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Textile Technology Development

Textile Mechanics Conference
NASA Langley Research Center
Hampton, VA
December 6-9, 1994

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Marietta, GA 30063-0648

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Introduction

Advanced Composite Structural Concepts and Materials Technologies for Primary Aircraft Structures.
NASA/LaRC Contract No. NAS1-18888

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LASC Program Mgr. : A. C. Jackson

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Bharat Shah	(Structural Methods/Mechanics/Analysis)
Jay Shukla	(Materials and Processes)
Dan Skolnik	(Manufacturing)

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Presentation Agenda

- Program Scope / Overview
  - ACT Tasks Accomplishments
- Mechanics of Textile Composites
  - Scope
  - Preform Architectures
  - Design Properties and Database
  - Performance Prediction Modeling
  - Impact Response Analysis
  - Bolted Joint Strength Prediction
  - Summary / Conclusions

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Advanced Composite Structural Concepts and Materials Technologies for Primary Aircraft Structures

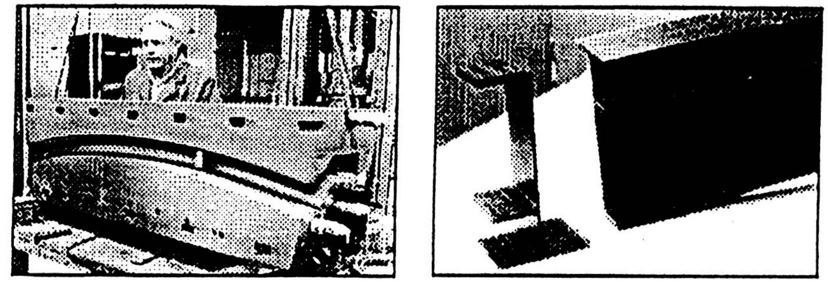
NASA / LaRC Contract No. NAS1-18888 / LASC Program Mgr: A.C. Jackson

CRITICAL TECHNOLOGY

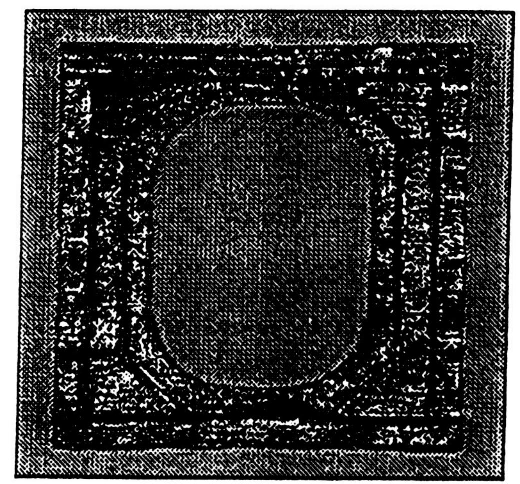
Automated Manufacturing of Fuselage Primary Structures
- Woven and Braided Preforms
- Resin Transfer Molding (RTM)
- Powder Coated Tows

OBJECTIVES

- Evaluate and Select Resin Systems for RTM and Powder Towpreg Material
- Develop/Evaluate Advanced Textile Processes
  - Compare 2-D and 3-D Braiding for Frame Applications
  - Develop Window Belt and Side Panel Structural Design Concepts
- Evaluate Textile Material Properties
- Develop Low Cost Manufacturing Processes/ Tooling



Braided "F" Frame (RTM Process)



Powder Coated Tow Preform
(Window Belt Reinforcement)

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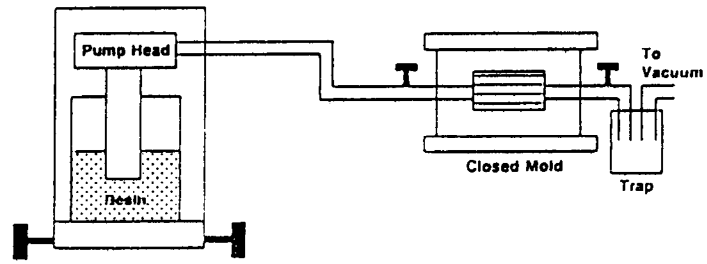
Task 1 - Advanced Resin Systems for Textile Preforms

- Evaluate Resin Systems for Resin Transfer Molding (RTM) & Powder Towpregging

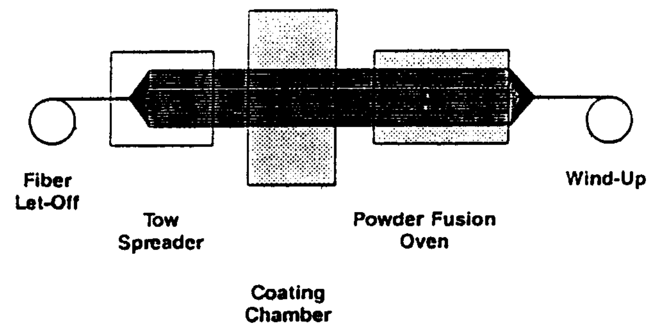
ACCOMPLISHMENTS

- Evaluated Three RTM Resins
  - PR-500 (3M)
  - RSL-1895 (Shell)
  - E905L (BP)
- Selected PR-500 Resin

- Evaluated Three Powder Coated Towpregs
  - PS-501 (3M)
  - RSS-1952 (Shell)
  - CET-3 (Dow)
- Selected PS-501 Powder Coated Towpreg (Now Called AMD-0036)



RTM Process



Powder Coating Process

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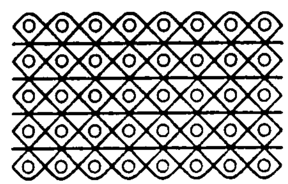
Task 2 - Preform Development and Processing

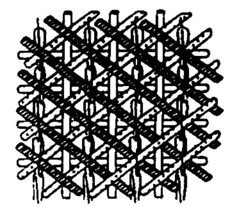
- Evaluate Textile Preforms and Develop Preliminary Data Base On Resin Transfer Molded (RTM) and Powdered Towpreg Materials

ACCOMPLISHMENTS

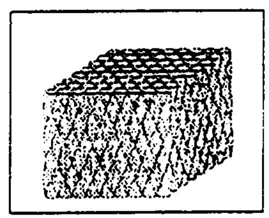
- Evaluated Seven Woven, Braided and Knitted Textile Processes
- Evaluated 3-D Woven and Braided Preform for Preliminary Data Base
- Resin Transfer Molding (RTM) Flat Panel Preforms and Preliminary Data Base
- Evaluated Flat Panel Preform Micro-Structures and Physical Properties
- Established Criteria and Limitations of Textile Processing for Advanced Design Concepts for Fuselage Structures
- Evaluated Powder Towpreg in Weaving Braiding and Knitting Processes



