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TEXTILE COMPOSITE FUSELAGE STRUCTURES DEVELOPMENT

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INTRODUCTION

Phase II of the NASA ACT Contract (NAS1-18888), Advanced Composite Structural Concepts and Materials Technology for Transport Aircraft Structures, focuses on textile technology, with resin transfer molding or powder coated tows. The use of textiles has the potential for improving damage tolerance, reducing cost and saving weight. This program investigates resin transfer molding(RTM), as a maturing technology for high fiber volume primary structures and powder coated tows as an emerging technology with a high potential for significant cost savings and superior structural properties. Powder coated tow technology has promise for significantly improving the processibility of high temperature resins such as polyimides.

This phase of the contract was initiated in October, 1991 and runs through April, 1995. Figure 1 shows the schedule for Phase II activities.

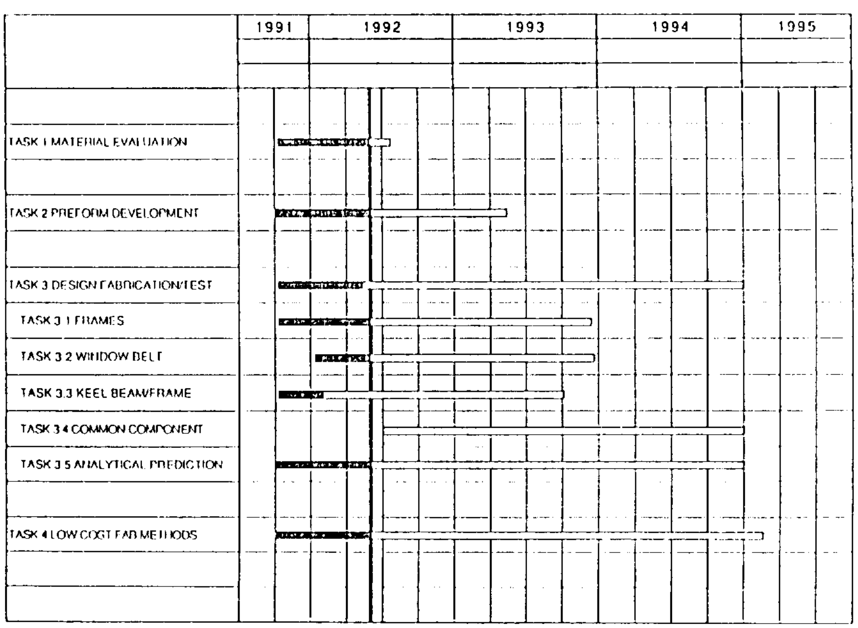

Figure 1, Program Schedule.

PROGRAM DESCRIPTION

This phase consists of four tasks. Task 1 covers material evaluation and involves the screening of three RTM resins and two powder resins for fiber coating. The evaluation approach shown in Figure 2, consists of fabricating panels using 8 harness satin weave fabrics, either dry and then resin transfer molded or woven from powder coated tows. Mechanical and physical tests are being performed on coupons cut from these panels to evaluate each system to aid in the selection of the resins to be used in Task 2.

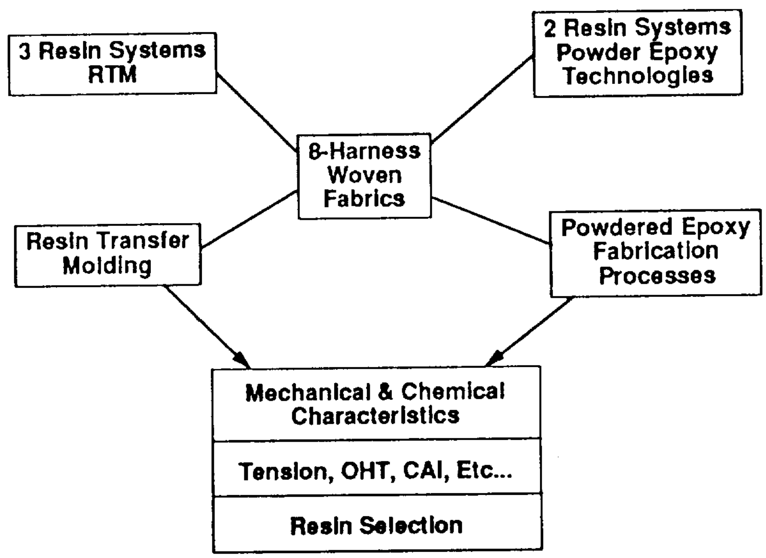

Figure 2, Evaluation Approach, Task 1.

The objective of Task 2 is to develop a data base for the selection of the processes which will lend themselves to the fabrication of net shape preforms for complex structural configurations, such as curved frames and window belt structure. The processes include 2-D braiding, 3-D braiding, 3-D interlock braiding, 2-D weaving, 3-D weaving and fiber placing. The evaluation approach is shown in Figure 3.

Task 3 consists of five subtasks. The first four subtasks involve the design, fabrication and testing of concepts for fuselage frames, window belt structures keel substructure and a common component for NASA testing. The common component was originally a crown panel but has recently been changed to a window belt panel because of the high potential for

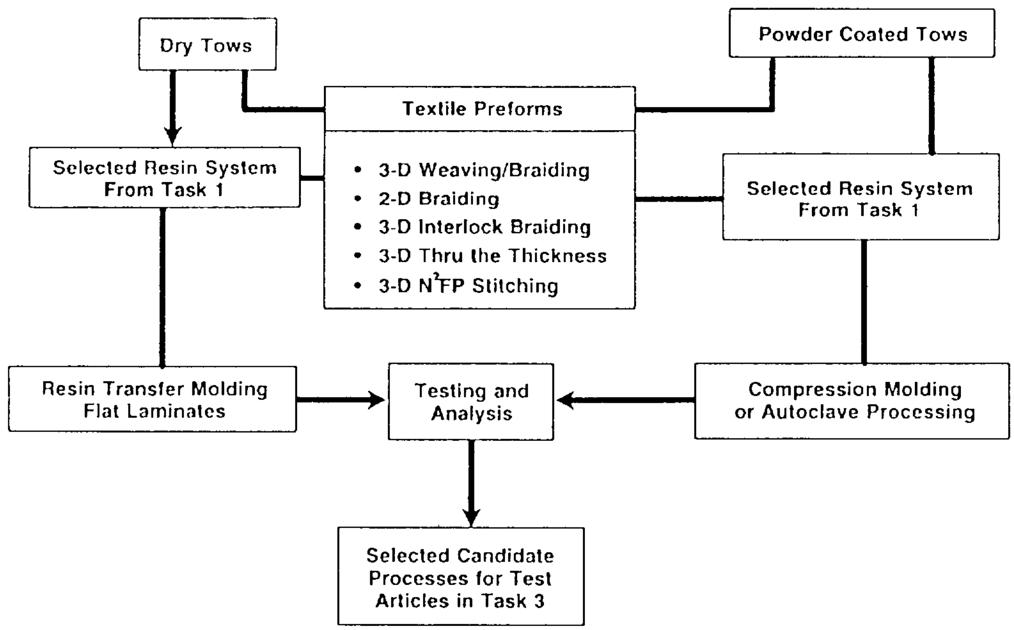

Figure 3, Evaluation Approach, Task 2.

textile preforms to payoff in this location. The fifth subtask covers the development of analytical methods for textile preform structural analysis.

