3.1 lb less than the shrouded CF6 blade). This amounts to about a 30-percent weight savings or about a 120 pound weight savings for a 38-blade stage. Based on the results of the preliminary evaluations, small spar configurations were selected for the fabrication of blade specimens.

3.0 FABRICATION PROCESS

The basic fabrication process developed for the SHC blades is shown schematically in figure 4. The fiber/resin composite portion of the SHC blade was composed of AS-type (high strength, medium modulus) graphite and S-glass fiber/epoxy preimpregnated plies, of about 80 and 20-percent fiber volume, respectively. The graphite/glass fiber/resin material was an intraply hybrid in which the fibers were intermixed in a side-by-side fashion within the same ply. This intraply hybrid material evolved from baseline impact studies conducted in reference 4. The individual B/Al plies were made from 0.0056-inch diameter boron fibers and type 1100 aluminum foil matrix. The titanium (6Al-4V) sheet material utilized for the outer blade plies had a thickness of 0.016-inches.

The titanium sheets were formed to the required blade shape by partially creep forming the materials in matched cast steel dies heated to a temperature between 1600° to 1700° F under an inert gas environment. At this temperature the titanium was in a superplastic condition. The preformed titanium blanks were then fully formed in the steel dies at a temperature of 1250° to 1350° F.

The same tooling was also used to form the B/Al materials. Two slave sheets of aluminum were press-formed in the die set. The B/Al-developed ply sheet was preformed approximately to size with a 15-degree angle ply orientation. The flat ply was then sandwiched between the two preformed aluminum slave sheets and placed in the die set. Pressure was applied to slowly creep form the B/Al foil to the compound curvature of the die profile by heating to a temperature of 875° F. This process provided highly accurate SHC metallic blade components with good thickness control and with minimum springback.

A low-flow, high-peel strength adhesive, designated AF3185, was selected for bonding the outer titanium ply to the B/Al plies and the B/Al to the fiber/resin SHC core. The use of this adhesive was found to be critical to the successful bonding of the blade components.

Four spars for each of the two SHC blade designs were machined from CF6 shrouded titanium fan blades. Both conventional and chemical milling techniques were used. Figure 5 shows a typical TiCore spar and figure 6 shows a typical TiCom spar.

Because of the small number of blades to be fabricated and the minute inconsistencies in the CF6 titanium blade geometries, a unique set of ply patterns was made for each blade specimen. Each blade was accurately located into the forming die and an epoxy tooling resin was cast around the spar to fill the die cavity, thereby making a concave and convex shell. Each shell was then used to generate the ply patterns by using conventional scribing techniques, as shown in figure 7. Typical hybrid composite ply patterns and preform assembly are shown in figures 8 and 9.

The various components of the SHC blades were assembled into a fixed preform using the mold tool (to be subsequently described) as an assembly fixture.

4.0 BLADE FABRICATION

The economics of fabricating a small quantity of blades dictated that a "soft" mold tool technique be utilized as opposed to the use of a steel mold for large quantity blade production. The mold was made from high temperature-resistant epoxy resins containing metallic additives. The mold tool was fabricated by casting each mold half around a master model titanium CF6 titanium blade which had the midspan shroud machined away. A view of the blade mold used is shown in figure 10.

The blade molding process was developed after molding parameters and adhesive type were determined from the fabrication of prototype blades.

The blades were molded by inserting the blade preform assembly into a mold preheated to 215° F. The mold was closed around the preform in a programmed closing-schedule and a pressure of 70 000 pounds was applied. The mold tool opening was monitored for a period of 30 minutes. By this time the mold was fully closed. After the 30-minute closing schedule was completed, the blade cure continued for 45 minutes at the same temperature. The mold temperature was then increased to 230° F and curing was continued for 180 minutes at a maximum load of 70 000 pounds. At the end of the cure cycle, the blade was removed from the press and post cured at 275° F for a period of 240 minutes.

After completion of post curing, the blade was processed to remove resin flash, and for tip trimming and weighing. Figures 11 and 12 show views of the completed SHC TiCore and TiCom blades, respectively.

5.0 DESTRUCTIVE EVALUATIONS

Each of the prototype blades was ultrasonically C-scanned after molding to assess blade quality prior to cross-section cutting of the blade for destructive analysis. Teflon washers were molded into the TiCore blade to demonstrate evaluation capability for locating possible delaminations. No detectable disbonds or excessive porosity were found during the C-scan tests (with the exception of the built-in Teflon defects). This indicated that the blades were well consolidated.