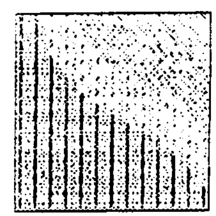
Through the Thickness Weaving



Multi-Axial Knitting/Stiching



3-D Through the Thickness Braiding



Multi-Axial "Weaving" Process

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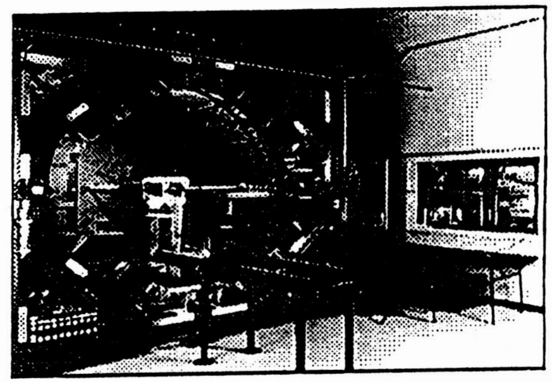
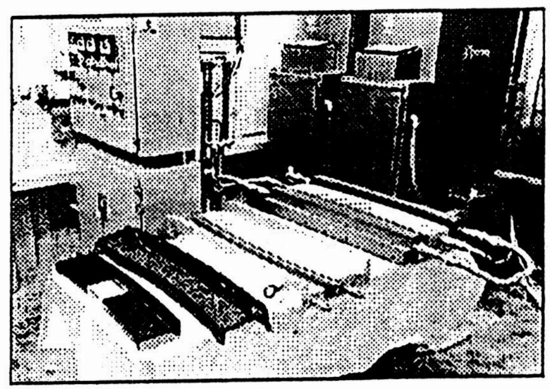
Task 3.1 - Fuselage Frame Development

- Conduct Trade Studies to Select Braiding Approach for Side Panel Circumferential Frames

ACCOMPLISHMENTS

- Developed 2-D and 3-D Braided Frame Concepts
- Costs Trades Indicate 2-D Braid Less Costly Than Metals
- Testing Complete, 2-D Frames Meet or Exceed all Requirements





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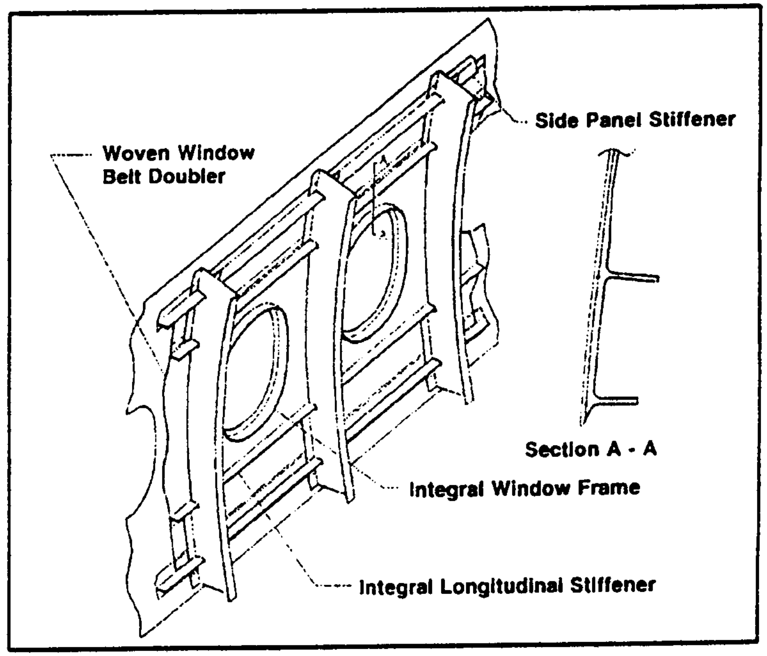
Task 3.2 - Fuselage Window Belt Development
- Develop Advanced Textile Concept for Fuselage Window Belt

ACCOMPLISHMENTS

- Developed Woven & Warp Knitted Concepts
- Completed Cost Analysis
- Woven Concept Shear Panel Test Completed
- Test Correlation In Progress
- Knitted Concept Dropped
  - Poor Performance in Knitting Trials



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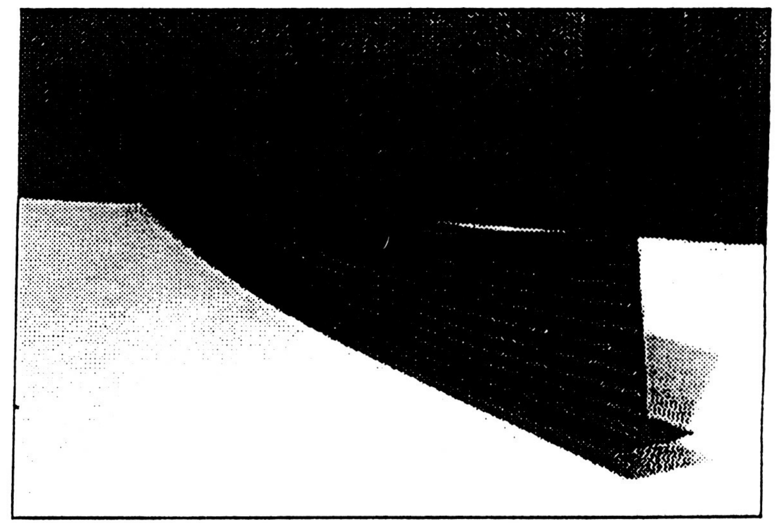
Task 3.3 - Keel Frame

- Develop Keel Frames for Boeing Test Components

ACCOMPLISHMENTS

- Twenty four (24) "J" Section 2-D Triaxially Braided / RTM Frames Shipped to Boeing
- 12 Frames Successfully Co-Bonded Into Aft Keel Test Panel (Boeing)
- 12 Frames Remain to be Co-Bonded in the Next Test Panel (Boeing)
- Frames for Forward Keel Currently Being Planned



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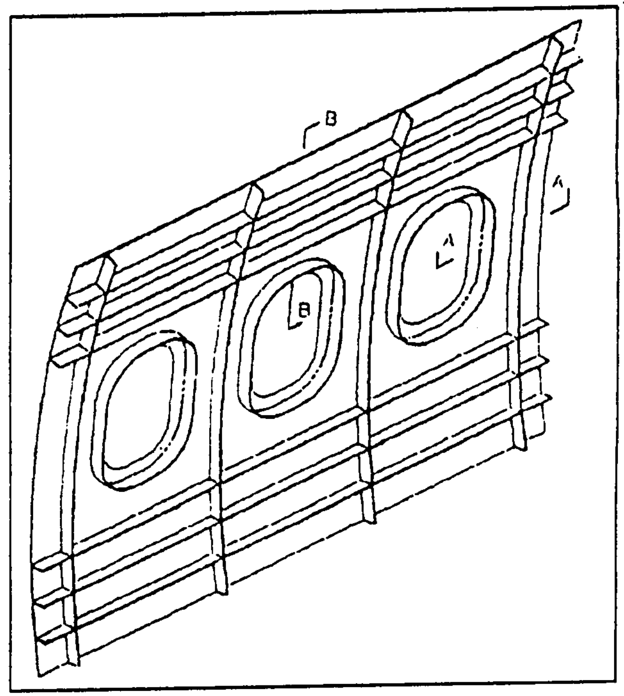
Task 3.4 - Benchmark Side Panel Common Structural Test Component

