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COMPOSITE INTERMEDIATE CASE MANUFACTURING SCALE-UP FOR ADVANCED ENGINES

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SUMMARY

This Manufacturing Technology for Propulsion Program developed a process to produce a composite intermediate case for advanced gas turbine engines. The method selected to manufacture this large, complex part uses hard tooling for surfaces in the airflow path and trapped rubber to force the composite against the mold. Subelements were manufactured and tested to verify the selected design, tools and processes. The most significant subelement produced was a half-scale version of a composite intermediate case. The half-scale subelement maintained the geometry and key dimensions of the full-scale case, allowing relevant process development and structural verification testing to be performed on the subelement before manufacturing the first full-scale case.

INTRODUCTION

The objective of this Air Force Manufacturing Technology for Propulsion program is to establish manufacturing methods for the fabrication of a composite intermediate case for the next generation of fighter aircraft engines. The work is being performed by Pratt & Whitney and DuPont under the direction of Mr. Kenneth Ronald of the Air Force Manufacturing Technology Directorate, WL/MTPN, under Phase Va of Contract F33615-85-C-5152.

The intermediate case in today's military gas turbine engines is a large complex titanium casting that is required to support front engine bearings, maintain blade clearances, handle multiple engine loads, and direct airflows into both the high-pressure compressor and the bypass duct. Figure 1 shows the location of the intermediate case in a typical jet engine. Figures 2 and 3 show the front and aft sides of a typical titanium intermediate case. The complexity of the part and the requirement that the part carry a substantial structural load presents a significant challenge to design and manufacturing.

The intermediate case also presents a materials challenge. Airfoils located further from the engine inlet, beyond the second stator vane, are subject to prolonged exposure to air at temperatures up to 371 C (700F) and at pressures of several atmospheres. Air oxidation tests have been run at P&W at a temperature of 371C (700F) and a pressure of 4 atmospheres, shown in Figure 4. These oxidation tests have shown that Avimid N, a fluorinated polyimide manufactured by DuPont, has a definite advantage over PMR-15 in atmospheric oxidation resistance.

TECHNICAL APPROACH

The approach used by DuPont, the supplier of Avimid N and the subcontractor to Pratt & Whitney in the intermediate case program, was to develop tooling and procedures for subelements and then progress to the manufacture of a full-scale case.

The process evaluation task was divided into four major subtasks:

Definition of subelements
Development of process parameters for fabrication of subelements
Fabrication of test subelements

Testing of subelements

The subelements selected were (1) half-scale rings, (2) struts and (3) a half-scale case with a half-scale outer ring and three full-size struts.

Half-scale Ring. The fabrication approach uses hard tooling for surfaces in the engine airflow path and a high-expansion rubber to generate and transmit the compaction pressure in all areas not in the path of the airflow. A high-temperature silicone rubber was chosen as the high-expansion material to generate pressure for the ring and other subelements.

Eight half-scale diameter outer ring subelements, measuring 45.7 cm (18 in.) in diameter, were manufactured to validate the fabrication approach. The first Avimid N ring, shown in Figure 5 exhibited good resin flow control and fair material consolidation. The results demonstrated that this fabrication approach is viable, and with some modifications to the approach, well-consolidated subelements could be produced. The expansion behavior of the rubber and prepreg layup techniques were investigated during the manufacture of the next seven rings.

Strut Subelement. The first strut subelement was laid up using preliminary ply shapes and cured to demonstrate the suitability of using rubber inserts in the tools to generate the consolidation pressure. Rubber expansion calculations had indicated that the relatively thick leading and trailing edges of the strut could pose consolidation difficulties. A simple strut subelement tool was designed to explore and resolve these problems. The tool and resulting strut are shown in Figure 6. Tool closing difficulties, associated with the bulk factor of prepreg materials, indicated that modifications of the ply shapes and layup techniques would be required.

A number of struts were laid up and cured with various cure cycles. All of the strut elements had poor consolidation compared to the ring described in the preceding section because the pressure developed by the rubber apparently varied from cycle to cycle. A separate study of the relationship between pressure increase of the rubber with temperature increase was linear, but the slopes of the lines were 30 degrees, 45 degrees, and 60 degrees.