A destructive analysis of the prototype blades was conducted. Sections of the blades were subjected to tensile and short beam shear tests. Figure 13 shows a typical view of the specimen cutting plan for a TiCom blade. The cutting plan also applied to the TiCore blade. The test results indicated that adequate material mechanical properties were achieved during blade fabrication compared to design requirements. Based on the test results, the remaining six SHC blades were fabricated for centrifugal strength and impact testing.

6.0 QUALITY ASSURANCE

Each of the six SHC blades were subjected to a rigorous nondestructive and dimensional analysis. A detailed evaluation of each SHC blade was conducted to assess overall blade quality and to judge acceptability of the blades for centrifugal strength and FOD testing.

A dimensional inspection was made on each blade at each of three airfoil sections: root, pitch, and tip. At each span location, four leading-edge-thickness measurements and maximum blade thickness measurements were recorded. All these measurements verified that the SHC blades were fabricated to the required CF6 airfoil dimensions.

7.0 CONCLUSIONS

The following conclusions are derived from the results of the superhybrid composite (SHC) blade fabrication investigation described in this report:

1. The SHC concept is feasible for fabricating prototype, lightweight, high-quality, large fan blades that have good structural properties.
2. The blade fabrication process developed in this investigation indicated that SHC blades could be fabricated with good uniformity and dimensional control.
3. A low-flow, high peel strength adhesive (designated AF 3185) was found to be critical for the successful bonding of the blade components.

8.0 REFERENCES

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4. Novak, R. C.: Multi-Fiber Composites (United Technologies Research Cen ter, R76-912098-11; NASA Contract NAS3-18941.) NASA CR-135062, Mar. 1976.

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9.0 BIOGRAPHIES

Mr. Lark is a member of the Space Transportation Engineering Division. He received his B.S. in Chemical Engineering (1948) from Case Institute of Technology. His current work assignments include the development of high pressure overwrapped composite bottles, and composite spacecraft structures. He is also responsible for composite wind turbine rotor technology for the Wind Energy Project Office. Other experience includes the development of positive expulsion devices, advanced fibers, resins and adhesives. He has contributed significantly to the advancement of aramid and carbon fiber composite pressure vessels, impact-resistant hybrid and superhybrid composites, and advanced composites in general. He is a member of SAMPE and SPE.

Dr. Chamis is a member of the Structures and Mechanical Technologies Division and has been employed at NASA Lewis Research Center since 1968. He received his B.S. in Civil Engineering (1960) from Cleveland State University, and an M.S. (1962) and Ph.D (1967) in Engineering Mechanics from Case Western Reserve University where he was a member of the Engineering Design Center. His current research is in the areas of analysis, design and optimization of composite structures and structural components and also in the analysis and design of testing methods for advanced composites. This research culminated in several journal and conference proceeding technical articles. Dr. Chamis is a member of several professional societies including SAMPE. He is a registered professional engineer in the State of Ohio.

Figure 1. - CF6 Titanium fan blade.

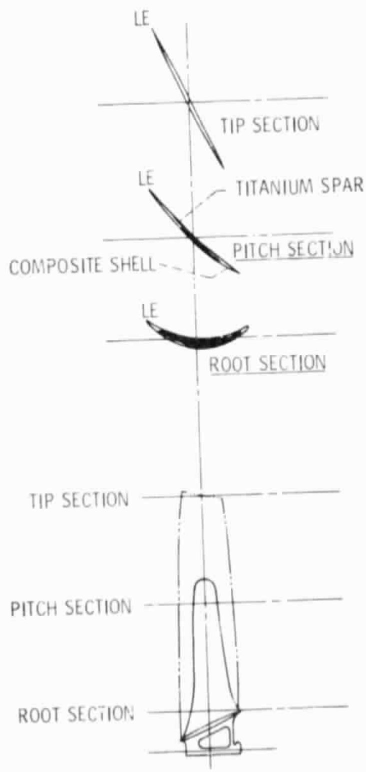

Figure 2. - TiCore blade configuration.

