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Process and Assembly Plans for Low Cost Commercial Fuselage Structure

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Design / Manufacturing Selection Process

Cost and weight reduction for a composite structure is a result of selecting design concepts that can be built using efficient low cost manufacturing and assembly processes. Since design and manufacturing are inherently cost dependent, concurrent engineering in the form of a "Design-Build Team" is essential for low cost designs. Detailed cost analysis from DBT designs and hardware verification must be performed to identify the cost drivers and relationships between design and manufacturing processes. Results from the global evaluation are used to quantitatively rank design, identify cost centers for higher ranking design concepts, define and prioritize a list of technical/economic issues and barriers, and identify parameters that control concept response. These results are then used for final design optimization (figure 1).

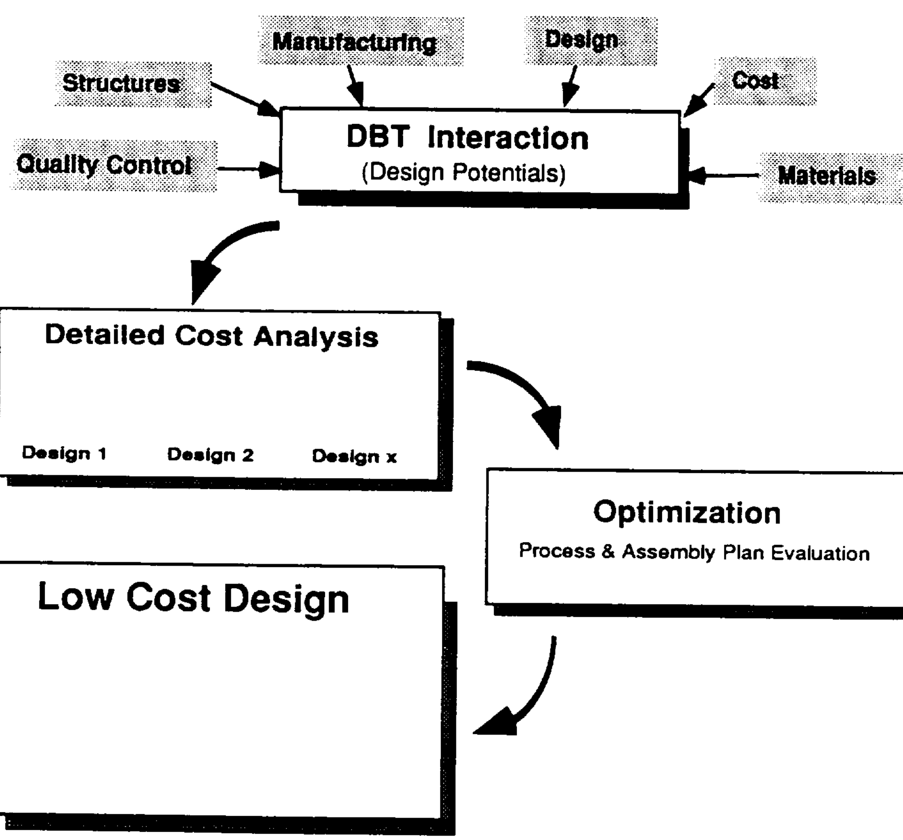


Figure 1.

Parameter Evaluation

A range of design concepts and several manufacturing processes were evaluated in order to isolate cost centers and identify cost efficient processes for a crown panel design (figure 2). A list of the major manufacturing parameters that effect cost are listed in Table 1. The cost driver for a design is not governed by one particular parameter but by the relationships of several parameters that are interdependent. Therefore, the optimal low cost design is realized when the optimal relationship is selected. These qualitative and quantitative relationships can be identified when trading design and manufacturing processes.

