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ADVANCED TEXTILE APPLICATIONS FOR PRIMARY AIRCRAFT STRUCTURES

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SUMMARY

Advanced composite primary structural concepts have been evaluated for low cost, damage tolerant structures. Development of advanced textile preforms for fuselage structural applications with resin transfer molding and powder epoxy materials is now under development.

INTRODUCTION

As part of the NASA Advanced Composite Technology Program, Lockheed Aeronautical Systems Company (LASC) is under contract to develop low cost, light weight primary aircraft structures. This contract, NAS1-18888, "Advanced Composite Structural Concepts and Material Technologies for Primary Aircraft Structures", consists of two phases.

Phase I has been underway since May 1989 and will be completed in March 1992. This phase consists of five tasks. Task 1, "Design/Manufacturing Concept Assessment", is complete. This task consisted of design trade studies for wing and fuselage structures. The results of these studies were presented at the NASA ACT Conference in Seattle, Washington in November of 1990. Task 2, "Structural Response and Failure Analysis", involved the development of generic structural models and postbuckling analysis. Task 3, Advanced Material Concepts", develops and evaluates polyisoimide and SIPN materials for High Speed Civil Transport applications. Task 4, "Advanced Concepts Assessment Review", involved the preparation and presentation of the plans for Phase II for NASA approval.. Task 5, "Composite Transport Wing Technology Development", involved fabrication and assembly of a transport wing center box. This box was tested by LASC earlier this year and the results are the subject of another paper at this conference.

Phase II, "Development and Verification of Technology", is now underway and will run to early 1995. This phase involves the development of advanced textile preforms, with resin transfer molding (RTM) and powder epoxy technology, to provide low cost, damage tolerant fuselage structures.

This phase consists of four tasks. Task 1, "Advanced Resin Systems for Textile Preforms", evaluates and selects RTM and powder epoxy systems. Task 2, "Preform Development and Processing", develops near- net-shape textile preforms for fuselage applications. Task 3, "Design, Analysis, Fabrication, and Test", covers four structural components: fuselage frames, window belt insert, keel beam/frame intersections, and a skin/stiffened fuselage panel. This task also includes supporting analytical methodology development and validation. Task 4, "Low-Cost Fabrication Development",explores innovative tooling concepts and advanced textile machine requirements.

This paper summarizes Phase I progress, the work underway in Phase II, and the plans to completion.

PHASE I EVALUATION AND INITIAL DEVELOPMENT

This phase is nearing completion. The remaining tasks are Task 2 which covers analytical methods development, and Task 3 which involves the development of advanced polymers for supersonic transport applications in the High Speed Research program.

Task 2 - Structural Response and Failure Analysis

The primary objective of this task is to develop analysis methods and modeling techniques to accurately evaluate the global response of stiffened structures to combined in-plane and out-of-plane loadings.

The finite element solution based approach was taken to address the complex interaction of nonlinearities due to pressurization, postbuckling, and geometric configurations for stiffened structures representative of wing cover panels, fuselage shells, spar webs, bulkheads, and ribs.

To produce an efficient solution and effective computer utilization during non-linear analysis, the Arc Length method due to Riks (1) was implemented in the DIAL finite element code. This method eliminates singularity in the tangent stiffness matrix at the critical point that causes major computational difficulties in a conventional trial and error approach. This method allows the unstable branch of the postbuckling response to be predicted. The implementation of the arc-length solution method has several unique features such as: automatic shifting between load and displacementcontrol to ensure numerical stability and trace out of the full response curve.

To illustrate this capability, for the spherical cap under a point load at the apex, a load/deflection curve is shown in Figure 1. The solution curve has two limit points - a local maximum (A) and a local minimum (B). Using only load control, the cap would dynamically snap to the inverted shape as soon as the point A is reached. The portion of the solution curve between the first limit point and the dynamic snap could not be traced. Using the Arc Length solution method - the solution starts off with the load control, switches automatically to the displacement control as the limit points are approached, and then back to the load control as limit points are passed. Figures 1 and 2 shows the DIAL non-linearsolution capabilities with a test problem consisting of an axisymmetr ic,'shallow spherical cap under a point load at the apex. The DIAL results are compared with published solution by Mescall (2), for pinned-roller support in Figure 1, and by other finite element programs (3,4), for clamped conditions in Figure 2.

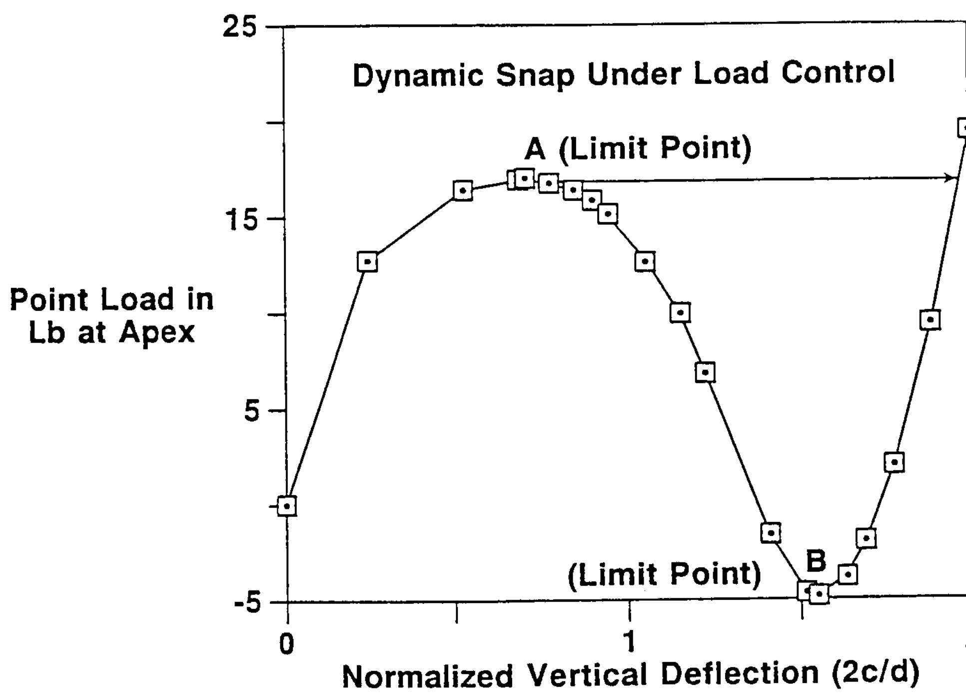


Figure 1. Load Deflection Curve and Limit Point Prediction for Spherical Cap

To develop a relatively simple analysis method for bonded structures, a new material model has been implemented in the DIAL finite element code for use with the 2-D and 3-D interface elements. This material model enables the interface elements to model a thin layer of bonding material with its shear stress-strain relationship to be generally non-linear. The stress field for interface elements consists of a normal stress perpendicular to the plane of the element and interlaminar shear stress(es). The verification of this upgrade was accomplished by comparing the DIAL results for a 3-D lap joint to those obtained by Sharifi and Sable (5). Figure 3 is a plot of the bond peel stresses at the failure load (P) of 4200 lb/in, from both the analyses. It can be seen that the agreement, is very good.

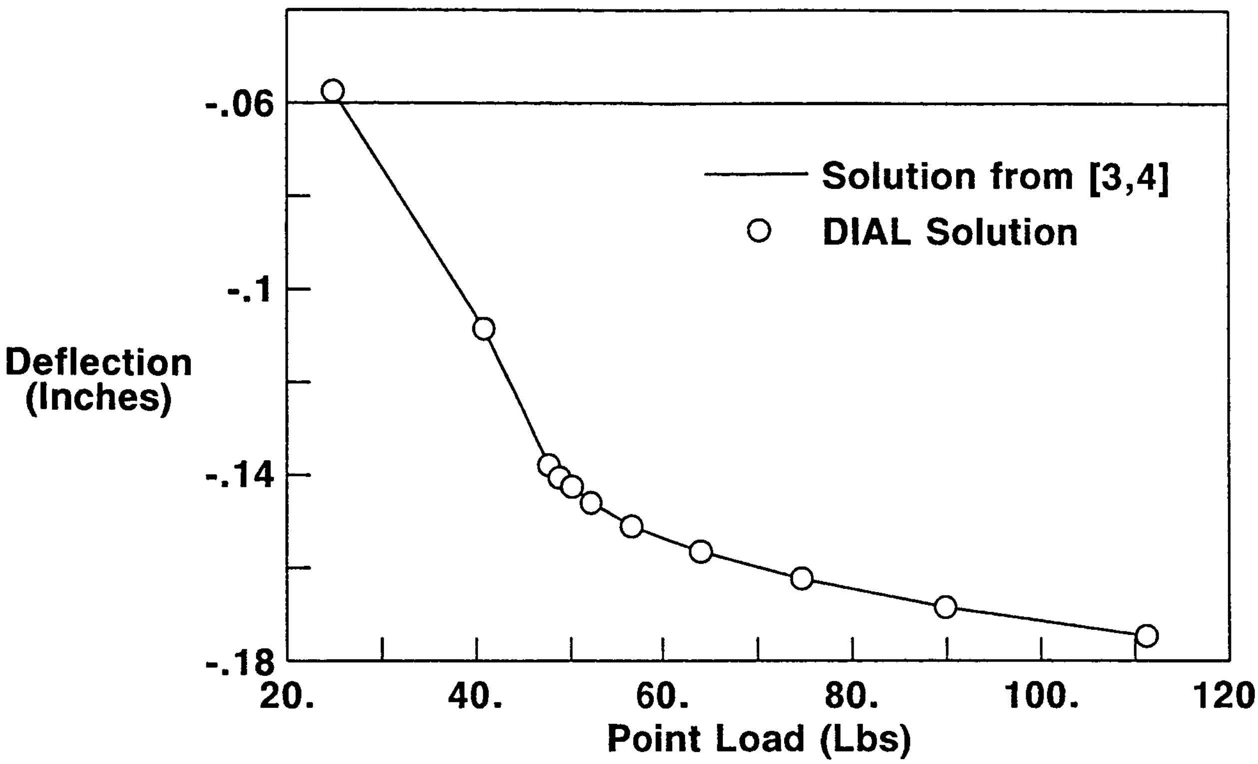


Figure 2. Displacement of Apex vs. Load for Example 2.

The AML (% Angle plies Minus % Longitudinal plies) laminate failure methodology has been implemented in the DIAL code. The AML method is a simplified approach to obtain the design allowable strain which account for fastener holes, barely visible impact damage, and internal defects in a symmetric and balanced laminate. Based on the user supplied AML values for tension and compression, the SCOPE post-processor in the DIAL computes margin of safety using AML failure strain at each integration point, in four fiber directions (0,+/- 45, 90) at the top, middle, and bottom of laminate. The minimum of the twelve margins at each integration point is used to generate a plot. As an illustration, a tubular panel, in Figure 4(a), subjected to a uniform compression loading was analyzed and contour plots of the AML margin of safety for each element of the panel were generated. Figure 4(b) shows one of the contour plot margin of safety of the bottom face sheet.

For streamlining the analyst's work during a concepts analysis/trade study, a series of DIALMATIC programs are developed. These programs combine a series of modules with the finite element code DIAL as its backbone, hence it is called DIALMATIC. Each DIALMATIC program is an interactive design tool that is intended to provide the means of performing a self-initiated preliminary analysis of specific primary composite structures, such as: flat stiffened panel, corrugated flat sandwich panel, curved stiffened fuselage panel, and curved geodesic fuselage panel. The DIALMATIC program requires the user to simply specify basic geometry, material properties,