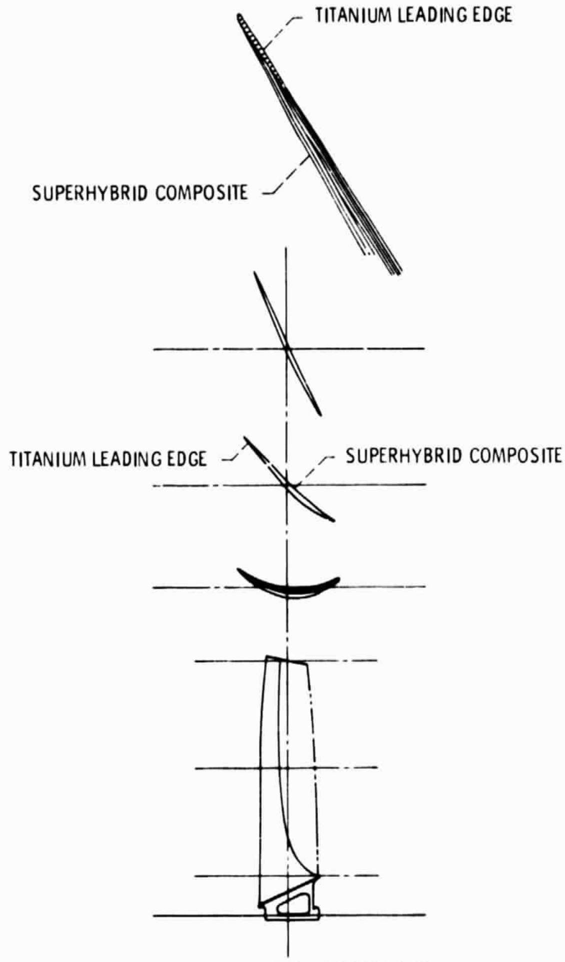

Figure 3. - TiCom blade configuration.

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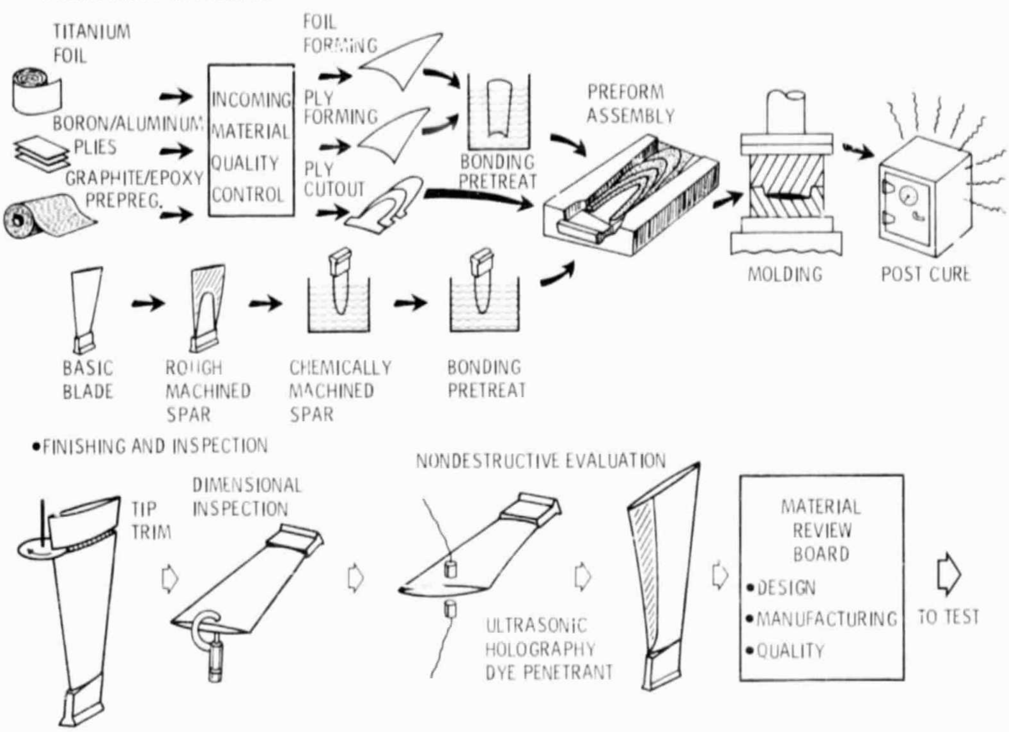

Figure 4. - Superhybrid composite blade fabrication process.