- Develop 100% Textile Side Panel Concepts
- Fabricate Benchmark Test Panel for Testing at NASA

ACCOMPLISHMENTS

- Four Advanced Textile Side Panel Concepts Designed for Relative Cost & Weight Savings and Structural Performance
- Down Selected to Two Promising Concepts for Detail Design and Structural Testing
  1. 3-D Woven (Techniweave) Integral Stringers and Window Frames
  2. Conventional 3-D Woven Pultruded Stiffeners Braided Window Frame

Task 3-4 To Be Redirected



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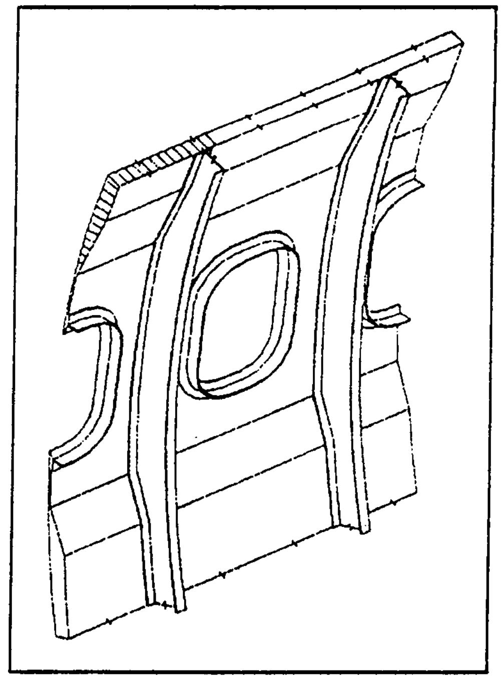
Task 3.4 - Sandwich Fuselage Panel

- Develop Fuselage Side Panel Including Window Belt Using ATP Honeycomb and Braided RTM

ACCOMPLISHMENTS

- Two Design Concepts Evaluated for Manufacturing Feasibility and Cost



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Task 3.5 - Analytical Methods Development and Validation

- Develop Design-to-Properties
- Predict Textile Composite Strength & Stiffness
  - Model Development & Verification
- Develop Impact Response Method
- Conduct Bolted Joint Test and Analysis

ACCOMPLISHMENTS

Textile Composite Properties Obtained by Test

- Strength Threshold High

Process-Microstructure-Performance Relationship

- Stiffness & Strength Prediction Models Developed
  - Currently Being Validated

Impact Response Method Development

- Finite Element Based Code - "3DIMPACT"
- Progressive Damage Criteria / Enhancement Incorporated

Bolted Joints Tests Completed

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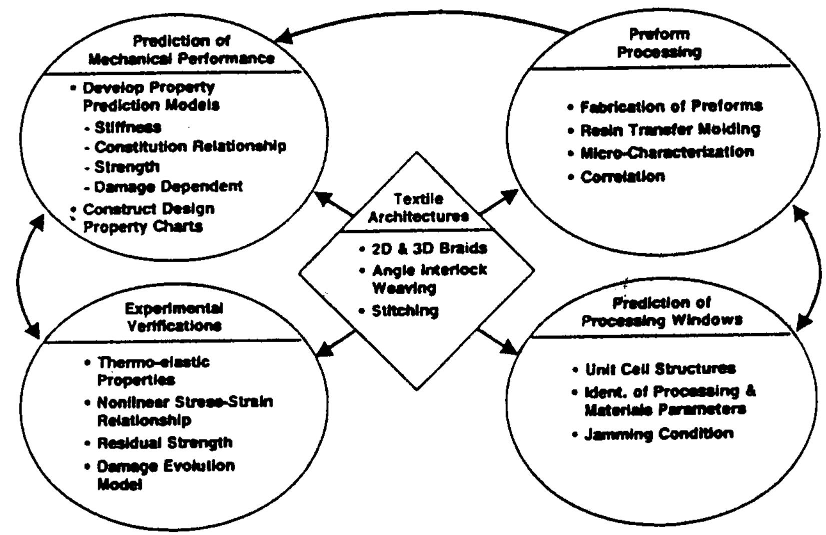

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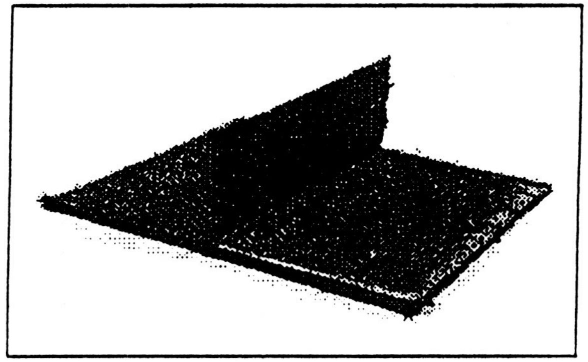
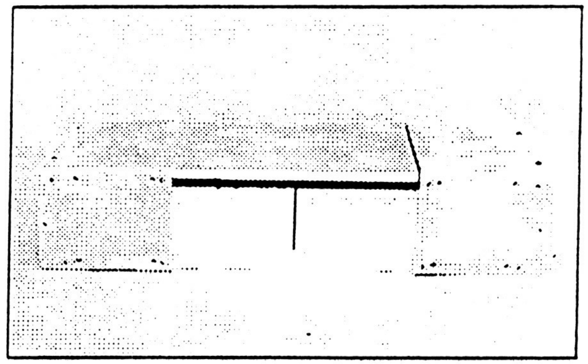
Task 4.0 - Low Cost Fabrication Methods

- Develop Methods of Fabricating Composite Materials Using Low Cost Textile Preforms

ACCOMPLISHMENTS

- Fabricated Flat Panels for Mechanical Property Testing Using RTM and Powder Towpreg Technologies
- Developing Methods to Debulk and Cure Components in a Cost Effective Manner
- Currently Debugging LIMS (Resin Flow Simulation)





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Objective/ Scope

- Develop " Design-to-Properties " of Textile Composites
- Establish the Material Level Damage Mechanisms
- Establish Damage Progression Characteristics
- Develop Performance Prediction Models
  - Stiffness Model(s)
  - Strength Model(s)
  - Damage-dependent Model
  - Impact Response Analysis Methodology
  - Bolted Joint Strength Prediction

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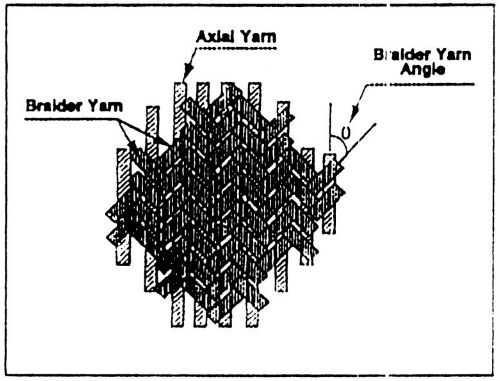
Textile Architectures

