Composite Overview
&
Composite Aerocover Overview

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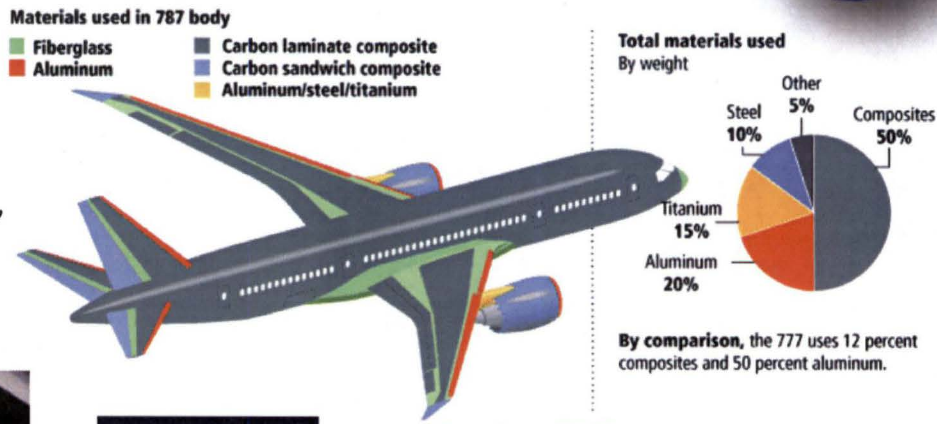
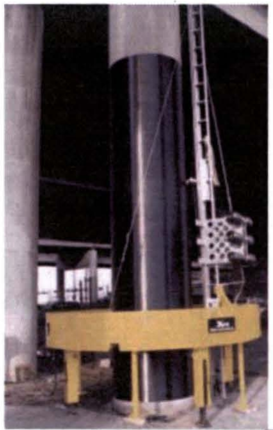
Composite Technology Overview

- Typical Applications:
  - Large components of commercial airliners
  - Large primary structures on military aircraft
  - Components of modern airliners
    - Radomes, spoilers, landing gear doors, fairings, interiors
  - Marine vessels and structures
    - Composite masts
  - Helicopter components
    - Rotor blades
  - Sports equipment
    - Bikes, tennis rackets, golf clubs
  - Medical Devices
    - Spinal implants
  - Wind turbines
  - Automobiles
  - Construction



Boeing 787



F35 JSF

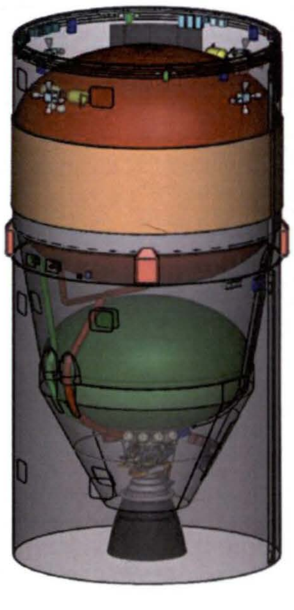
Stretcher

Heavy Lift Launch Vehicle Applications

Payload Fairing

Intertank

Interstage



Composite Technology Overview

- Advantages:
  - High strength and stiffness-to-weight ratio
  - Optimized structures
  - No metal fatigue
  - No corrosion
  - Easily molded to complex shapes
  - Fewer parts
  - Lower tooling
  - Aerodynamic smooth surface
  - Stealth
- Disadvantages:
  - Expensive materials
  - Special storage and handling
  - Not always recyclable
  - Labor-intensive
  - High capital equipment costs
  - Easily damages
  - Special training and skills are required
  - Galvanic corrosion
  - Health and safety concerns

Matrix Technology

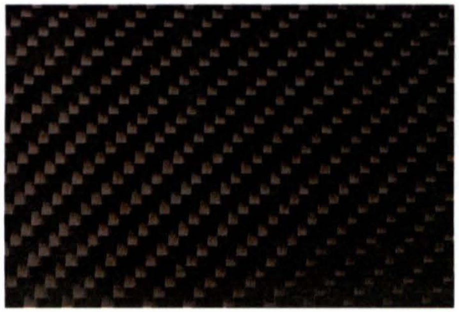
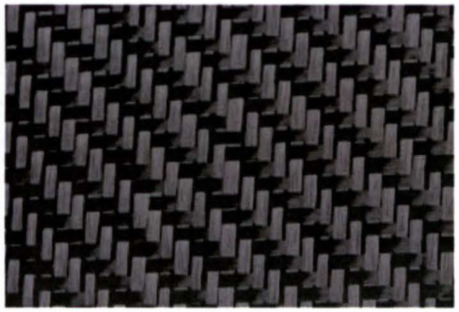
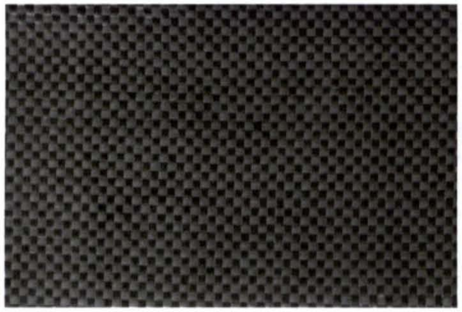
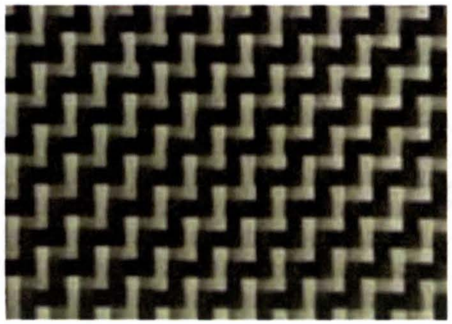
- Thermoset – molecules chemical reacted and joined via cross-linking. These bond well to fibers.
  - Bis-Maleimides (BMI)* - good high temp
  - Epoxy* - workhorse resin
  - Phenolic
  - Formaldehyde
  - Polyester* - considerable emissions
  - Vinyl Ester*
  - Cyanate Ester* - low CTE
  - Polyimide*
  - Polyurethane
  - Silicone

  *Common Thermoset Matrix Systems
  - Thermoplastic – Branch-chain molecular structures. No chemical links.