Task 4 covers low cost fabrication development and evaluation for advanced textile preforms. In this task Lockheed has purchased a Venus Gusher RTM machine which is now installed in Marietta. The task also involves the exploration of innovative tooling concepts and establishing advanced machine requirements and automation potential.

RESIN TRANSFER MOLDING

Resin transfer molding has been a commercial process for many years. Until recently however, fiber volumes were generally very low and cured properties poor. In the last few years considerable progress has been made. Parts can now be fabricated with fiber volumes of 60 percent and good cured resin properties, thus making this a viable process for major load carrying structures. The chemical companies have been working to steadily improve both the processibility and the mechanical properties of the resin systems. The resin transfer molding process is illustrated in Figure 4.

Three epoxy resin systems have been evaluated in this program. They are: Shell RSL-1895; 3M PR-500; and BP E905L. This evaluation is discussed in detail in a later paper (Reference 1).

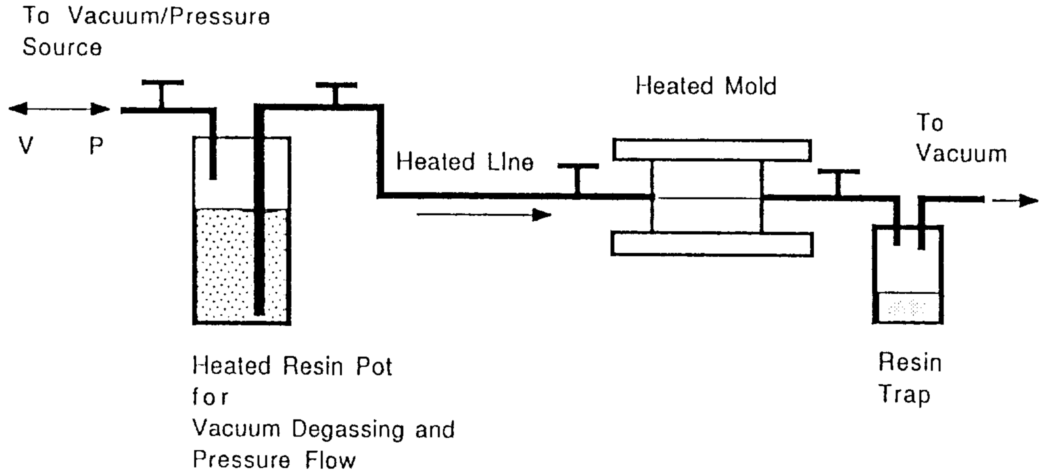

Figure 4, Schematic of RTM Process.

In order for Lockheed Aeronautical Systems Company (LASC) to be able to evaluate the processing of these systems, an RTM machine was purchased from Venus Gusmer and has been installed at LASCs Marietta Georgia facility. A picture of this machine is shown in Figure 5.

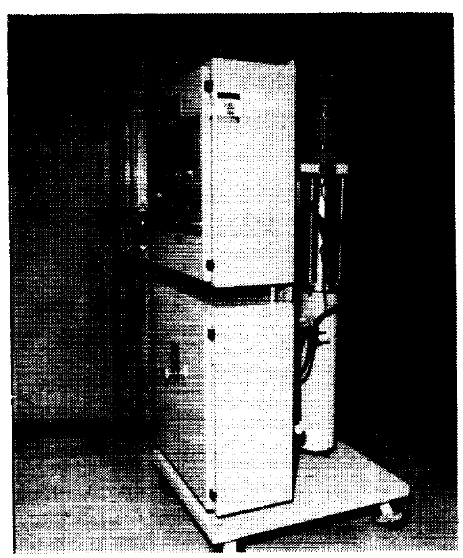

Figure 5, Venus Gusmer RTM Machine.

POWDER COATED TOWS

In the last few years considerable effort has been directed toward the development of techniques for depositing polymer powders on tows and sintering the powder to provide a weavable and braidable tow material. This work has been spearheaded by Norm Johnston at NASA Langley Research Center and by Professor John Muzzy at Georgia Institute of Technology. BASF Materials in Charlotte North Carolina is under NASA contract to scale up a process which they have developed for coating tows. The Georgia Tech process is now being commercialized by Custom Composites Inc of Atlanta, Georgia.

Several other researchers are pursuing new approaches for powder coating , including Professor Larry Drzel at Michigan State University, and Dr. Douglas Hirt at Clemson University.

Currently two resin systems are under evaluation: Shell RSL-1952 coated onto AS4 tows by BASF Materials; and 3M PR500 coated onto AS4 by Custom Composites. These tows were woven into 8 harness satin fabrics by Fabric Development of Quakertown, Pennsylvania and textile Technologies Incorporated of Hatboro, Pennsylvania.
LASC used these fabrics to develop the processing and to fabricate panel for mechanical properties. This is also discussed in more detail in reference 1. The powder coating process is shown schematically in Figure 6.