3-D Braid(TTT)



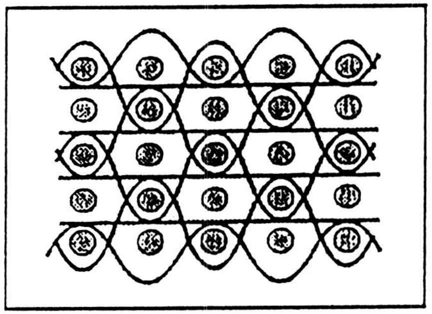
Pattern I

	.12" thick	.16" thick	θ°
Axial	6K(30.3%)	6K(30.9%)	0
Braider	6K(69.7%)	6K(69.1%)	60

Pattern II

	.12" thick	.16" thick	θ°
Axial	18K(56.3%)	18K(57.2%)	0
Braider	6K(43.7%)	6K(42.8%)	60

3-D Woven(LTL)



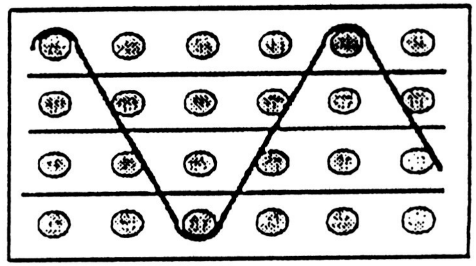
Pattern I

	Tow Size	Approx. Yarn Distribution(%)
W(0°)	6K	45.7
F(90°)	6K	46.1
z	3K	8.2

Pattern II

	Tow Size	Approx. Yarn Distribution(%)
W(0°)	12K	46.3
F(90°)	6K	45.6
z	3K	8.1

3-D Woven(TTT)



Pattern II

	Tow Size	Approx. Yarn Distribution(%)
W(0°)	12K	47.7
F(90°)	6K	44.4
z	3K	7.9

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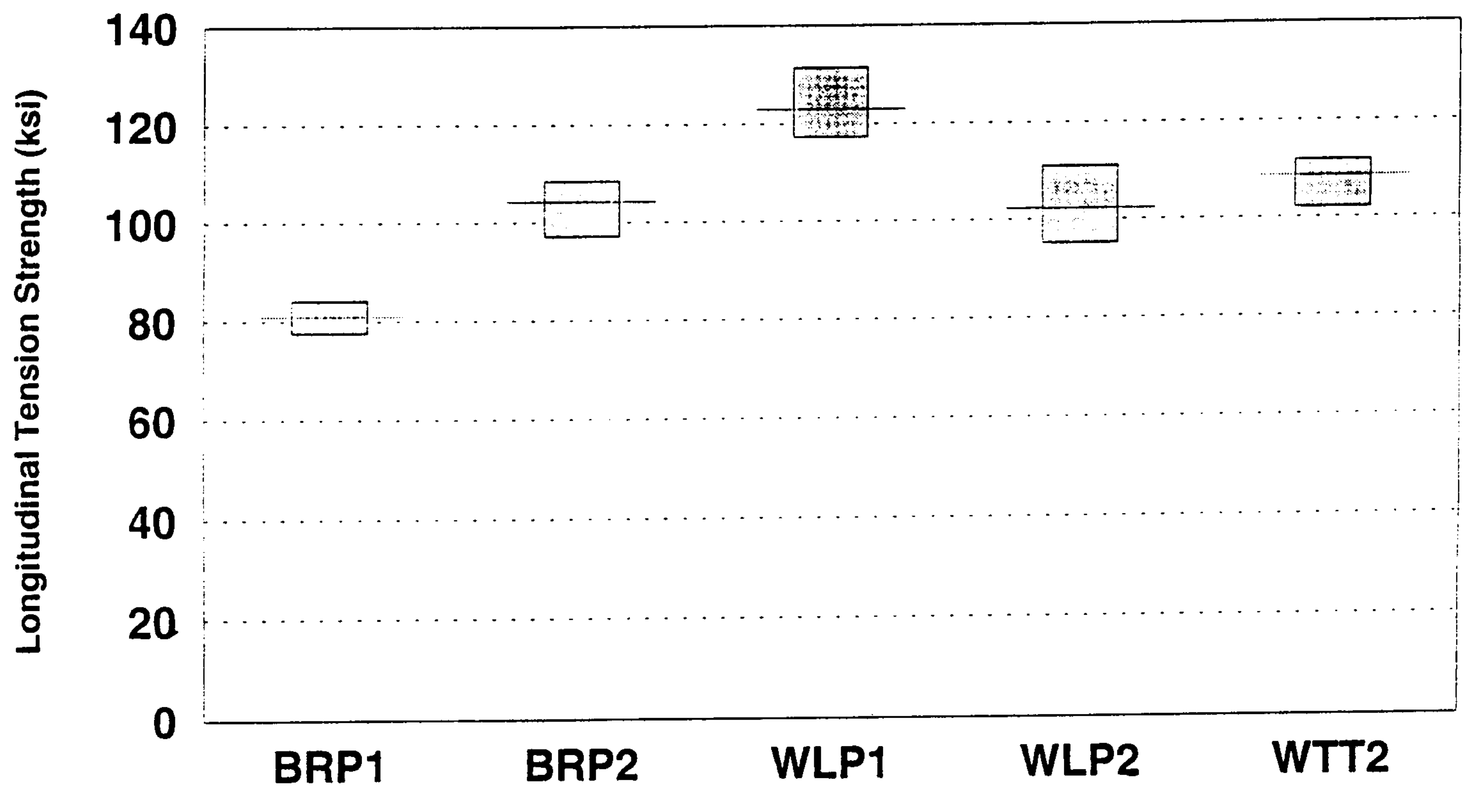
Longitudinal Tension Strength

3D Textile Composite [AS4/PR500]