Fiber Reinforcements

- Common Reinforcement Fibers
  - Glass
  - Carbon
  - Aramid (Kevlar)
  - PE (Spectra)
  - Ceramic Fibers (Boron, Silicon Carbide, Alumina-silica, Quartz)
  - Polyphenylenebenzobisozazole (Zylon)

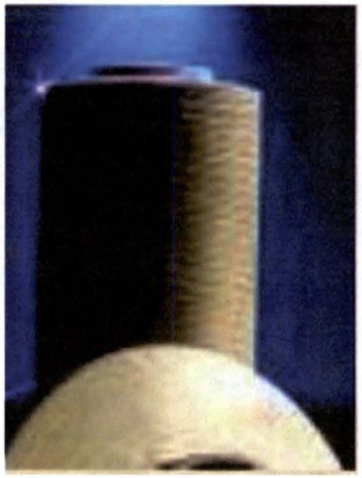
- Forms
  - Filament
  - Strand
  - Yarn
  - Tow
  - Woven Roving
    - Plain weave, basket weave, 4 harness satin, twill, etc.
  - Tape
  - Fabric
  - Mat

Reinforcement Materials

Fiberglass

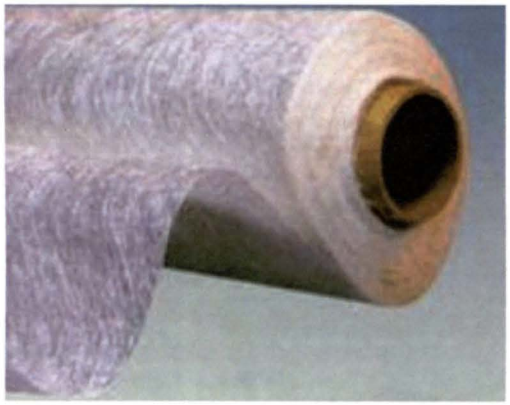
Carbon/Graphite



Aramid

UHMWPE

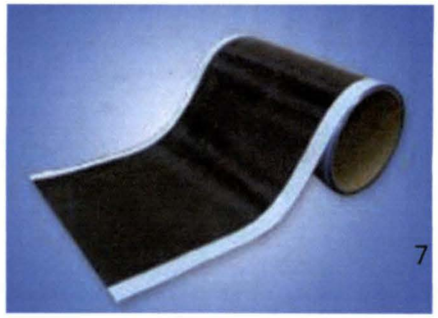
Mat



Tow

Cloth Fabric

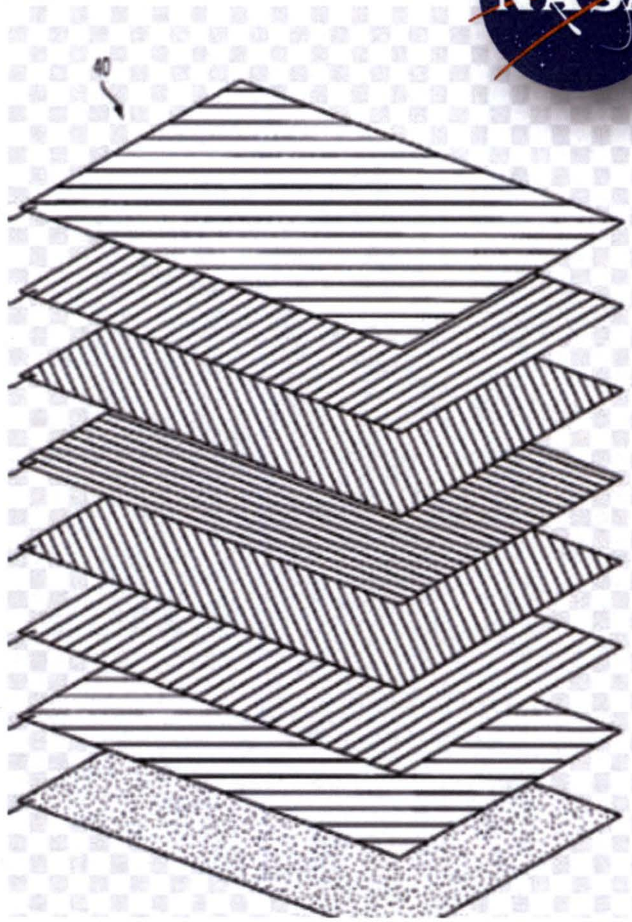
Prepreg



Basic Design Considerations

- Matrix Dominated Properties
  - Compressive strength
  - Bending stiffness
  - Interlaminar shear strength
  - Service temperature
- Fiber Dominated Properties
  - Tensile strength
  - Flexural modulus

- Solid Laminate Panels
  - Thin skins bonded to lightweight thick core material
    - Offer higher bending stiffness-to-weight ratios
- Sandwich Core panels
- Temperature and Moisture
- Ply orientation
- Resin to Fiber Ratio
  - 60% fiber / 40% resin by volume



Manufacturing

- Open Molding
  - Hand layup
  - Spray-up
  - Filament winding
- Closed Molding
  - Vacuum bagging
    - Base plate, non porous tooling/mold, laminate, perforated film/peel ply, bleeder, separator, breather, vacuum pump, vacuum hose, vacuum gauge.
  - Hand Layup / Prepreg layup
  - Vacuum Infusion
  - Resin Transfer Molding – complex shapes
  - Pultrusion
  - Matched Die Forming
  - Compression Molding
- Mold release agents

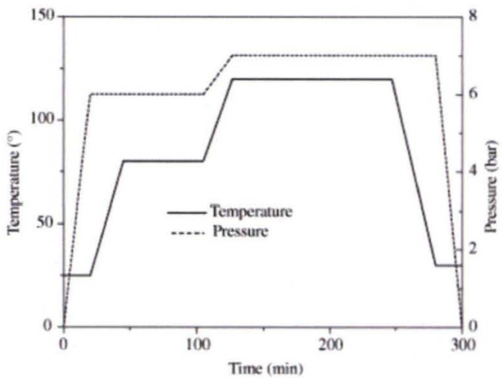


Figure 4. Typical autoclave cure cycle for metal/fiber laminates and thermo-setting composites.

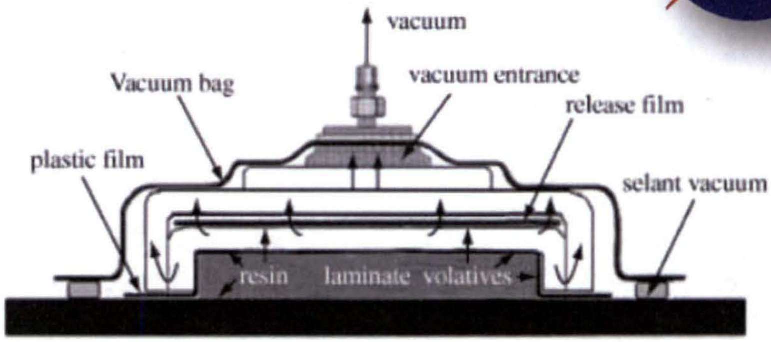
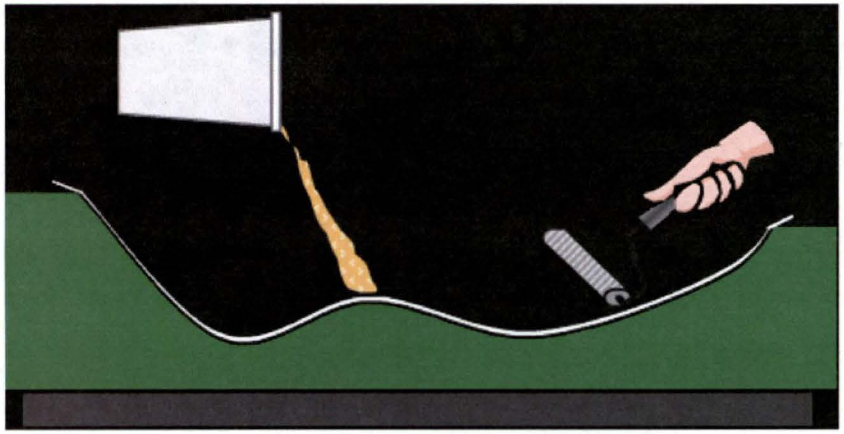