A high-temperature pressure transducer was procured to perform direct measurement of cure pressure generated by the rubber expansion material. A consolidation pressure of 12.42 MPa (1800 psi) was measured. Devolatilization times were also adjusted to achieve adequate resin flow for good consolidation. These process modifications resulted in the well-consolidated strut shown in Figure 7.

Half-scale Subelement. The next major step in the process development phase was to design and manufacture a half-scale version of the full-scale case.

The half-scale subelement has a diameter half the size of the full-scale intermediate case and contains three struts instead of six (Figures 8 and 9). The struts in the subelement are approximately full-size axially, radially and in width. This geometry maintains key dimensions of the full-scale part such as the strut chord and the curved distance between struts. Features of the subelement are:

An outer shell produced from three arced segments with composite flanges and boxed reinforcements at each strut.

Three hollow airfoil-shaped struts with splitter tabs attached at the midspan, aft edge. The struts were approximately full-scale in both chord and radial span.

A conical inner shell with flanges for the bearing supports and boxed reinforcements at each strut.

The subscale case was thermally cured in a hard mold shown in Figure 10 that controlled the aerodynamic surface features within the gas flowpath areas. During the cure, the mold was loaded axially in a press. A silicone rubber compound was used inside the hollow struts and around the inside diameter and outside diameter surfaces to pressurize the flowpath areas against the mold during the cure process. The flange features were then machined into the composite material.

The test article detailed in this report had a circumferential linear manufacturing defect through the midspan of the outer shell, between strut No.'s 1 and 3. Another manufacturing problem that occurred was intrusion of the silicone rubber pressurizing material into other strut areas during the cure process. This caused delaminations within the struts and weakened the splitter tab attachments. Although, the extent of rubber intrusion was unknown, the case was considered adequate for structural testing. However, observations during and after the tests revealed that the rubber intrusion was much more extensive than expected. This problem was addressed during the manufacture of the full-scale case by adding sacrificial protective plies .

Since the half-scale subelement was a scaled down version of the full-scale case, it was tested extensively to verify the design and structural strength predictions for the full-scale case. The test loads used for the subelement were based on predicted engine operation and flight maneuver conditions. The test rig, shown in Figure 11, is capable of applying loads of 90,718 kg (200,000 lb). The load conditions tested were:

Combined Bearing Radial Loads	Limit
Outer Flange Axial Load	Limit
Outer Flange Combined Loads	Limit
Splitter Axial Thrust Load	Limit
No. 2 Bearing Radial Load	Limit
Splitter Axial Thrust Load	Limit
No. 2 Bearing Radial Load	Ultimate
No. 3 Bearing Radial Load	Ultimate
Splitter Axial Drag Load	Limit
Combined Bearing Radial Loads	Ultimate

Limit load requirements were successfully met by the part. Ultimate load test performance was less than anticipated but the problems were attributable to rubber intrusion, not design or material inadequacy.

Full-scale Case Manufacture. After completing the subelement testing, full-scale cases were manufactured. Over 3000 individual plies were cut on a Gerber cutter and laid up on subelement preform tools. The subelements were then assembled into the full-scale case preform tool and the final plies were added to complete the case.

The first full-scale case manufactured, a tool proof case, had well consolidated struts and inner ring but flanges and the outer ring had areas that were poorly consolidated. Cure temperature ramp rates were adjusted and thermal blankets were added to the outer ring tool to correct this problem.

The second full-scale case was well consolidated but the splitter tabs were damaged during fabrication. This problem was corrected by modifying the cure tools to aid tool disassembly and ensure complete strut tool closure during cure.

The third full-scale case has been manufactured and tested. The test results will be reported in the final report of Air Force contract F33615-85-C-5152.

CONCLUSION

This program has demonstrated that a complex part such as an intermediate case for gas turbine engines can be produced from a high temperature composite material. The half-scale subelement, which maintained key dimensions and contained the geometrical complexity of the full-scale part was a significant factor in developing this manufacturing technology. Tests performed on a half-scale subelement verified that a composite case could meet the rigorous structural requirements of this important engine component.