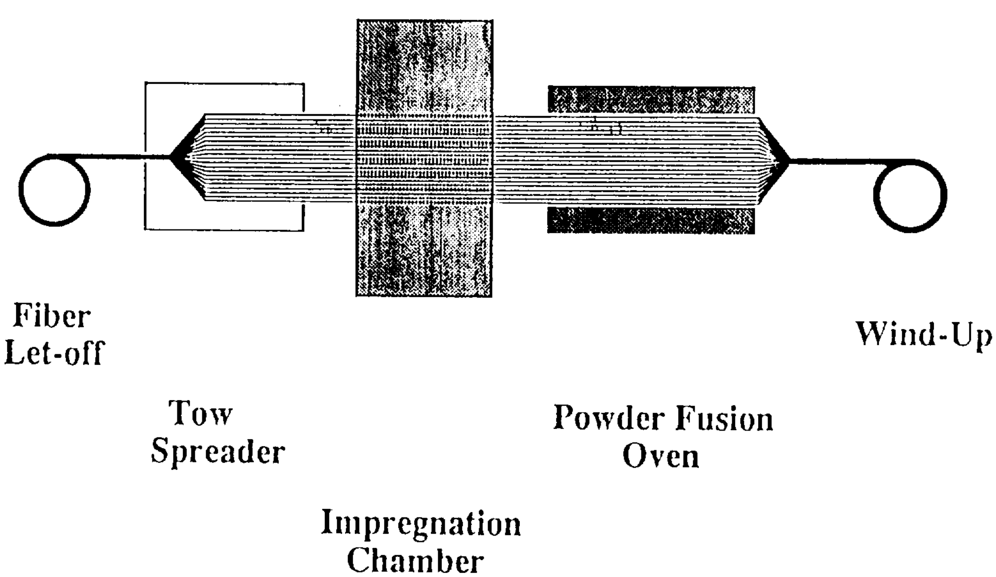

Figure 6, Schematic of Powder Coating Process.

Powder coating of the tows has the advantage that the resin is intimately dispersed through the tows so that flow is not generally a problem. Also, as the powder is sintered on the fibers after deposition, the tows can be stored at room temperature indefinitely. The powder coated tows can be woven , braided, pultruded and processed in other ways without the use of solvents or the emission of hazardous byproducts.

The coating processes fall into two general categories: dry and wet. The dry processes rely on the formation of a cloud of resin powder which is deposited onto the spread tow fibers and adheres by electrostatic means. The powder is then sintered by microwave or other heating process. The wet processes rely on the deposition of a slurry onto the spread fibers with a subsequent drying and sintering process.

Considerable progress has been made in determining the correct amount of resin which needs to be deposited on to the fibers to provide the required cured resin content. The textile processes cause some loss of powder and although this has not proved to be a problem it would be preferable if this could be eliminated or at least minimized.

PREFORM DEVELOPMENT

A survey was made of the weaving and braiding industry and the most promising processes were selected for evaluation. A summary of the vendors and the processes under evaluation is shown in Table 1.

Table 1, Vendors and Processes Evaluated.

VENDOR	PROCESS
Fiber Innovations	2-D Braiding
Albany International	3-D Interlock Braiding
Atlantic Resrarch	3-D Through the Thickness Braiding
Textile Technologies	3-D Weaving
Hexcel Hi-Tech	3-D Multi-Axial Warp Knit
Cooper Composites	Near Net Fiber Placement
Techniweave	3-D Multi-Axial Weave

A large cross section of the weavers and braiders with the capability to do the development work has been included in this program. Under braiding, Fiber Innovations is fabricating the 2-D panels, Albany International the 2-D Interlock panels and Atlantic Research the 3-D Through the Thickness panels. Under weaving, Textile Technologies is fabricating the 3-D panels and Techniweave the Multi-axial panels. Hexcel Hitech is fabricating the Multi-axial Warp Knit panels and Cooper Composites the Near-Net Fiber Placement panels. We are also investigating the Quadrax braiding process which permits continuous braiding of infinitely long panels.

The Atlantic Research braider is shown in Figure 7. A typical loom is shown in Figure 8. Again this task is discussed in more detail in reference 1.

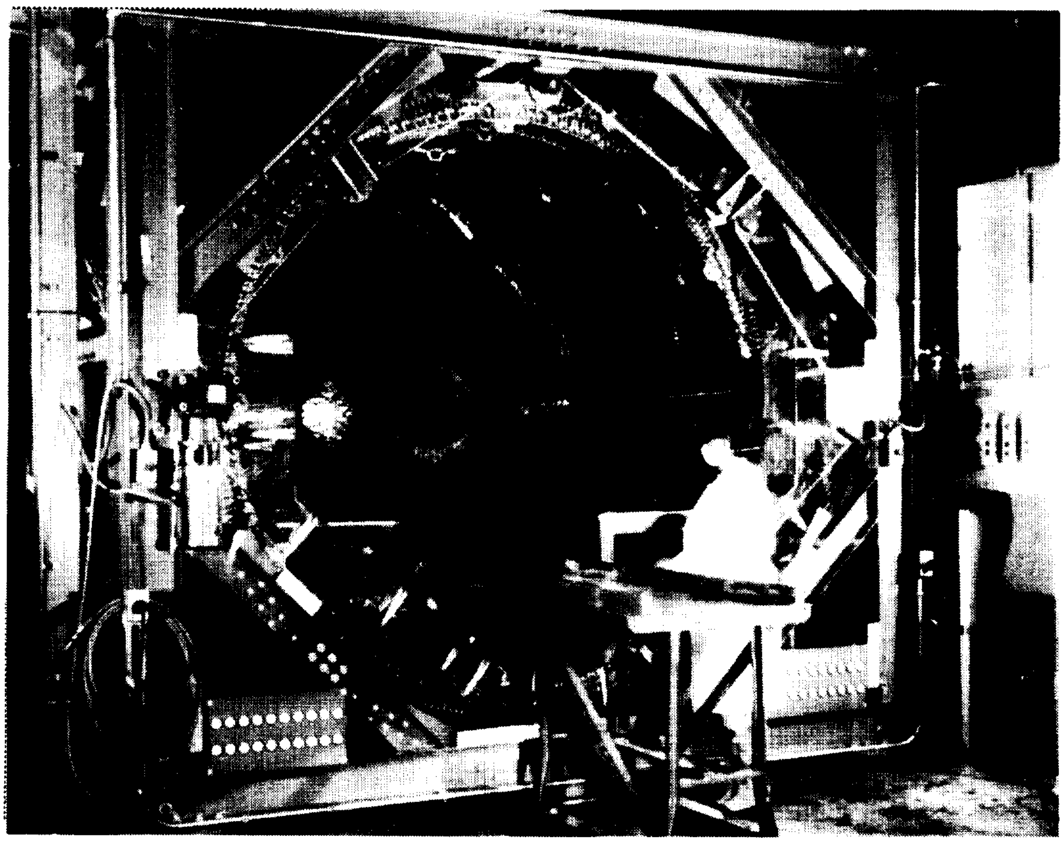

Figure 7, Atlantic Research Braiding Machine.

FUSELAGE BASELINE DESCRIPTION

The baseline airplane for this study is the Boeing 7X7. This is a two engine wide-body passenger transport airplane. A schematic of the fuselage is shown in Figure 9. LASC is working closely with the Boeing Commercial Airplane Group in the execution of this program and LASC will provide the textile subcomponents for Boeing to incorporate into their tests components. To this end LASC and Boeing have been working in joint Design Build Teams to develop the designs and processes for the frames, the keel and the side panel structure.