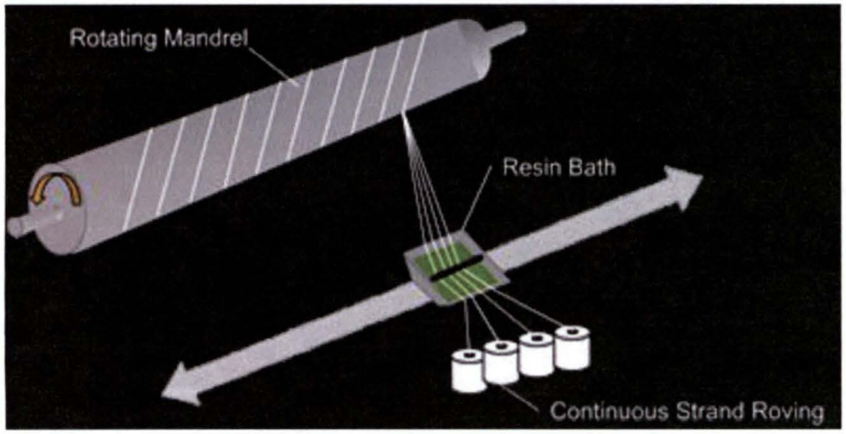
Figure 3. Schematic representation of vacuum bag system.

- Mix Ratios
  - Two part resin systems
- Pre-preg system
  - Cure cycles
    - Recipes that define time, temperature, vacuum and pressure requirements at time intervals
      - Derived from viscoelastic properties of resin properties
      - Too fast/too slow causes problems

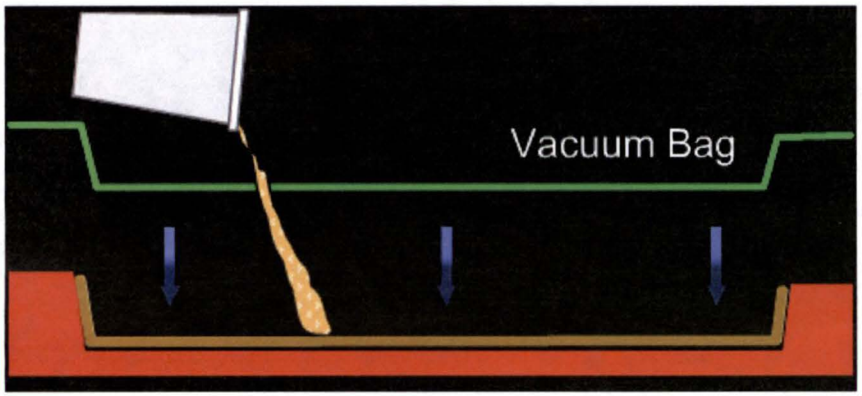
Manufacturing Techniques



← Hand Lay-up (Manual Process)