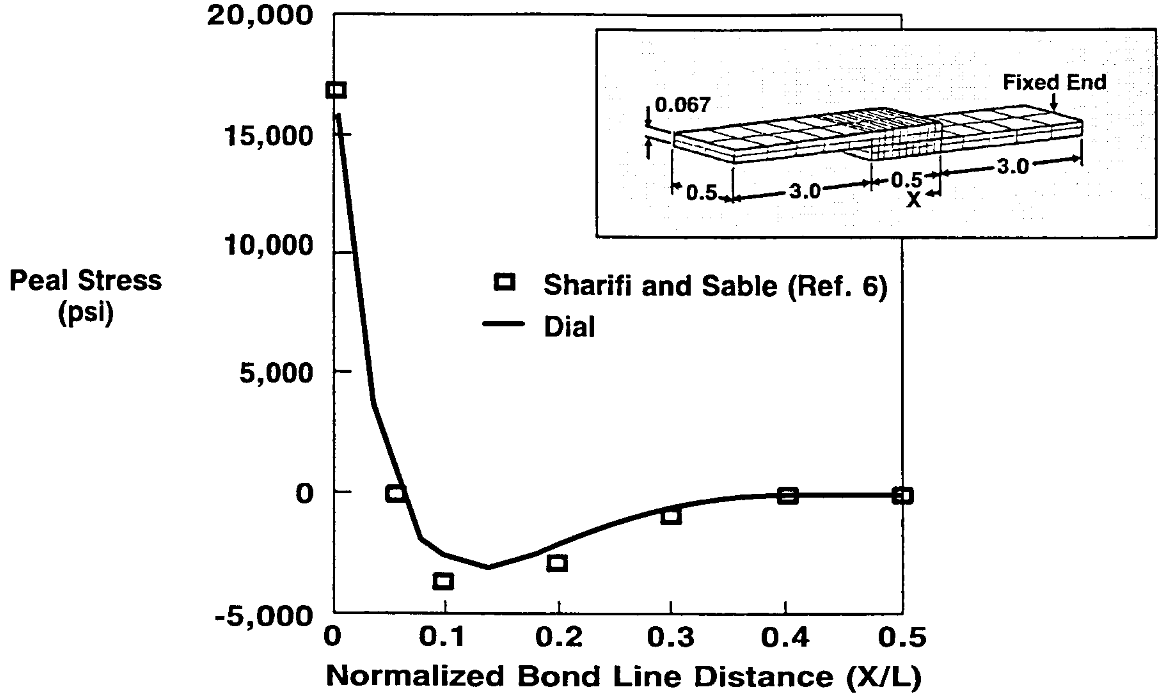


Figure 3. Peel Stresses in Adhesive at Failure

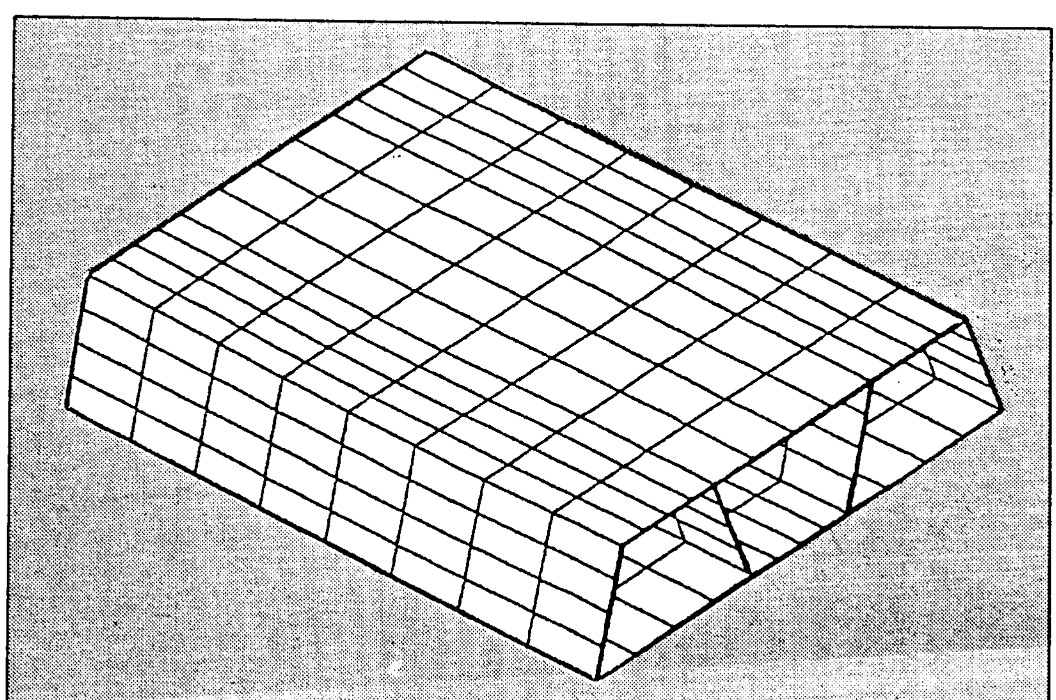


Figure 4(a). Tubular Sandwich Panel Model

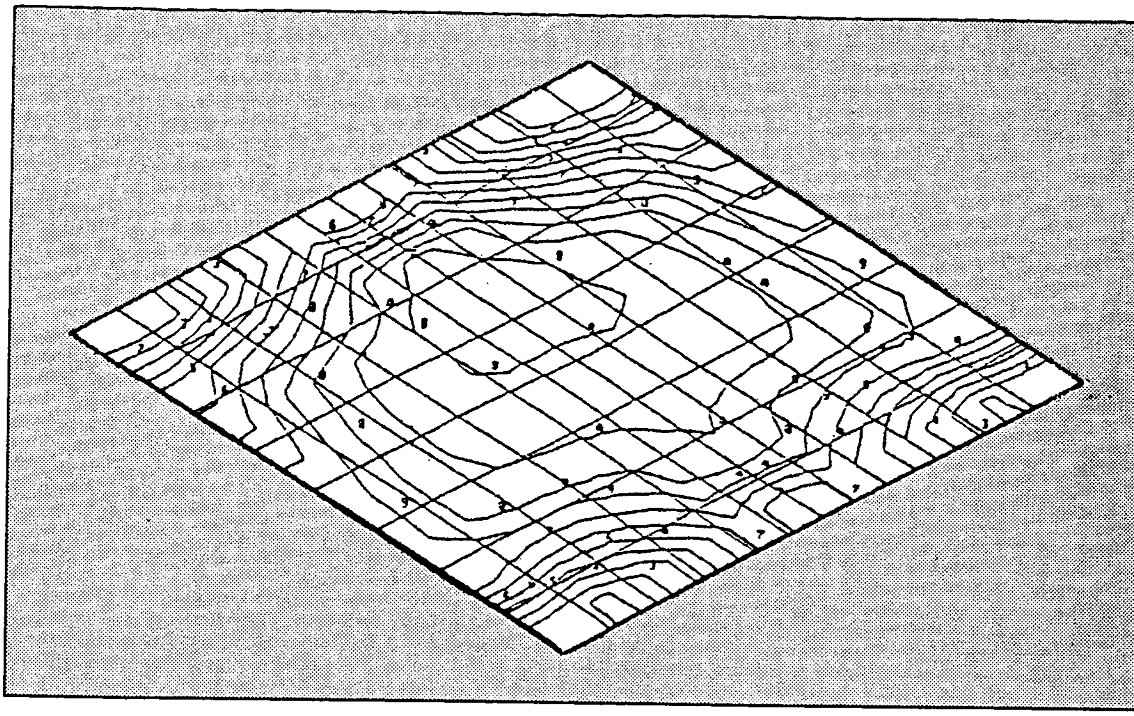


Figure 4(b). Contour Plot of AML Margin-of-Safety - Bottom Face Sheet

loads information, boundary conditions, and types of analysis. The program utilizing this information generates the finite element model automatically and performs the analysis. The output in the form of summary tables of stress or margin of safety, contour plots of loads or stresses or strains and deflected shape plots which may be used to determine the adequacy of the specific design concept. Figure 5 illustrates the mesh generated by the four modules, each with different types of stiffening elements.

The last part of this task concerns the development of bolted composite joint strength prediction methodology. The motivation of this task was in direct response to the need for an accurate strength prediction for multifastener composite joints and to alleviate significant costs associated with obtaining strength data through testing. The methodology developed is a 2-D non-linear finite element based analysis considering material and geometricalnon-linearity. It also conducts an in-situ strength failure analysis and applies material degradation models. To date significant progress has been made in the development of the analysis code. The developed code is interactive and has the capacity to analyze matrix tension and compression failure, shear- out failure, and fiber failure. Work is in progress to include a bearing failure model. Validation of the code (called TEXTJOINT-X) developed to date is in progress and the predicted versus test results for a T300/1034 doubler shear joint with 100 percent load transfer.

Task 3, Materials Development

The objective of this task is to establish the feasibility of bridging the current polymer composites technology with future technologies for supersonic transport systems.

Current research is concerned with the high-performance attributes of polymer materials, which include: high level of thermal and thermo-oxidative stability, high level of fracture toughness, high modulus and strength, especially in compression and environmental durability.

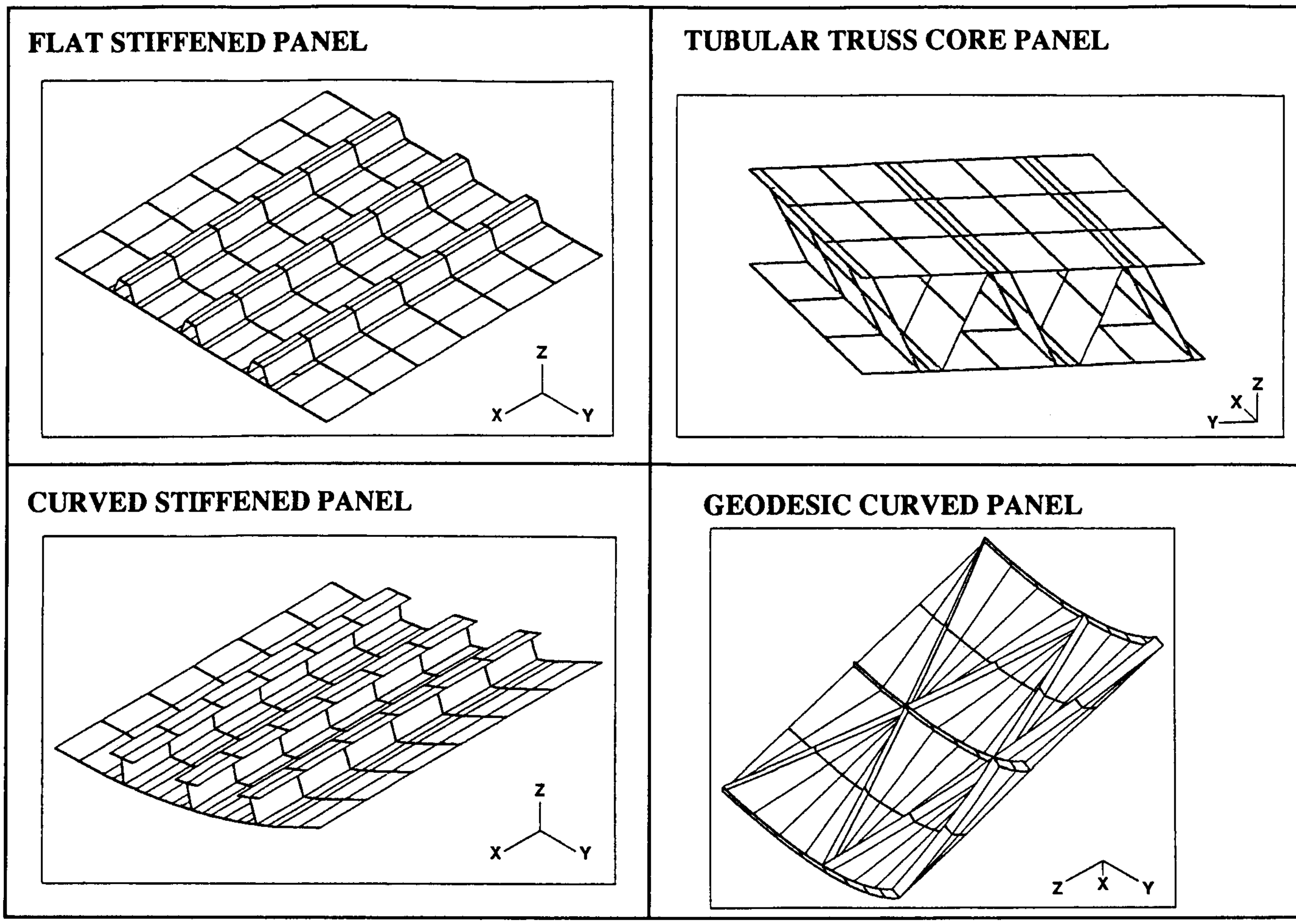


Figure 5. Mesh Generated for Four Typical Modules

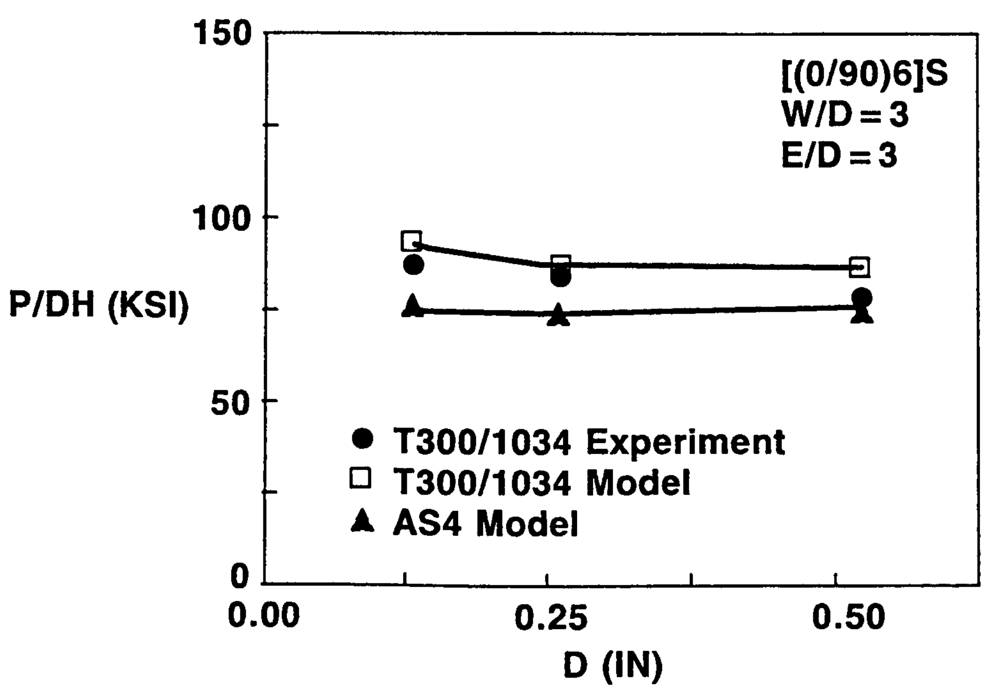


Figure 6. Comparison of Failure Load of Bolted Joints

The emphasis is on an interdisciplinary study, involving chemistry, mechanics, and processing of imide based copolymers which are amenable to chemical modification through the isoimide technique for processibility enhancement. Property tailoring is examined through polymer blending and copolymer techniques. Various polymer blends can be designed for different operating temperature ranges.