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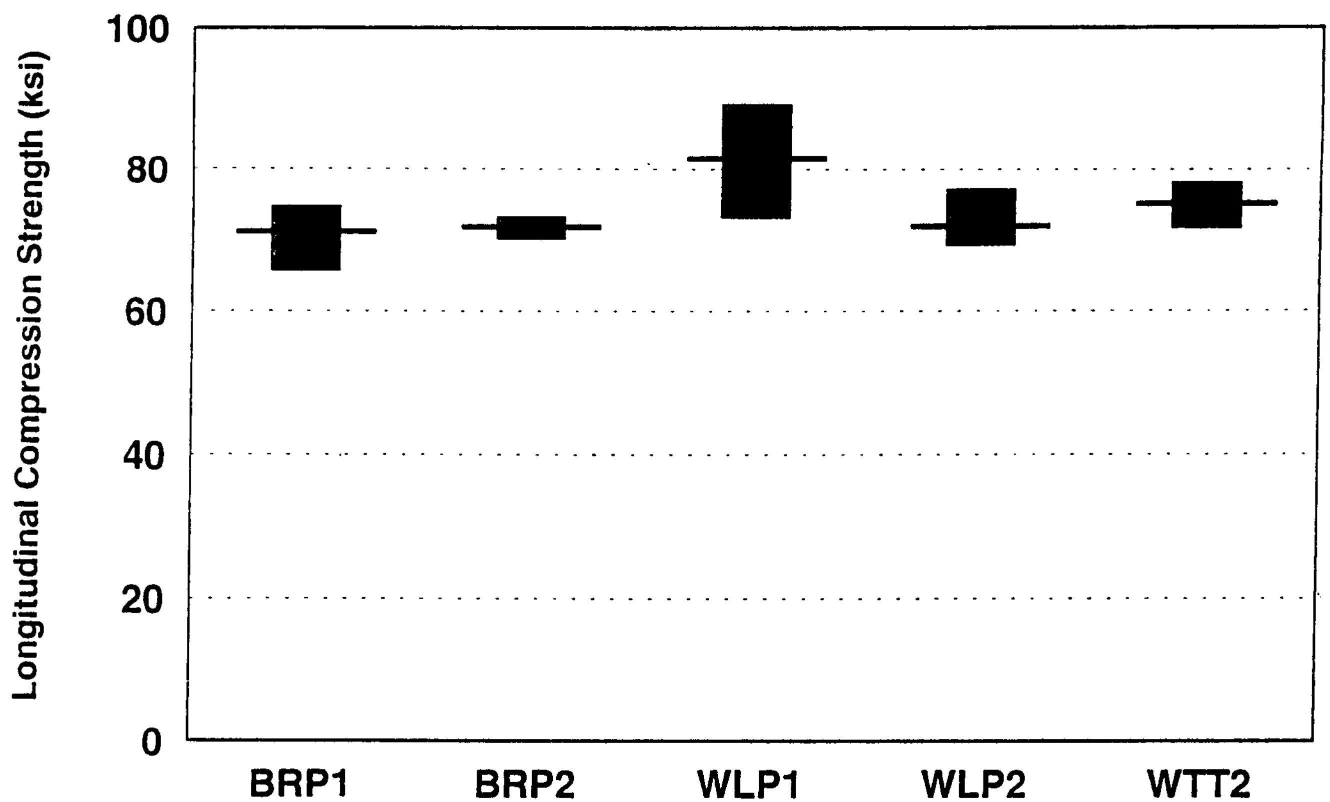
Longitudinal Compression Strength

3D Textile Composites [AS4/PR500]



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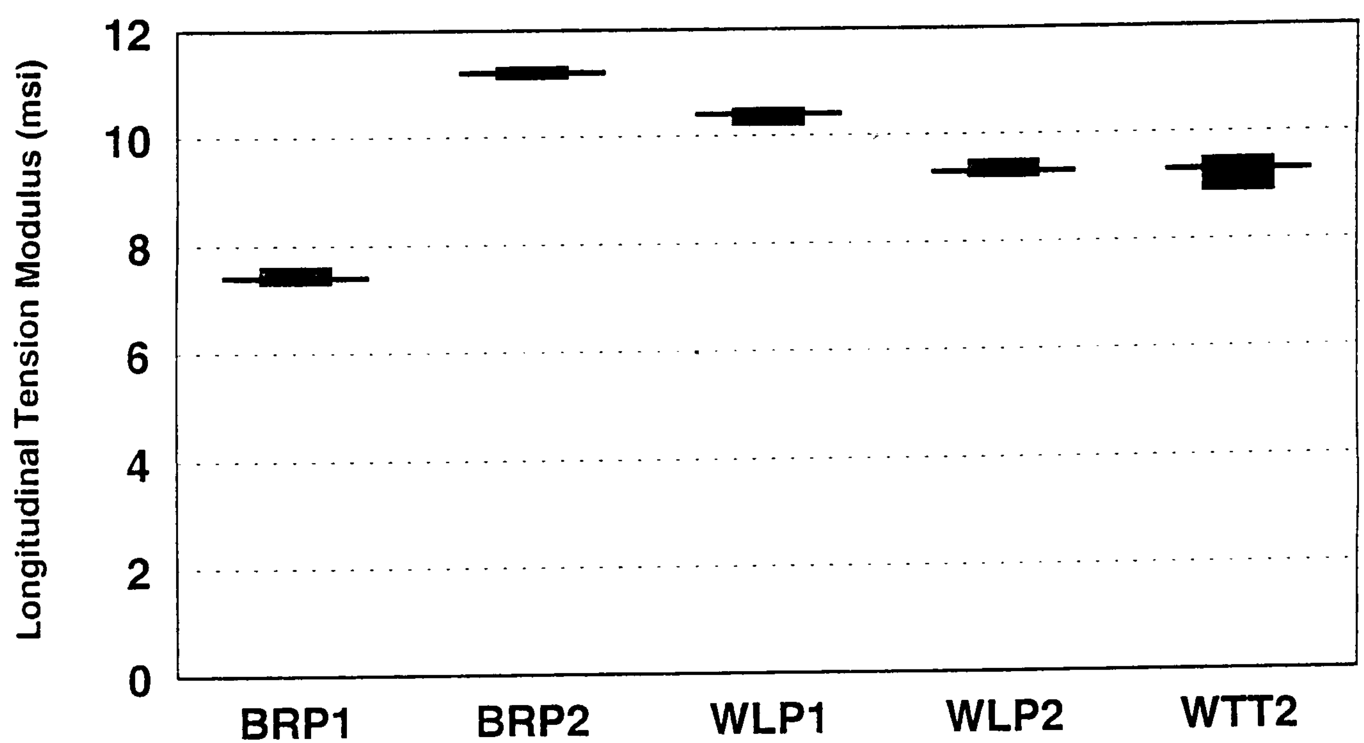
Longitudinal Tension Modulus

3D Textile Composite [AS4/PR500]