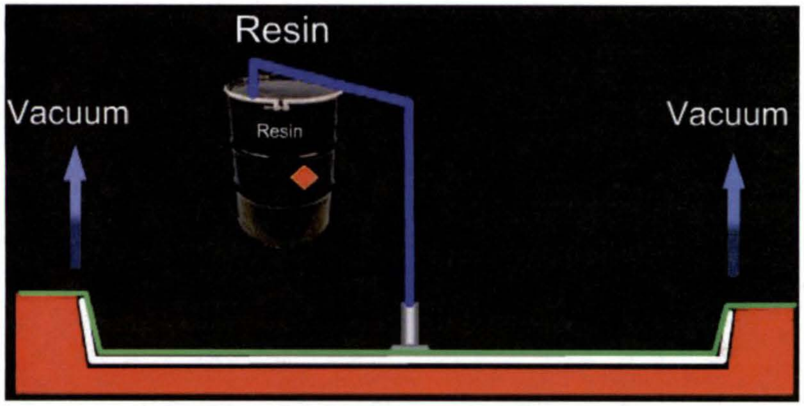
← Filament Winding



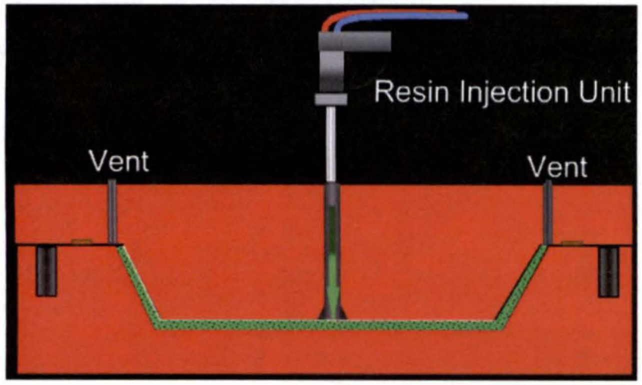
←Wet Layup
- Vacuum Bagging

Images: SAMPE Overview of Composites

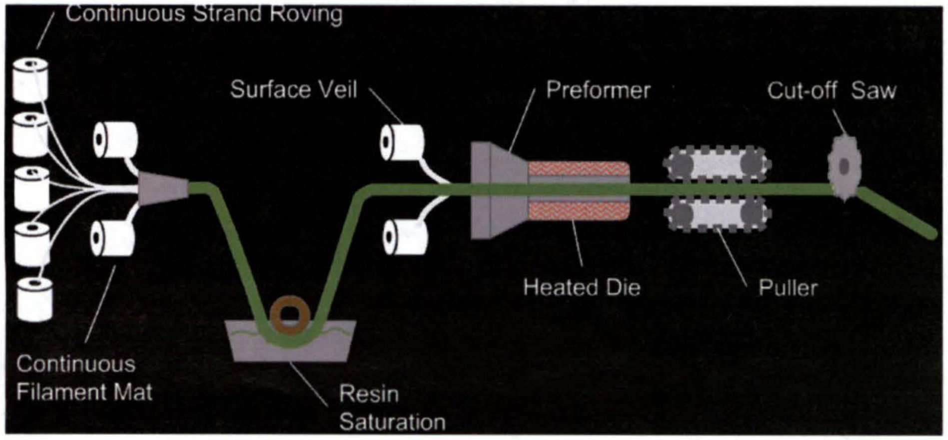
Manufacturing Techniques



← Vacuum Infusion Processing



← Resin Transfer Molding

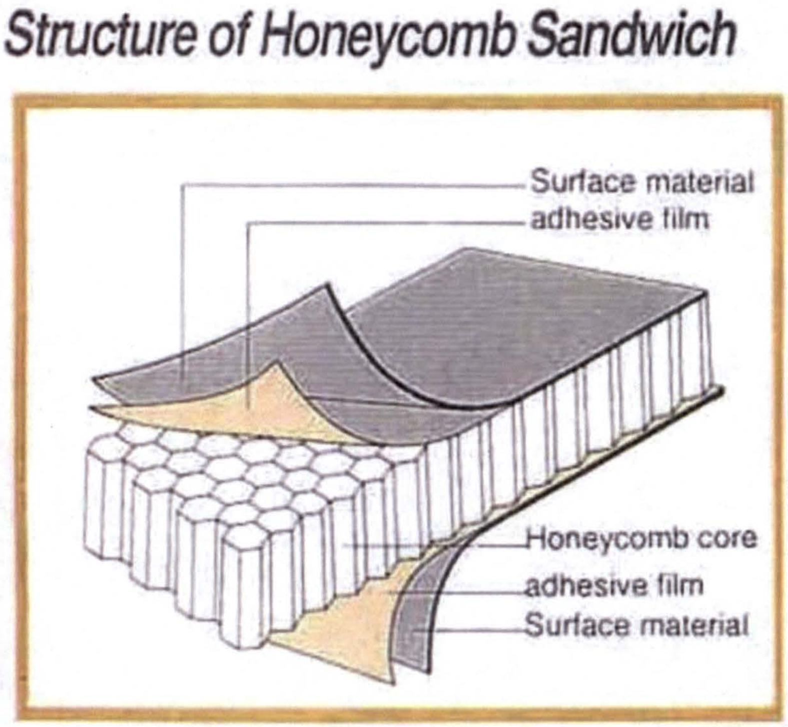


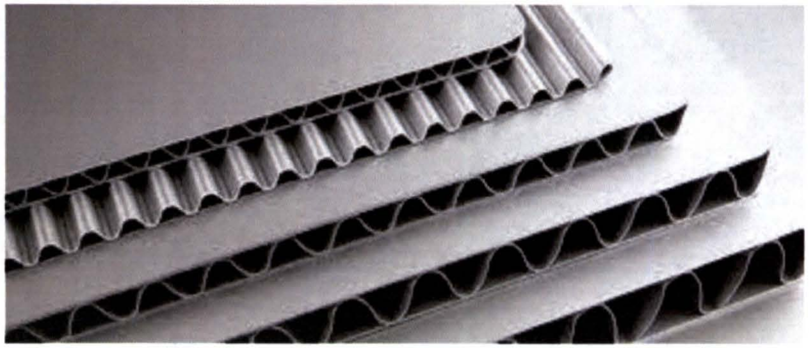
← Pultrusion Process

Images: SAMPE Overview of Composites

Core Material

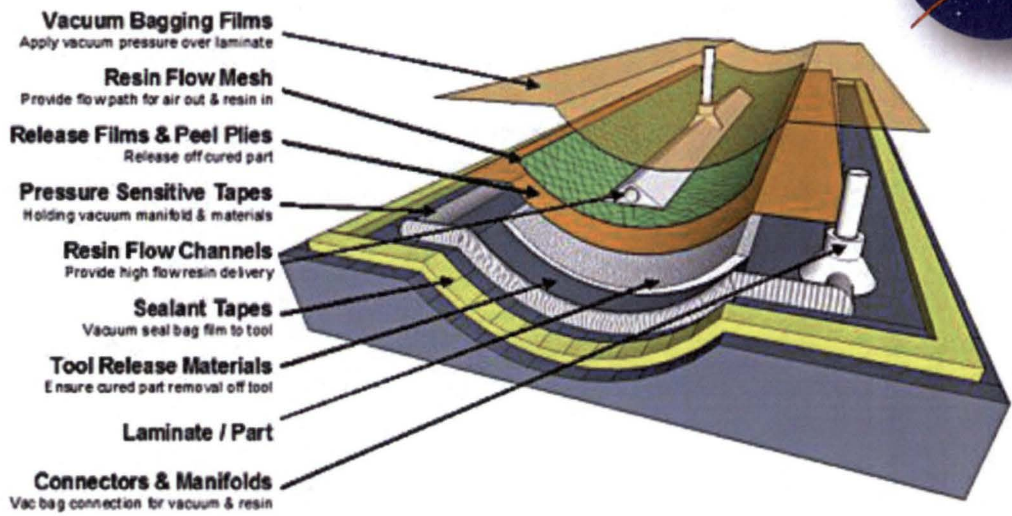
- Honeycomb, corrugated, foam core.
- Why use core?
  - Thermal insulation / thermal transfer
  - Dampening of vibration and noise
  - Filling of hollow spaces to limit water ingression

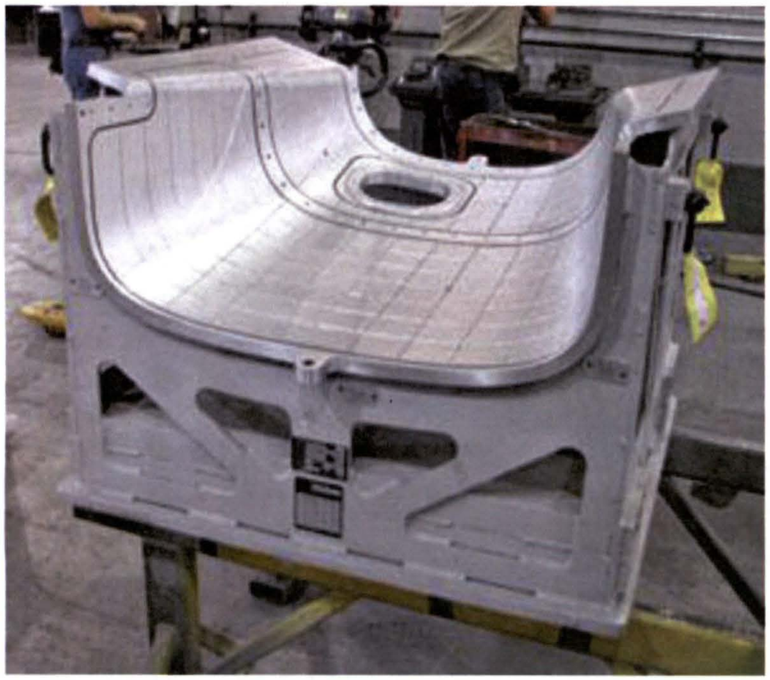


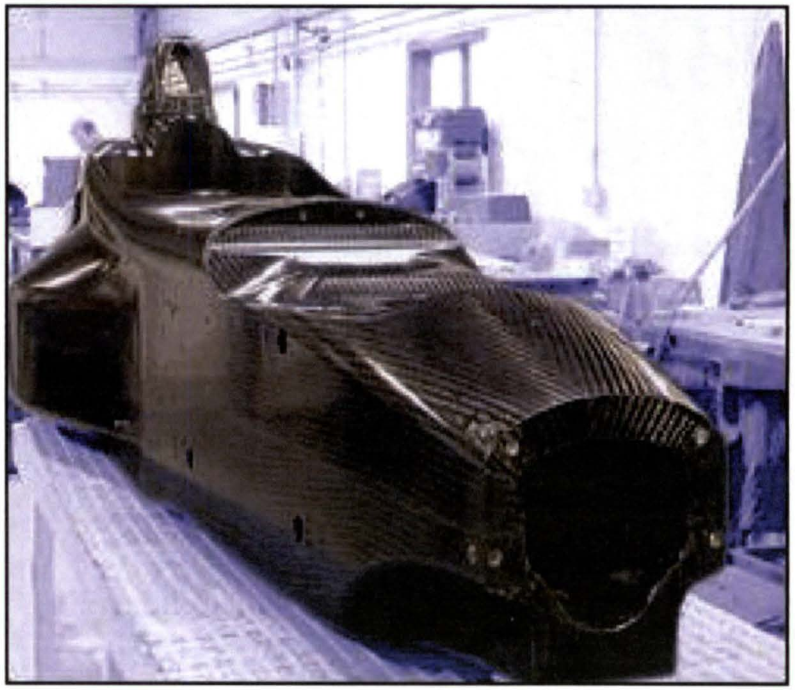


Tooling

- Important considerations
  - Coefficient of thermal expansion
  - Weight, transportation, handling
  - Operator friendly
  - Cost
  - Designing part removal







