1995122414

N95- 28835

Manufacturing Scale-up of Composite Fuselage Crown Panels [1]

S12-24

K. Willden, M. Gessel
Boeing Commercial Airplanes
Seattle, Washington

C. Grant, and T. Brown
Hercules Aerospace
Magna, Utah

ABSTRACT

The goal of the Boeing effort under the NASA ACT program is to reduce manufacturing costs of composite fuselage structure. Materials, fabrication of complex subcomponents and assembly issues are expected to drive the costs of composite fuselage structure. Several manufacturing concepts for the crown section of the fuselage were evaluated through the efforts of a Design Build Team (DBT) (Ref.1). A skin-stringer-frame intricate bond design that required no fasteners for the panel assembly was selected for further manufacturing demonstrations. The manufacturing processes selected for the intricate bond design include Advanced Tow Placement (ATP) for multiple skin fabrication, resin transfer molding (RTM) of fuselage frames, innovative cure tooling, and utilization of low-cost material forms. Optimization of these processes for final design/manufacturing configuration was evaluated through the fabrication of several intricate bond panels. Panels up to 7 ft. by 10 ft. in size were fabricated to simulate half scale production parts. The qualitative and quantitative results of these manufacturing demonstrations were used to assess manufacturing risks and technology readiness for production.

INTRODUCTION

Large manufacturing demonstration panels were designed to meet the ATCAS program objectives. Manufacturing risk, technology readiness, and cost for an optimized panel configuration were evaluated. The crown panel design used the cost advantages of the ATP process for skin and stringer fabrication and braiding and RTM technologies for frame fabrication. Additionally, intricate tooling for cocuring the skin and stringers and cobonding the frames in one cure cycle was developed (Figure 1, Refs. 2, 3 and 4). The crown panel assembly was further optimized such that one tool served as the panel assembly tool and the cure tool.

1 This work was funded by Contract NAS1-18889, under the direction of J.G. Davis and W.T. Freeman of NASA Langley Research Center

[redacted]

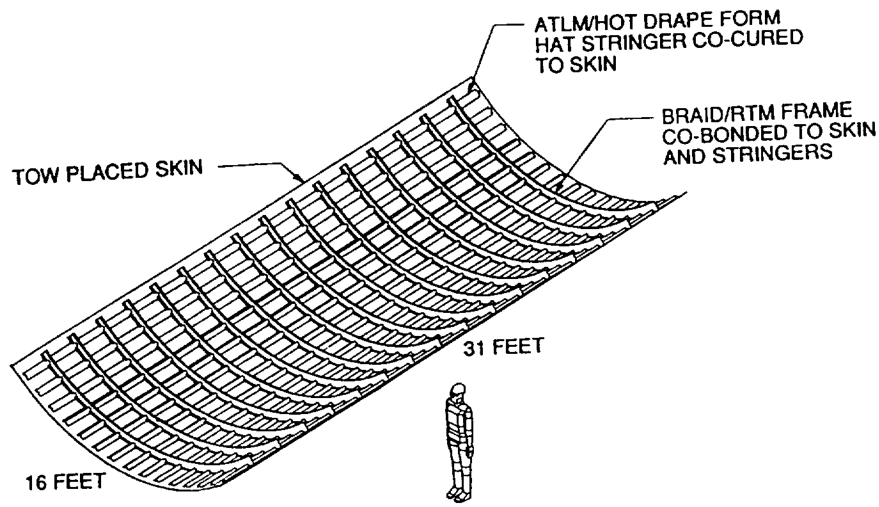


Figure 1: Intricate Bond Panel Configuration

Innovative IML cure tooling concepts were critical to the success and cost reduction of the intricate bond design. The tooling was optimized through a series of tool trials to reduce manufacturing risk and increase the part quality and structural performance. Scale-up issues were considered such that manufacturing concepts demonstrated on small panels would accommodate large panels without increasing manufacturing risks. Several types of manufacturing demonstration panels were identified to validate the tooling and intricate bond process (Figure 2).

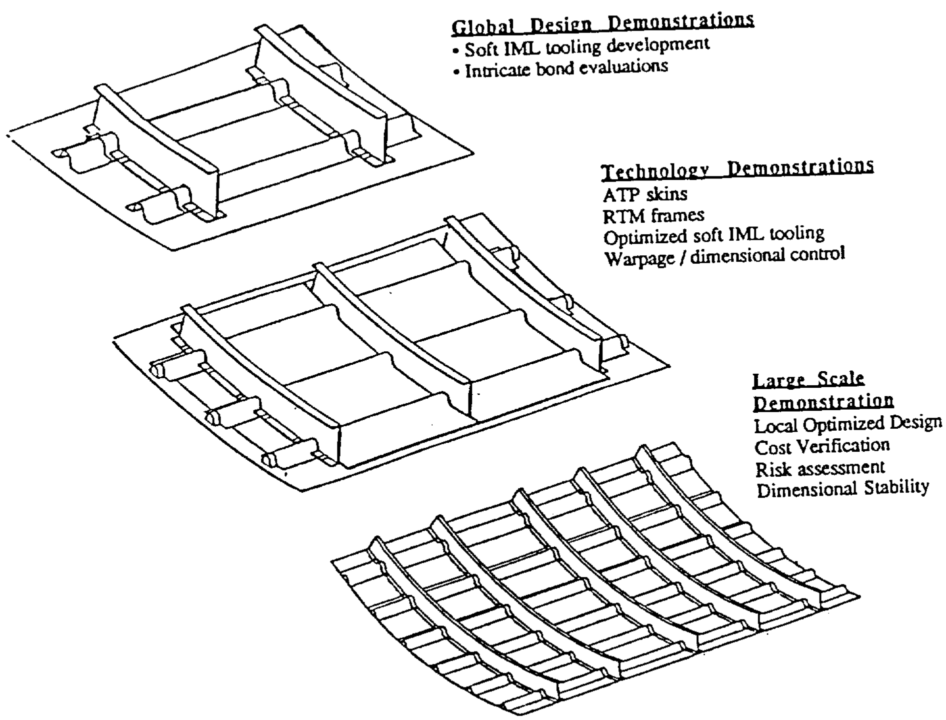


Figure 2: Manufacturing Technology Demonstrations

Manufacturing Demonstration

The initial IML tooling concepts were optimized by fabricating two-frame, two-stringer flat and curved panels (Figure 3). Panels 3 ft. by 5 ft. were fabricated at Hercules with the same soft IML tooling concept. These panels used ATP skins, drape formed stringers, and RTM frames (Figure 4). The results of these panels were used to optimize the tooling for the 7 ft. by 10 ft. manufacturing demonstration.