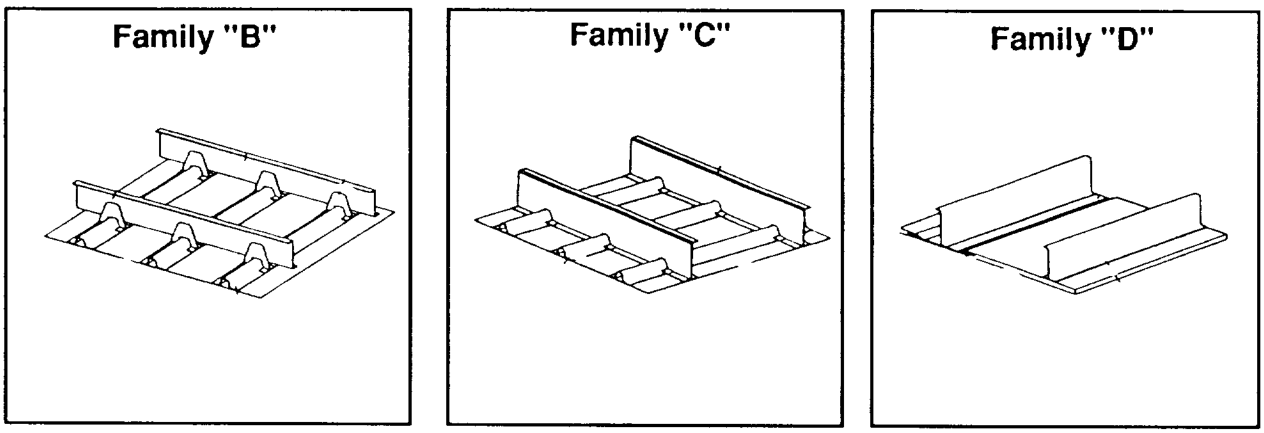


Figure 2.

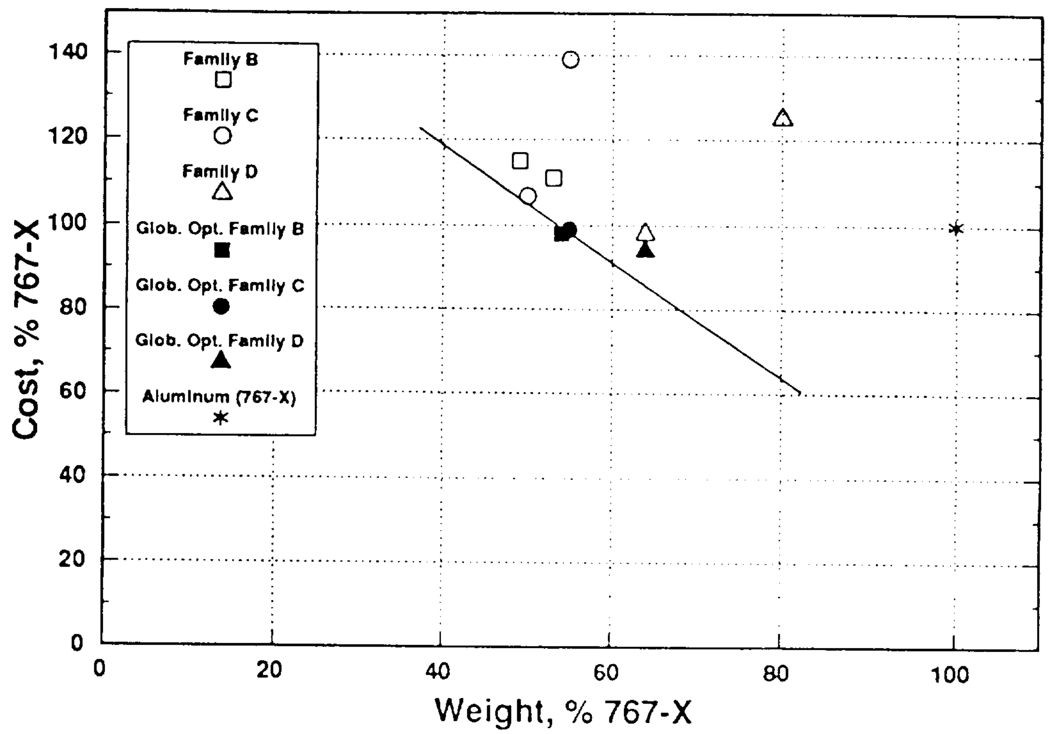
Process & Assembly Parameters

Minimize	Maximize
Material Cost / Scrap	Tolerance control
Part Complexity	Part commonality
Part Count	Automation
Tooling	Tooling Simplicity
Shimming	Material Performance
Touch Labor	Quality-Process Control
Inspection	Lay-up / Forming Efficiency
Repair	Assembly Accessibility
Maintenance	

Table 1.

Crown Panel Global Optimization
Process & Assembly Selection

The most cost effective materials, fabrication processes, and component designs were combined to provide the most cost and weight efficient design. Figure 3 shows that all designs benefited from the global optimization process with significant cost savings and little weight penalty. Although all three globally optimized designs were comparable in cost and weight, the intricate bond design is more damage tolerant (figure 3.). The globally optimized intricate bond design uses precured RTM braided frames, drape formed constant gage stringers and tow placed tailored skin cured together.