Composite Aerocover Overview

- History
  - Materials Science Division within the Engineering Directorate tasked by the Ares Launch Vehicle Division (LX-V) and the Fluids Testing and Technology Development Branch (NE-F6) to design, fabricate and test an aerodynamic composite shield for potential Heavy Lift Launch Vehicle infusion and a composite strut that will serve as a pathfinder in evaluating calorimeter data for the CRYOSTAT (cryogenic on orbit storage and transfer) Project.
  - ATP project is to carry the design and development of the aerodynamic composite cover or "bracket" from cradle to grave including materials research, purchasing, design, fabrication, testing, analysis and presentation of the final product.
  - Effort consisted of support from the Materials Testing & Corrosion Control Branch (NE-L2) for mechanical testing, the Prototype Development Branch (NE-L3) for CAD drawing, design/analysis, and fabrication, Materials & Processes Engineering Branch (NE-L4) for project management and materials selection; the Applied Physics Branch (NE-L5) for NDE/NDI support; and the Chemical Analysis Branch (NE-L6) for developmental systems evaluation.
  - Funded by the Ares Launch Vehicle Division and the Fluids Testing and Technology Development Branch will provide ODC

Composite Aerocover Overview

- Basic Concept
  - Evaluate previously certified composite systems, newly developed out of autoclave systems, and systems in development, i.e., aerogel/carbon fiber systems.
  - Developmental work (aerogel/carbon fiber systems) if successful could be expanded into future areas of composite rocket design, composite cryotanks, and future Habitat Demonstration Unit (HDU) projects.
  - Could eliminate the need for lengthy preparation time (applying primer, sanding), and the need for environmental control (for cure times, etc.), and allows for easy removal of closeout versus removing Spray on Foam Insulation (SOFI) by mechanical means such as scraping, digging, vacuuming.
  - Would eliminate the need for expensive foam application machinery, and time consuming SOFI applications.
  - In a contingency scenario, composites allows for expedited and clean removal, and avoids possible damage to flight hardware since minimal mechanical action is required to remove or reinstall.
  - Advance Kennedy Space Center's important role in the development of aerogel structural composites for NASA's future exploratory missions.

Composite Aerocover Overview

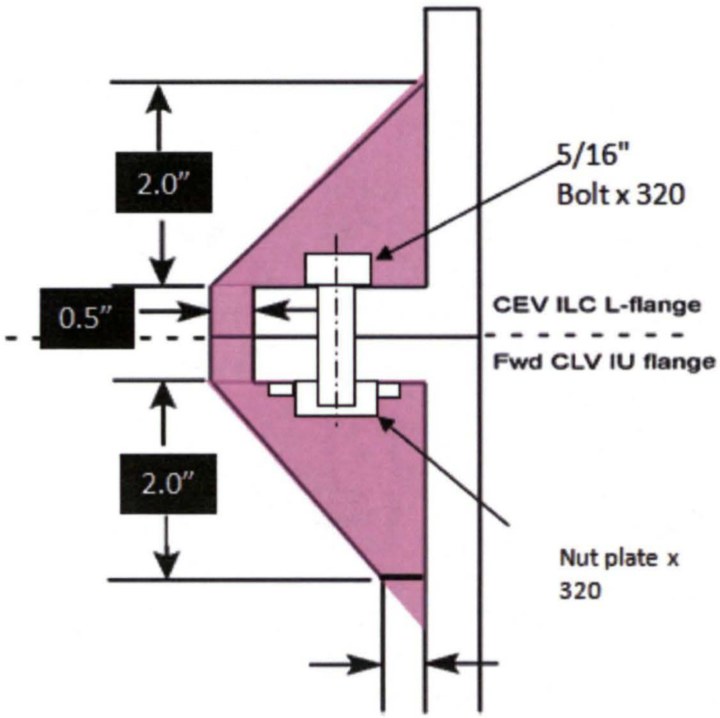
- Critical Milestones
  1. Fabricate composite control panels (panels without aerogel)
  2. Perform mechanical testing according to required ASTM methods
  3. Use mechanical data and input into Pro E and Comp Pro software
  4. Analyze data from Pro E and Comp Pro
  5. Fabricate panels using analysis from Pro E and Comp Pro (these panels will include aerogel blanket)
  6. Perform NDE (verify that there is not any defects as a result of manufacturing)
  7. Perform Mechanical Tests
  8. Compile and analyze mechanical data
  9. Manufacture aerodynamic cover using a mold system for composite fabrication
  10. Write a report and submit to LX-V

Composite Aerocover Overview

- ASTM Testing:
  - ASTM D 2734-90: Void Content Analysis: Standard Test Methods for Void Content of Reinforced Plastics.
  - ASTM D3039 / D3039M – 08: Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.
  - ASTM: D 3518/D 3518M – 94: Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a +/-45° Laminate.
  - ASTM C 297/C 297M – 04: Standard Test Method for Flatwise Tensile Strength of Sandwich Constructions.
  - ASTM D7264 / D7264M – 07: Standard Test Method for Flexural Properties of Polymer Matrix Composite Materials.
- Perform thermal conductivity analysis from the Cryogenics Test Laboratory for composite strut data.
- Receive on the job training for composite fabrication and composite mold fabrication.

Composite Aerocover Overview

- Reasons for Composite Aerodynamic Cover
  - To replace BX-265, a close-out foam insulation on Space Shuttle external tank.
    - Polyurethane foam (aka SOFI). Lightweight, proven operability, heritage use.
    - Lengthy processing time. Not environmentally sound as it contains 1,1-Dichloro-1-fluoroethane (HCFC 141B).



Interstage Join with TPS System in Pink

BX-265 - Spray on Foam Insulation - SOFI

Upper Flange Spray

Lower Flange Spray

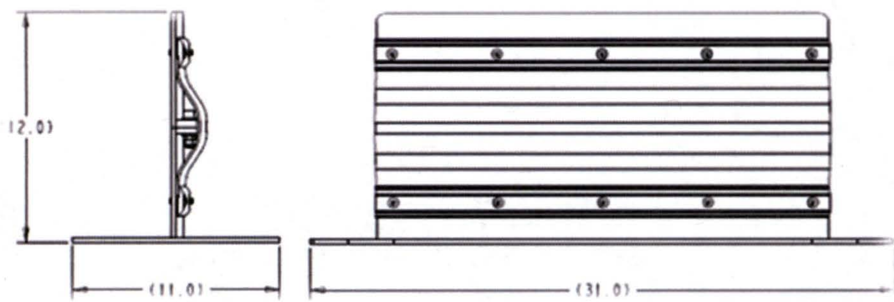
Time Consuming...