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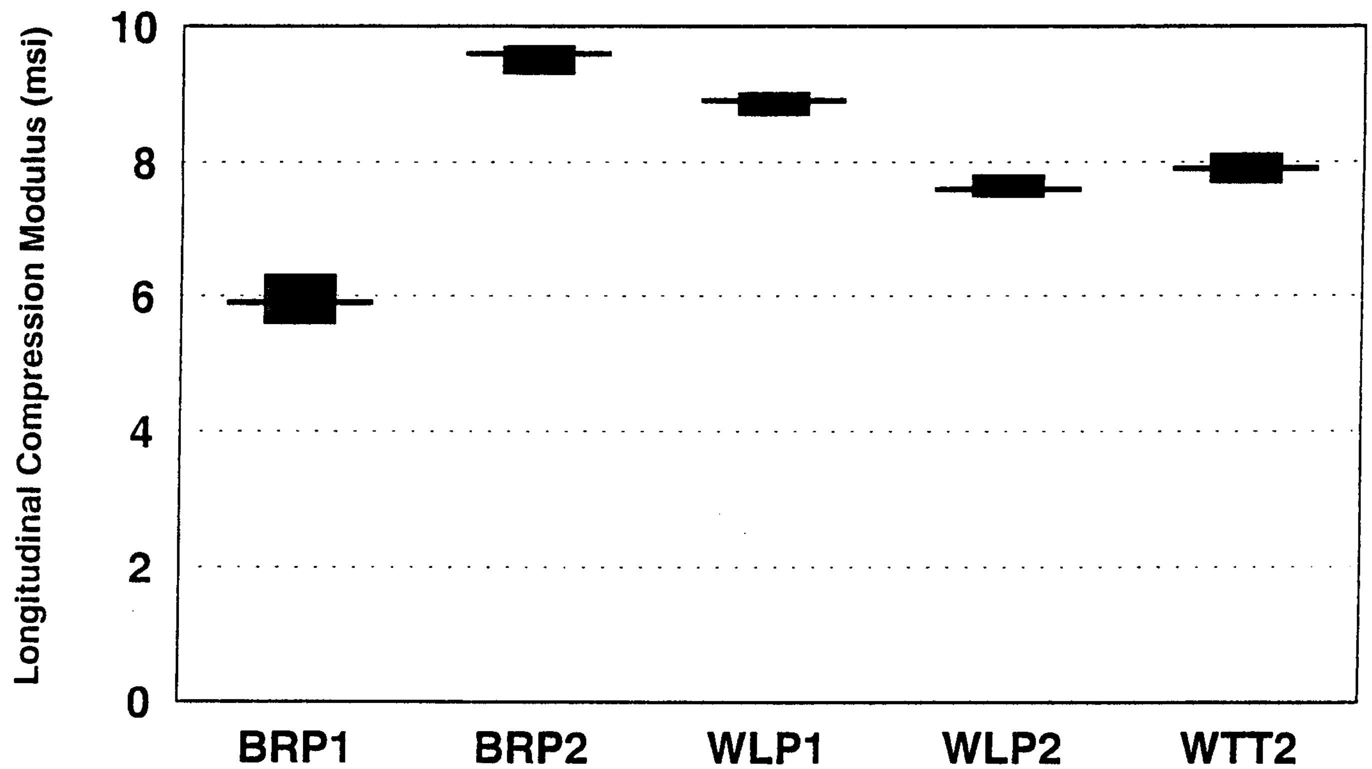
Longitudinal Compression Modulus

3D Textile Composite [AS4/PR500]



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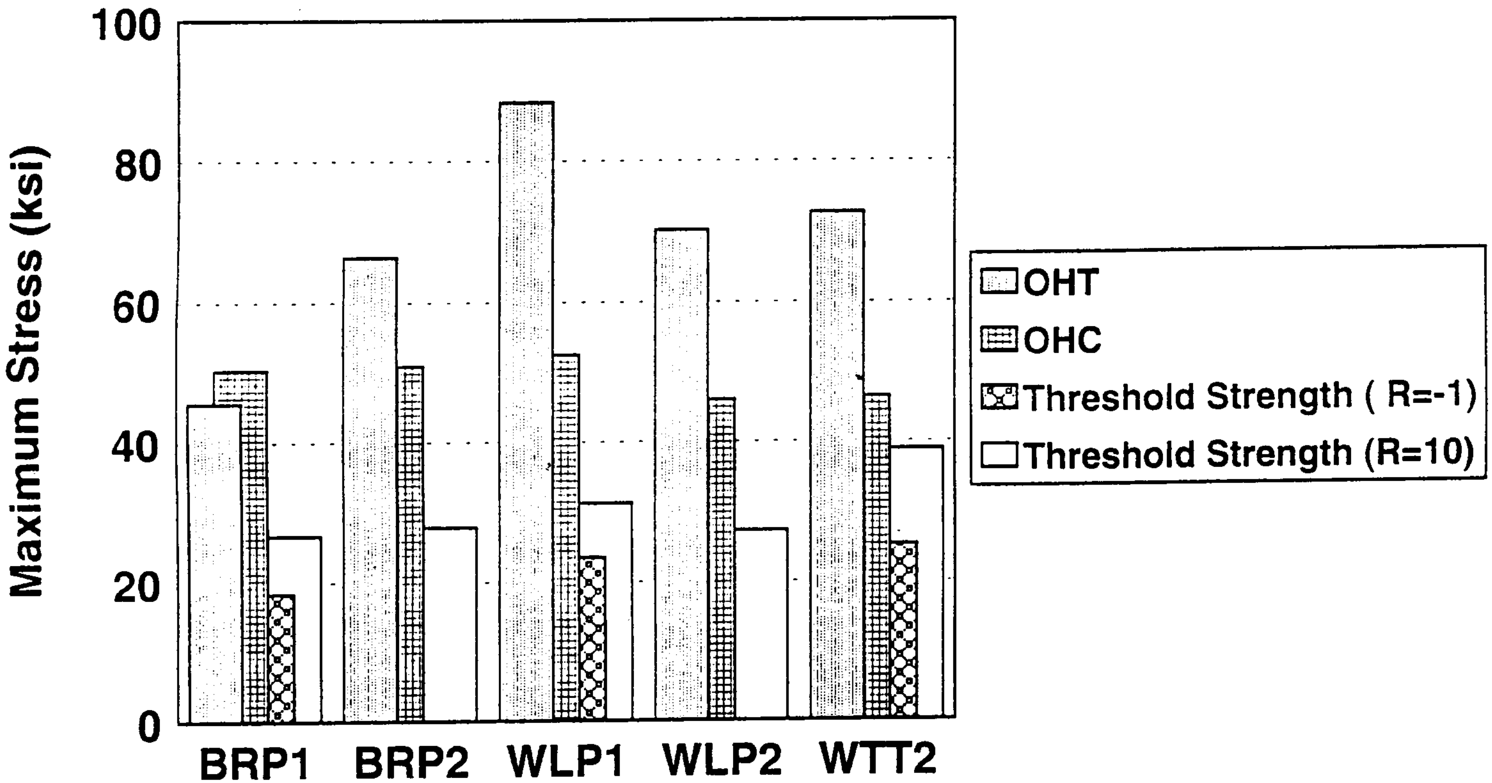
Open-Hole Fatigue Characteristic

3D Textile Composite (AS4/PR500)



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Experimental Textile Database

AS4/PR500 [RTM]

Elastic Constant	UNT [L/T]	UNC [L/T]	Fatigue	OHT	OHC	Bolt Bearing	FHT	FHC	CAI	ILT
				3D	Weave	LTL				
x	x/x	x/x	x	x	x	x	x	x	x	x
				3D	Weave	TTT				
x	x/x	x/x	x	x	x	x	x	x	x	x
				3D	Braids					
x	x/x	x/x	x	x	x	x	x	x	x	x
				2D	Braids					
x	x	x		x	x				x	
			Multi	Axial	Warp	Knit				
x	x	x		x	x				x	
				8HS	Fabric					
x	x	x		x	x				x	

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Experimental Textile Database

AS4/ AMD0036 [Powdered Towpreg]