Frames

Compression Molding
Pultrusion
RTM / Textile
(Batch mode)
Stretch Forming

Stringers

Drape Formed
Pultrusion

Constant/ non Constant Gage
Precured, Cocured

Skins

Tow Placement
CTLM

Element Attachments

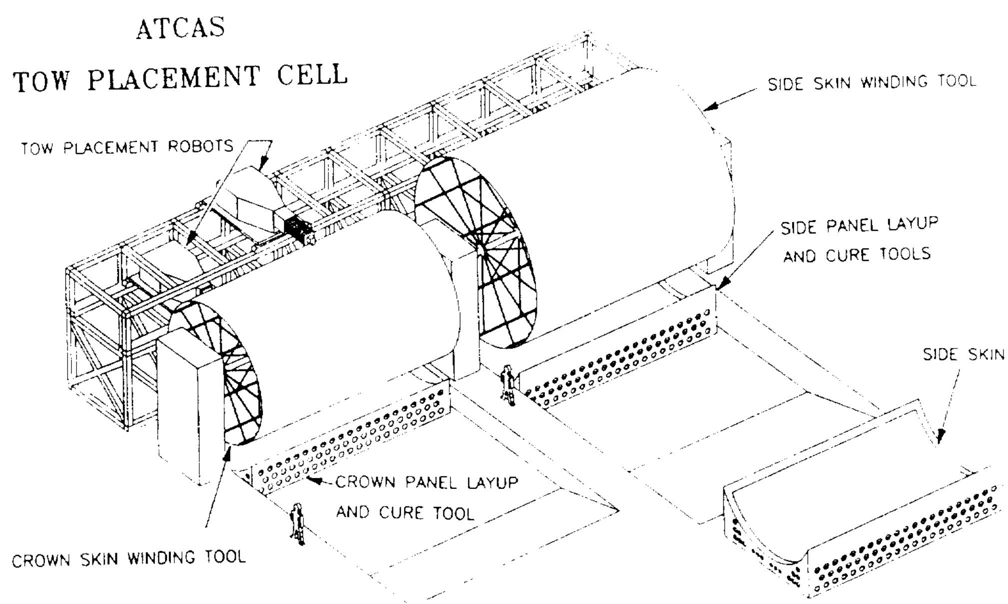
Cocure
Co-bond
Fastened

Figure 3.

Crown Panel Skin Fabrication

The ability to accurately and efficiently fabricate tailored skins on contoured surfaces with various forms of materials, makes the tow placement process ideal for crown panel fabrication (figure 4). Additional advantages are realized when considering batch mode fabrication of several crown panels on one mandrel. The same work station can also produce side and keel panels or a full barrel fuselage section. The pay-out rate for a single head ranges between 10-50 lbs./hr. depending on design requirements. Although the tow placement head has been demonstrated for a single head dispenser, additional heads that are single or multiple task oriented may be implemented. The use of multiple robot end defectors within the same work station can perform additional operations such as trimming and in-line inspection. These types of improvements could increase skin fabrication by 100% if the cost of increased efficiency is justified.

Tow Placement Work Station



- o Full Barrel Capabilities
- o Efficient Ply add/drop
- o Cut and Trim Capabilities
- o Ply Thickness Control
- o Hybrid Material Handling
- o Scrape rate 5-20%
- o Single Head rate -50 lbs./hr.
- o Temperature Conditioning

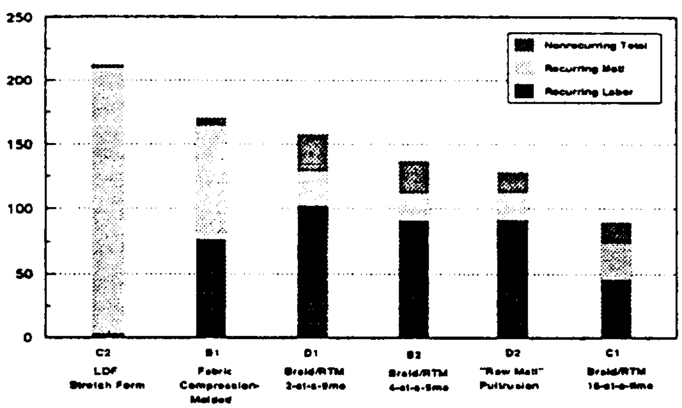
Figure 4

Crown Panel Frame Fabrication

Some of the significant cost drivers for frame fabrication that were identified from the global evaluation were dimensional tolerance control for skin-stringer bond integrity, batch mode processing, and use of raw material forms. Textile/RTM frames offer these advantages for low cost structure that can not be fully realized by other frame processes for the given design requirements. (See figure 5.) Batch mode RTM processing shows at least a 30% cost reduction over other methods for Design C1.