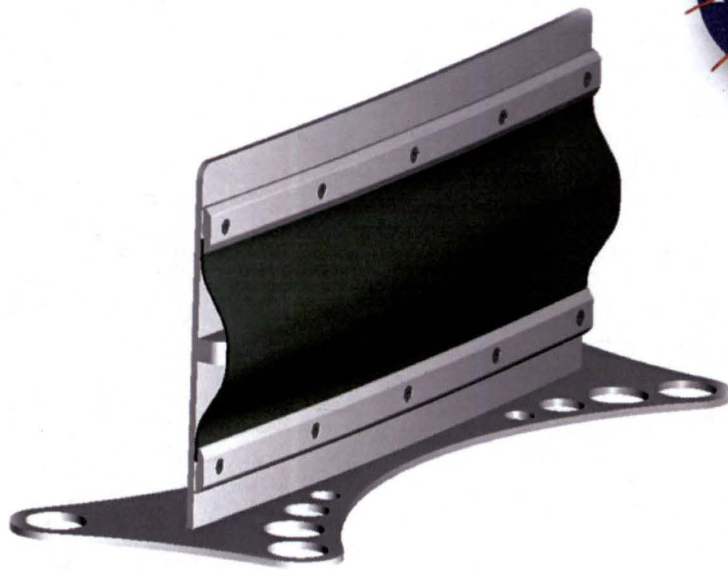
Composite Aerocover Overview

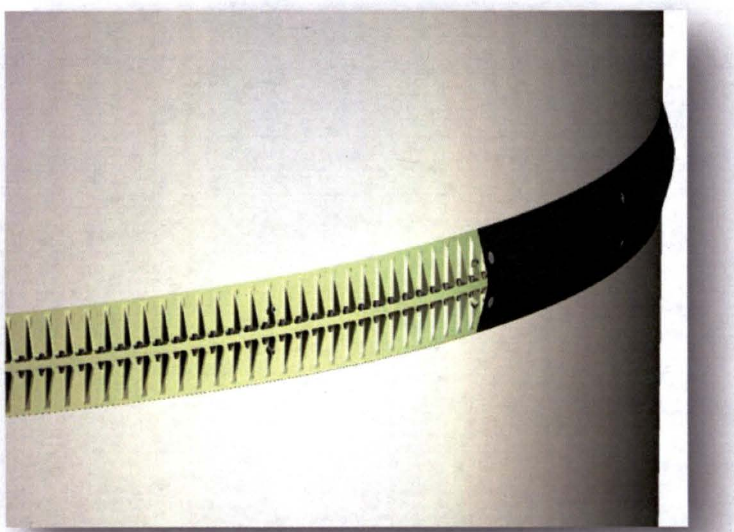
- **Requirements** for NEW proposed insulation candidate:
  - Minimize TPS mass
  - Minimize time and labor required to apply TPS
    - 4 hour nominal, 12 hour maximum target noted from vehicle integration timeline
    - Minimize TPS cure time and inspection of TPS bond line
  - Minimize environmental controls required during application and curing
    - Minimize impact to VAB timeline
  - Minimize FOD (foreign object debris) risk during ground operations and flight processing
  - Minimize TPS defects such as voids that form in difficult areas such as behind fasteners and corners which will help eliminate potential TPS debris
  - Minimize use of products that may cause contamination of flight hardware during application and curing such as:
    - Xylene, heptane, silicone
  - Minimize time and cost to remove and replace TPS for de-stack contingency
    - Also minimize time to repair TPS if damaged during ground processing
  - Minimize development cost