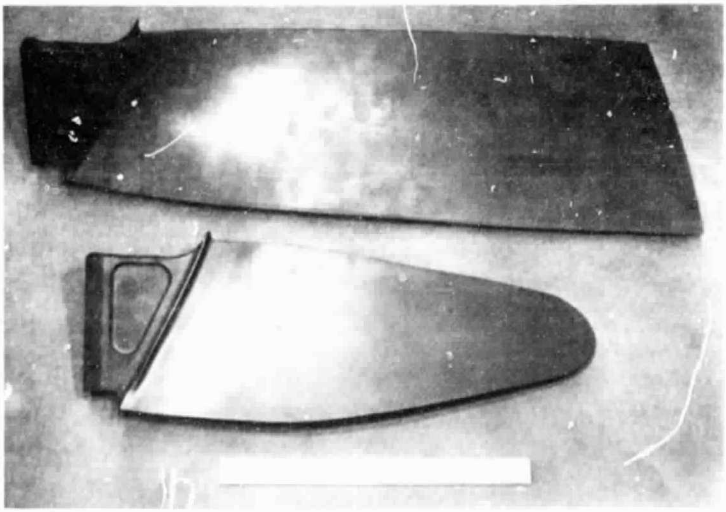

Figure 5. - Ticore blade shown with internal spar.

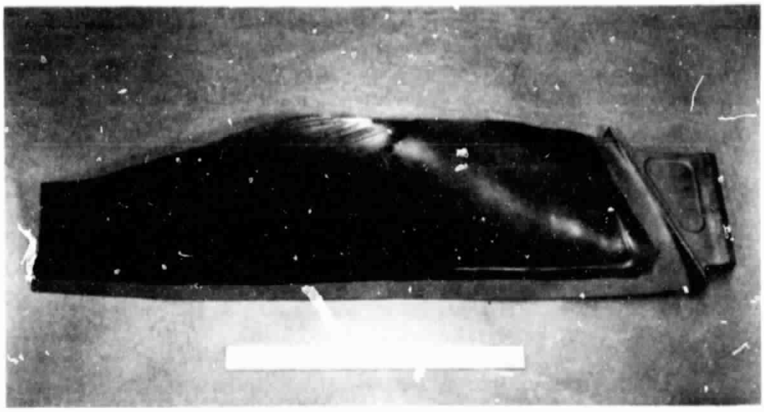

Figure 6. - Ticom spar after application of prebonding primer.

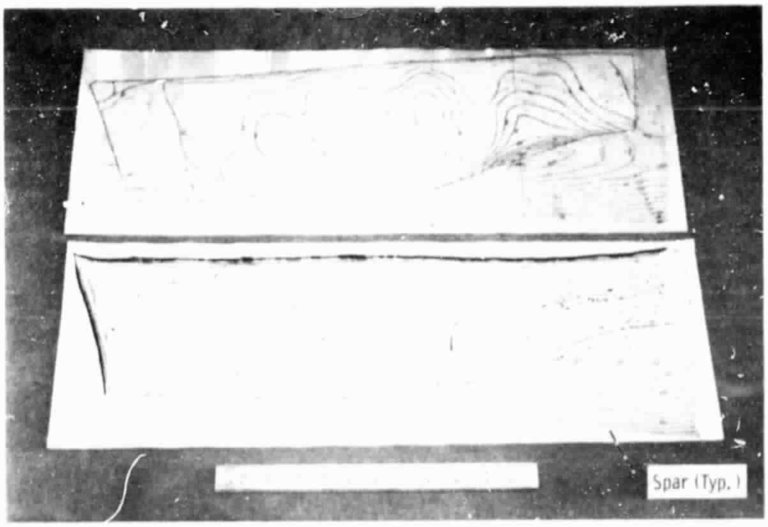

Figure 7. - Ply contours of spar and shell superimposed for Ticom blade.

Figure 8. - Typical graphite/epoxy ply patterns.

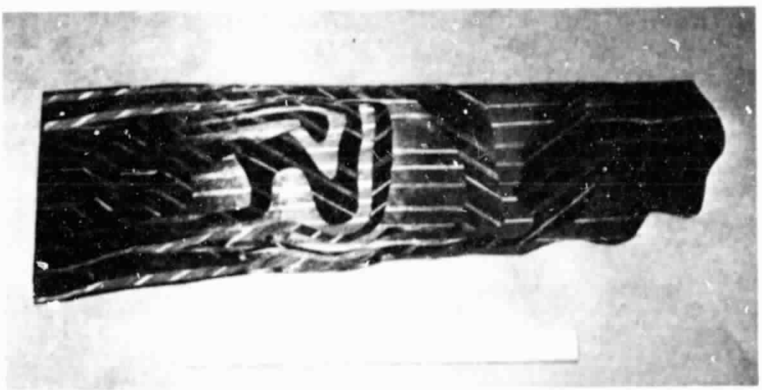

Figure 9. - Graphite/glass epoxy preform assembly.

Figure 10. - Prototype blade mold.