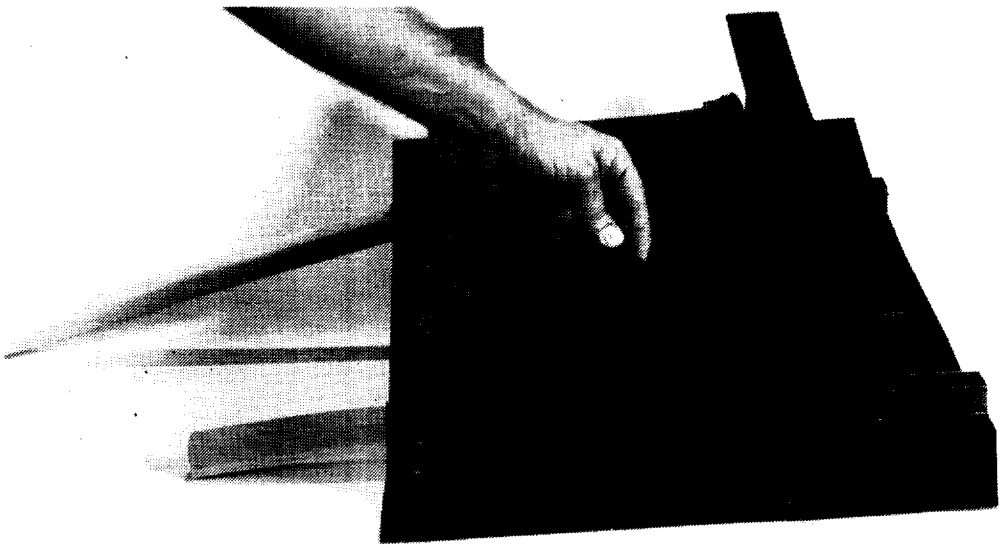


Figure 3: IML Tooling Trials

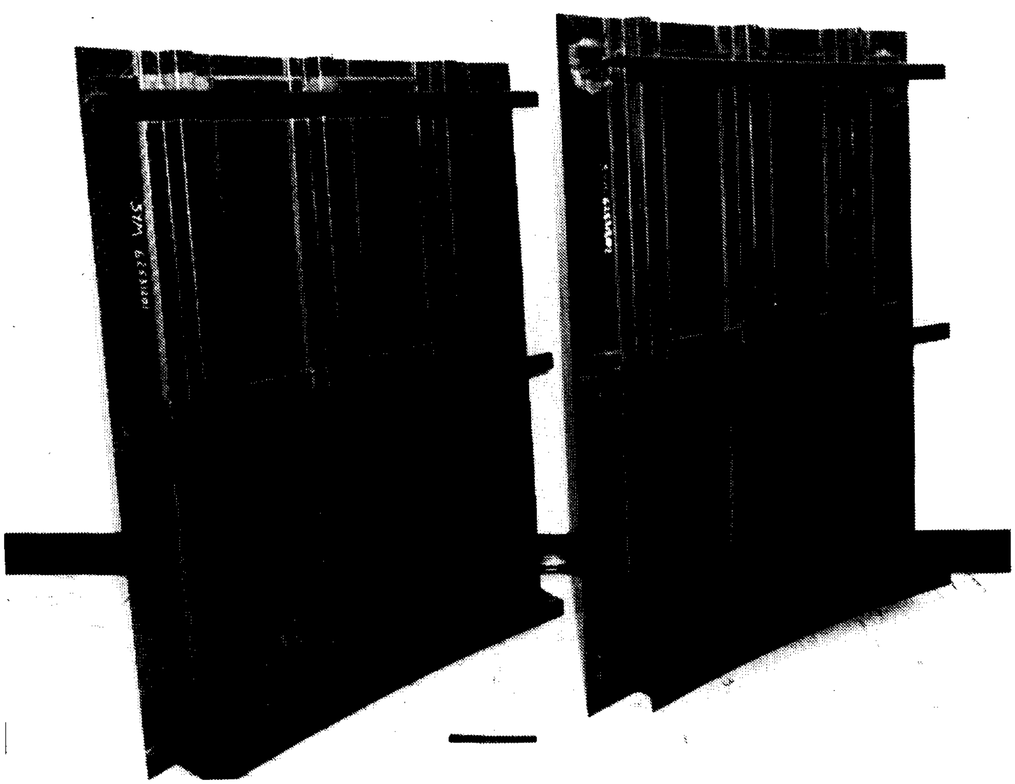
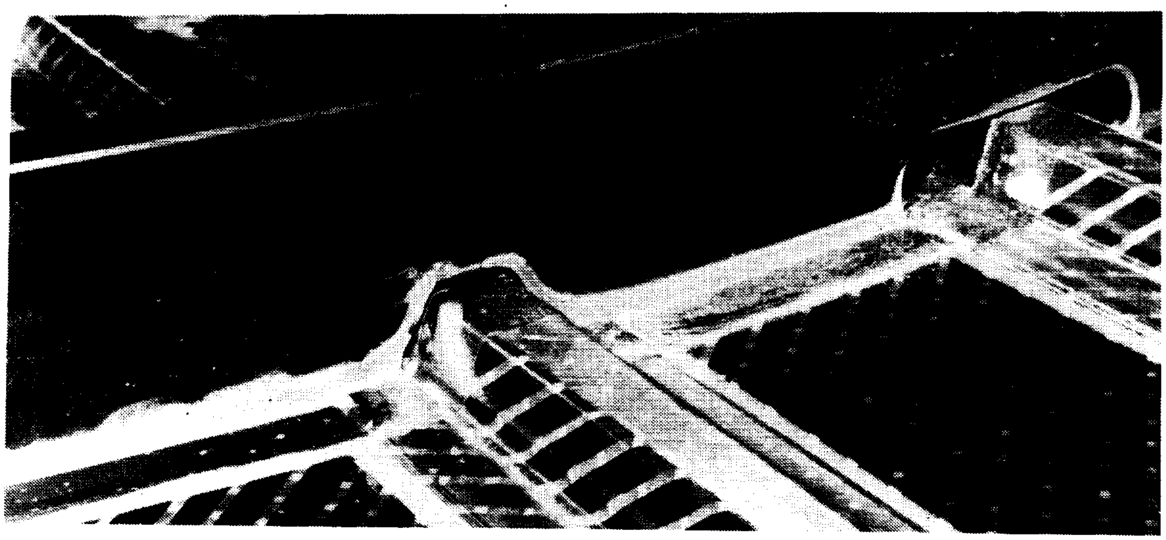


Figure 4: 3 ft. by 5 ft. Intricate Bond Panels

Inspection of the two 3 ft. by 5 ft. panels showed several manufacturing anomalies that required additional development of the stringer cure mandrels and soft IML tooling. Figure 5 shows excess resin in frame flange radii that bled from the stringer and skin. Since the cauls had net molded stiff corners, any significant frame mislocation created a gap for resin flow during the cure.



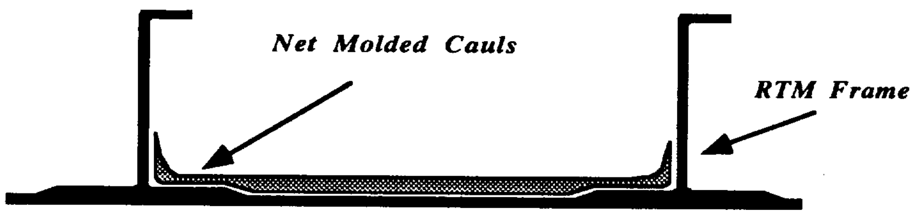


Figure 5: IML Tooling Results (3 ft.by 5 ft. Intricate Bond Panel)

The cauls were redesigned without the molded corners for more flexibility to prevent the resin from bleeding into the frame flange radius (Figure 6). This new concept was assessed by fabricating a 3 ft. by 5 ft. panel. The caul redesign required the addition of mouse hole plugs to transfer autoclave pressure to the stringers and minimize potential bag bridging at the frame-stringer intersections.

Figure 6: Modified Caul Results (3 ft.by 5 ft. Intricate Bond Panel)

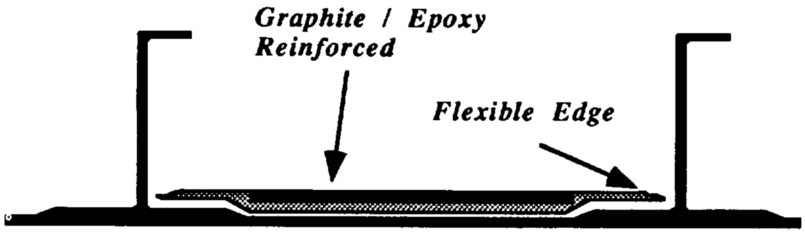


Figure 6 (cont.): Modified Caul Results (3 ft.by 5 ft. Intricate Bond Panel)

Stringer gage thickness and location were difficult to control with the original IML tools. Because the stringer laminates could not be fully compacted prior to cure, the excess bulk gage thickness caused an interference fit between the caul and the stringer charge. This interference fit caused the hat cavity of the caul to spread open which compromised stringer location tolerance (Figure 7). To minimize this problem the stringer drape forming process and caul design were modified.