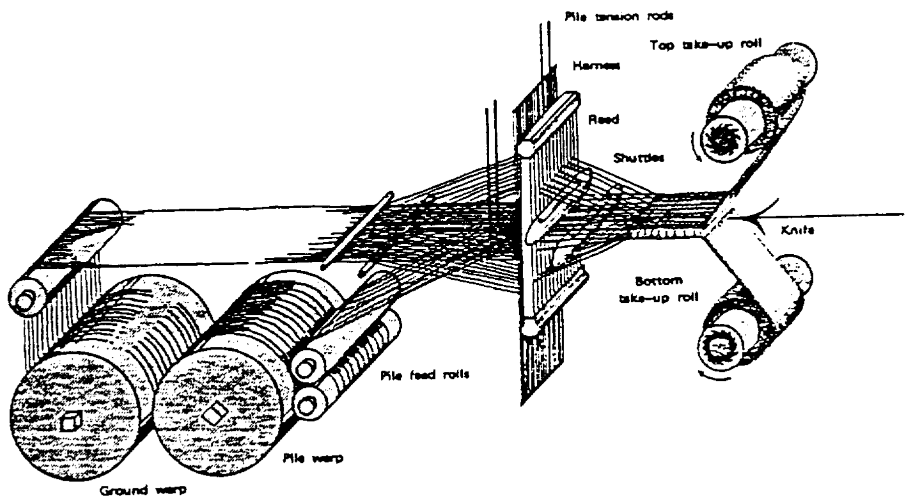

Figure 8, Weaving Loom.

The baseline fuselage is a typical ring and stringer stiffened structure. It is a wide body aircraft designed with up-to-date technologies which are proven low cost. The objective of this program is to develop and demonstrate composite textile technology as a lower cost approach to structures for fuselage frames, window-belt reinforcement, door surrounds and keel frames and intercostals.

FRAMES

The frames are designed primarily by bending loads due to the discontinuity of the floor beams and posts and by the tension due to aircraft pressurization.

Several frame design configurations were initially considered for textile preform

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application. A simple "J" configuration was determined to be the lowest cost approach. However, when this design was "mouse-holed" to allow the stringers to be continuous the outer frame cap is interrupted and an unsupported edge is introduced in the web area as shown in Figure 10. This unsupported edge is prone to buckling and delamination. In order to eliminate these structural deficiencies, an additional flange is introduced to the frame web immediately inboard of the mouse-hole cut out. The resulting "F" frame configuration is shown in Figure 11. Although this configuration is more complex from the manufacturing standpoint, it is extremely efficient structurally. Consequently the "F" configuration has been selected as the primary concept for the continuing studies.

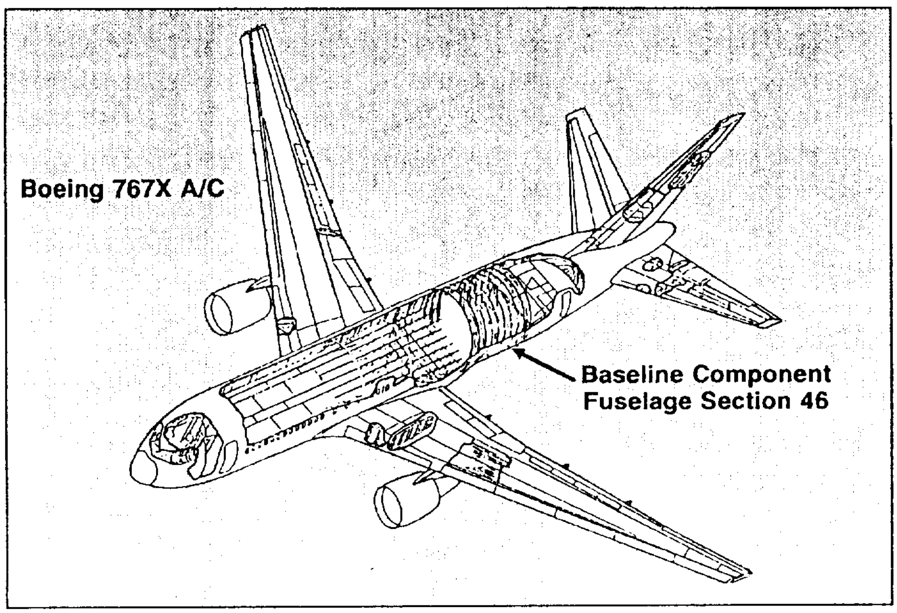

Figure 9, Boeing 7X7 Fuselage Configuration.

Three alternate textile processes are currently being evaluated for the fabrication of the "F" frame preforms: 3-D braiding; 3-D interlock braiding; and 3-D weaving. The 3-D braiding process has been developed by Atlantic Research Corporation, Alexandria, Virginia. The 3-D interlock braiding has been developed by Albany International, Mansfield, Massachusetts. The 3-D weaving process has been developed by Techniweave, Rochester, New Hampshire.

The 2-D braiding process, which is a viable process for the "J" frame configuration, has been extensively evaluated by Boeing and their results will be compared with the Lockheed results on the various 3-D processes.

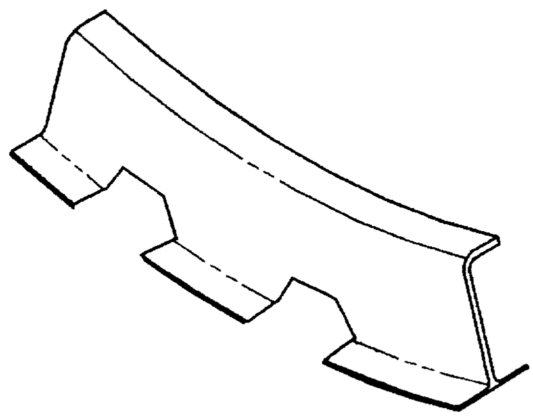

Figure 10, "J" Frame Configuration.

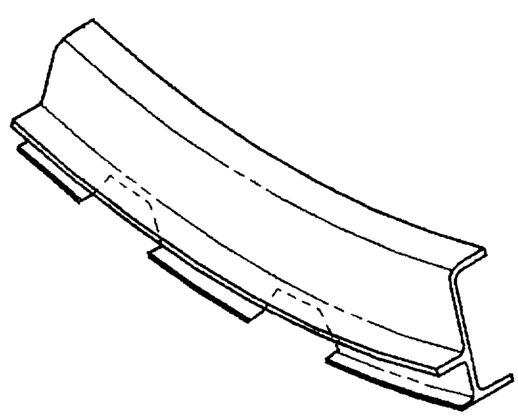

Figure 11, "F" Frame Configuration.