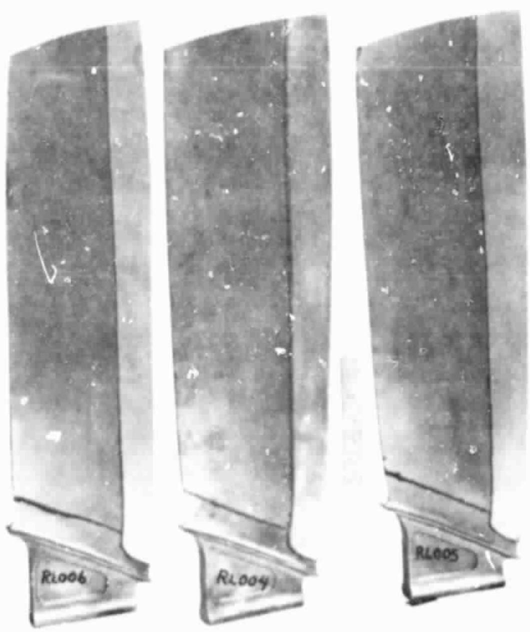

Figure 11. - Superhybrid ticore blades after construction (convex surfaces).

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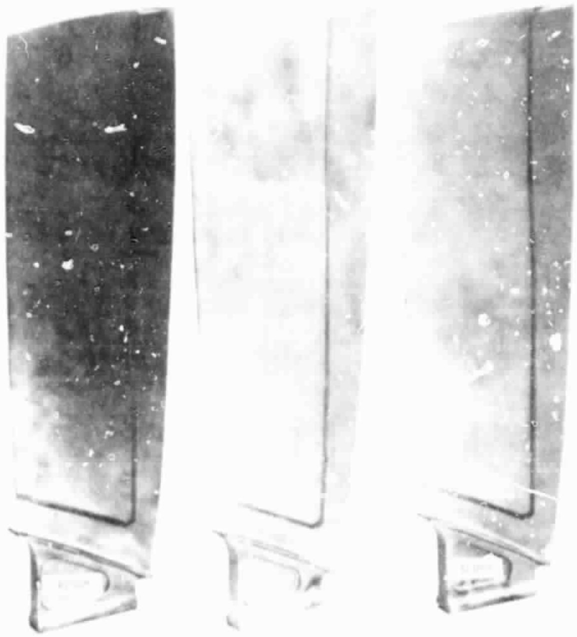
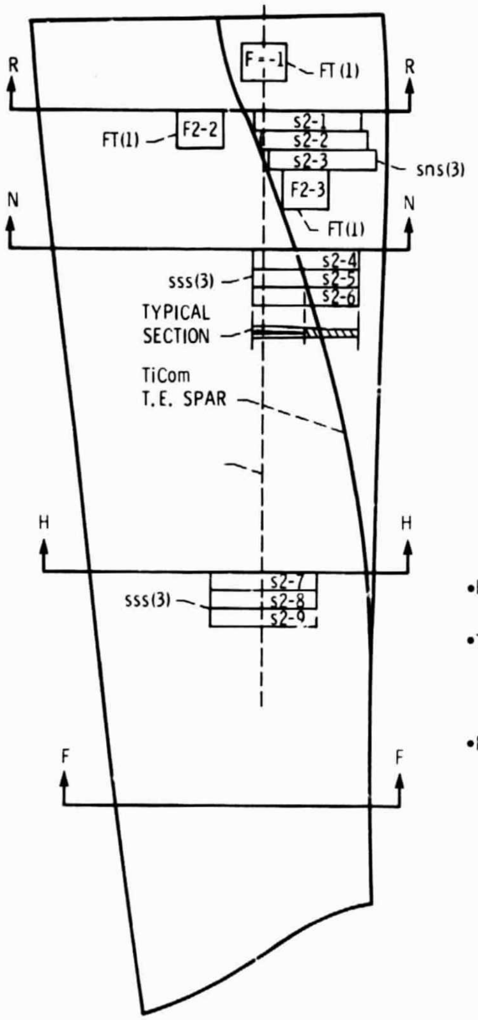


Figure 12. - Superhybrid ticom blades after construction (convex surfaces).



SPECIMEN LOCATIONS

- RADIAL SECTIONS AT RR, NN, HH, AND FF
- TRANSVERSE SHORT BEAM SHEAR (SBS) (9 SPECIMENS, 3 LOCATIONS) BASED UPON AVERAGE LENGTH TO AVERAGE THICKNESS RATIO OF 5
- FLATWISE TENSILE (FT) (3 SPECIMENS)

Figure 13. - Quality assurance specimen cutting plan.