Isoimide modification of polymides generally improves melt and solution processibility of imide containing thermoplastics, such as polymides, poly(imide-sulfones), poly(ether-mides), poly(ether-ketone-imides, and imide-hetrocycle hybrids. The isoimide form permits easier processing. The isomide then converts to the imide during cure without the generation of volatiles. The chemical transformation from monomers to polyamic acid, which in turn forms the isoimide and imide, is well defined chemistry and providesreproducible synthesis and thus easy quality control.

Polymides are ideal candidates due to there overall high performance. The key issues, however, are processibility and cost-effectiveness. The supply of monomers allows permutations of these monomers to generate new polymers and copolymers. Using these available monomers, NASA developed such thermoplastic polymides as LARC-TPI, LARC-ITPI, LARC-CPI, and LARC-PIS. The constructive monomers of a variety of high performance polyimides are commercially available to synthesize these polymars.

Other high-temperature resistant polyimide systems include Ube's Upilex polyimides andoxybis (3,4-dicarvoxyphenyl) dianhydride based polyimides. The semicrystalline nature of LARC-CPI and Upilex permits molecular orientation to achieve modulus enhancement.

Table 1 summarizes the rankings of the various polyisoimides studied. LARC-ITPI is the most attractive material system for near-term applications. A strong second choice is the copolymers of poly(TDA-APB)isoimide and poly(BTDA-3,4'-ODA)isoimide.

The three systems currently being prepregged and tested are LARC- ITPI isoimide, Copolyisoimide 0-11, and Copolyisoimide 0-13.

Table 1, Ranking of Polyimide candidates

Final Ranking	Trivial Name	Polymer Constituent		Criteria		
		Dianhydride	Diamine	Cost Comp	Ease of Synth	Good Prelim Results
1	LARC-ITPI Polyisoimide	IPDA	MPDA	1	1	Yes
4	Polyisoimide O-10	BTDA	3,4'-ODA	2	2	Yes
2	Copolyisoimide O-13	BTDA	APB(3) 3,4'-ODA(1)	2	1	Yes
2	Copolyisoimide O-11	BTDA	APB(1) 3,4'-ODA(1)	2	1	Yes
5	Polyisoimide B-10	BTDA	BAPP	1	2	need more evaluation
6	OPDA-based Polyisoimides	OPDA	Various Diamines	2	-	need evaluation

PHASE 11 DEVELOPMENT AND VERIFICATION OF TECHNOLOGY

This phase has been entirely rescoped as a result of the ACT Steering Committee recommendations late last year. The objectives of this phase are: to develop and exploit textile preform technology, resin transfer molding and powder resin technology, to produce low-cost components for fuselage structures. Lockheed is working closely with Boeing and will produce the textile preform components to be incorporated into the large Boeing test panels. To this end Lockheed is participating in the Boeing Design Build Teams for the keel and window belt structures on the Boeing 767X baseline airplane.

This phase is just getting underway, Initial evaluation of the resins and textile technologies is proceeding. A resin transfer molding machine is being ordered. Lockheed personnel have been participating in the Design Build Team for keel structure.

This phase is scheduled to cover 42 months and will provide parts in a building block approach for testing up to the final curved fuselage panels, 85 inches long by 60 inches wide.

Task 1, Advanced Resin Systems for Textile Preforms

The epoxy resin systems currently used for resin transfer molding (RTM) fall short in their performance for aircraft primary structures. In particular their damage tolerance characteristics and environmental resistance are inadequate. These deficienciescan be offset by exploiting 3-D textile woven and braided preforms. New toughened resin systems offer an opportunity to significantly improve these properties when combined with the textile preforms. The use of near net preforms and non-autoclave processes offers a substantial cost reduction potential for aircraft primary structures.

An alternative approach is to fabricate the preforms from a powder coated tow which can be processed by pultrusion, compression molding, autoclave molding, and if additional resin is needed then by RTM.

The resin selection criteria for RTM and for powder resins are different. Figure 7 shows the flow of resin evaluation. The emerging toughened resin systems are currently being evaluated by NASA and the Aerospace Industry for potential applications in aircraft primary structures. Much of these data will be available to aid in resin selection for this program.

Resin selection criteria for RTM

- Low viscosity (300 500 cps)
- Long pot life (6-8 hours)
- Processibility
- Environmental resistance (180*F wet)
- Toughness for damage tolerance
- Cost and performance

The following systems have been selected for initial screening:

- PR-500 (3M)
- RSL-1895 (Shell Chemical)
- E-905L (BP Chemical)
- CET-3 (Dow)

Screening will be accomplished by fabricating 8-harness satin fabric laminates by RTM with each of the resins. Each laminatewill be cut up and tested according to the test matrix shown inTable 2. The ease of processing static and dynamic test performance and cost will be the primary factors for selection. The selected system will be used in Task 2 to evaluate the textile preforms.

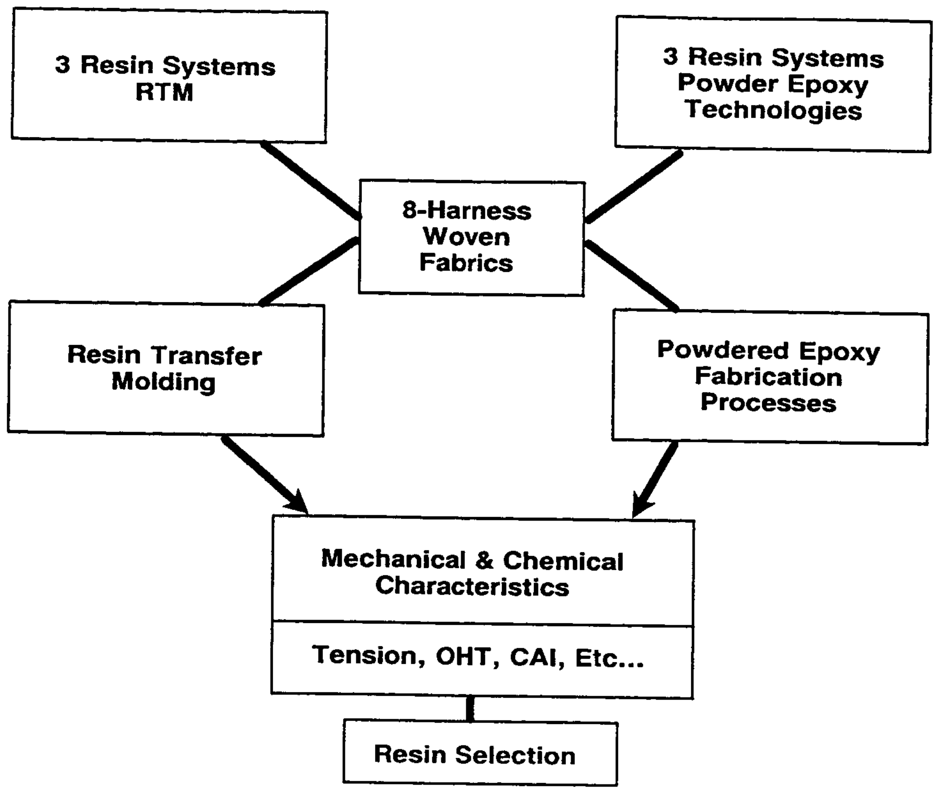


Figure 7. Task 1 Evaluation Approach

Table 2. Material Screening Test Matrix

Laminate Orientation	Test Type/Loading	Specimen Size	No. of Specimens @ t °F				Test Method
			t (in)	-65°F	RTA	180°F Wet	
0°	UNT	1.0 x 12.00	0.045	3	3		ASTM D-3039
0°	UNC	1.0 x 5.50	0.12		3	3	
±45°	UNT	1.0 x 10.00	0.08		3		ASTM D-3518
QI	UNT	1.25 x 12.00 DB	0.12		3		ASTM D-3039
QI	OHT	1.25 x 12.00	0.12	3	3		ASTM D-3039
QI	UNC	1.25 x 12.00 DB	0.12		3		Modified A-11
QI	OHC	1.25 x 12.00	0.12		3	3	Modified A-11
QI	CAI	4 x 6 (Boeing)	0.16		4		Boeing

Powder technology offers major potential benefits for the fabrication of near net shape composite structures at reduced cost. Labor intensive hand layup is eliminated, improved fiber/resin interface will allow tight weaving and braiding to be maintained.

The powder towpreg can be converted into preforms by 3-D weaving, braiding, knitting, and stitching processes. These preforms can be processed into parts by compression molding, pultrusion, and autoclave molding.

Two types of powder coating processes will be evaluated for low cost towpreg. The first is a solution coating with a water base slurry and the second is an electrostatic coating process. Selection will be based on the adhesion of the resin to the fibers, coated tow flexibility and weavability and braidability of the coated tows.

Powder resin selection criteria:

- o Shelf-life at room temperature
- o Particle size
- o Environmental resistance
- o Toughness for damage tolerance
- o Viscosity
- o Glass transition temperature
- o Cost and performance

The shelf life of the resins at room temperature is of prime importance not only in the powder form but more importantly when coated on the fibers and tows, because the towpreg will go through various room temperature processes in the weaving, braiding, and knitting before processing into its final form. Thermal and chemical stability will be acceptance criteria.

Particle size is also a critical element in achieving good coating. For example, the slurry bath requires particle sizes ranging from 30 to 100 microns and for electrostatic coating 100 to 200 microns. A low glass transition temperature (60 C) and low moisture absorption is needed for the slurry process. Low moisture absorption is also required for the electrostatic process along with large particle size for uniform high cloud formation. The degree of fusion and fibre/resin interface is also extremely important for subsequent textile operations and part fabrication. The handlability and flexibility of the powder towpreg will be dependent on the degree of fusion and will require tailoring to meet specific textile processing criteria.

The following resins were selected for initial screening:

- o PR-500 (3M)
- o RSS-1892 (Shell Chemical)
- o CET-3 (Dow Chemical)

These resin systems meet the basic criteria for powder coating processes. Flat laminated will be made from 8-harness satin fabric woven from powder towpregs. The screening test matrix is shown in Table 2. Processibility in powder coating and textile operations, performance and cost will be the determining factors in selection of one resin system for Task 2.

Task 2, Preforms Development and Processing

The objective of this task is to evaluate advanced textile preform technologies which provide improved damage tolerance and lower overall cost of advanced composite structures by reducing part count and assembly operations. Recent advances in textile processing have heightened interest in low cost fabrication methods such as RTM, pultrusion, resin film infusion (RFI), and compression molding for near net shaped structures. The following textile processes will be evaluated in this task:

- o 3-D interlock weaving/stitching

- o 3-D weaving
- o 2-D braiding
- o 3-D interlock braiding
- o 3-D through the thickness braiding
- o 3-D multi-axial warp knitting/stitching
- o 3-D Near Net Fiber Placement (N^2FP), stitching

Flat laminates will be produced from dry tow and from powdered tow with the above processes and used for screening. The size and process limitations will be determined for subsequent use in task 3 for the fabrication of fuselage subcomponents. These laminates will be fabricated by RTM, compression molding, or autoclave molding and will be tested as shown in Table 2. The evaluation criteria and process are shown in Figure 8.