TABLE OF FIGURES

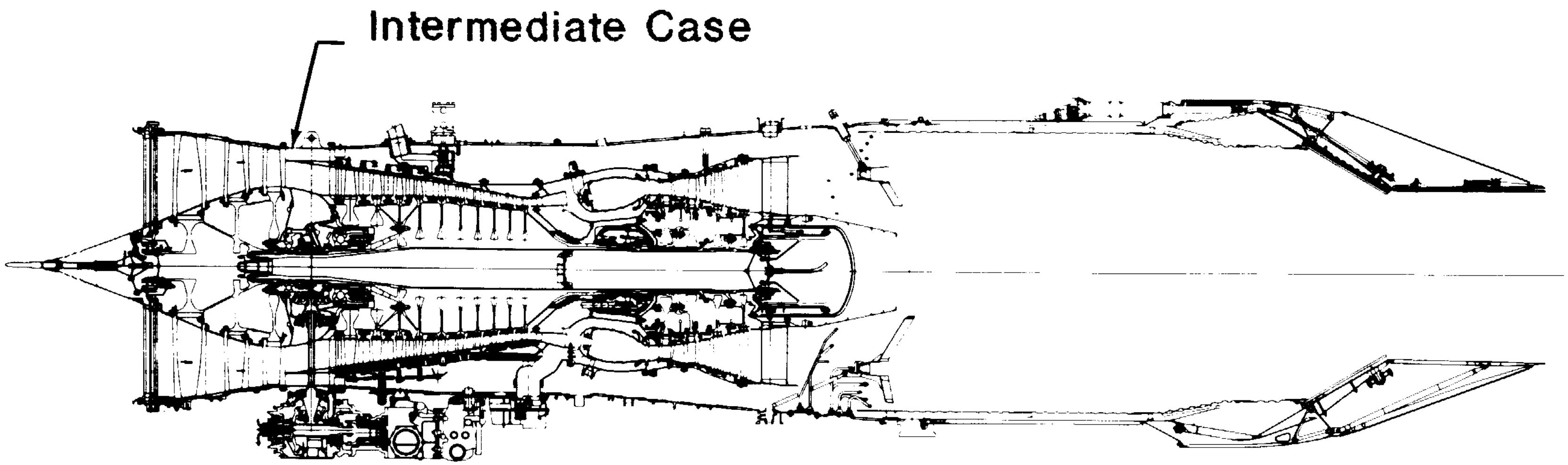

Figure 1. Engine Cross Section

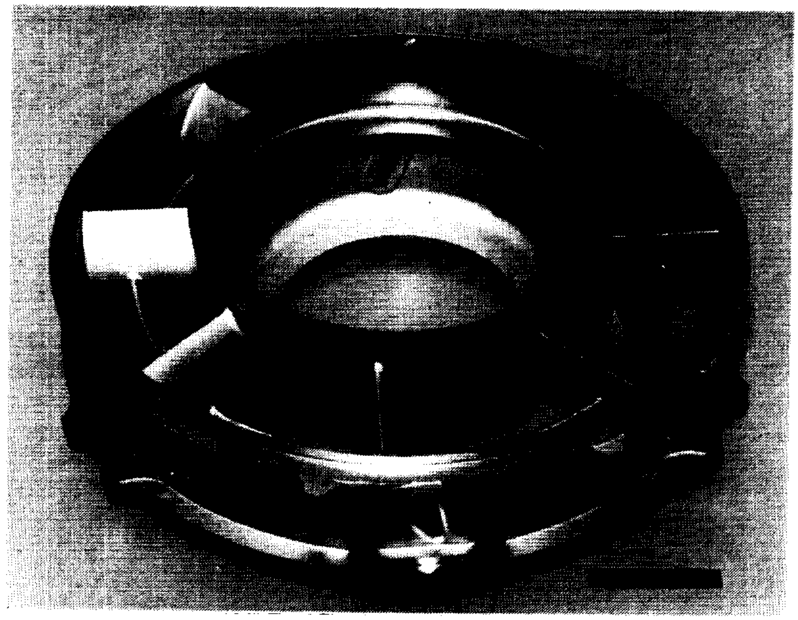

Figure 2. Front Side of Typical Titanium Intermediate Case