The RTM/ frame work station uses four key processes; 1) controlled triaxial braiding, 2) automated flange cut and fold techniques, 3) batch mode resin transfer molding of long constant gage frames, and 4) controlled edge trimming. The 17' long triaxial braided mandrels are separately braided and trimmed and then located into the mold cavity for subsequent resin transfer molding. After cure, the frames are demolded and edges and mouse holes are trimmed. The parts are then inspected for panel bond assembly. It is critical that feedback control is required for these processes to ensure part quality and cobond integrity.

RTM / Frame Work Station



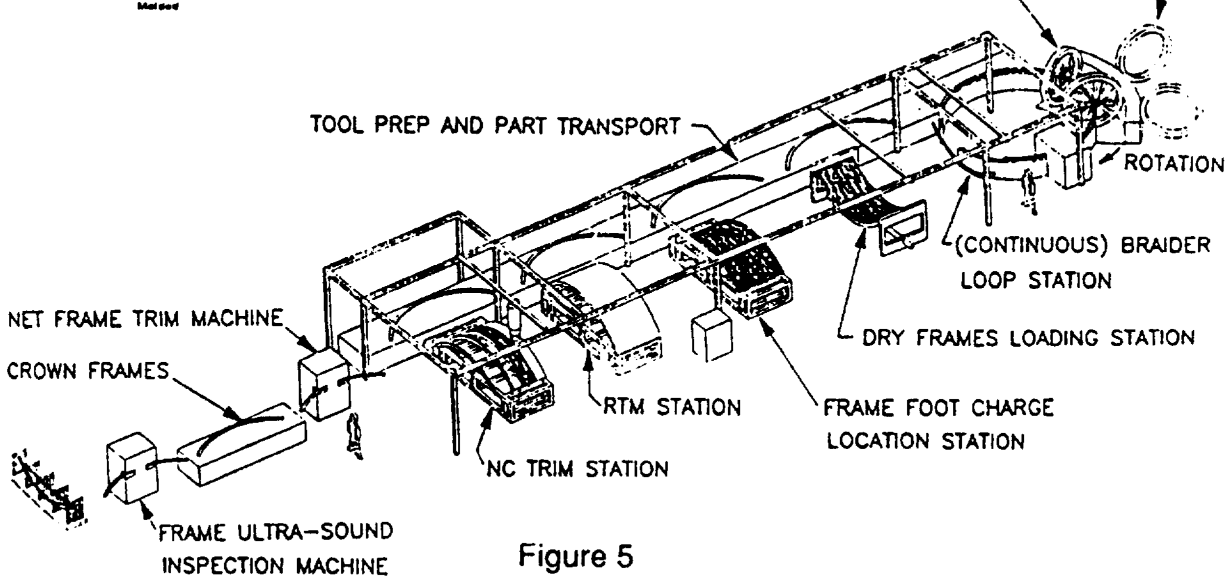
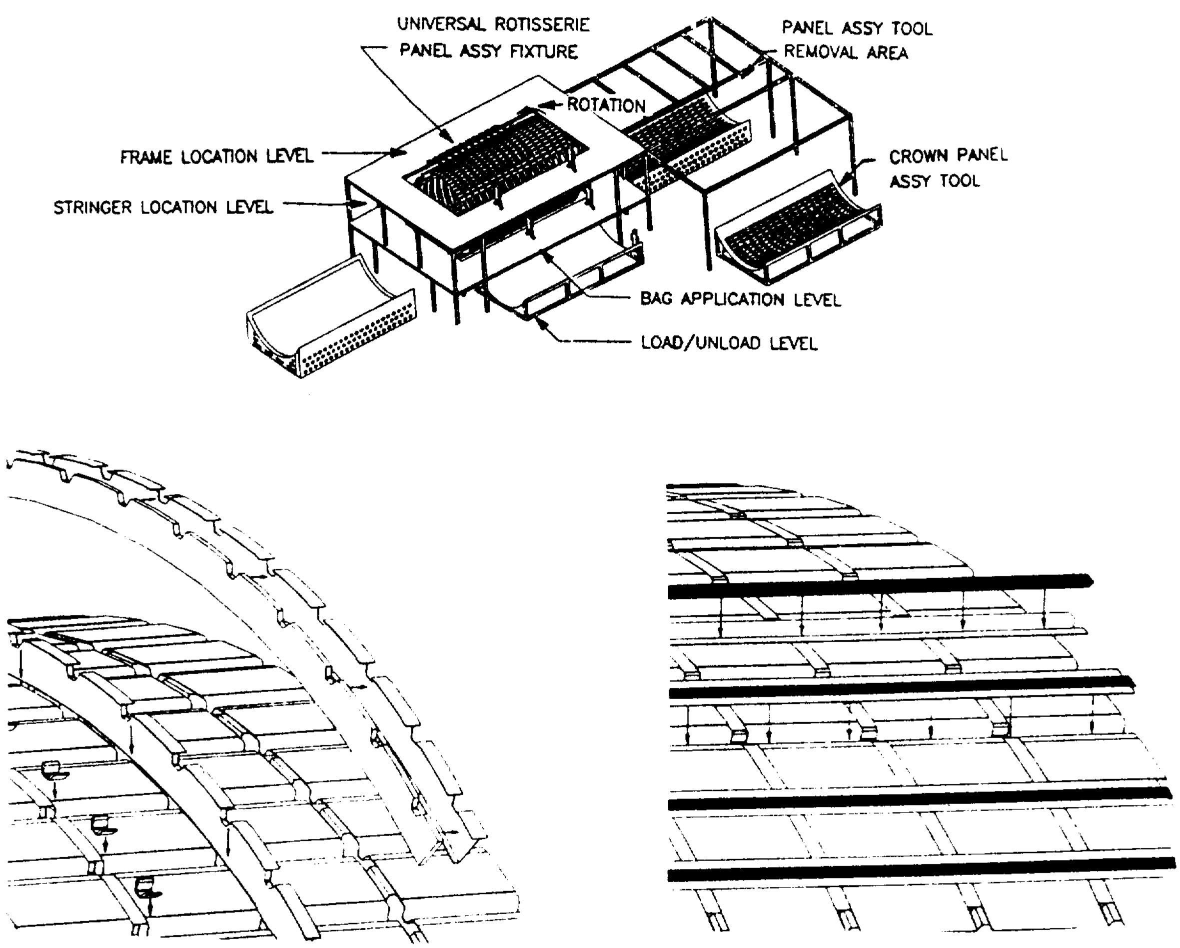