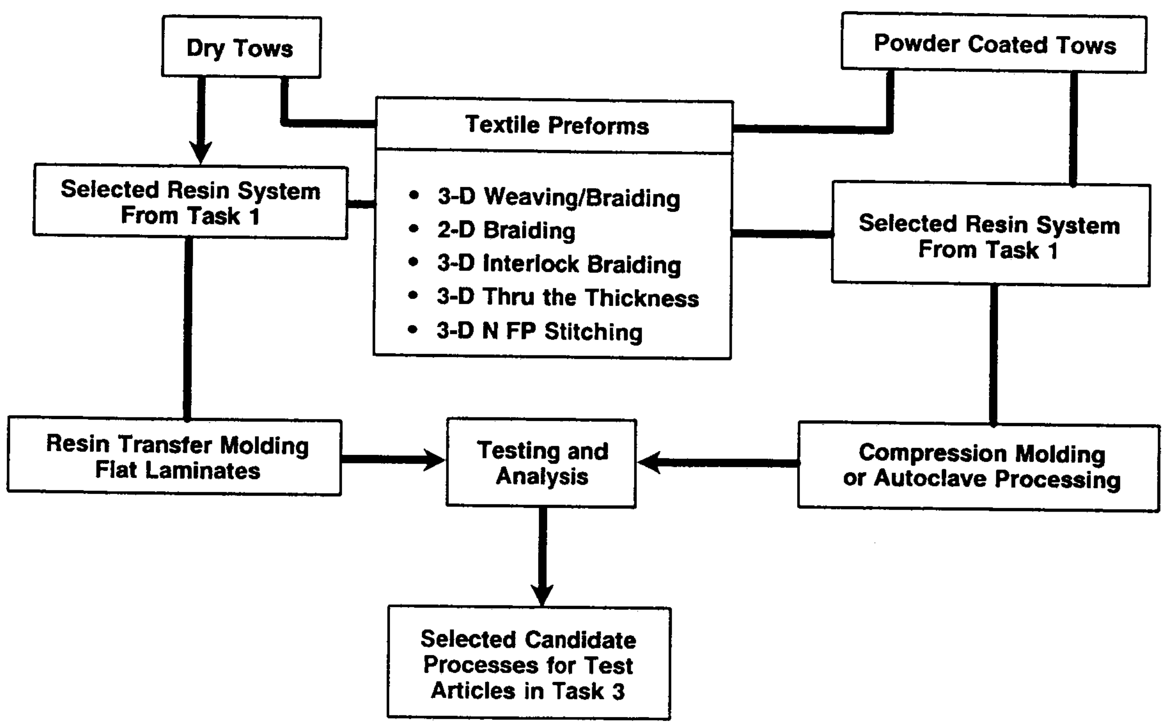


Figure 8. Task 2 - Evaluation Approach

Current Status of Textile Processes

Figure 9 shows textile processes being evaluated and typical yarn paths. The current status and limitations of these processes are briefly reviewed.

(1) 3-D Weaving

3-D interlock weaving has been used to produce cruciforms, nose cones, and other aerospace components. However, it can only produce 0°/90° multi-layer fabric. It is therefore limited in its use for aircraft structures since biased (45°/135°) plies cannot be woven. Efforts are underway in the textile industry to overcome this deficiency. The 3-D weaving of quasi-isotropic, multi-layer fabric has been attempted by a manual process. In this task we will screen 3-D interlock woven/biased ply stitched materials.

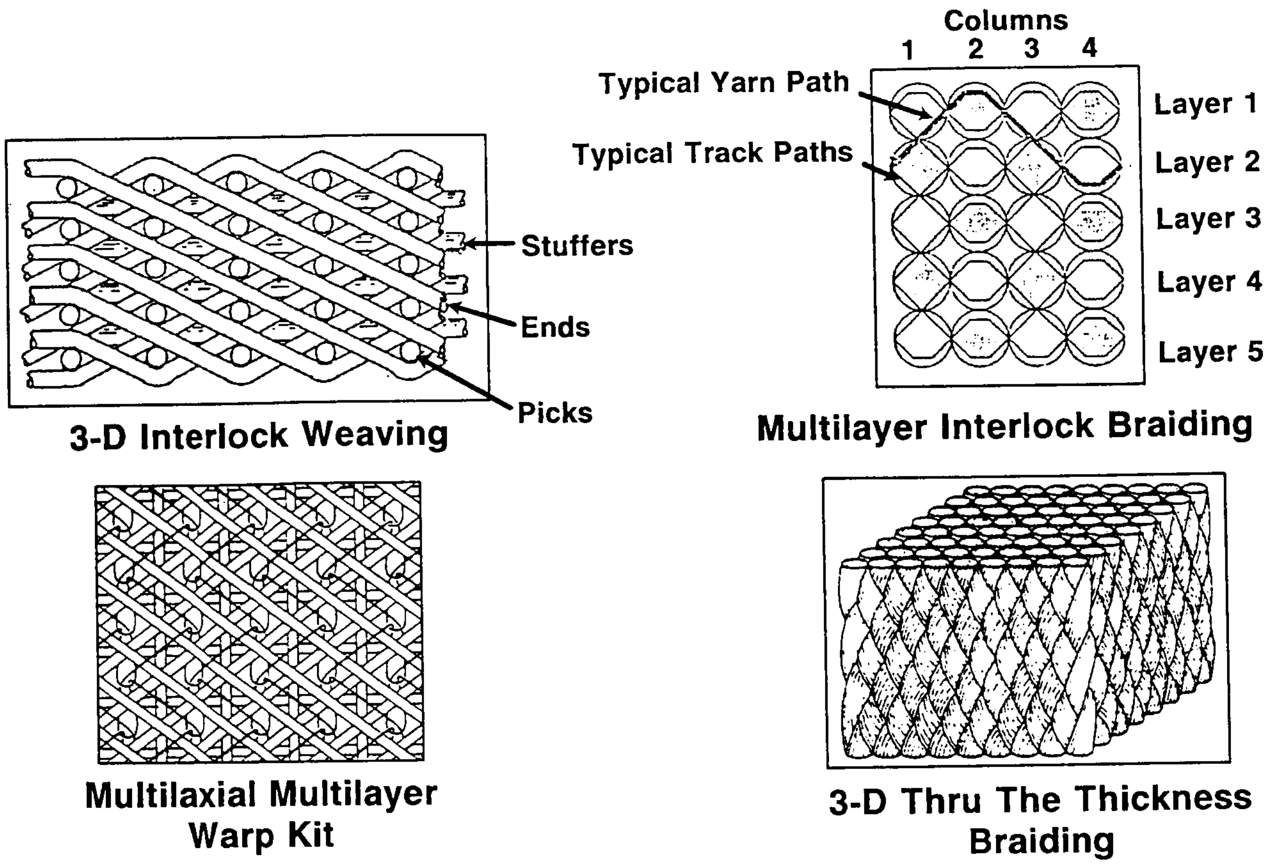


Figure 9. Textile Architectures

(2) 3-D Braiding

2-D braiding/stitched preforms such as frames and stiffeners have been explored for aircraft structures. Size limitations, yarn coverage and manual operations limit this process to narrow parts. Advances in 3-D through-the-thickness braiding offer potential benefits in producing stiffened panels and other complex shapes. 3-D interlocking flat braiding has potential applications in near net size components such as 'J' frames, hats, and floor beams.

(3) Multi-axial Warp Knitting/Stitching

Quasi-isotropic 4 to 7 multi-layer fabrics can produced by this process. Stiffened panels and window frames can be produced.

(4) N^2FP Stitching

Preforms using this process can be made in any orientation, but may have some limits in thickness. The yarn path can be programmed for various shapes. Potential candidates include window frames and window belts.

The textile preform screening conducted in this task will aid in the selection of the textile processes to selected for the Task 3 elements and subcomponents.

Task 3. Design, Analysis, Fabrication and Test

The baseline article selected for Lockheed's Phase II studies is an aft fuselage segment of the Boeing 767X commercial passenger airplane shown in Figure 10. This segment, which is also the Boeing ACT baseline article represents the latest in design and manufacturing technology for aluminum airplanes, thus providing an excellent baseline with which to compare the advanced composite structural concepts being developed under this program. The selection of a common baseline for the Boeing and the various textile processes being pursued by Lockheed and (2) components incorporating textile p[reforms can be supplied to Boeing for incorporation in larger test articles (see Figure 11).

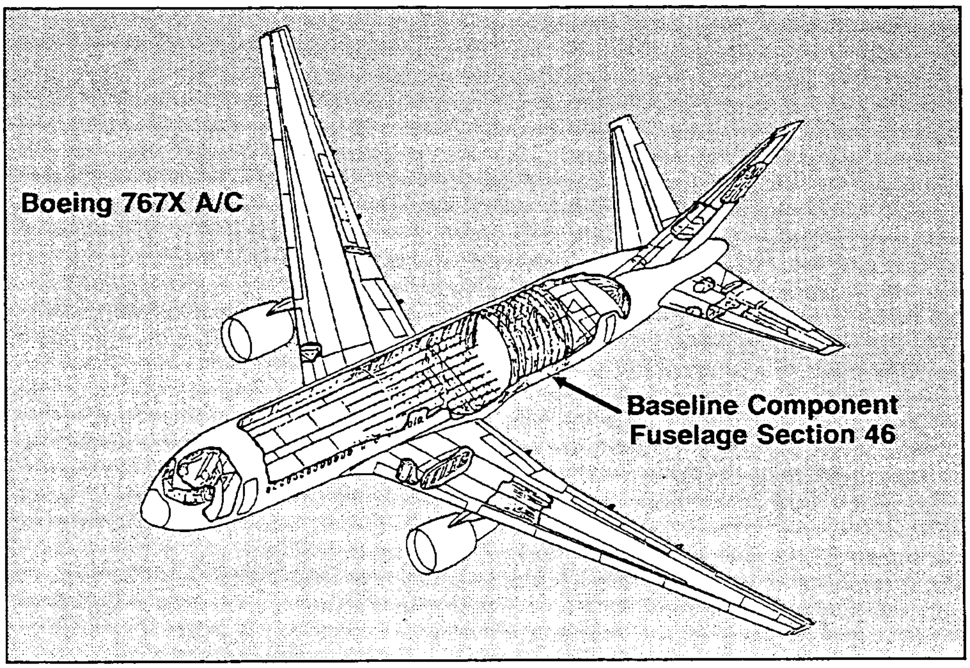


Figure 10. Baseline Airplane and Segment

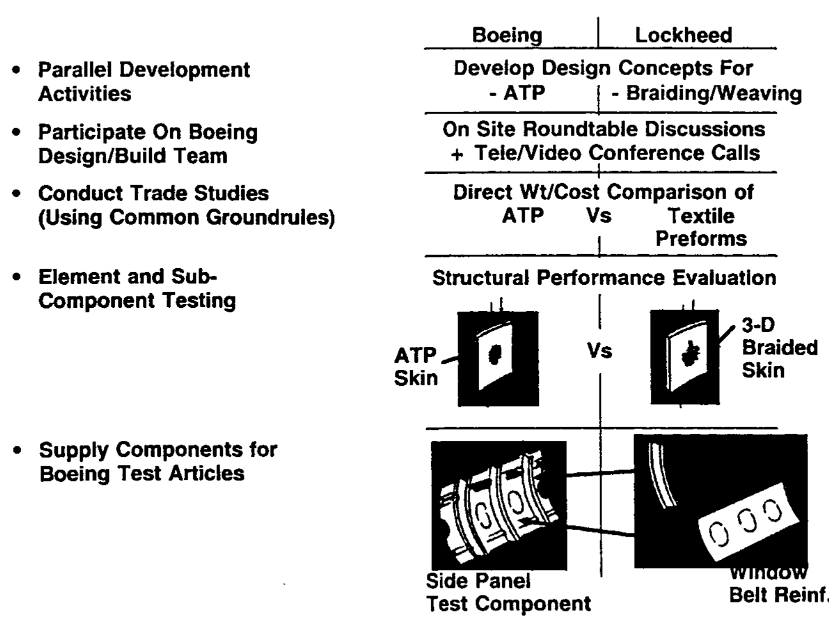


Figure 11. The Boeing Connection

The total scope of Lockheed's Task 3 activities is shown in Figure 12. It covers the design, analysis, fabrication, and test of four structural components: circumferential frames, window belt reinforcement, cargo floor support structure, and stiffened skin fuselage panel (The NASA Technology Benchmark Test Article). For each of these test components, innovative design concepts amenable to automated textile fabrication processes will be developed and evaluated with respect to structural efficiency and low cost. Those concepts judged to have a high potential for achieving the program objectives will be further evaluated through element and subcomponent testing (see Figure 13).

Design, Analysis, Fabrication and Test of:

- **Circumferential Frames**
- **Window Belt Reinforcement**
- **Cargo Floor Support Structure**
- **Stiffened Skin Fuselage Panel (NASA Technology Benchmark Test Article)**

Figure 12. Task 3, Scope

For Each Component

- **Establish Baseline Requirements (767X Drawings, Loads, Environment, Interfaces, etc.)**
- **Evaluate Alternative Material Systems and Textile Processes**
- **Evaluate Fabrication Methods and Tooling Concepts**
- **Develop Innovative Design Concepts Incorporating Textile Preforms**
- **Conduct Trade Studies**
- **Select Concepts for Further Development**
- **Conduct Element, Subcomponent and Panel Tests**

Figure 13. Development Approach

Circumferential Frames

A wide variety of design/manufacturing approaches will be evaluated for fuselage circumstantial frames. Figure 14 shows the major options being considered. They range from discrete detail parts to design concepts which are totally integrated with the skin. Here the potential benefits of one-piece components (where part and fastener counts are minimized) will be weighed against process and tooling complexity. To support the Boeing test program, only discrete frame concepts which can be used in conjunction with ATP skins will be considered. Two advanced textile fabrication processes currently being evaluated for these components are shown in Figure 15. Both of these concepts employ 3-D tri-axial braiding. Various fabrication methods including RTM and pultruding powder prepreg will be investigated. Proposed element and subcomponent testing for these design concepts are shown in Figure 16.