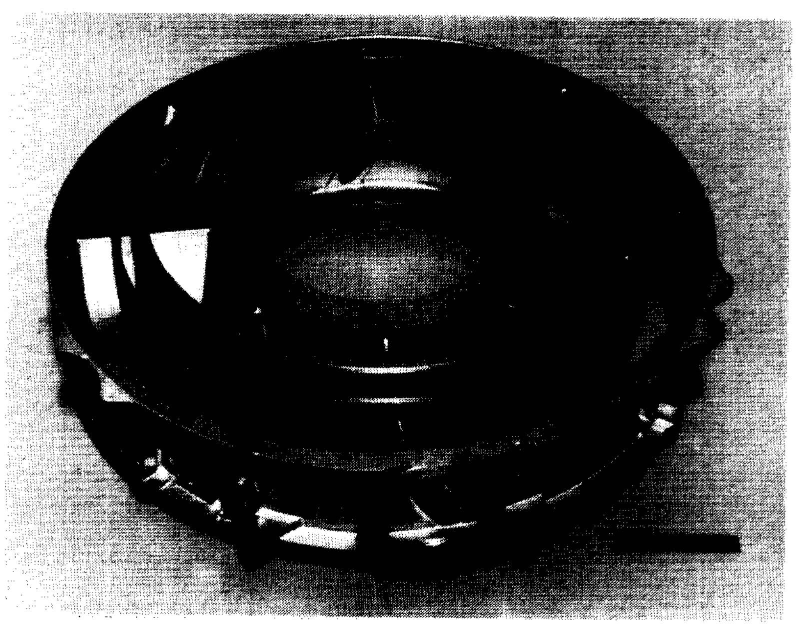

Figure 3. Aft Side of Typical Titanium Intermediate Case

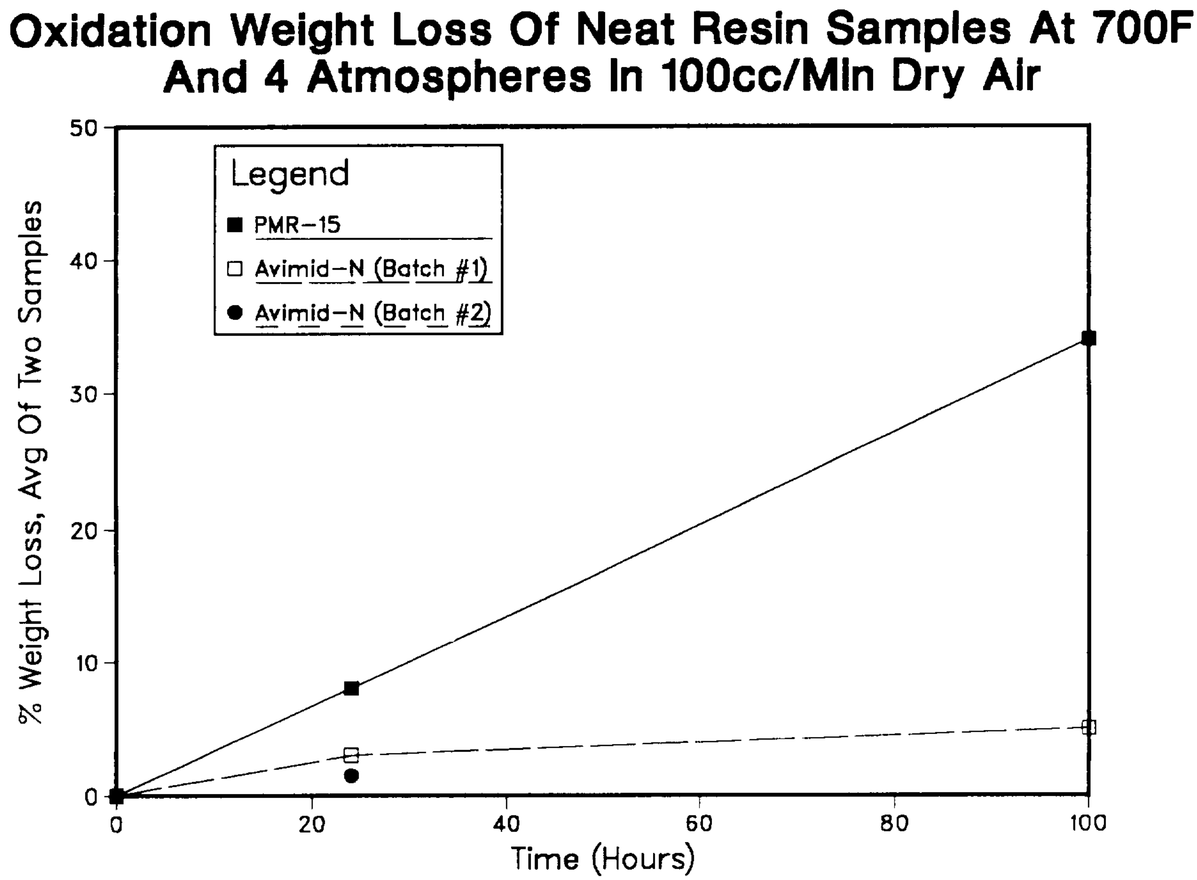