Elastic Constant	UNT [L/T]	UNC [L/T]	CAI	OHT	OHC	Bolt Bearing
2D Triaxial Braids [$0°_{6k}$, +/- $60°_{6k}$] 33% Axials						
x	x/x	x/x	x	x	x	x
2D Triaxial Braids [$0°_{18k}$, +/- $60°_{6k}$] 50% Axials						
x	x/x	x/x	x	x	x	x
3D Weave (Techniweave) [(+/- $45°_{6k}$, $0°_{6k}$, $90°_{6k}$) , Z_{3k} $]_{NS}$						
x	x/x	x/x	x	x	x	x
3D Multi-layered Weave [(+/-$45°_{6k}$, Z_{3k}) , (0°/$90°_{6k}$, Z_{3k})$]_S$						
x	x	x	x	x	x	x

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Experimental Textile Database

Bolted Textile Joints

Bearing / Bypass 2 Ratios	Single Lap Shear Tension t=.12in.	Single Lap Shear Tension t=.16 in.	Double Lap Shear Tension	Double Lap Shear Compression	Double Lap Shear Trans. Tension	Fastener Push Through
2D Triaxial Braids $[0^\circ_{12k}, \pm 60^\circ_{6k}]$ 33% Axials						
x	x	x	x	x		x
3D Braids $[0^\circ_{6k}, \pm 60^\circ_{6k}]$ 33% Axials						
x	x	x	x	x	x	x
3D Weave (Techniweave) $[(\pm 45^\circ_{6k}, 0^\circ_{6k}, 90^\circ_{6k}), Z_{3k}]_{NS}$						
x	x	x	x	x		x
3D Multi-layered Weave $[(\pm 45^\circ_{6k}, Z_{3k}), (0^\circ/90^\circ_{6k}, Z_{3k})]_S$						
x	x	x	x	x		x

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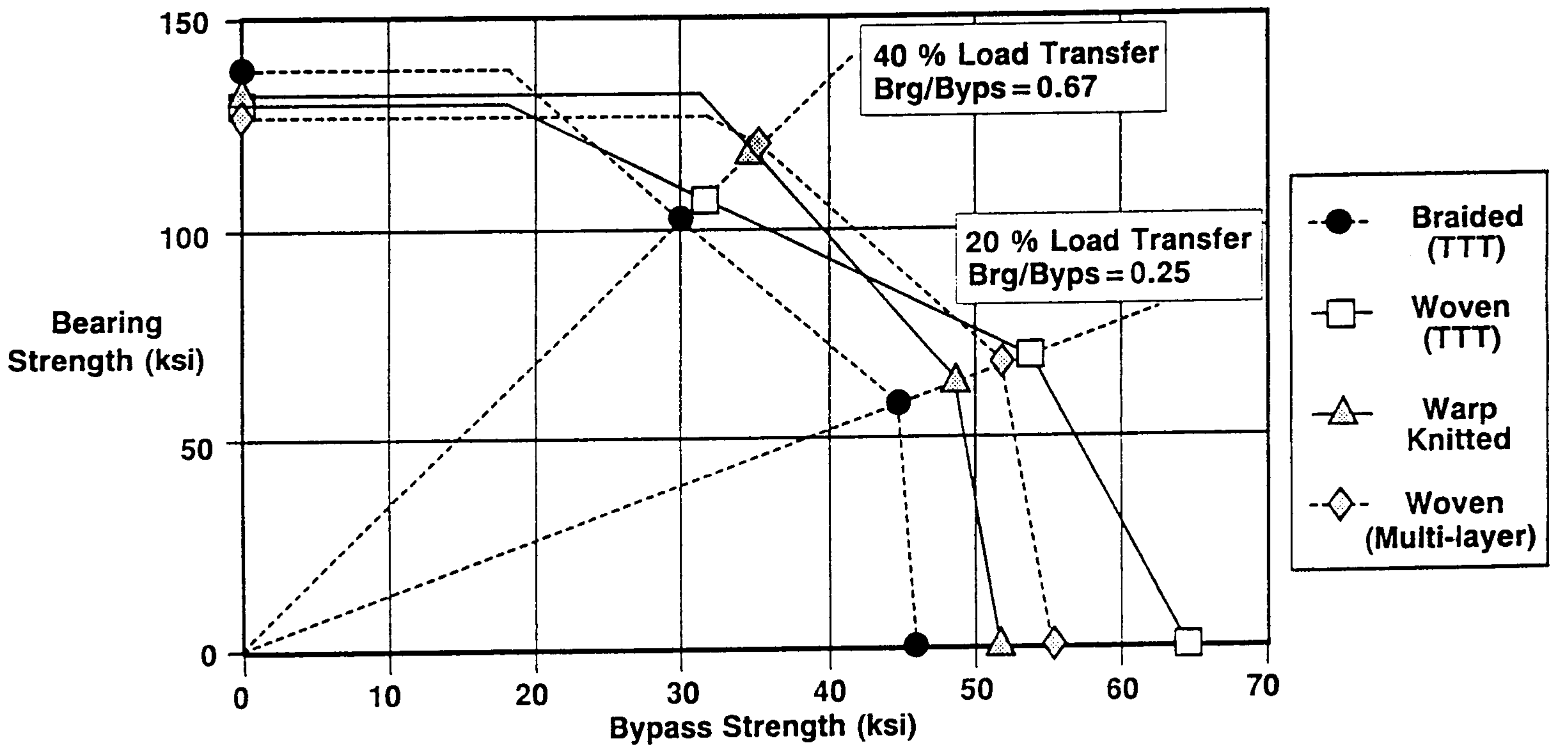
Bearing Bypass Interaction



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Material Properties Database

M/VISION Implementation

- Approach
  - Employ Existing Client-Server Workstation Network
  - Store All Results in an Electronic Databse
    - Automate Data Reduction Methods
    - Improve Accessibility to Test Data
    - Difficult-to-Predict Material Behavior can be Examined Empirically
    - Rapid Comparative Property Evaluation