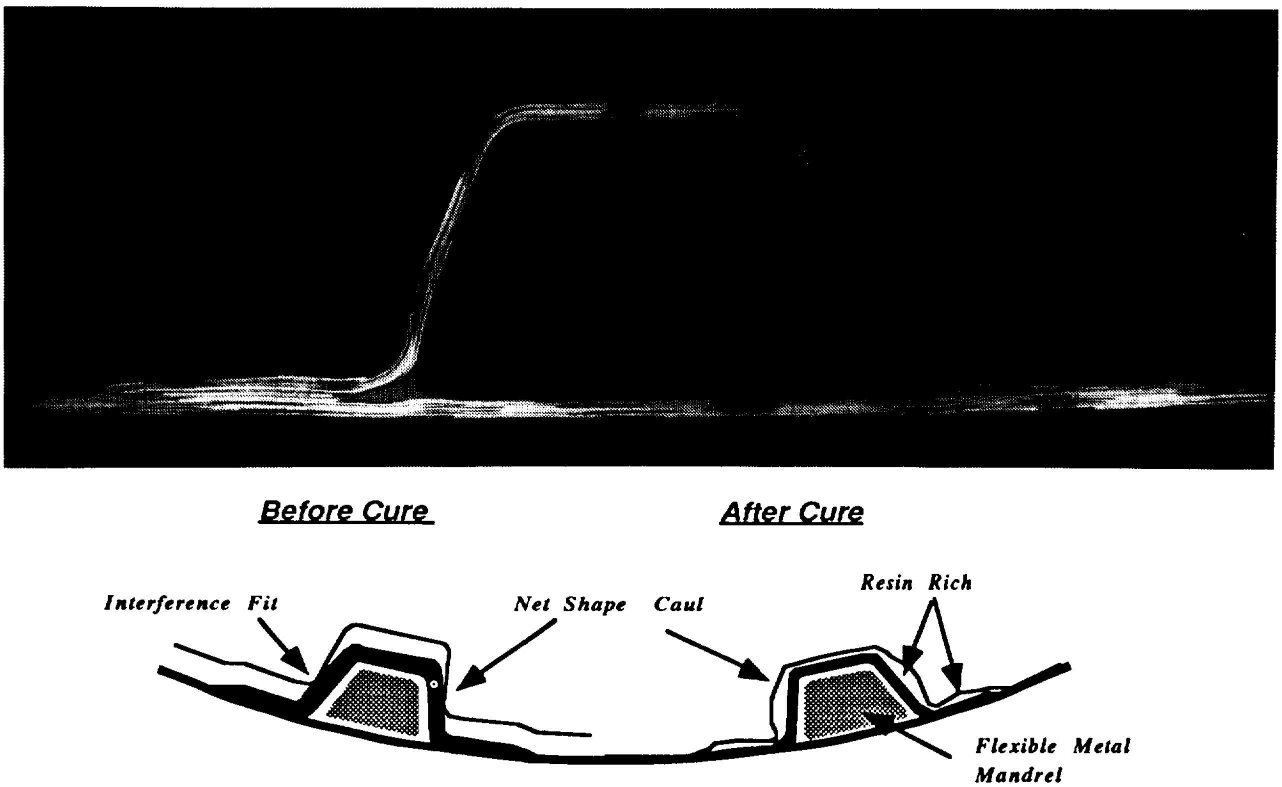


Figure 7: Unstiffened Caul Results (3 ft.by 5 ft. Intricate Bond Panel)

The cauls were redesigned with four plies of graphite prepreg between the stringers and up to ten plies to stiffen the stringer shape. To compensate for the stringer bulk thickness, net sized and over sized cauls were evaluated. A two stringer panel ten feet in length was fabricated to evaluate an over sized (+0.030 in.) and a net shaped caul. Results from both cauls show an improvement of stringer cross sectional shape and gage thickness control. The over sized cauls controlled the stringer gage thickness better than the net shape cauls (Figure 8).

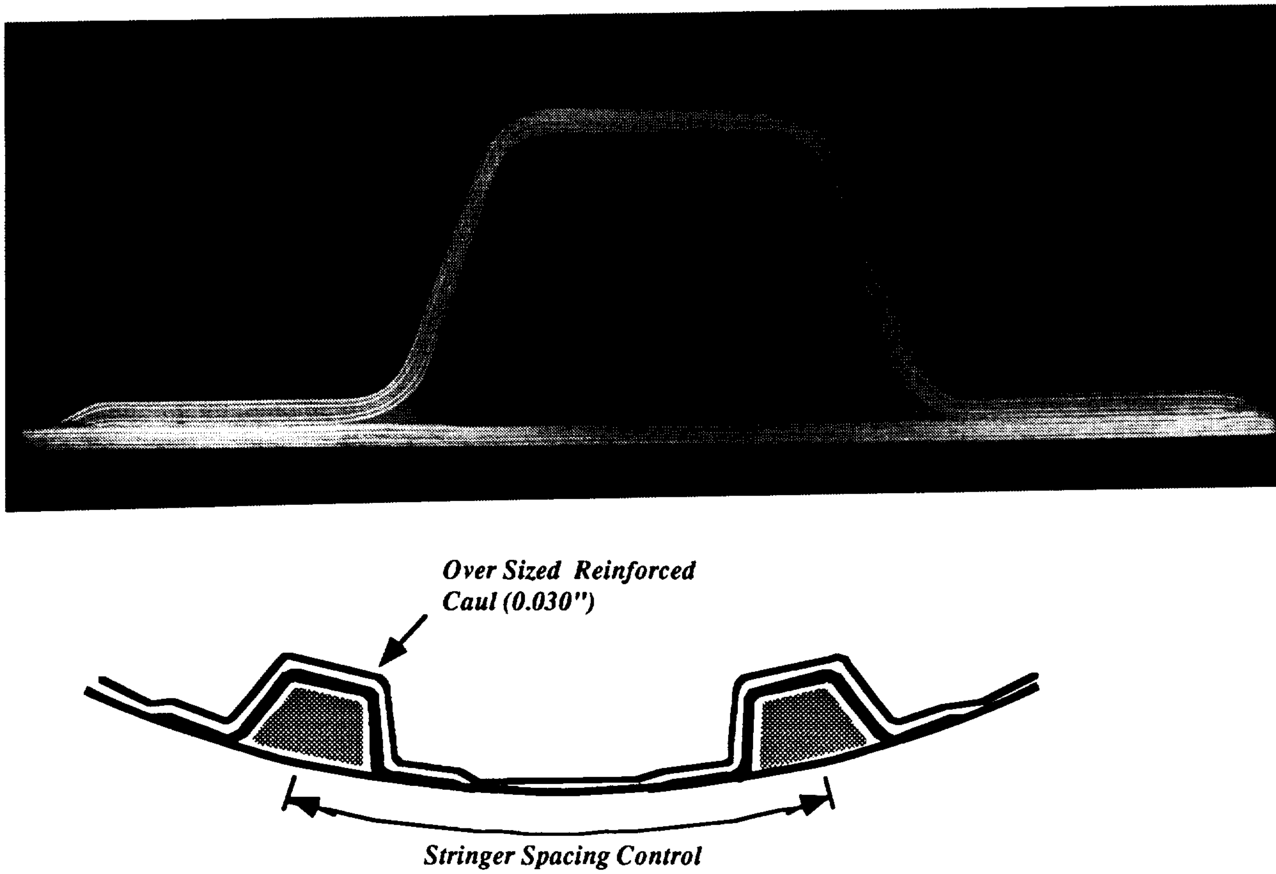


Figure 8: Results of Oversized Stiffened Caul Trials

The over sized caul was designed to be used with a higher expansion stringer tool such as rubber. During cure the mandrel expands and applies pressure to the stringer laminate without deforming the stiffened cauls. The net shape caul was designed to be used with low thermal expanding stringer cure tools. This tooling concept was used in the fabrication of the 3 ft. by 5 ft. panel. The cure mandrels were flexible, low CTE (coefficient of thermal expansion) metal mandrels designed for an after cure clearance of 0.015 in. between the mandrel and stringer. Extraction of the metal mandrels from the hat stringers proved difficult due to an interference fit between the stringer and mandrel. Further evaluations with FEM models (Ref. 5) revealed that the large adhesive noodle in the bottom corners of the hat stiffeners caused this interference fit (Figure 9). This was a result of the difference in CTE between the stringer laminate and adhesive. To minimize this effect, a smaller radius noodle or a lower CTE radius filler material could be used. Another option is the rubber mandrel could be molded to net shape eliminating the need for a radius noodle. The oversized stiffened cauls and net shaped silicone molded mandrels were selected as the tooling option for the 7 ft. by 10 ft. panels.

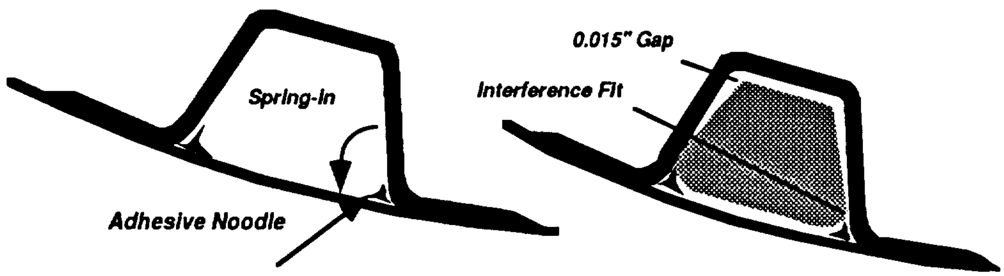


Figure 9: Mandrel Interference

Fuselage Frame Development

Under the fuselage frame development program, 8 ft. frames were fabricated for the intricate bond design. One of the critical requirements for cobonding the frame to the skin was the tolerance control of the 122 in. frame radius. The development of 3 ft. frames with aluminum tooling provided insight for scale-up for 8 ft. frames. The processing conditions and tooling for resin transfer molding of two 3 ft. frames at a time were developed so that the same processing conditions and tooling would be applicable for the 8 ft. frames (Ref.6). The tool was designed for resin impregnation to be independent of the frame length.