Figure 4. Comparison of Thermal-oxidative Stability PMR-15 and Avimid N

Figure 5. Avimid N Ring Subelement

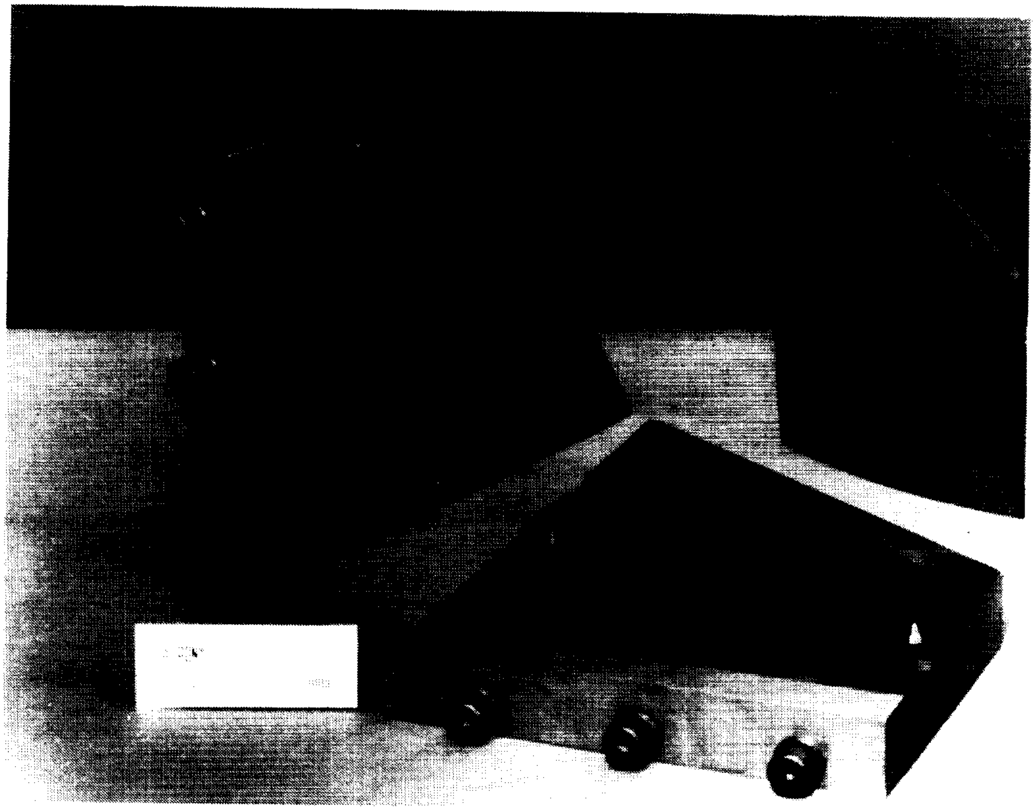

Figure 6. Strut Subelement Tool and Cured Strut