Figure 5

Quadrant Panel Assembly

The intricate bond design (Family "C") dictates that unique tooling concepts be employed to control component location and bond quality. One of the major concerns is the ability to locate each component and account for tolerance build-up at the stringer / frame intersections. Some tolerance pay-off can be realized with a combination of sacrificial adhesive and resin flow during cure of the skin and stringers. Due to the panel curvature, a reverse assembly of the skin, frame, and stringers is required to eliminate interference during part subassembly (figure 6). One possible tooling approach uses a reusable net shape bag/overpress located onto the rotisserie tool. The precured frames with the associated cure tooling are located into the net-shaped pockets of the overpress. Depending on the mouse hole configuration, designed pressure pads are then located into the mouse hole cavities of each frame. The uncured hat stringers are then located. After the stringers and frames have been assembled, the exposed surface can be inspected for out-of-tolerance conditions. The skin and stringer / frame subassembly are then collocated with the prefabricated skin into a OML cure tool.



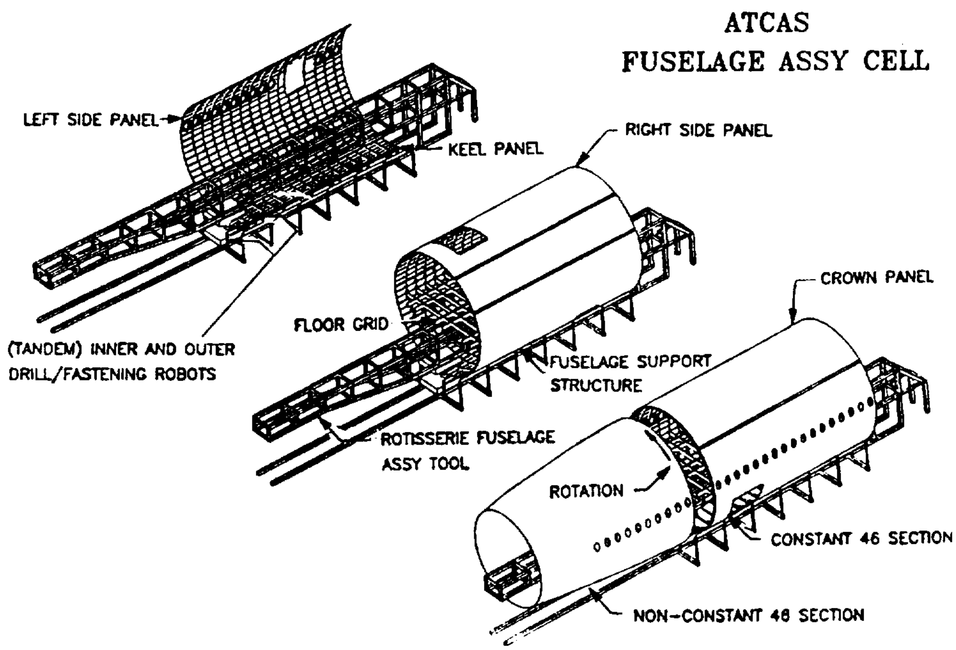
Frame and Pressure Pad Insertion

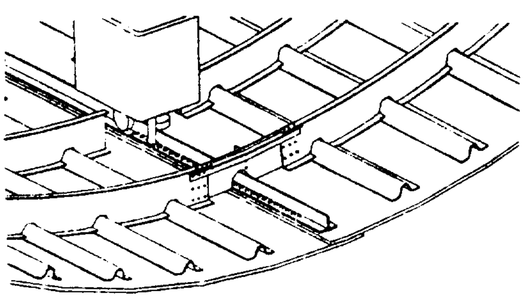
Stringer Insertion

Figure 6

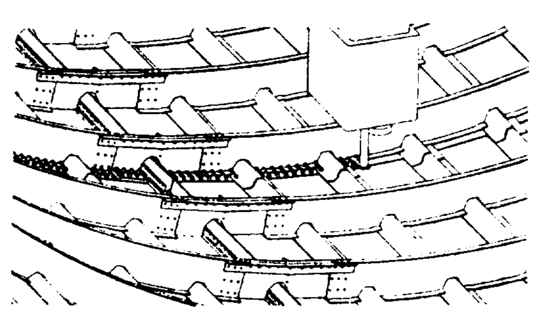
Fuselage Assembly

Low cost assembly of large stiff composite panels assumes that panel warpage as well as stringer and frame alignment are controlled to minimize expensive detail splicing. This requirement can only be maintained by controlling all previous subassembly fabrication processes. The four panel assembly process starts by overlapping the side panels with the keel panel as shown in figure 7. Tandem multi-head robots drill, clean, insert, and fastens the bolts along the lap joints. The precured composite frame splices are then installed along the lap joint. The crown panel is installed in the same fashion so that it overlaps the two side panels. After all the frame splices have been installed, the adjoining body section is mated and the circumferential joint is fastened. An internal splice plate is located and fastened to the two fuselage sections and stringer splices are installed. The remaining sections are assembled and mated with the same process.





Lap Splice and Frame Splice



Circumferential and Stringer Splices

Figure 7

Fuselage Factory Concept

The cost for building a composite fuselage section depends on the factory logistics. Since the quadrant panels are 21' x 32', material, part handling, and work cell capacity must be coordinated to avoid a factory flow bottle-neck syndrome. Fig. 8 shows one possible scenario of a composite fuselage factory based on some of the results of the crown panel evaluations. Each work station is automated except where cost is prohibitive or manual intervention does not effect part quality. An automatic guided delivery and retrieval vehicle is used to transfer parts or material to the requesting work station. Quality control is maintained at each work station with techniques such as Statistical Process Control instead of the traditional step by step inspection.