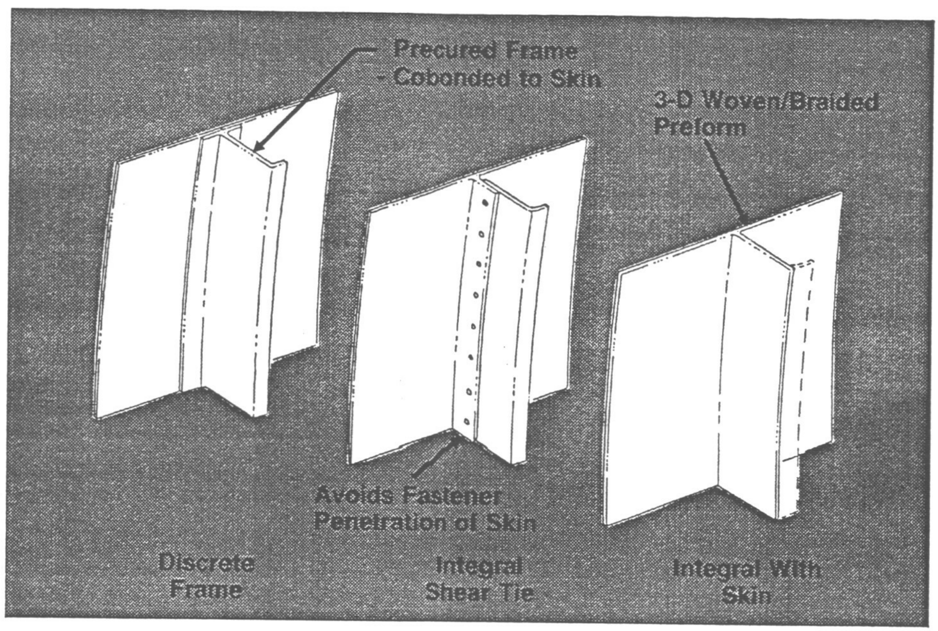


Figure 14. Frame Design Options

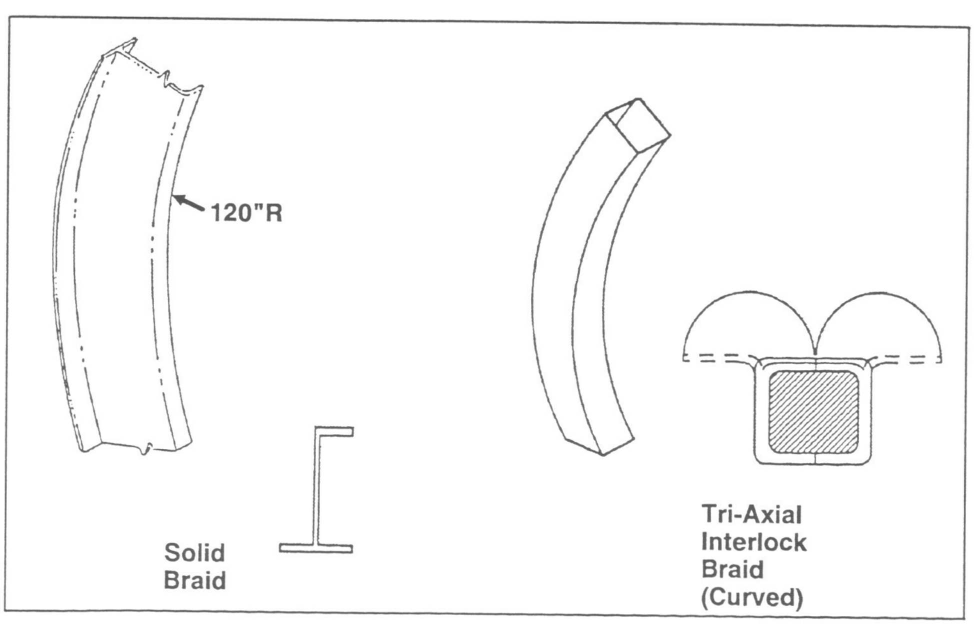


Figure 15. Fuselage Frame Concepts

Window Belt Reinforcement

The use of textile preforms is being evaluated as an efficient method of reinforcing the window belt cutout area in composite fuselage side panels. In metallic fuselages the window belt is generally reinforced by significantly increasing the skin thickness and mechanically attaching window frames. This approach is inefficient for conventionally laid up composite structures due to the discontinuity of fibers and the inerlamina stresses induced in a weak direction. The use of textiles offers an opportunity to provide continuous fibers around the cutout and through-the-thickness reinforcement, thereby providing a much more efficient structure. One such design concept currently being considered is shown in Figure 17.

this concept uses 3-D braided techniques to provide a continuous band of reinforcement as well as for individual window frames. By using powder prepreg material in the braiding process these components may be cured together with an ATP skin in a single molding operation.

Two other promising concepts being evaluated are shown in Figures 18 & 19. In the first a textile process called Near Net Fiber Placement (NFP), which allows fibers to be placed in any prescribed orientations is being considered. In the second a 3-D braiding technique is used to form the window frame from a basic belt preform. Details of a comprehensive test plan to investigate these concepts is shown in Figure 20.

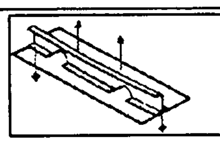
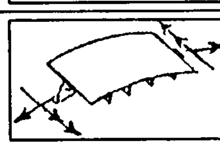
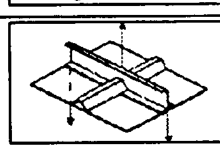
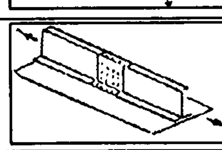
Test	Test Configuration	Specimen Configurations (Replicates)	Total Number Of Tests Planned	Conditions
Frame Bending		2 (2)	4	4 Point Bending RTD
Combined Bending And Hoop Tension		2 (1)	2	RTD
Frame/ Stringer Attachment		2 (1)	2	Cyclic Loads RTD
Frame Splice		2 (1)	2 1	RTD Cyclic Loads

Figure 16. Fuselage Frames, Test Plan

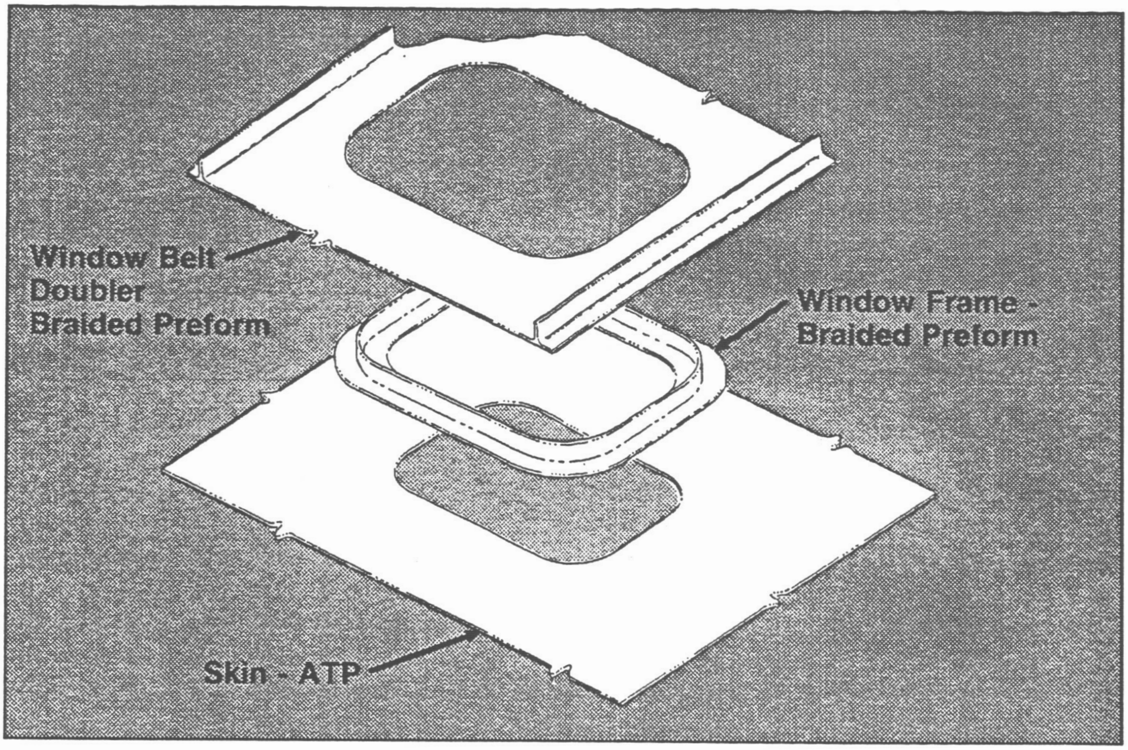


Figure 17. Window Belt Reinforcement Concept

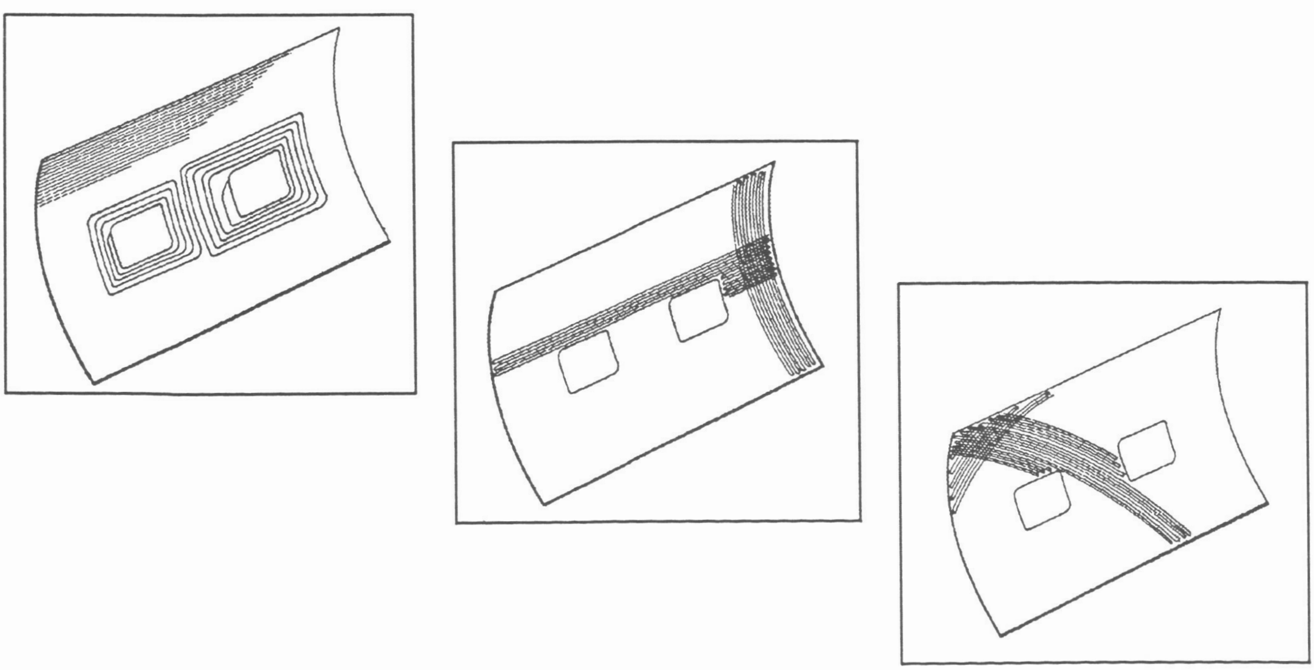


Figure 18. Window Belt Concept Using Near Net Fiber Placement

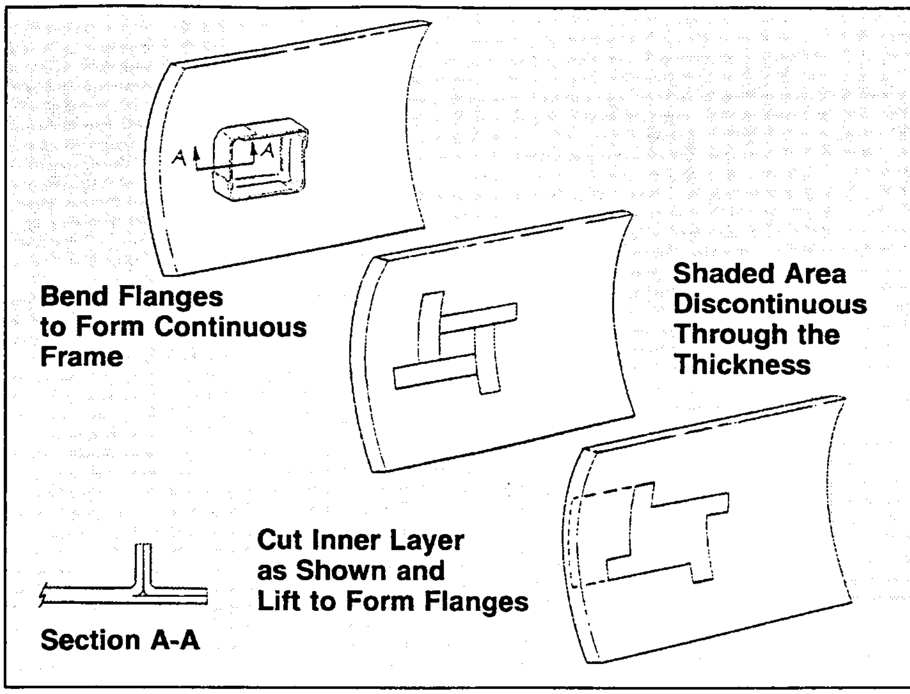


Figure 19. Window Belt Concept Using 3-D Braiding Technique

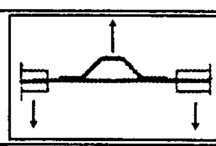
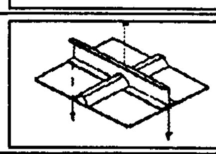
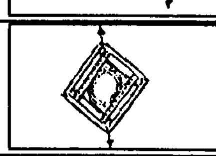
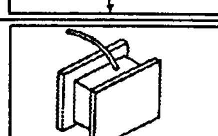
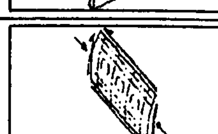
Test	Test Configuration	Specimen Configurations (Replicates)	Total Number Of Tests Planned	Conditions
Stringer Pull-off		3 (2)	6	RTD (4) ETW (2)
Frame Pull-off		2 (2)	4	RTD
Picture Frame Shear		3 (2)	6	RTD
Pressure Integrity		2 (2)	4	Impact Damage
Combined Compression And Shear		2 (2)	2	Impact Damage