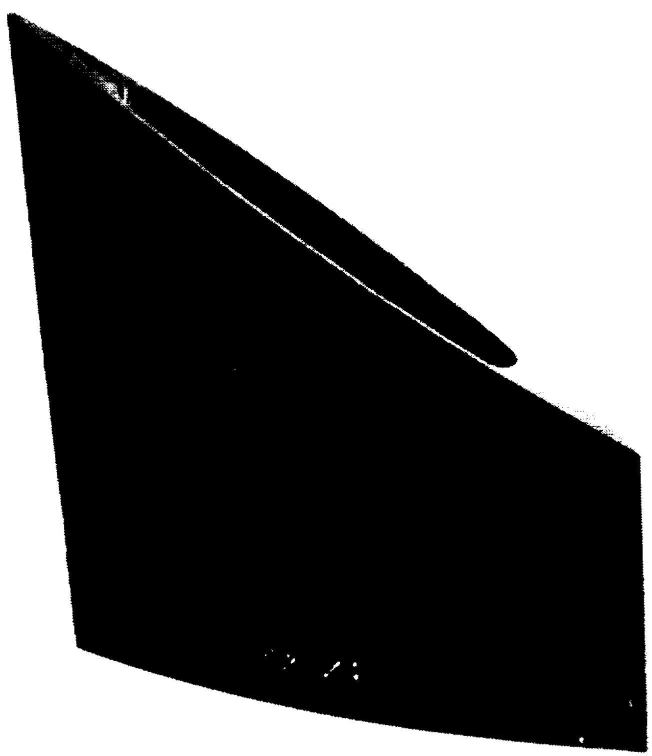

Figure 7. Strut with Good Consolidation

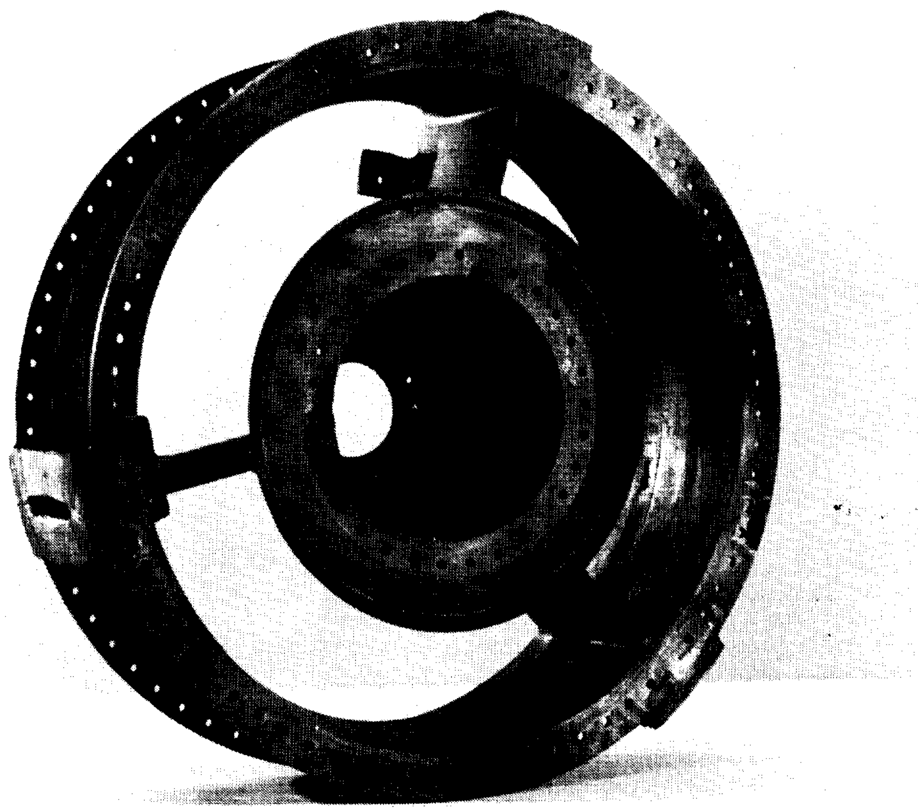