The major advantage of the 3-D braiding process is that one-piece, net-section preforms with full through-the-thickness tow capability can be produced in a totally automated process. One method for achieving this is illustrated in Figure 12, where back-to-back frame segments are produced on a rectangular cross-section mandrel which is curved to match the fuselage mold line. The two flanges shown folded out from the braiding mandrel are achieved by cutting through half of the web thickness in a pocket area where the tows which run through the thickness are in fact terminated at the midplane or other specified level. This feature known as bifurcation can be achieved in both the interlock and the through-the-thickness 3-D process.

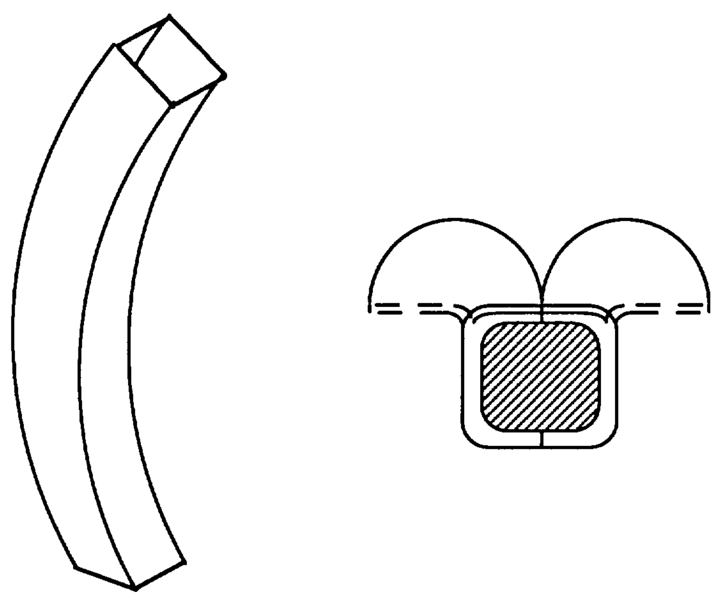

Figure 12, Back-to-Back "J" Frame Braiding.

KEEL AREA SUBSTRUCTURE

The critical studies of the keel area concentrated on the cargo floor support structure, see Figure 13. This structure consists of stiffened web frames, supported by longitudinal intercostals at the more highly loaded regions and floor beams with support posts at the more lightly loaded regions. Figures 14 and 15 show several design concepts incorporating textile preforms which have been evaluated. Before design trade studies of these concepts were completed, Lockheeds efforts were redirected to evaluate only those concepts which were required for the Boeing test articles, namely the frame caps for attachment to the keel sandwich skin panels. Both "J" and "T" members have been considered for this application, with triaxial solid braiding being the preferred manufacturing process.

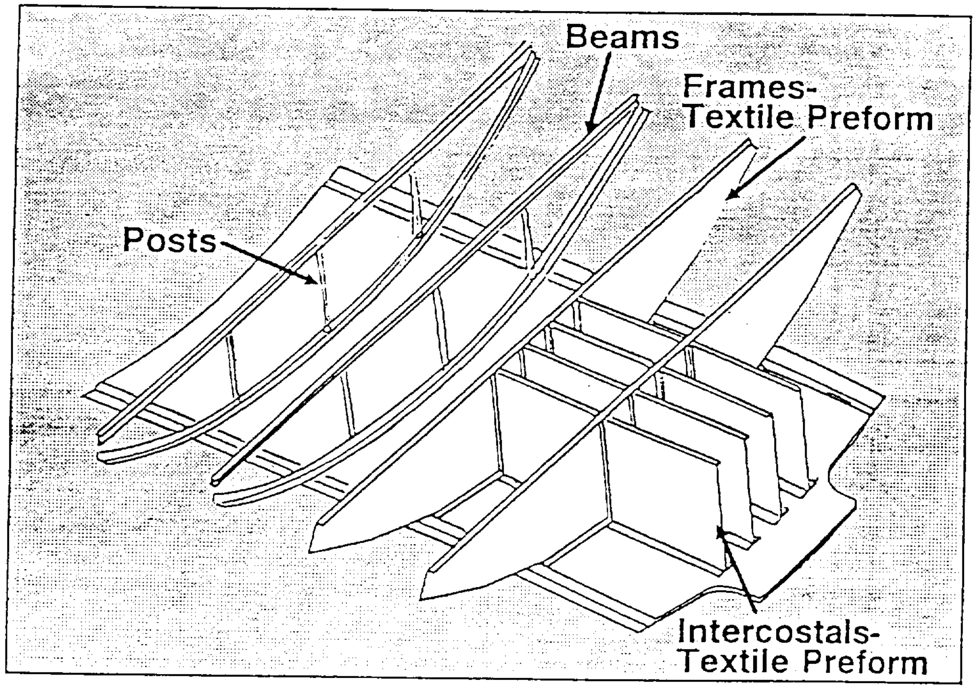

Figure 13, Cargo Bay Subfloor Structure.

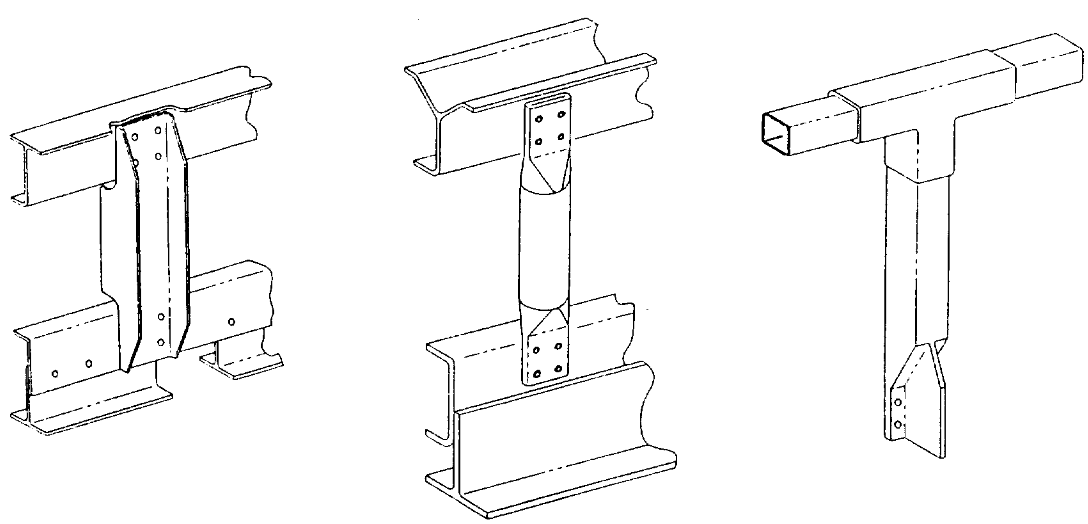

Figure 14, Cargo Floor support Post Concepts.