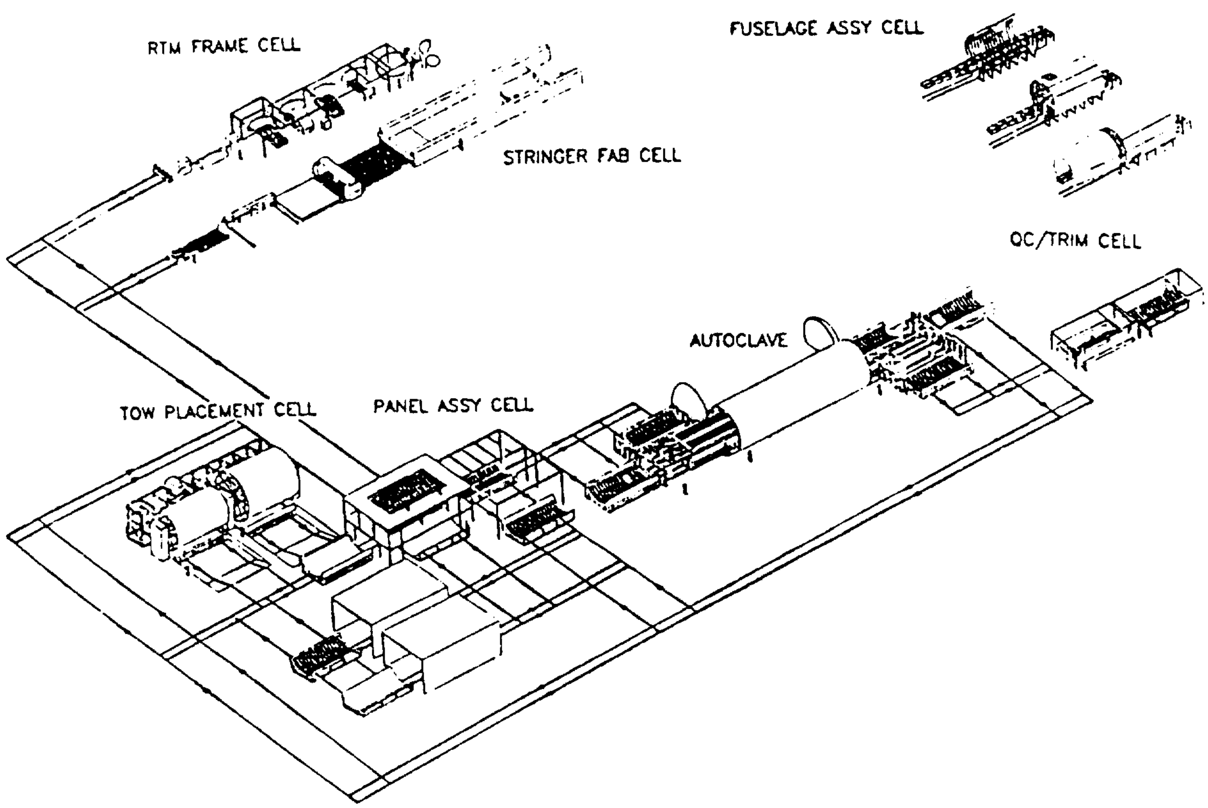


Figure 8.

Program Status

Several tests and hardware coupons are or have been completed to understand the cost impact of material /structural performance and manufacturing processes for low cost structure. (See figure 9.) Low cost damage tolerant materials and processibility of these materials are under investigation and will be demonstrated in support of the near term local optimization for the crown panel and future activities with the keel and side panels. Panel warpage and part tolerance control will be demonstrated with innovative tooling, fastening, and splice details.

To Date

- **Tow placed flat hybrid panels**
  (AS4 / S-2, AS4 / T-1000)
- **Tow placed tailored hat and blade panels**
  (combinations of 977-2, 938, AS4, IM6, RC 35%,44%)
- **Thermoplastic fastener trials**
- **Tooling trials for blades, hats, and intricate bond**

Near Term

- **Large Intricate bond demonstration panels**
  (Tooling Development 8'x9')
- **RTM-braided frames (3'-10')**
- **Panel warpage / assembly evaluations**
- **Innovative design splices**

Figure 9.

Fiber Placement of Tappered Stiffened Panel

Figure 10 shows one of the eight fiber placed panels (24" x 110") produced by Hercules on the seven axis fiber placement machine. Eight panels with various combinations of resins (Fiberite 938, 977-2), resin contents (35 %, 44%), fibers (AS4, IM6), and stringer geometries (blade, hat) were fabricated for impact damage evaluations. The blade and hat stringers were also tow placed into charges and then individually trimmed and formed. The panel thickness varied from 12 plies to 24 plies. Each tow was conditioned to a .0074" tow thickness for uniform panel thickness control. The flexible hat cocure tooling permitted the stringer to conform to the tapered skin without sacrificing bond quality.