Figure 8. Front Side of Composite Half-Scale Case Subelement

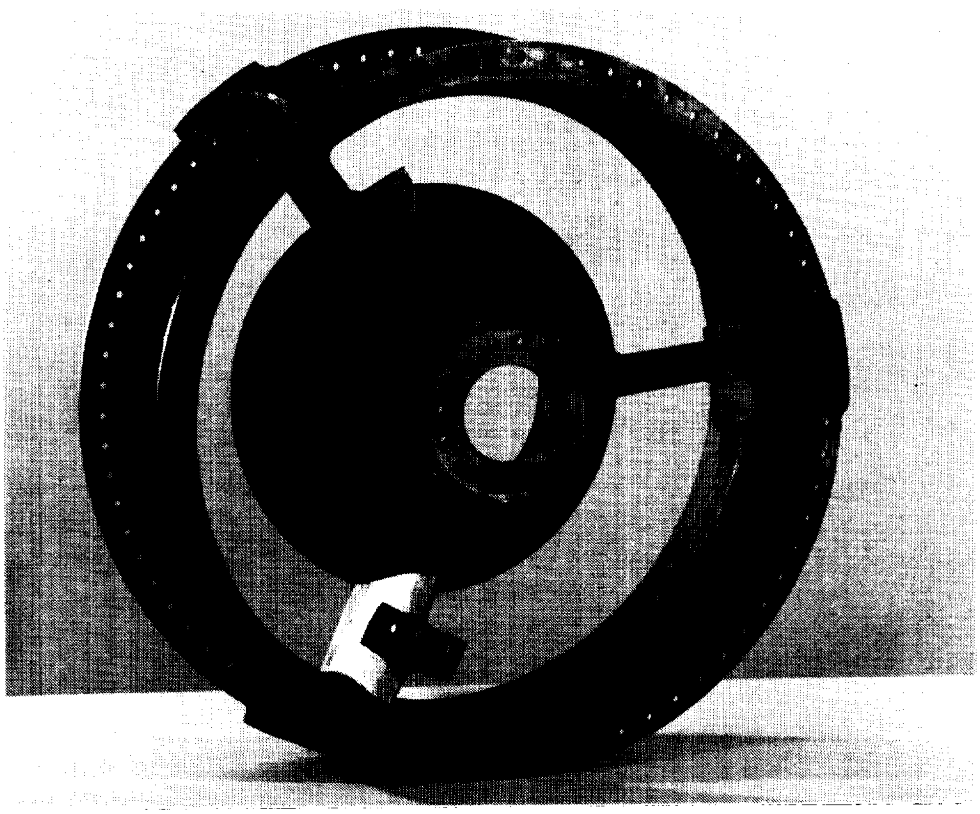

Figure 9. Aft Side of Composite Half-Scale Case Subelement

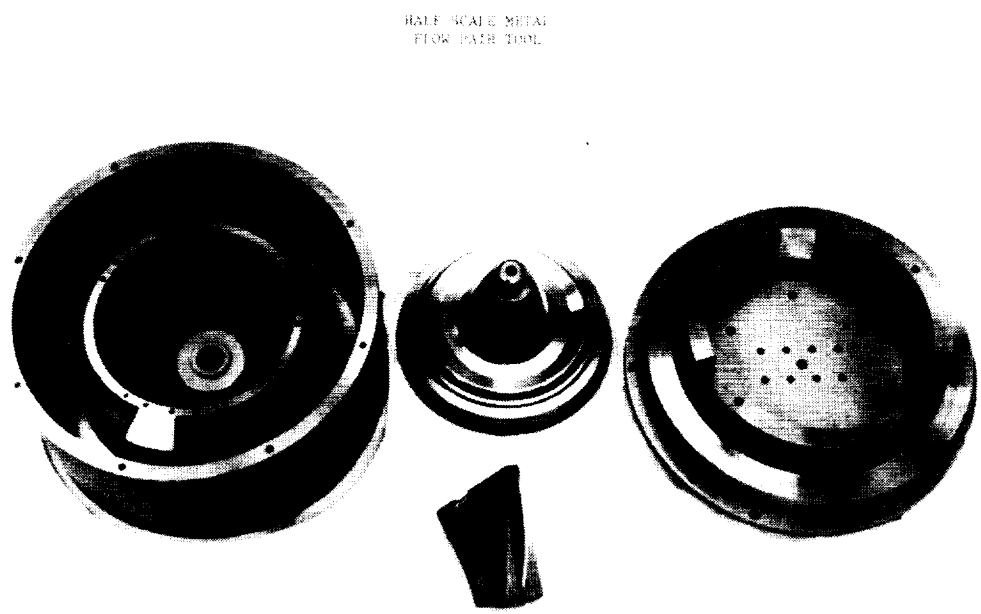