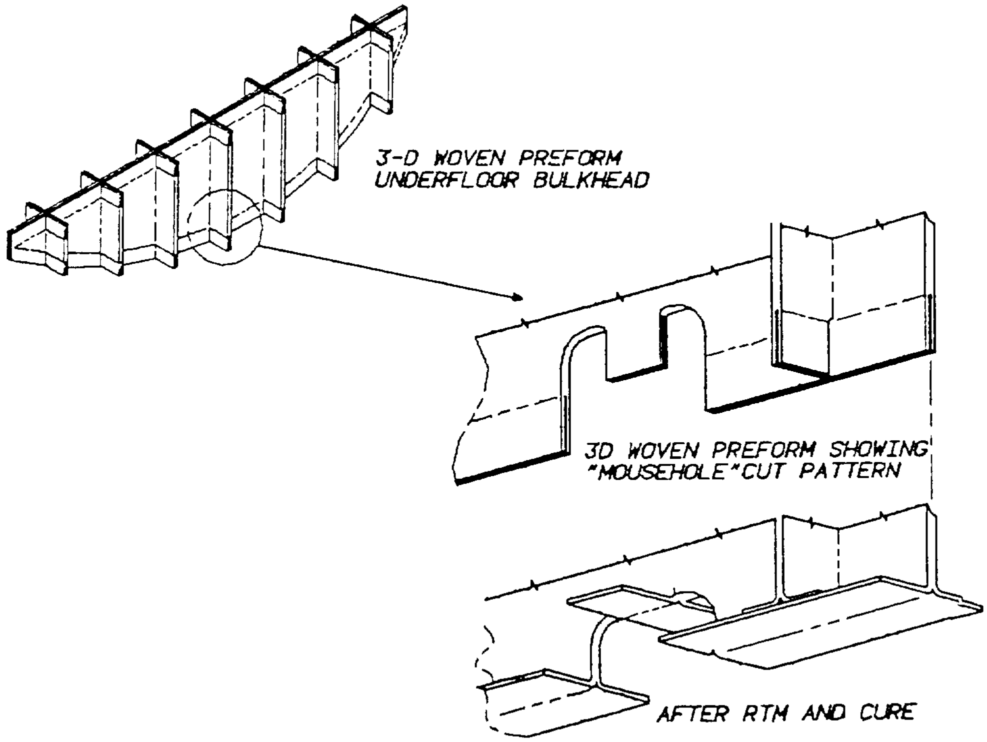

Figure 15, Cargo Floor Support Concepts.

The final design is critical as it is intended to bond or cocure the frame to the sandwich skin. A finite element model of the flange was constructed to facilitate the design effort. The model is shown in figure 16. The analysis showed that the flange must be tapered to minimize the peel stresses.

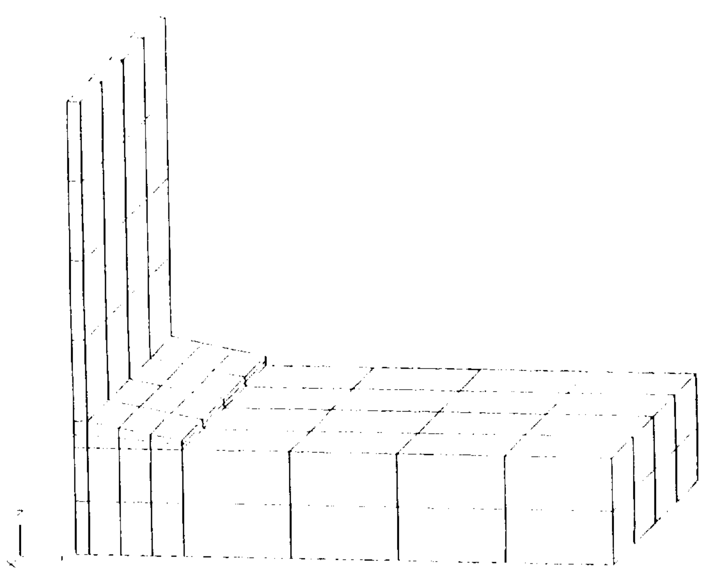

Figure 16, Finite Element Model of "T" Frame.

SIDE PANEL APPLICATIONS

The fuselage side panel is a prime candidate for textiles because of the structural complexity resulting from the window cutouts, window frames, passenger and cargo door cutouts, together with the associated load reinforcement. A typical side panel is shown in Figure 17.

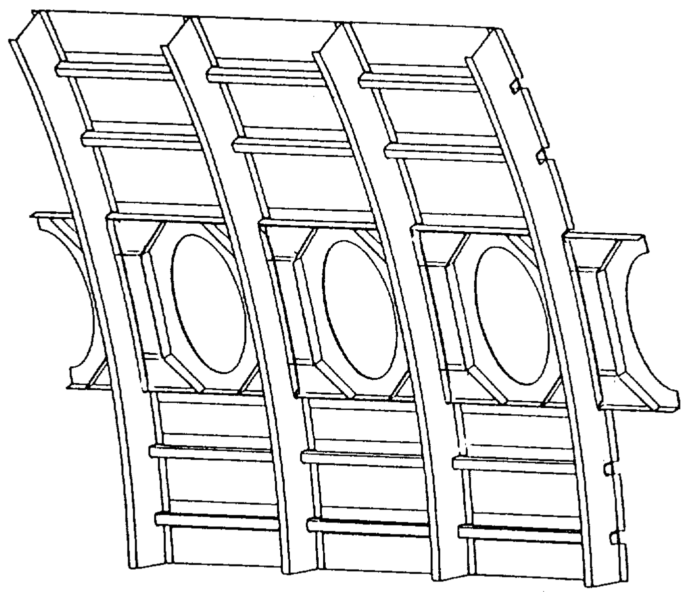

Figure 17, Typical Side Panel.

WINDOW BELT

The side panels in commercial transport airplanes are designed primarily by shear and pressure loads. The structure is complicated by the cutouts required for windows, for passenger doors and for cargo doors. Ideally the frames and longitudinal stiffeners should both be continuous. The window cutout reinforcements can be woven or braided as individual units or integral with other structure. The primary consideration here will be the fail-safe requirements. If the textile preforms do exhibit superior damage tolerance properties, then it may prove possible to meet the requirements without resorting to the traditional multiple element approach.