Composite Aerocover Overview

- Aerodynamic Cover Design



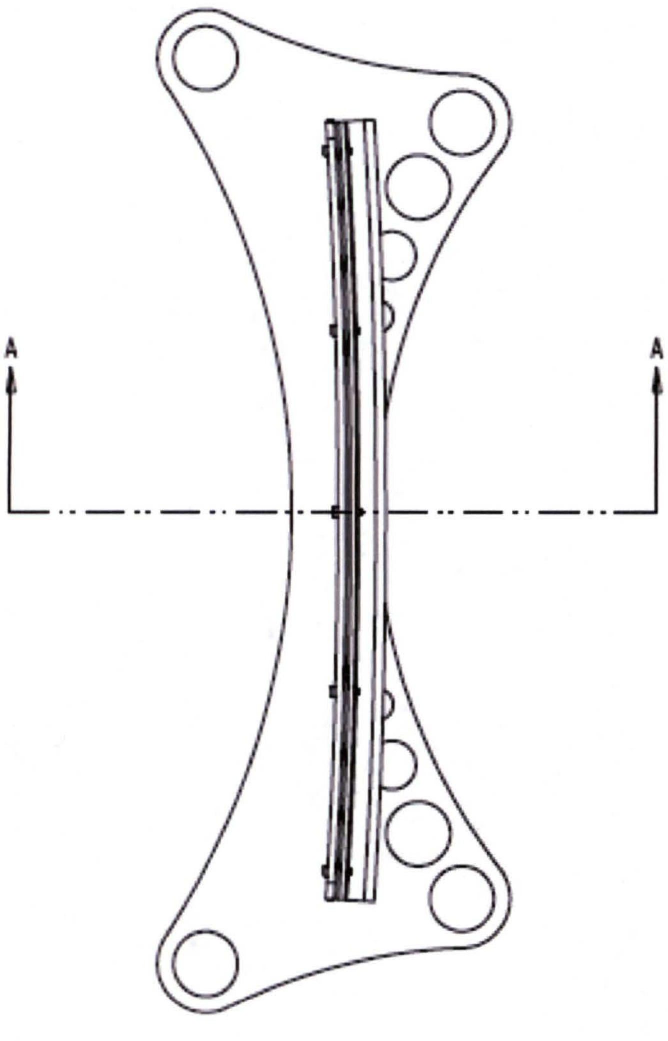




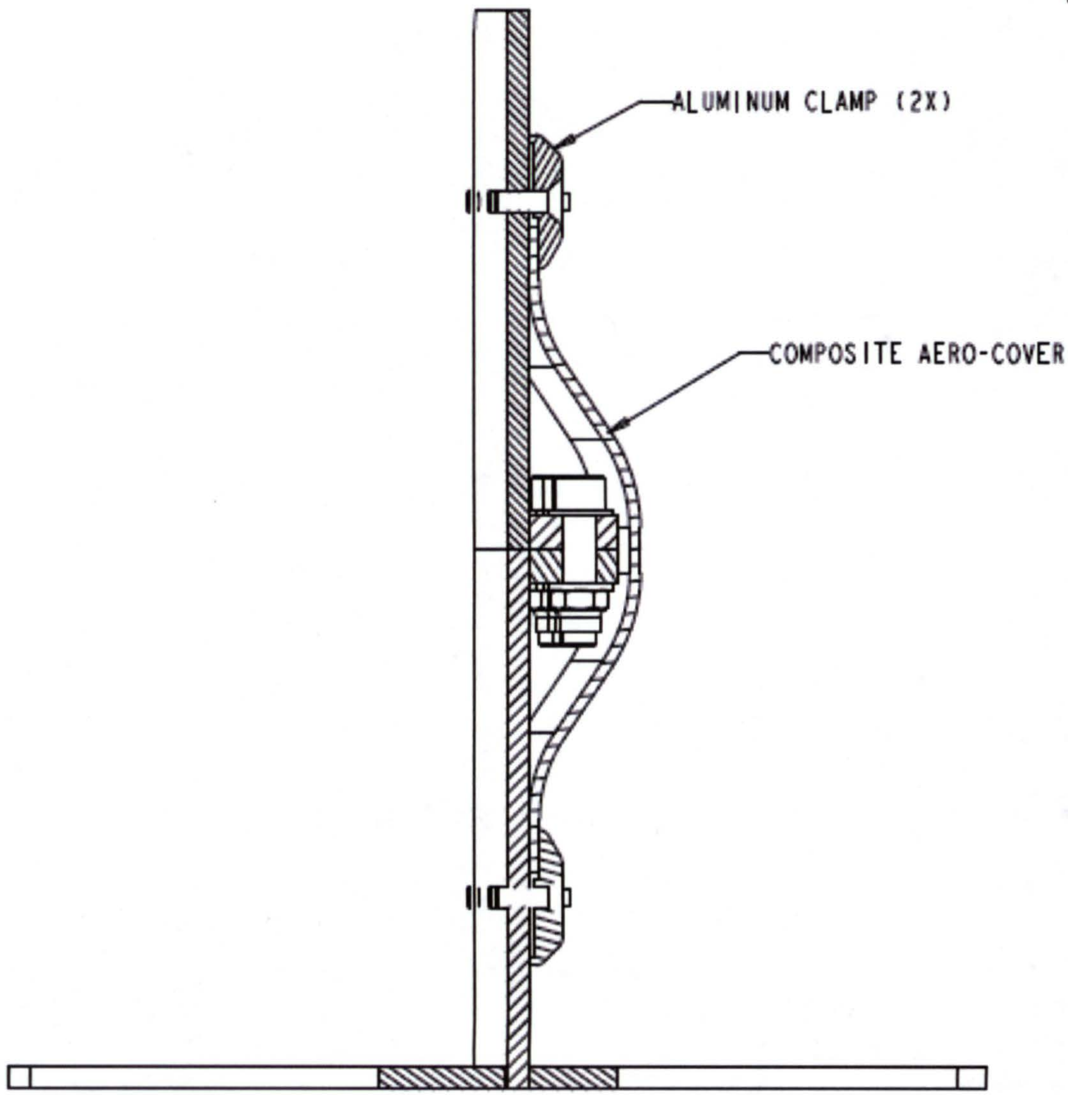
Composite Aerodynamic Cover Revealing Layered Structure for Realistic Attach Method

- Represents a 24 inch segment of the 10 meter circumference of the Constellation Ares V heavy lift vehicle architecture.
- At the time of this project there was no existing architecture of the future heavy lift vehicle.
- The cover is mounted on a display stand and slipped into upper and lower brackets. These brackets are screwed into the display structure. There are many possible concepts on how to attach the aerodynamic cover to the actual vehicle structure.
- A concept was developed for realistic attach methods to a launch vehicle
- For this project, the analyses of loads were performed only on the solid composite aerocover, and not the fixture or aerocover attachment sequence.