The 8 ft. frame preforms were fabricated on a 144 carrier braider. A swing arm was constructed to drive the braiding mandrel through the center of the braider at a controlled speed to maintain fiber orientation (Figure 10). The preform consisted of six plies of triaxial braided AS4 fiber. The bias ±66 degree fibers were 6k tow and the axial fibers were 18k tows. Preform distortion from handling was minimized by integrating the mandrel as part of the RTM mold. The mandrel and attached preform were inserted into the RTM mold cavity. Prior to closing the mold a simple cut and fold operation of the three outer plies was done to form the bottom flanges of the two "J" frames. The braided preform was impregnated with Shell RSL 1895 resin and cured in a convection oven and strip heaters were also attached to the outside of the tool for preferential heating.

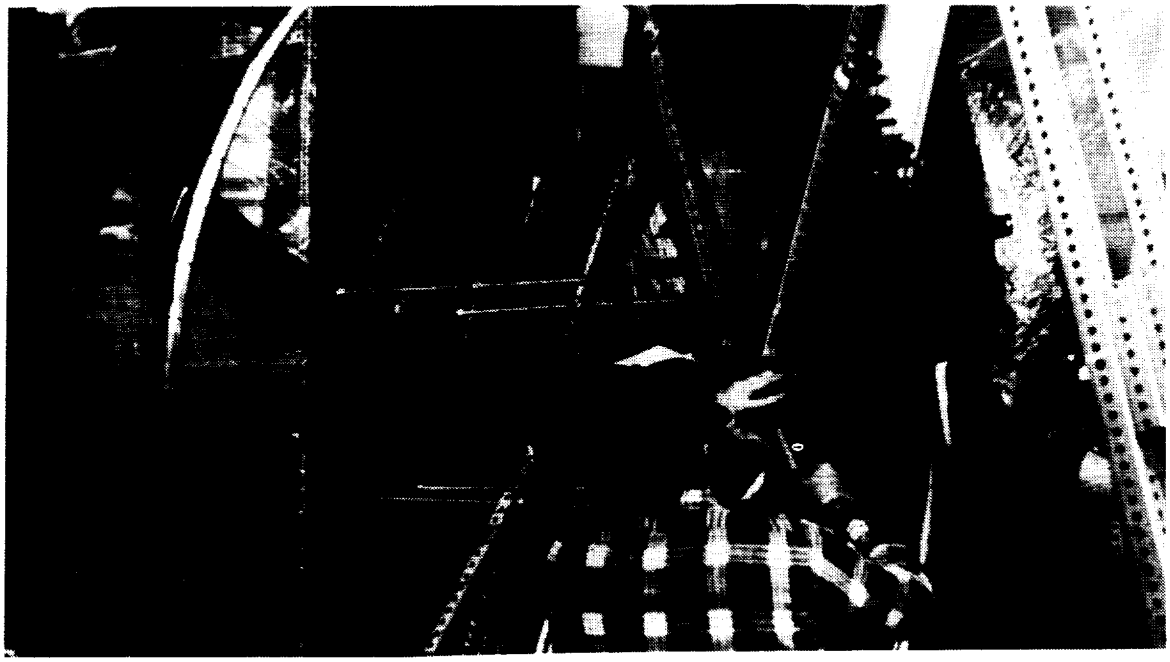


Figure 10: Braiding Frame Preform

Dimensional inspection of the 3 ft. frames revealed a 1° spring-in of the bottom frame flange. The amount of web twist shown in Figure 11 required less than 2 lbs. of force to remove. The gage thickness variations on all flange and web areas were held to ±0.010 in. The part was designed for a 121.89 in. radius but the measured radius was 122.16 in.

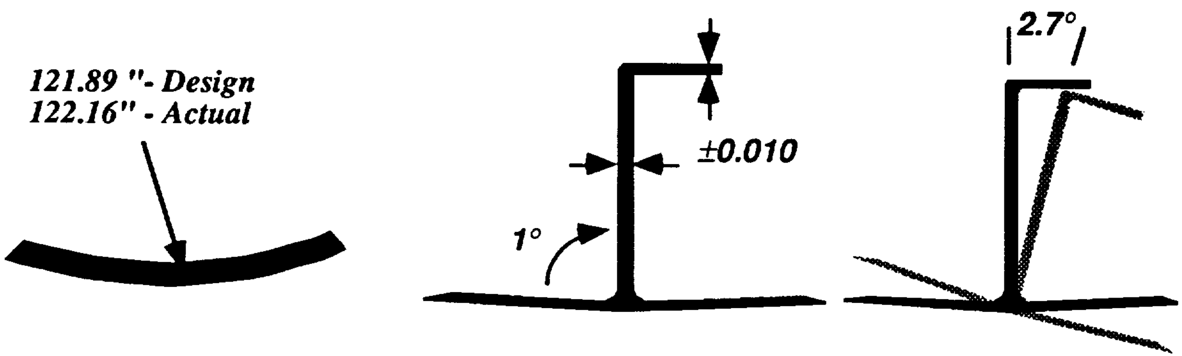
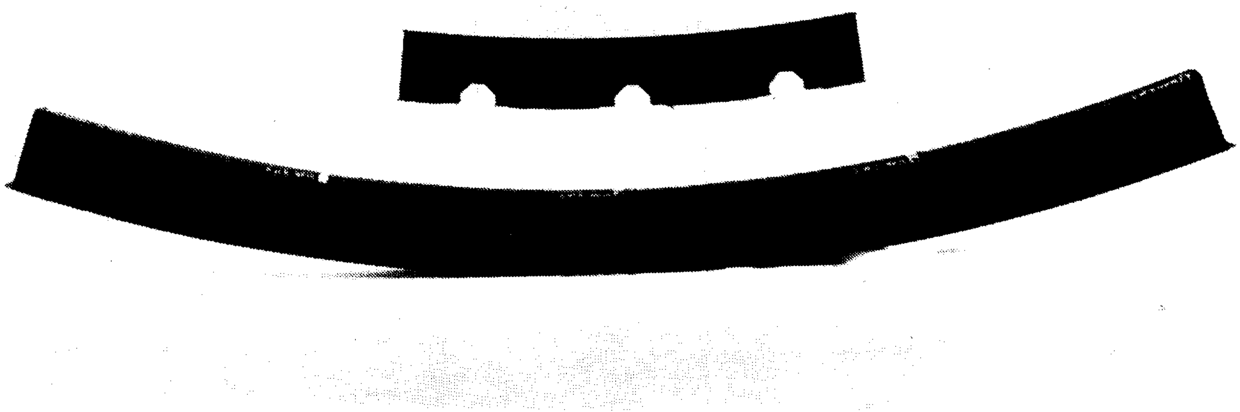


Figure 11: Tolerance Control of the 3 ft. Frames

A finite element model of the aluminum RTM tool during cure was evaluated which indicated a 122.34 in. radius at 350° f. The use of aluminum material for a larger frame would cause high residual stresses during tool cool down due to this change in radius. Therefore, tooling material for the 8 ft. cure tool was changed to Invar 36 so that the CTE mismatch between the frame and RTM tool would be minimized. Since Invar 36 has a lower heat up rate than steel or composite, strip heaters and a convection oven were used.

Thirty five 8 ft. frames were processed with the Invar RTM mold (Figure 12). Inspection was performed on the frames with and without mouse holes cut outs. The frames without mouse holes met the desired frame radius of 121.90 in. ±0.010 in.but sprung open to 123.00 in. after the mouse holes were cut into it. Less than 20 lbs was required to fit the frame to the 121.89 in. radius during panel assembly. The Invar RTM mold was machined to compensate for the 1° spring-in. Frame spring-in measurements indicated that no spring-in occurred; therefore, the frames were molded with a 1° spring-out. The web twist was .1° compared to 2.7 ° twist measured with the frames made with the aluminum tool.