Figure 20. Window Belt, Test Plan

Cargo Floor Support Structure

The configuration of the various components constituting the cargo floor support structure offers several possible applications for textile preforms as shown in Figure 21. Some frames are of a stiffened web design while other less highly loaded frames have a beam and post configuration. The stiffened web frame design shown in Figure 22 uses 3-D woven and braided details to produce a structurally efficient cocured assembly. A major benefit realized through the use of braided cruciform members is that fiber continuity is maintained in both the web and the intercostal direction. A rather more ambitious concept is shown in Figure 23. In this concept stiffeners, cap and web are produced from a single textile preform. Several concepts for post type frame applications are shown in Figure 24. A wide variety of fabrication techniques has been proposed for these concepts. They will be fully evaluated in the trade studies and through subcomponent testing as outlined in Figure 25.

Technology Benchmark Test Component

This component was introduced into the ACT programs to provide a direct comparison of cost and structural efficiency for a variety of fabrication processes. The Lockheed test article will highlight the latest textile processes. This large component shown in Figure 26 is approximately 85 inches by 60 inches and includes 3 frames and 4 different stiffener segments. A major goal of this subtask is to provide a one-piece co-cured assembly which does not rely on stitching to provide the out-of-plane performance. Two such concepts are shown in Figures 27 and 28. These designs together with other promising concepts will be fully evaluated through cost/weight trade studies and the test plan shown in Figure 29.

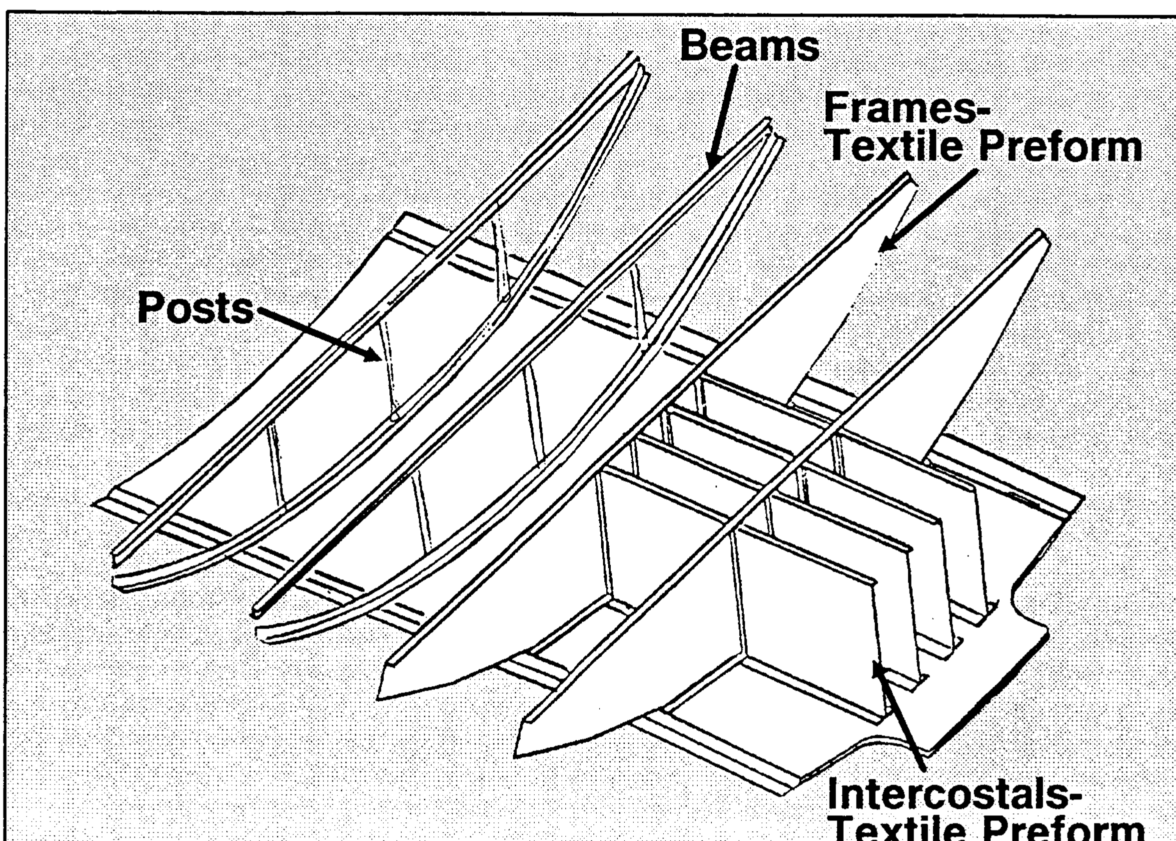


Figure 21. Keel structural configuration

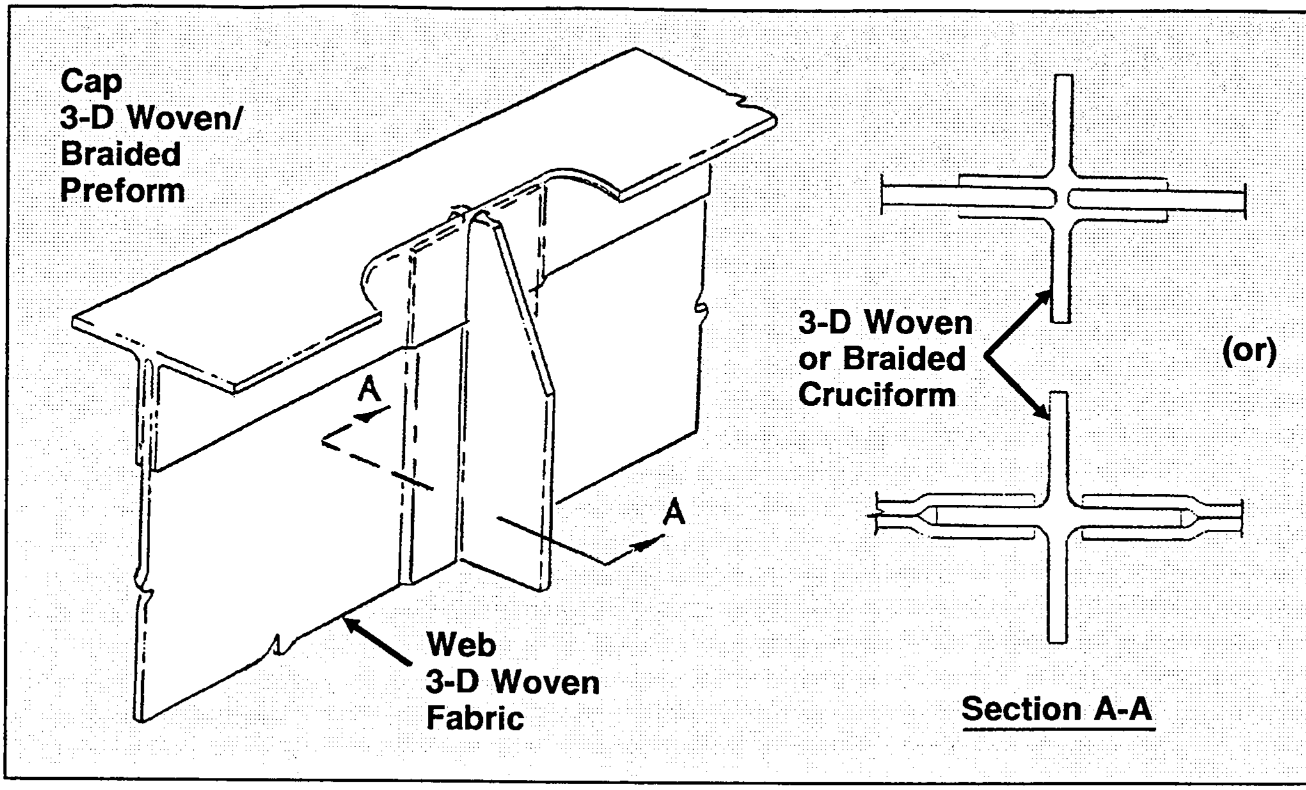


Figure 22. Configuration for Underfloor Frame Built with Woven and Braided Preforms