Two concepts are being evaluated for window belt structure. In the first concept which is shown in Figure 18, the window belt area is reinforced by the addition of a continuous 3-D woven or braided preform which is approximately 22 inches wide and which incorporates upper and lower longitudinal stiffeners and frame attachment flanges. The window frame is fabricated separately using a 3-D braiding process. These reinforcing members are cocured together with the automatic tow placed skin, by Boeing, in a single autoclave cycle.

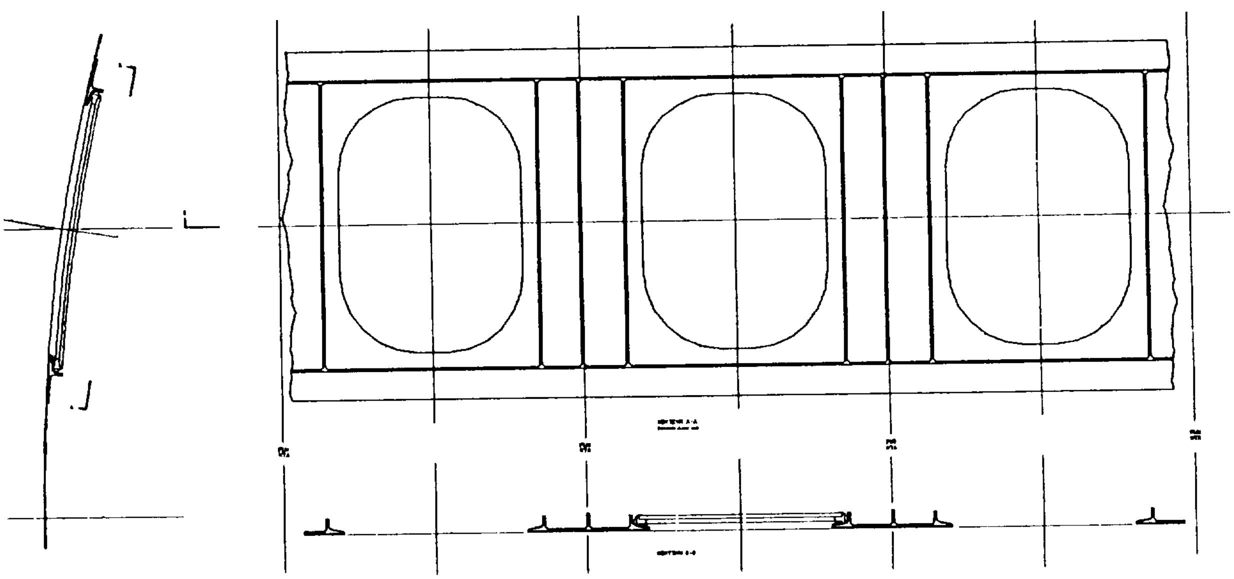

Figure 18, Window reinforcement Concept Number 1.

The second window belt concept, shown in Figure 19, uses a unique 3-D weaving process currently under development by Techniweave of Rochester, New Hampshire. This process allows the window aperture, the window frames, the longitudinal edge stiffeners and the frame attachment members to be produced as a one piece preform. The skin is woven 0°, 90°, and +/-45° tows, while the stiffeners in both directions contain only 0° and 90° oriented tows. The +/-45° at this time has to be added as overwrap fabric.

Door Cutout Reinforcement

The passenger doors remove a large portion of the structure locally in the side of the fuselage. This requires extensive reinforcing of the area around the door to redistribute the axial, the hoop and the shear loads. The door cutout area is also subject to considerable wear and tear and to out-of-plane forces. The z direction reinforcement of textiles makes them ideal candidates for structures of this type.

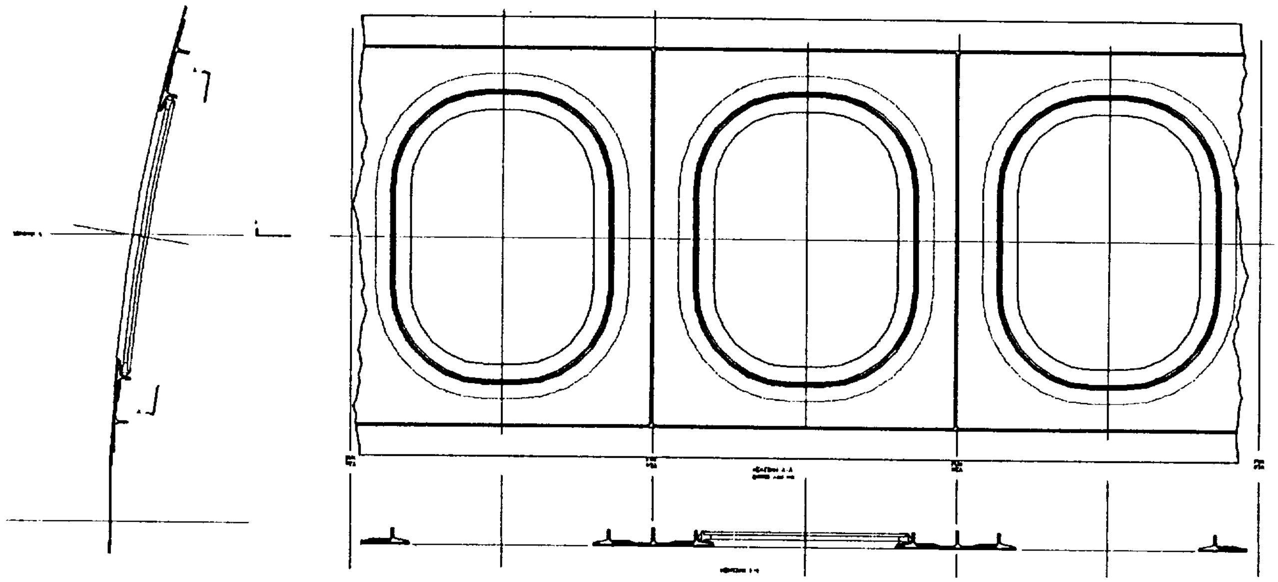

Figure 19, Window reinforcement Concept Number 2.

Side Panel

The side panel as used here refers to the structure outside of the immediate window reinforcement area and generally below the windows. The concept for this structure is similar to that of the crown panels. The frames in this case will be "F" configuration. Figure 20 shows the general approach to the fabrication of this structure.