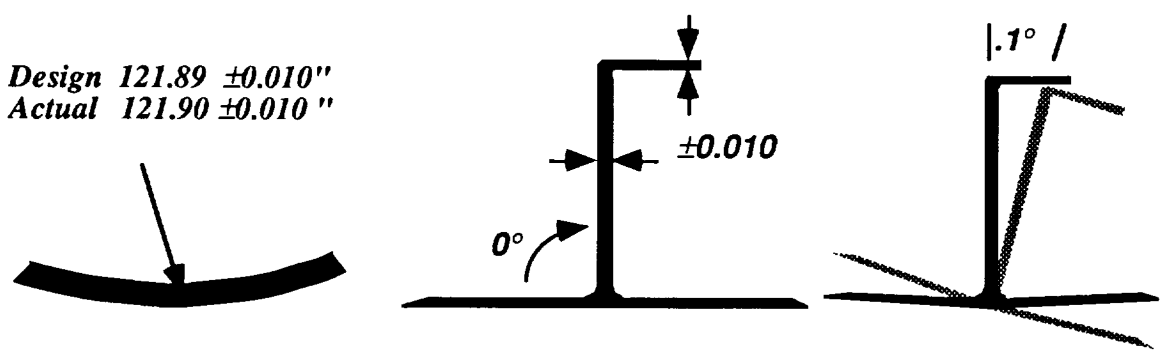


Figure 12: 8 ft. RTM Frame Inspection

Surface porosity was found in the same region of each frame during initial RTM processing. Processing variations and enlarged resin ports eliminated this problem. Inspection of the frames with TTU techniques (@ 6 db) showed long narrow defects running parallel to the axial fibers. Photomicrographs were compared to TTU results from various sections of the frame. In areas where white axial streaks occurred, the axial fibers from each ply were aligned to form resin rich areas and high fiber volume areas (Figure 13a,b). This significant variation in density produced a signature similar to a defect. Photomicrographs of areas with no transmission loss revealed that the axial tows of the six plies were offset resulting in a more nested configuration. The photomicrographs also showed no signs of porosity or internal micro-cracks.

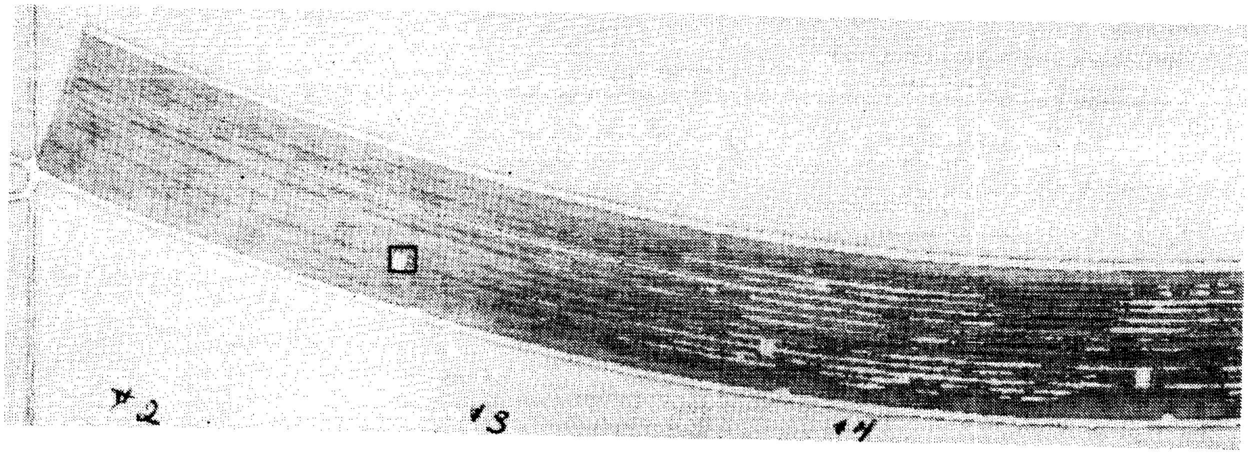


Figure 13a TTU of RTM Frames (6 db loss)

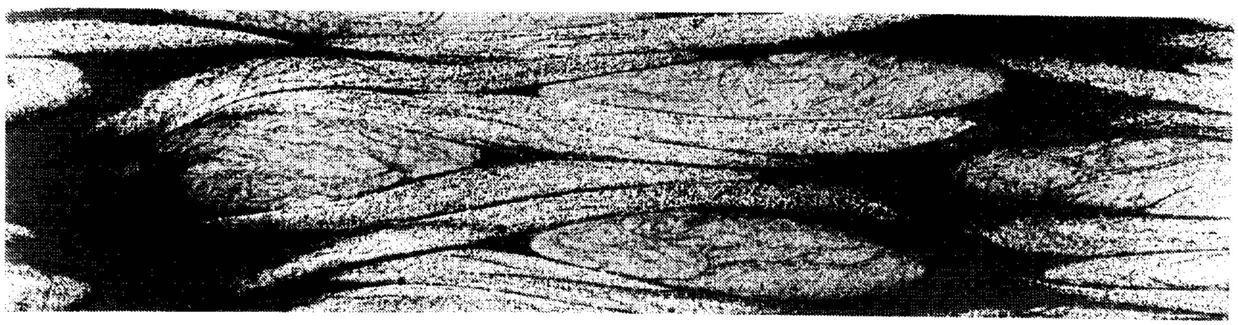


Figure 13b Stacked Axial Yarns

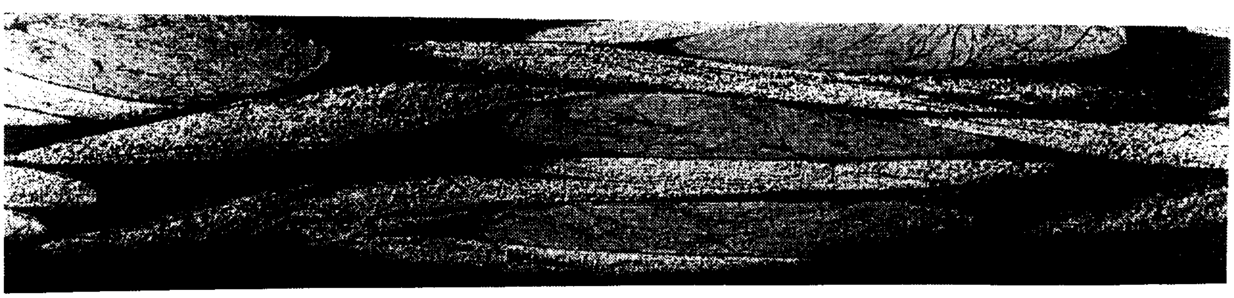


Figure 13c Nested Axial Yarns TTU of RTM Frames

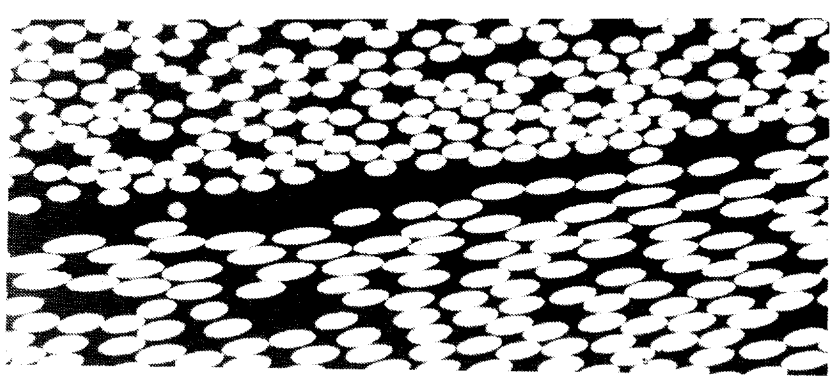


Figure 13d Architecture Resin Wet Out

Intricate Bond Panel Fabrication

IN an effort to demonstrate manufacturing feasibility for large quadrant panels, RTM frames and IML tooling was again used with the ATP process to fabricate a 7 ft. by 10 ft. intricate bond panel. The 7 ft. by 10 ft. skin and stringer charges were fiber placed at Hercules with the four inch wide band head. After the stringer charges were individually trimmed, they were formed into the hat stringer shape with a one step drape forming process. A silicone cure mandrel and an aluminum female tool were used to form the hat section. Prior to placement of the stringers on the skin, adhesive was placed on skin stringer interface areas (Figure 14). The IML cauls aided in locating stringers on the skin (Figure 15).