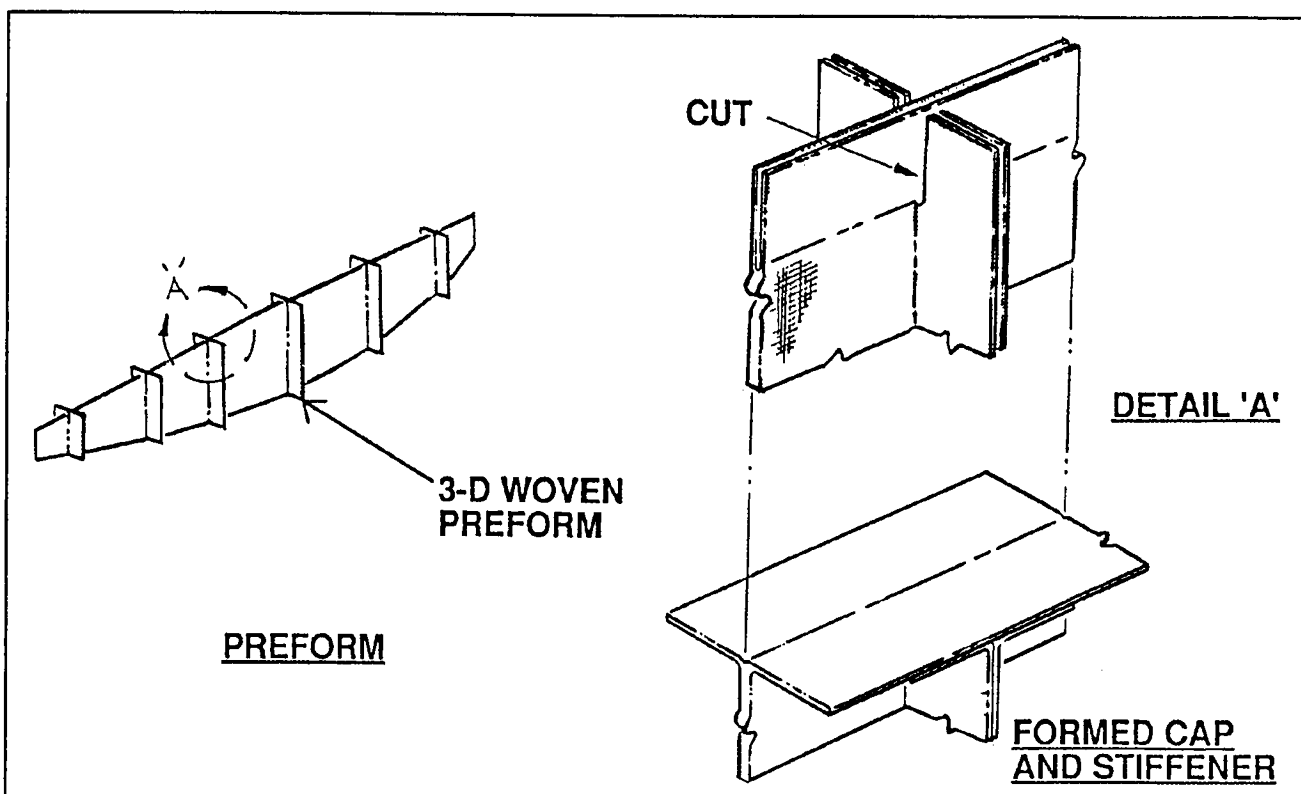


Figure 23. Configuration for Underfloor Frame Using Single Textile Preform

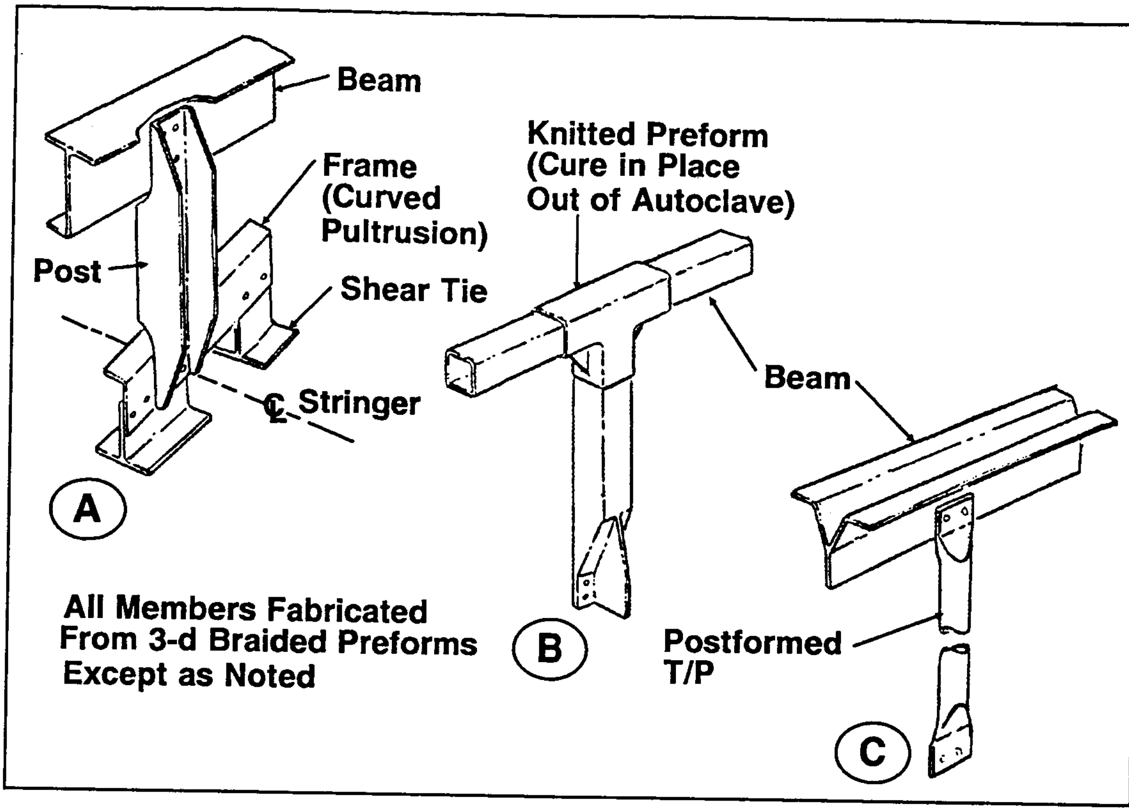


Figure 24. Concepts for Post/Beam Underfloor Frames

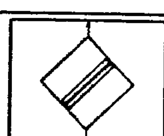
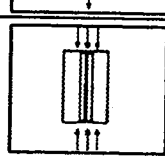
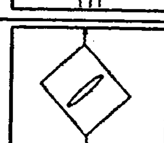
Test	Test Configuration	Specimen Configurations (Replicates)	Total Number Of Tests Planned	Conditions
Frame Shear Panel		2 (2)	4	RTD
Frame Crippling Panel/Stiff		2 (2)	4	RTD
Intercostal Shear Panel		2 (2)	4	RTD

Figure 25. Keel Test Plan

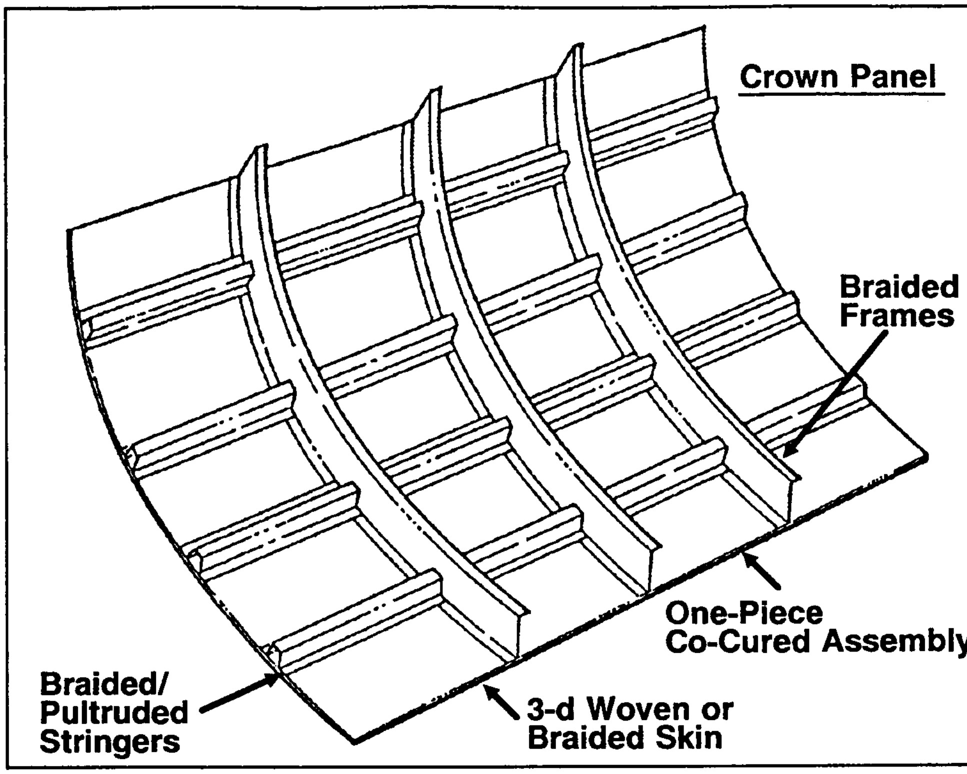


Figure 26. Technology Benchmark Test Component

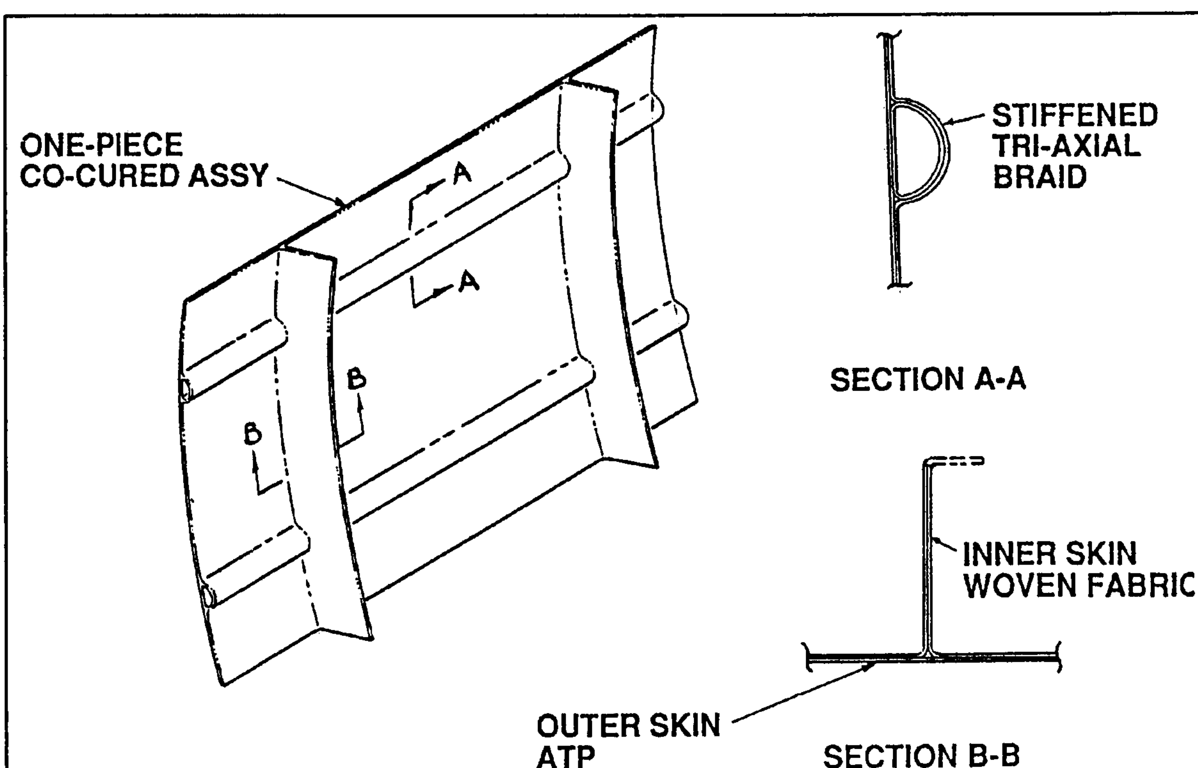


Figure 27. Fuselage Side Panel Concept

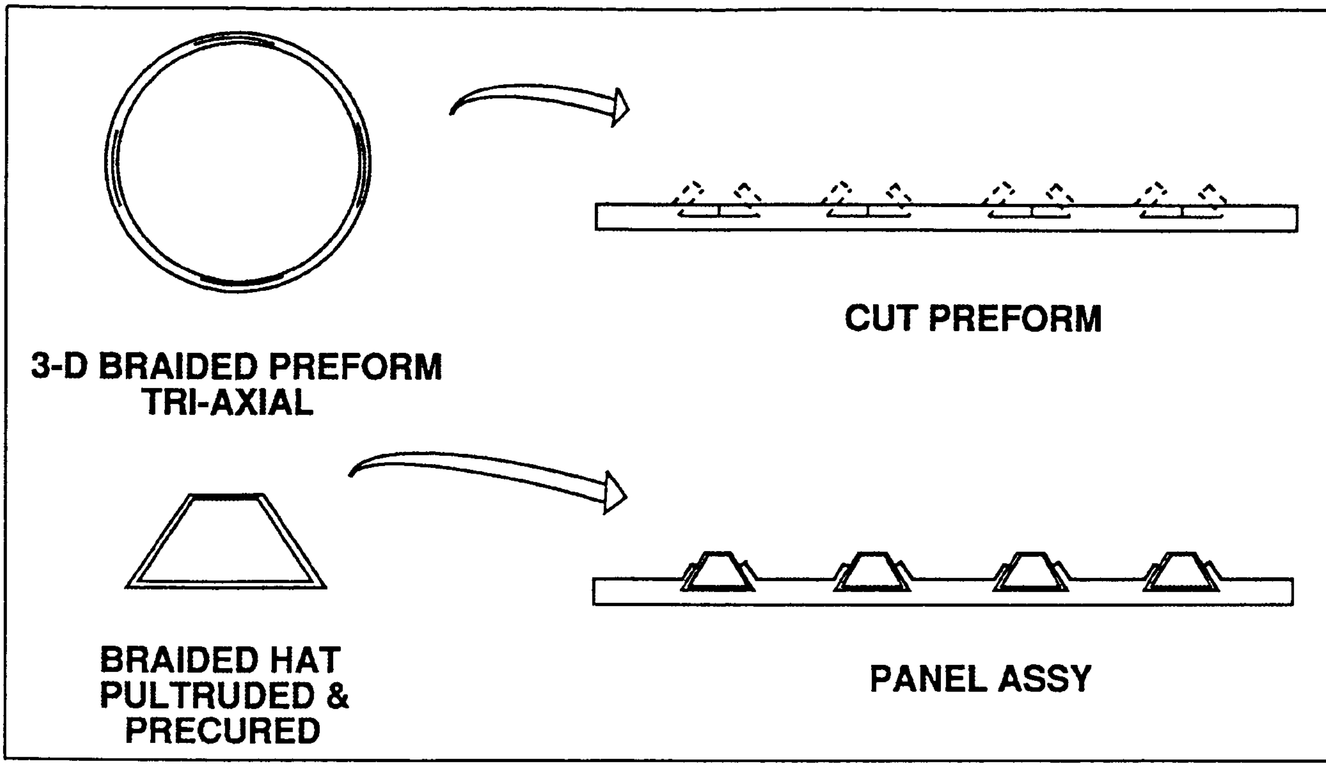


Figure 28. Braided Stiffed Skin Concept

Task 3.5 Supporting Design Analysis Methodology

In support of the design development of the four structural components, in the task three of NASA/LASC - ACT program, analytical techniques/methods applicable to textile reinforced composites are planned to be developed and validated through component tests. Also included in this task is the element testing for obtaining design-to mechanical properties of the potential textile architectures.

Use of the textile reinforced composites in primary structure applications have potential for reducing costs and increasing damage tolerance. Unlike in a conventional laminated composite where fiber distribution is highly uniform, the textile reinforced composite is highly nonuniform, as it is effected by the size of the individual yarn and "Unit Cells". Such nonuniformity in textile composites presents a problem in the measurement and analysis of stresses at the "local" scale for the prediction of damage evolution, requiring development of mechanics methods to predict: the thermo-mechanical properties, the out-of-plane strength, durability, impact damage resistance and tolerance, damage repair method, and mechanically fastened joint strength.

As illustrated in Figure 30, the textile composites "performance prediction" will be a systematic and integrated approach encompassing preform microstructure design, preform processing science, composite fabrication, and performance characterization. The aim of the effort is to establish the "performance maps" of the textile composites through development of analytical models, theoretical predictions, and experimental verification. This effort will include 2D & 3D braids, angle inter-lock weaving, and stitching. The maximum use of the test data generated under Task 2, Preform Development, will be made in the characterization.