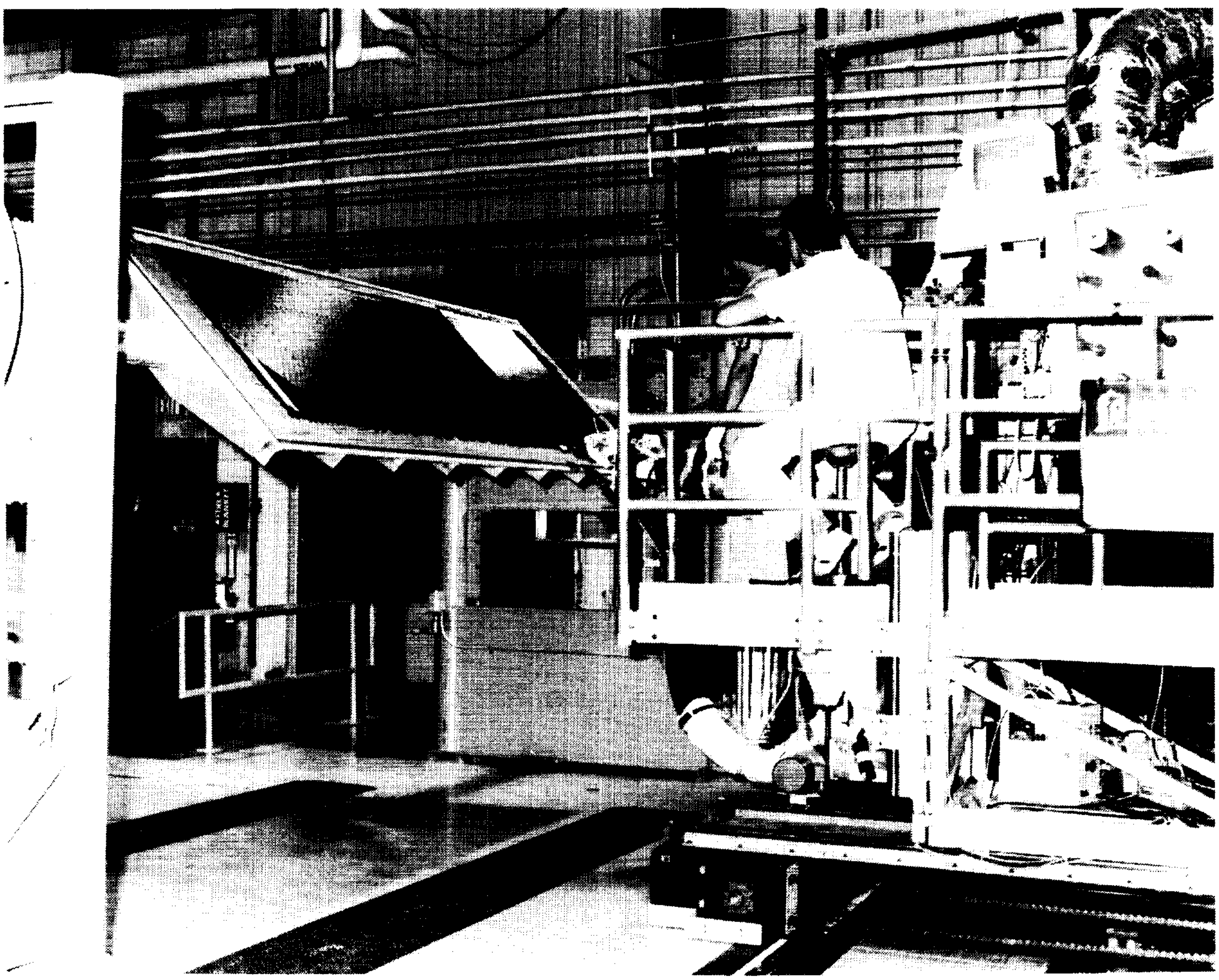


Figure 10.

Fiber Placement of Hybrid Panel

Figure 11. shows one of the seven intraply hybrid panels that were fabricated by Hercules with the fiber placement process. To determine relationship between tension/ fracture performance and material cost, S-2 glass and T-1000 fibers were used to hybridize a AS4/938 system (57% fiber volume). Hybridizing - fiber ratios of 25% and 50% of S-2/AS4 fiber were used to determine the cost/weight impact of a less expensive, lower stiffeness fiber. A second combination of T-1000 (25%) / AS4 fibers was also used to determine weight reduction with a more expensive, higer performance fiber. A twelve or four tow repeat pattern was used for the various fiber combinations to evaluate the performance impact of tow pattern sequence.

Figure 11.

BIOGRAPHY

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Graduated from Brigham Young University with a Bachelor and Masters degree in Mechanical Engineering. Experience includes advanced research and development of manufactured composite structures with General Dynamics and Boeing.