Prior to locating the RTM frames, adhesive film was applied to the bottom frame flanges. The frames were then positioned with the aid of frame finger clamps positioned along the length of the Invar cure tool (Figure 16). The frame fingers maintained frame spacing during the cure but allowed the frames to move normal to the skin. Once the frames were positioned, the precured two ply pressure bridge was located in each frame mouse hole (Figure 17). The cauls were then placed between frame bays (Figure 18). The cauls were designed so that they would overlap each other in the mouse holes areas to control resin flow. Once the silicone plugs were placed in each mouse hole, the textured silicone bag was placed over the assembly (Figure 19, 20). This bagging approach minimized the amount of non-reusable bagging material and associated labor. Neither breather or separator film was used between the cauls and the IML surface.

After cure the silicone bag and stringer mandrels were removed. The panel was inspected and all frame and stringer bond lines were defect free (Figure 21). One small void was detected in the stinger-skin bond area but was determined to meet production requirements. Examination of the stringer cross section showed good control of the resin flow for stringer shape and spacing. Laminate wrinkling in the stringers did occur near each two-ply mouse hole pressure bridge. Resin flow control was also maintained at all stringer frame intersections. The designed frame spacing was 22.00 in. +0.000, -0.050 in. compared to the desired frame spacing of 22.00 in. ±.030.