Figure 10. Mold for Half-Scale Case Subelement

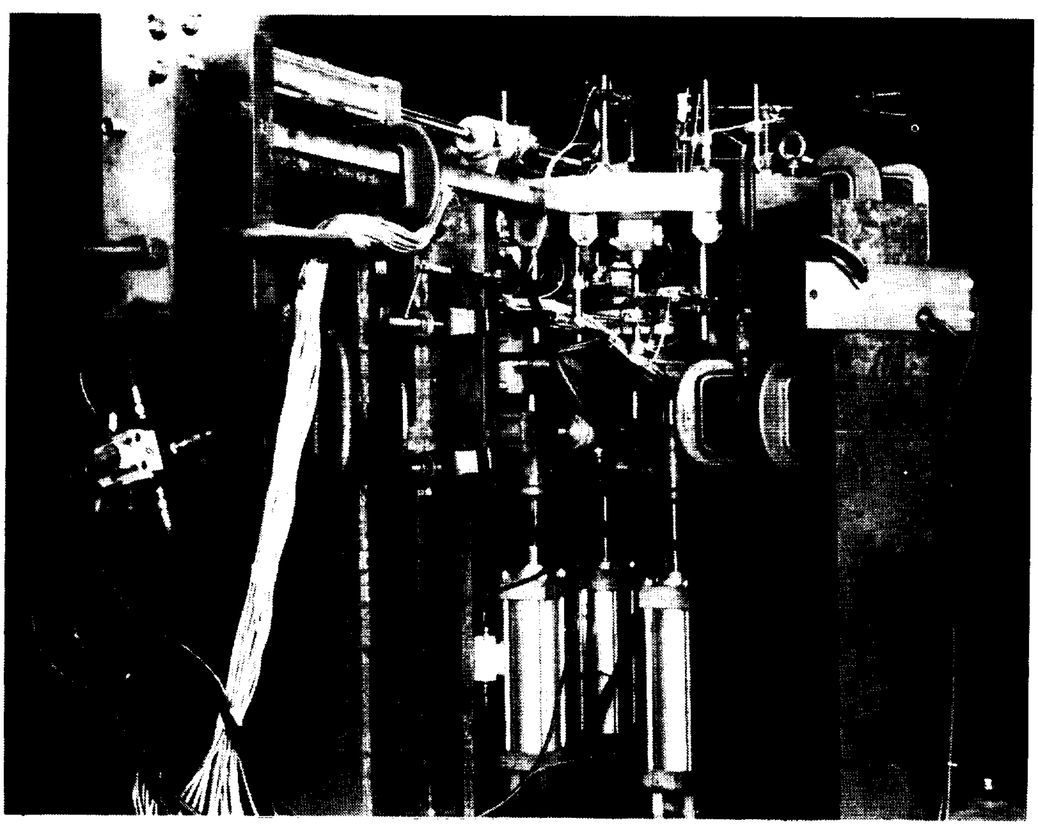

Figure 11. Test Rig for Structural Testing of Composite Subelements