The following fundamental behaviors of the textile composites will be modeled: 1) Non-linear Stress-Strain - behaviors under uniaxial tension and compression, off-axis tension and compression, and shear. 2) Residual Strength - analytical methodology will be developed to quantify the residual strength of textile composites as a function of damage size and damage mode. The interaction of tension and compression induced defects is also

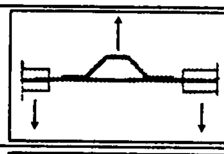
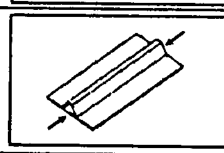
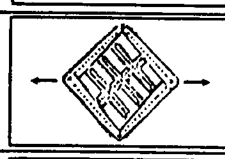
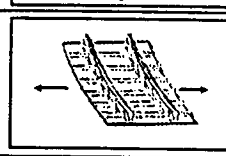
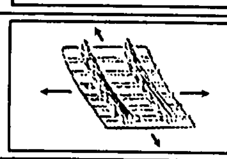
Test	Test Configuration	Specimen Configurations (Replicates)	Total Number Of Tests Planned	Conditions
Stringer/Shell Pull-off		3 (3)	9	RTD
Stringer Compression		3 (3)	9	RTD
Picture Frame Shear		3 (1)	3	RTD (2) ETW (1)
Combined Tension And Shear		1 (1)	1	Impact Damage Cyclic Loads
Biaxial Tension		1 (1)	1	Damage Tolerance Cyclic Loads

Figure 29. Common Structural Component, Test Plan

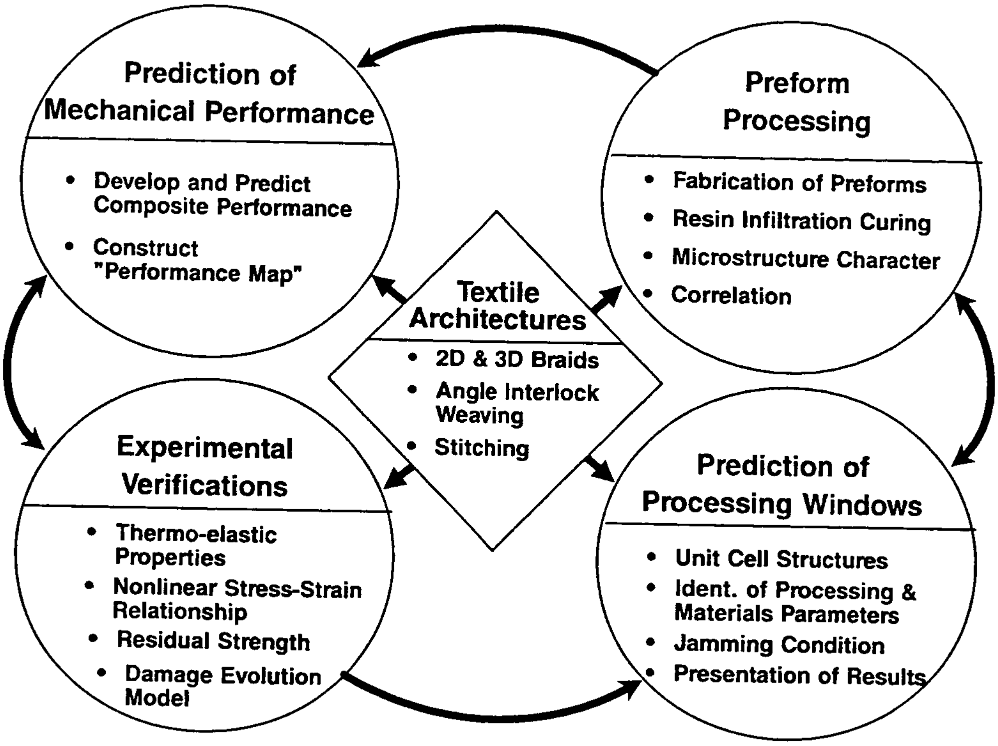


Figure 30. Textile Composite Performance Prediction

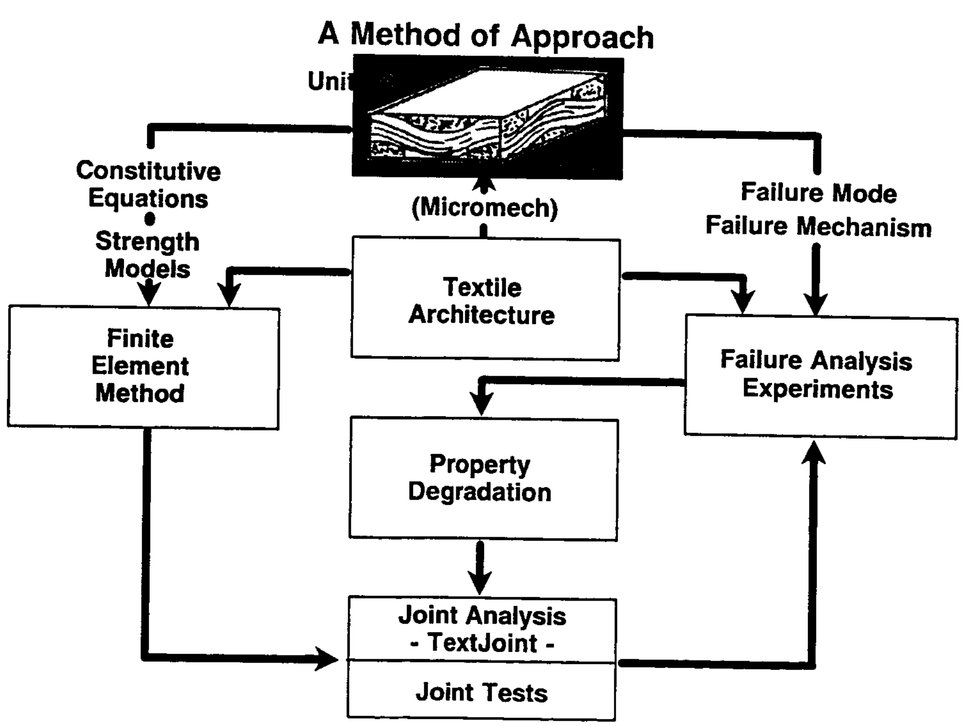


Figure 31. Textile Bolted Joint Strength Prediction - A Method of Approach

essential to the study of biaxial loadings and tension-compression fatigue. 3) Fracture Toughness - The crack driving force, or strain energy release rate, of 3-D composites is sharply reduced owing to through-the-thickness reinforcement. The fracture toughness of 3-D textile composite is greatly enhanced compared to 2-D laminates. The crack fiber interactions in Mode I and Mode II fracture will be investigated by finite element analysis.

TEXTJOINT côde developed in Phase I will be extended to bolted joint strength prediction for textile composites. The method of approach, shown in Figure 31, includes modifying an in-situ failure analysis with observed with observed failure and postmortem characterization, constructing constitutive equations for textile preform architectures, extending 2-D finite elements to 3-D, and verification through the test and the analysis correlation.

Task 4, Low Cost Fabrication and Automation

The specific objectives of this task area follows:

- o Develop analytical methods to predict parameters for RTM part/tool combinations.
- o Purchase RTM equipment, evaluate fabricability of various preforms and develop a data base to aid in selection..
- o Evaluate powder coated epoxy towpreg for fabricating standard elements and develop a data base.
- o Survey textile industry developments to determine automation requirements.

Resin flow through a preform can be predicted using analytical models developed for flow through a porous media using Darcy's law. The permeability of the fiber is dependent on the wetted surface area and free volume for resin flow. Analytical modes will be used to permeability and flow through preforms. The resin flow front analysis will aid in the design of the tools. Similarly, thermokinetic and viscosity models will be used to predict the degree of cure and viscosity as a function of time and temperature. Analytical modelling will be carried out in house. The University of Delaware will flow front work for 3-D textile preforms to be evaluated in Task 2. A flow chart showing thermokinetic and viscosity models and a model for permeability predictions is shown in Figures 32 and 33.

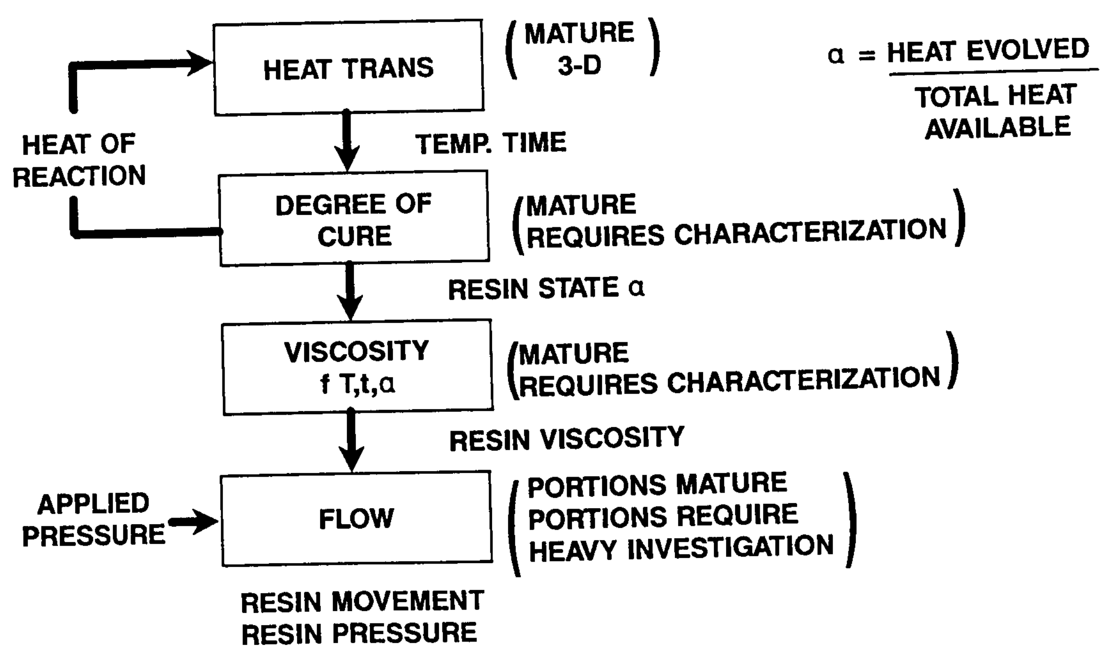


Figure 32. Science Base Modeling Concept, Modular Approach

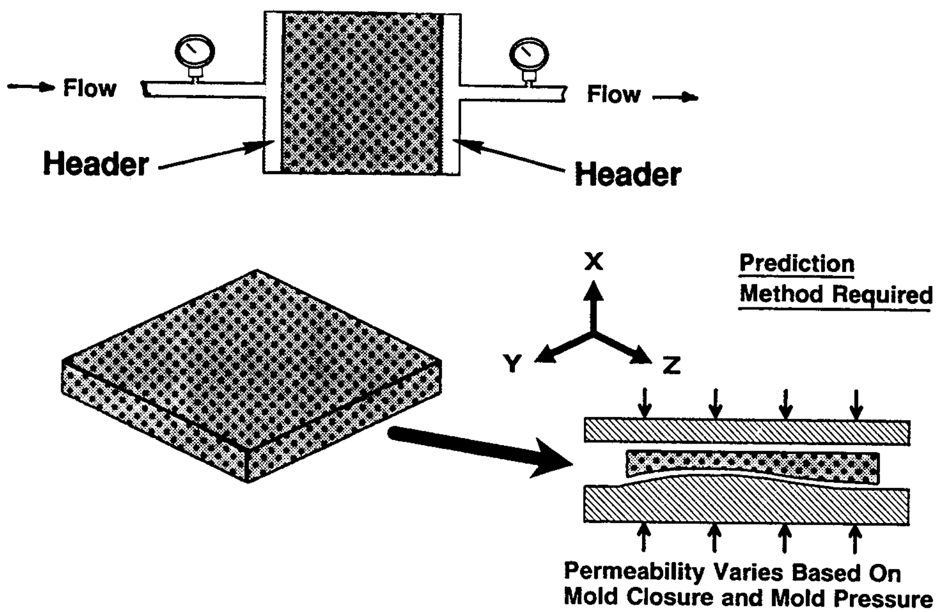


Figure 33. Measuring Permeability

Compaction studies for textile preforms made with both dry tow and powder coated tows will be carried out. High bulk factors in textile preforms will require innovative tooling approaches be developed in order to meet part tolerance requirements.

New developments in textile processing will be surveyed and automation requirements for cost-effective textile processing will be determined. This effort will be tied closely to work on-going in the Composite Automation Consortium.

A specification for resin transfer molding equipment has been completed and quotes are currently being solicited.

SUMMARY

Work is now underway to develop advanced textile technology to fulfill the needs of the Aerospace Industry. Initial efforts are focussing on RTM, because this technology is the more mature. Several RTM resin systems are available for evaluation in this program immediately. Only one powder resin system is sufficiently advanced to be used immediately, however. Powder coated tows for textiles have a high potential for meeting the low cost goals of this program.

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