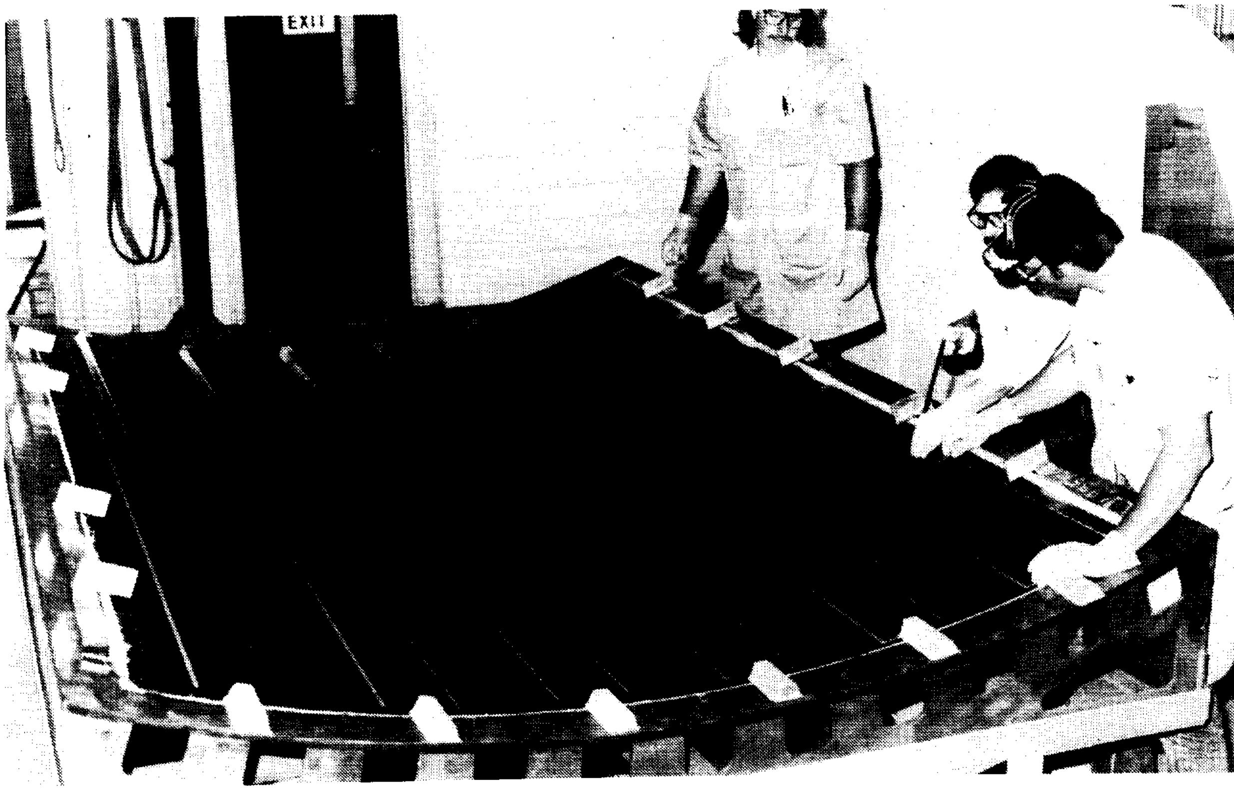


Figure 14: Stringer Placement

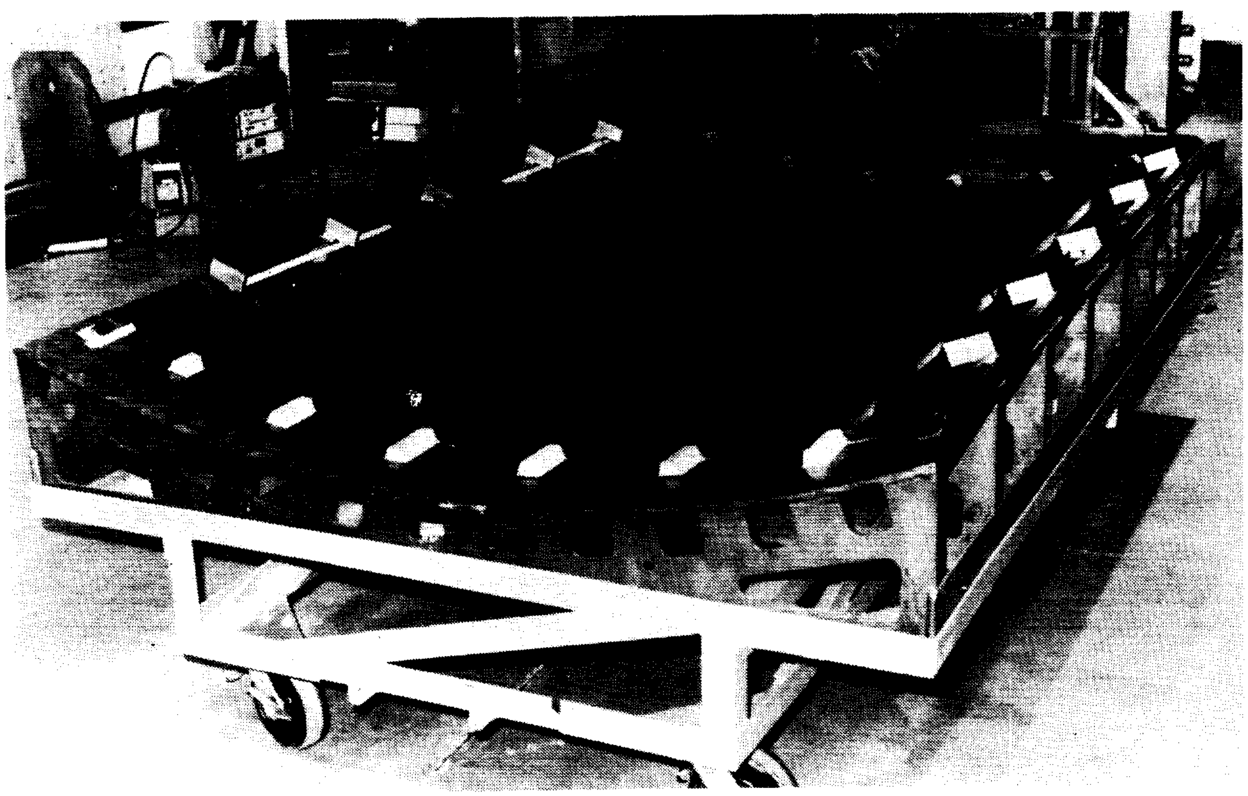


Figure 15: Locating Stringers with IML Cauls

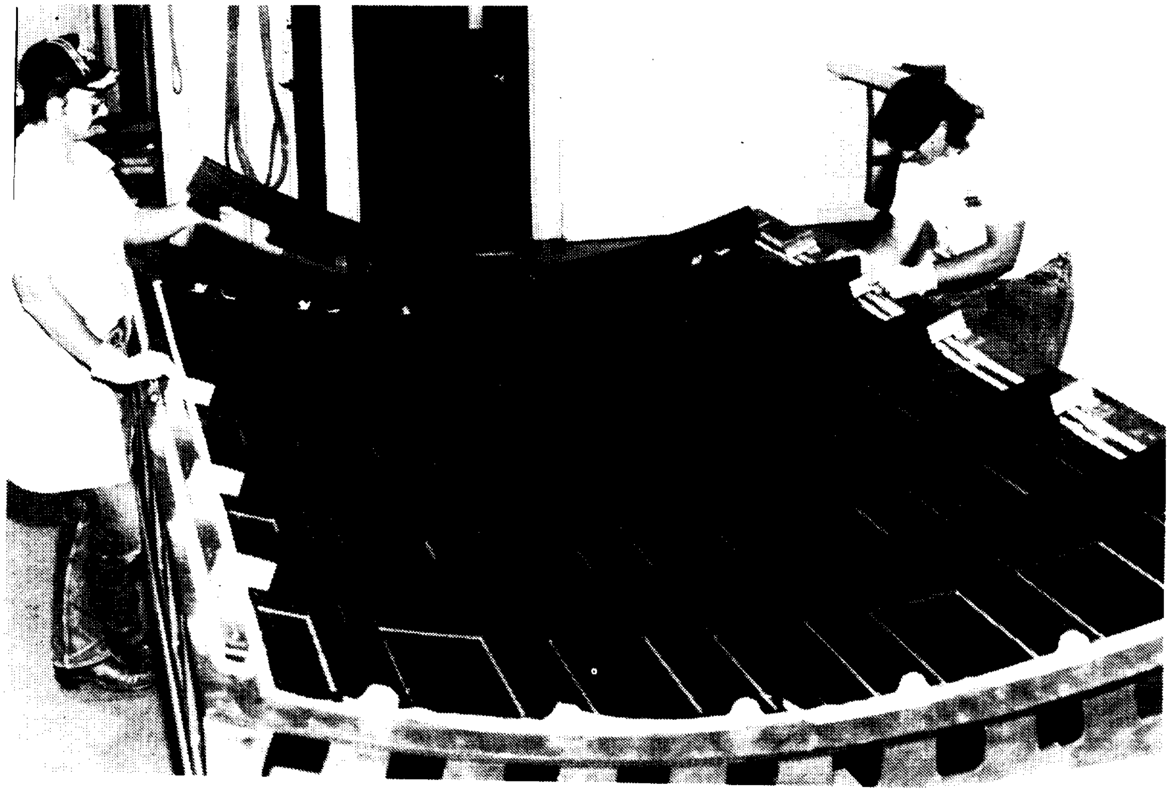


Figure 16: Loading Frames into Assembly Fingers

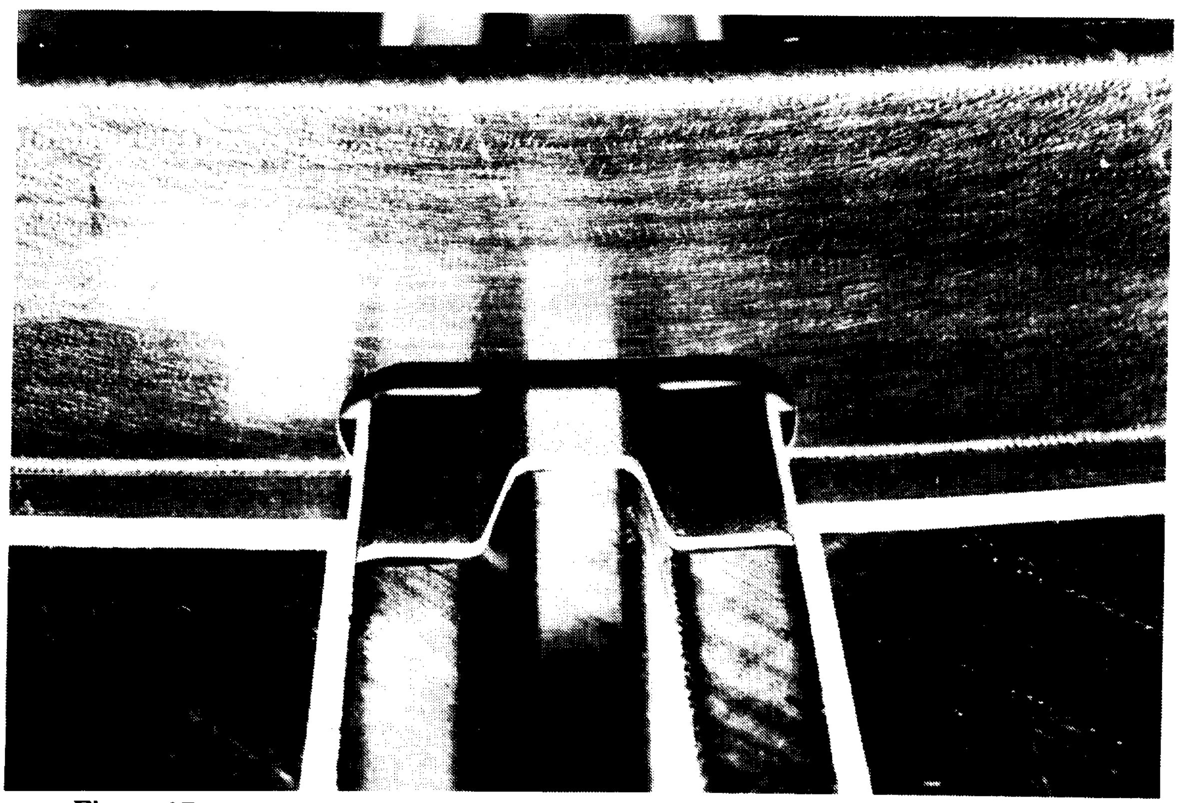


Figure 17: Installation of Mouse Hole Pressure Bridges

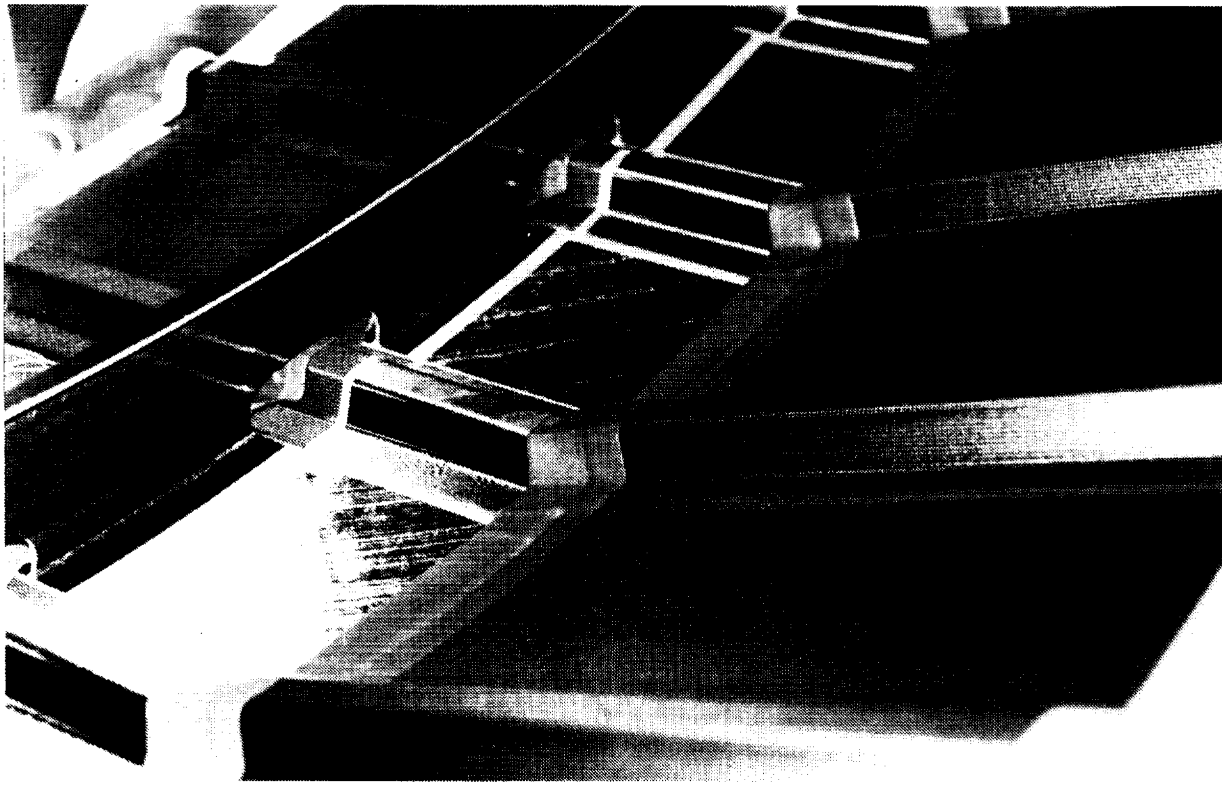


Figure 18: Installation of Cauls

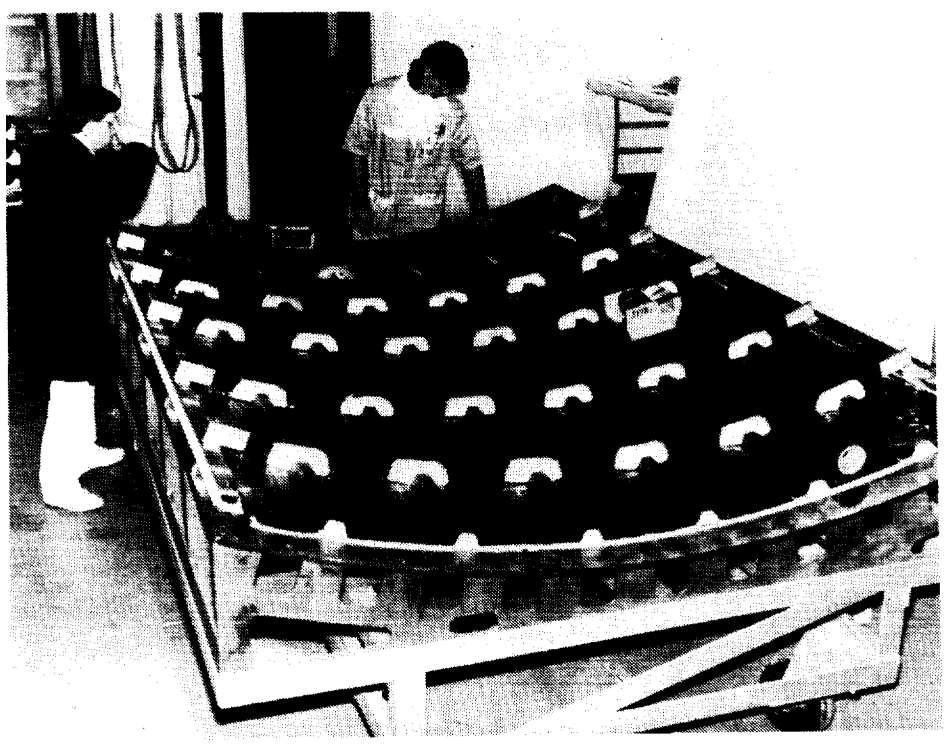


Figure 19: Installation of Pressure Intensifiers

Figure 20: Reusable Cure Bag

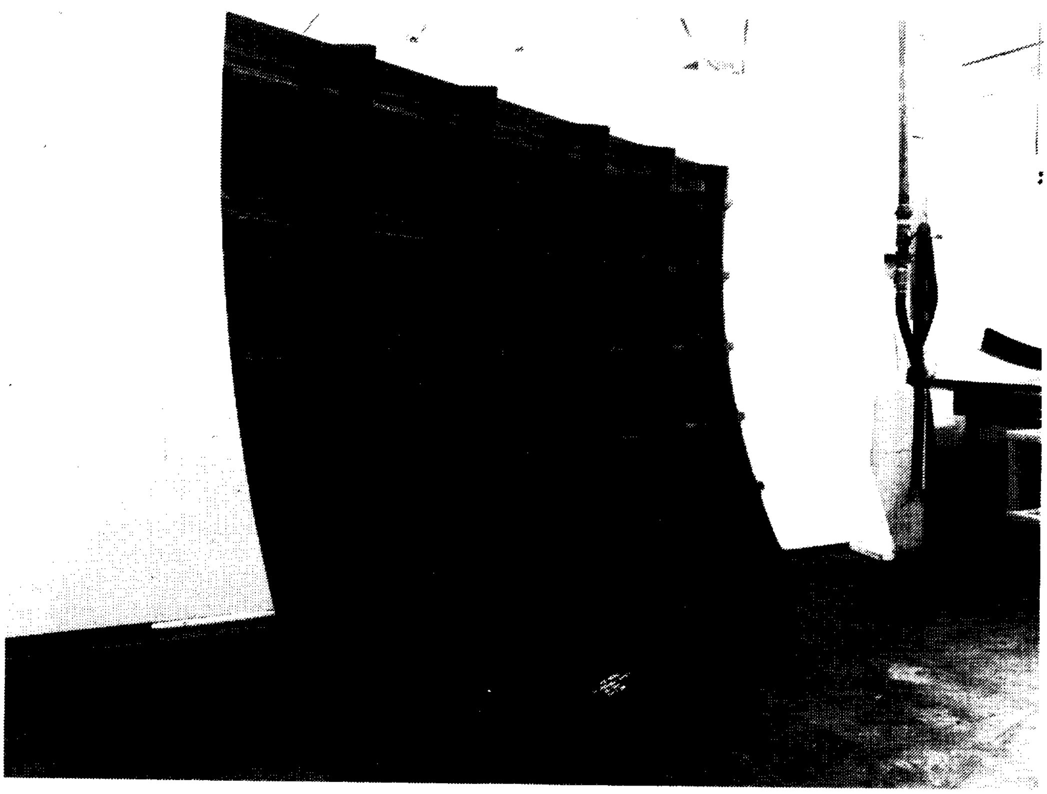


Figure 21: 7 ft. by 10 ft. Intricate Bond Panel

Conclusion

The fabrication of the 7 ft. by 10 ft. composite crown panel showed the potential for large quadrant panel fabrication. The use of fiber placed skins and stringers and the resin transfer molding of long frames were also demonstrated and optimized to further reduce risk and cost. One of the major technology risks evaluated was the ability to cure the skin and stingers and co-bond the frames to the skin at the same time without sacrificing quality. This was accomplished with dimensionally accurate RTM frames and unique IML tooling that reduced panel warpage. Initial measurements indicate that the tooling concepts did control frame and stringer spacing for subsequent quadrant panel assembly.

This development program is still in progress and additional evaluations for structural performance, warpage, and dimensional stability will be conducted. Additional intricate bond panels will be fabricated to evaluate cost and manufacturing anomalies. Cost and learning curve data for the fabrication of the frame, skin