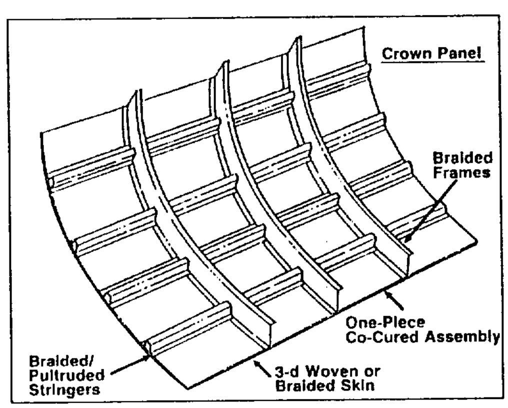

Figure 20, Side Panel Fabrication Approach.

DESIGN/MANUFACTURING DEVELOPMENT

Textile technology for primary structures has been limited to the use of 2-D fabrics and stitching because of the difficulty of impregnation. RTM resins were not available with the high flow and the high structural properties required. The recent development of new resin systems and the advent of powder coated tow technology has opened up a whole new field in manufacturing aircraft structures. Lockheed has purchased an RTM machine from Venus Gusher of Seattle, Washington, under the contract, in order to develop the processing of the RTM preforms and resins. The machine is shown in Figure 5. It is being used to flat panels using the tool shown in Figure 21 and to make frame segments using the tool shown in Figure 22.

The powder coated tow preforms present a challenge in compaction. The coated tows are more bulky than the dry tows and the preforms must be compacted prior to final processing. It is preferable to do this compaction in the final tool if at all possible. This effort is just getting underway. The results will be reported in the Monthly Technical Progress Reports and at the next NASA ACT Conference.

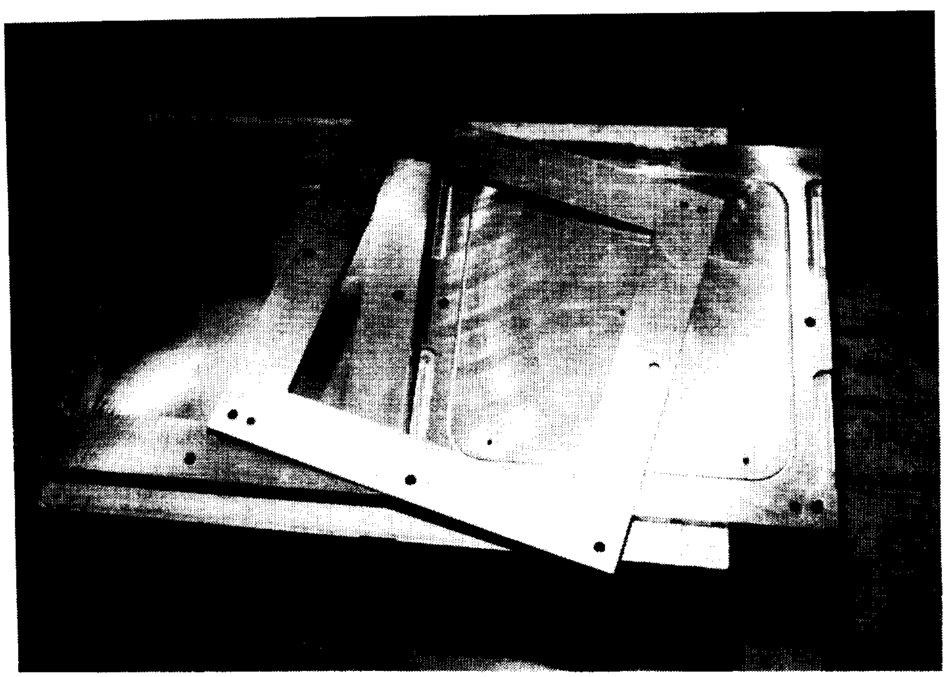

Figure 21, Flat Panel RTM Tool.

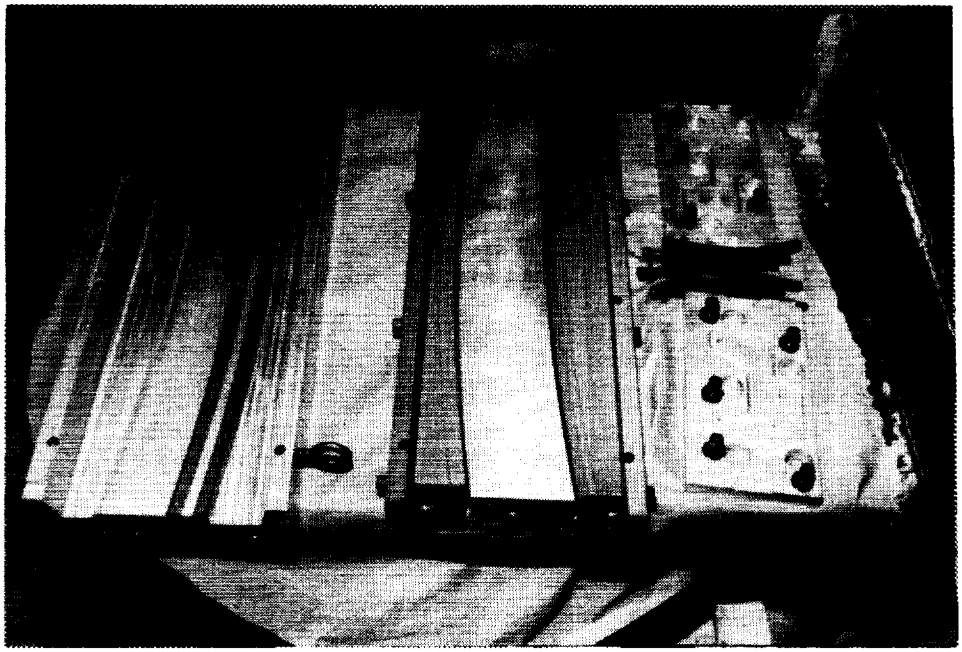

Figure 22, "F" Frame RTM Tool.

SUMMARY AND CONCLUSIONS

A program to evaluate and develop textile technology with RTM and powder coated tows is now well underway. The screening of the resins and the textile processes is progressing well and down select will occur in the next few months. Initial results are promising and show that the technologies are viable. The cost of some of the processes is high at this time. The scale-up and automation potential of these processes is under critical review. Some of the processes show significant potential for meeting the program goals of low cost and structural efficiency.

REFERENCES

1. Shukla, J. G and Bayha T.; Advanced Resin Systems and 3-D textile Preforms for Low Cost Composite Structures, third NASA Advanced Composite Technology Conference, June,1992.