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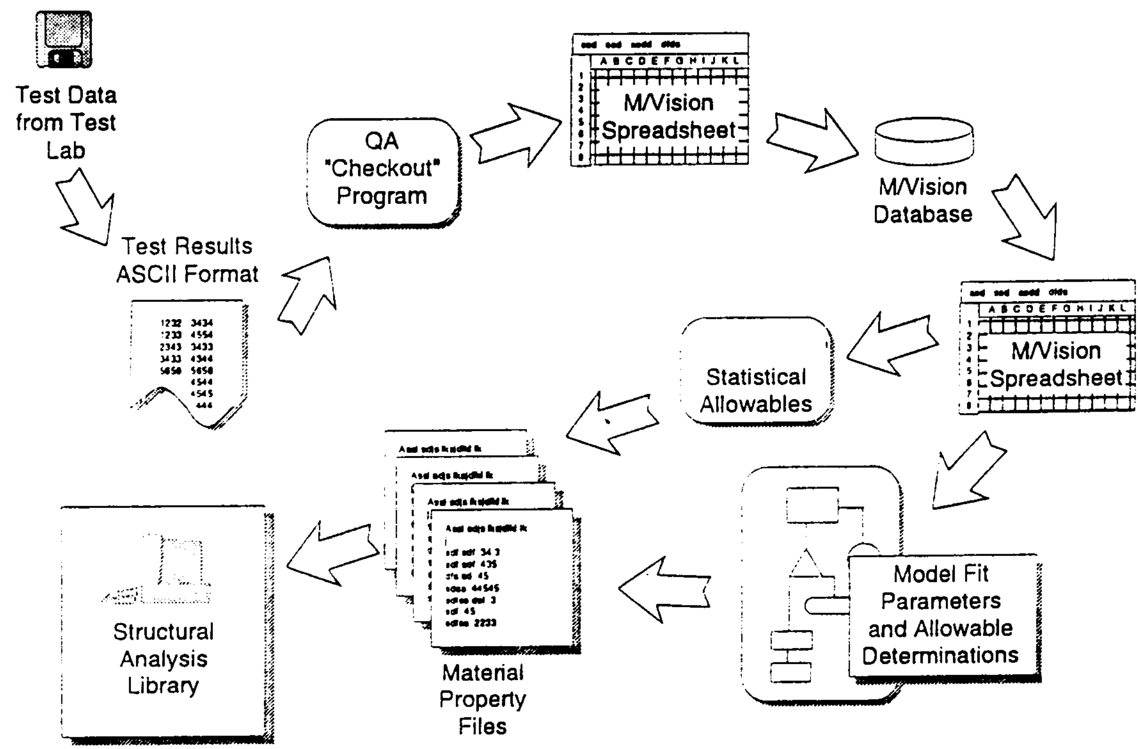
M/Vision Implementation

Database System Flow



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Textile Performance Modeling

Preform	Elastic Constant	CTE's	UNT Strength L/T	UNC Strength L/T	Shear Strength	Joint Strength	Impact Resistance	Impact Tolerance
3-D Weave	x	x	x	x	x	x	x	x
3-D Braids	x	x	x	x	x	x	x	x
2-D Braids						x	x	x

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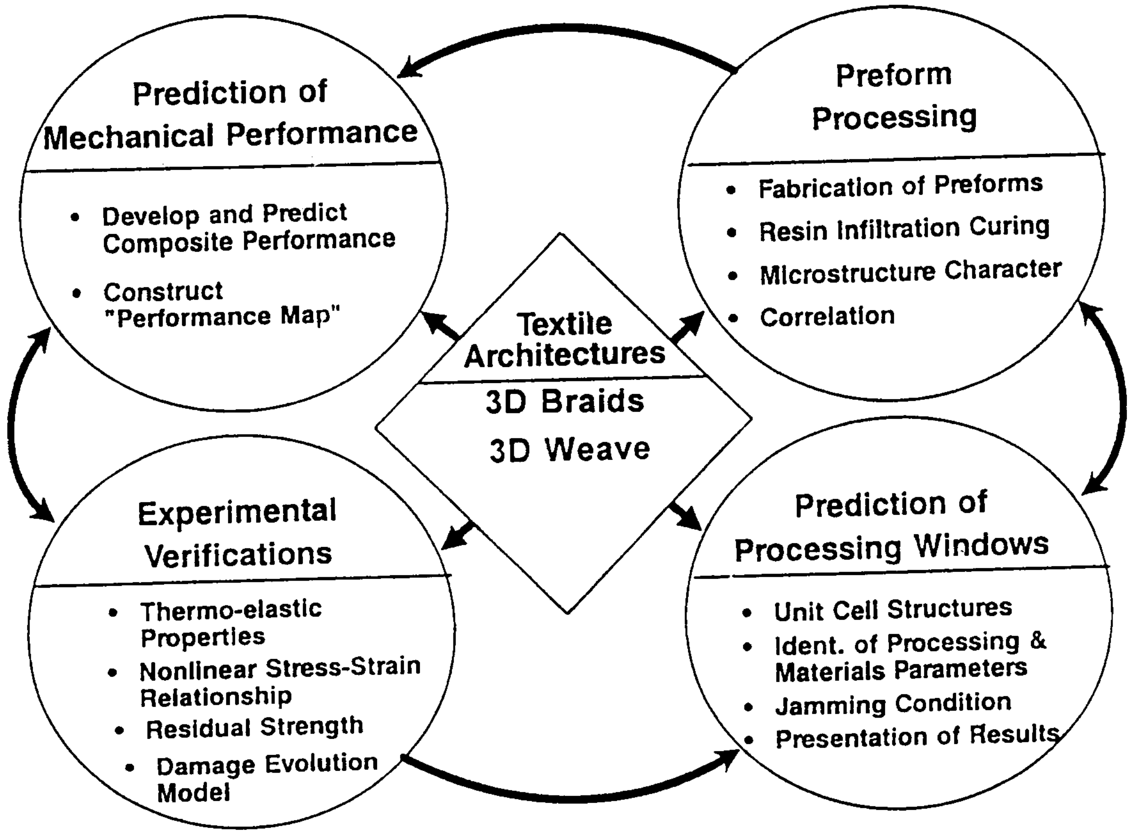
Performance Prediction Modeling

University of Delaware Effort



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Properties Prediction Modeling

- Geometrical modeling of 3D textile composites
- Stiffness computation modeling
  - stiffness averaging approach
  - homogeneous boundary approximation
- Strength modeling
  - tensile strength : volume fraction approach
  - compressive strength: shear mode buckling analysis
  - shear strength : Sun's single param. yield criteria
  - off-axis strength : one parameter yield curve
- Bending response modeling
  - Ambursumyan's model
  - Jone's model
- Damage modeling with multi -scale-multi-grid method
- Bolted textile joints analysis - "BOLTEX"

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Impact Response Analysis Methodology

3DIMPACT - Code

- Existing Capabilities
  - 3D Transient Finite Elements Code
  - Low Velocity Impact of Laminated Composite
  - In-Plane and Out-of-Plane Stresses
  - Extent of Delamination
- Capabilities Update
  - Contact Force Distribution
  - Laminated and Textile Composites
  - Progressive Damage Model
  - Residual Strength Prediction

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Summary / Conclusions

- Textile Composites Properties Characterization completed
  - Longitudinal properties goals were met
  - Out-of-plane property goal was not met
  - Transverse properties of 3D-braided composite are poor
  - Shear strength of 3D-braided composite is good
  - Bearing strength of 3D- composites lower than fabrics
  - Powdered towpreg textile composite properties characterization is in-work
  - Textile properties database (MVISION] established
- 3D- textile composites strength and stiffness models shows very good results
- Impact response analysis method developed
  - Impact resistance and tolerance prediction capability installed
  - Predictions for laminated composite very good
  - Predictions for textile composite needs improvement
- Textile joint strength prediction method developed
- Methods improvement issues
  - Limited test data
  - Out-of-plane properties unavailability
  - Damage mechanisms and mechanics

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