and stringer will be evaluated with the use of a cost model to determine optimal cost for production rates. Optimization of the RTM frames will continue with the evaluation of additional braided architectures to increase the structural performance.

REFERENCES

1. L.B. Ilcewicz, T.H. Walker, G. Truselove, K. Willden, G.D. Swanson, and C. Pfahl, "Application of a Design-Build-Team Approach to Low Cost and Weight Composite Fuselage Structure,"NASA CR-4418, NAS1-18889, May 15, 1989.

2. T.H. Walker, P. Smith, G. Truselove, K. Willden, S. Metschan, C. Pfahl, " Cost Studies for Commercial Fuselage Crown Designs", First NASA Advanced Composite Technology Conference, Seattle, WA, October 29-November 1, 1990, NASA-CP-3104

3. L.B. Ilcewicz, P. Smith, T.H. Walker, R. Johnson, " Advanced Technology Composite Aircraft Structures", First NASA Advanced Composite Technology Conference, Seattle, WA, October 29-November 1, 1990, NASA-CP-3104

4. K.S. Willden, S. Metschan, V. Starkey, " Process and Assembly Plans for Low Cost Commercial Fuselage Structure", First NASA Advanced Composite Technology Conference, Seattle, WA, October 29-November 1, 1990, NASA-CP-3104

5. R. Lundquist, B. Flynn, G. Swanson, and G. Mabson, “Dimensional Stability of Curved Panels with Cocured Stiffeners and Cobonded Frames”, presented at the Third NASA Advanced Composite Conference, Long Beach, Ca, June 8-11, 1992. NASA CP-3178

6. M.J. Fedro, K.S. Willden, " Characterization and Manufacture of Braided Composites for Large Commercial Aircraft Structures", presented at the Ninth DoD/NASA/FAA Conference on Fiberous Composites in Structural Design, Lake Tahoe, Neveda, November 4-7, 1991