Composite Aerodynamic Cover Concept



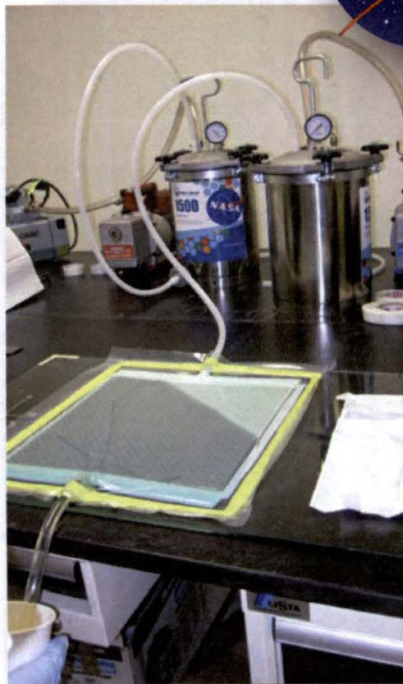
TOP VIEW



SIDE VIEW

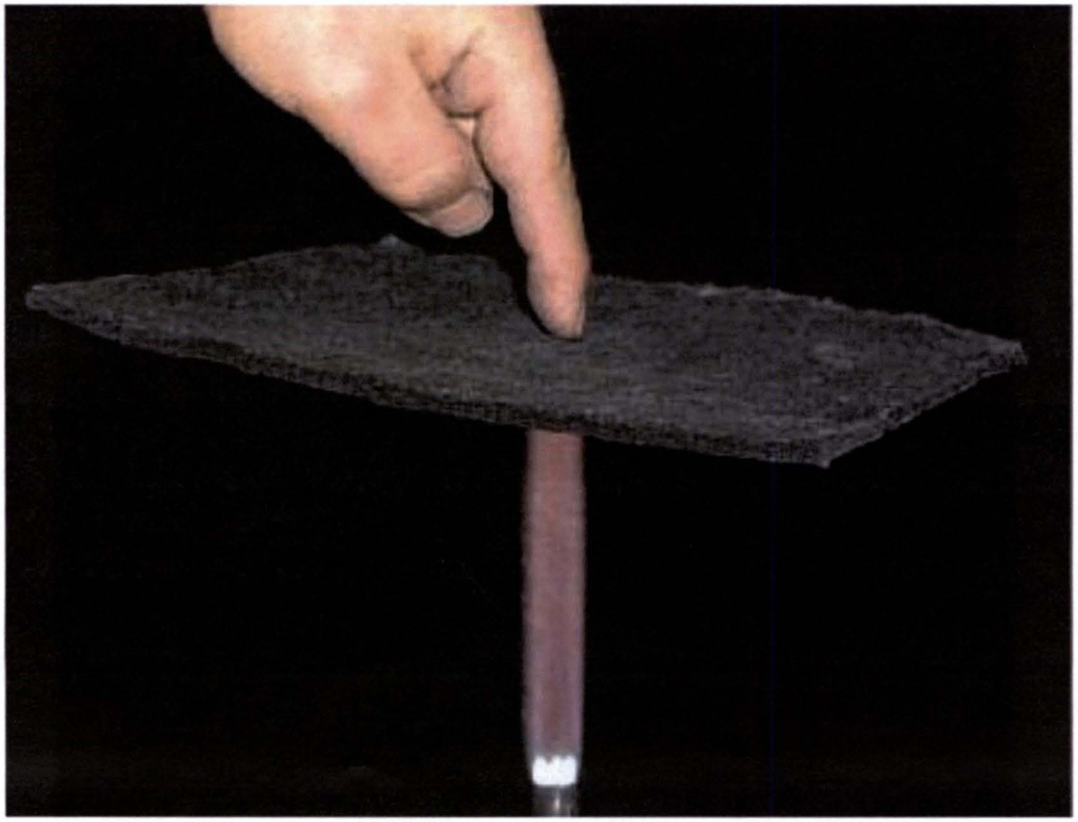
Composite Aerocover Overview

- Composite Shell
  - **Resin:** Aeropoxy, a two-part epoxy: PR5320/PH 3660
  - **Fibers:**
    - 3K Carbon Fiber Reinforcement - plain weave, 5.8 oz/yd^2
    - Rayon based Graphite Fiber Reinforcement ("Shuttle Cloth")
  - **Core:**
    - Pyrogel® 2250Low thermal conductivity, high temperature resistance
    - 392°F and is 0.08 inches
  - **Adhesive:**
    - AX-2120 by Axiom Materials
      - low temperature cure, epoxy film adhesive, designed for prototype development and foam layup applications.
      - Cure temperature 160°F
      - Service temperature of 220°F.
      - AX-2120 adhesive material was sent to KSC as a free test sample, which is why it was used for this prototype development project. In the future, other high performance adhesives can be used such as FM products.



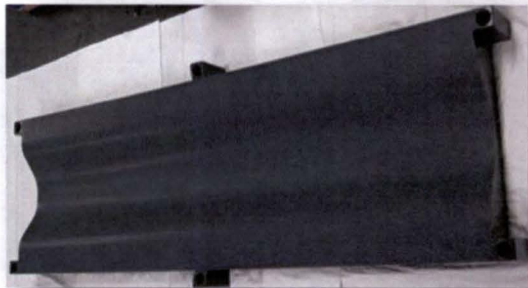
Core Material: Pyrogel®

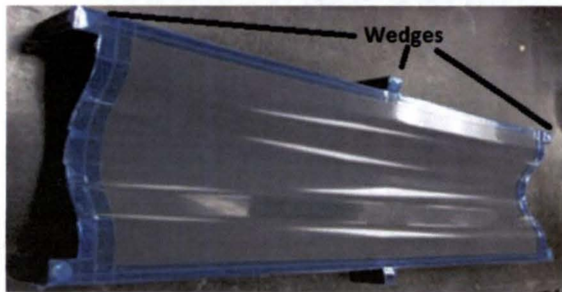
- Pyrogel – Silica Aerogel embedded into black reinforcing fiber
- Flexible, nano-porous, insulation
- Withstand torch impinging on bottom surface (1000C) and maintain cool surface temperature!



Composite Aerocover Overview

- **Tooling:**
  - MP-1065 Model Plank tooling board from Cass Polymers
  - 40lb/ft^3 density, 136°F heat deflection temperature
  - excellent machinability with carbide cutters
- **Sealant**
  - Machined and coated with approximately 3-5 mils of DuPont™ epoxy sealant system (DuPont™ Low VOC Prime'NSeal® 2710S™ / 2740S™ / 2770S™).
  - Applied in two separate coats
  - Treated with 600 mesh sand paper for a smooth finish
  - Small pinholes that were left on the mold, but they did not leave any macroscopic positives on the final aerocover part.
  - Pin holes may have resulted from the mold being treated with Xylene as a cleaning agent prior to the epoxy sealant layer, with only several minutes of drying time between layers.
  - Xylene may have seeped into the tooling board and then at its escape, creating small pinholes in the part.
  - holes may have also been so deep in the porous polymer tooling material that the DuPont sealer was unable to fill the void space completely.
- **Mold Release**
  - Zyvax Waterworks - 3 step system comprised of a cleaner, sealer (pre-flight) and departure mold release agent.
  - Easy to use, non-hazardous and designed specifically for the aerospace industry.
  - 500°F.
  - Blue Flashbreaker tape was applied to the edges of the tooling board to maintain a surface free of mold release.





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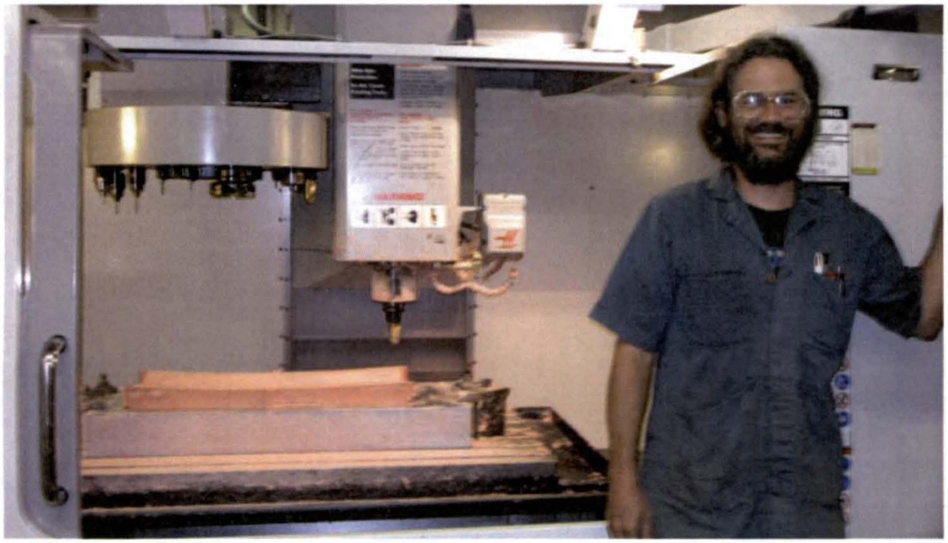
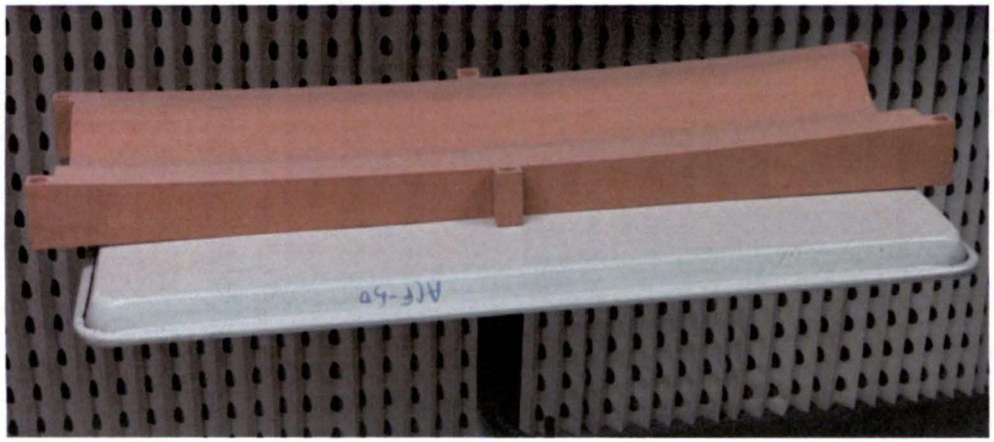
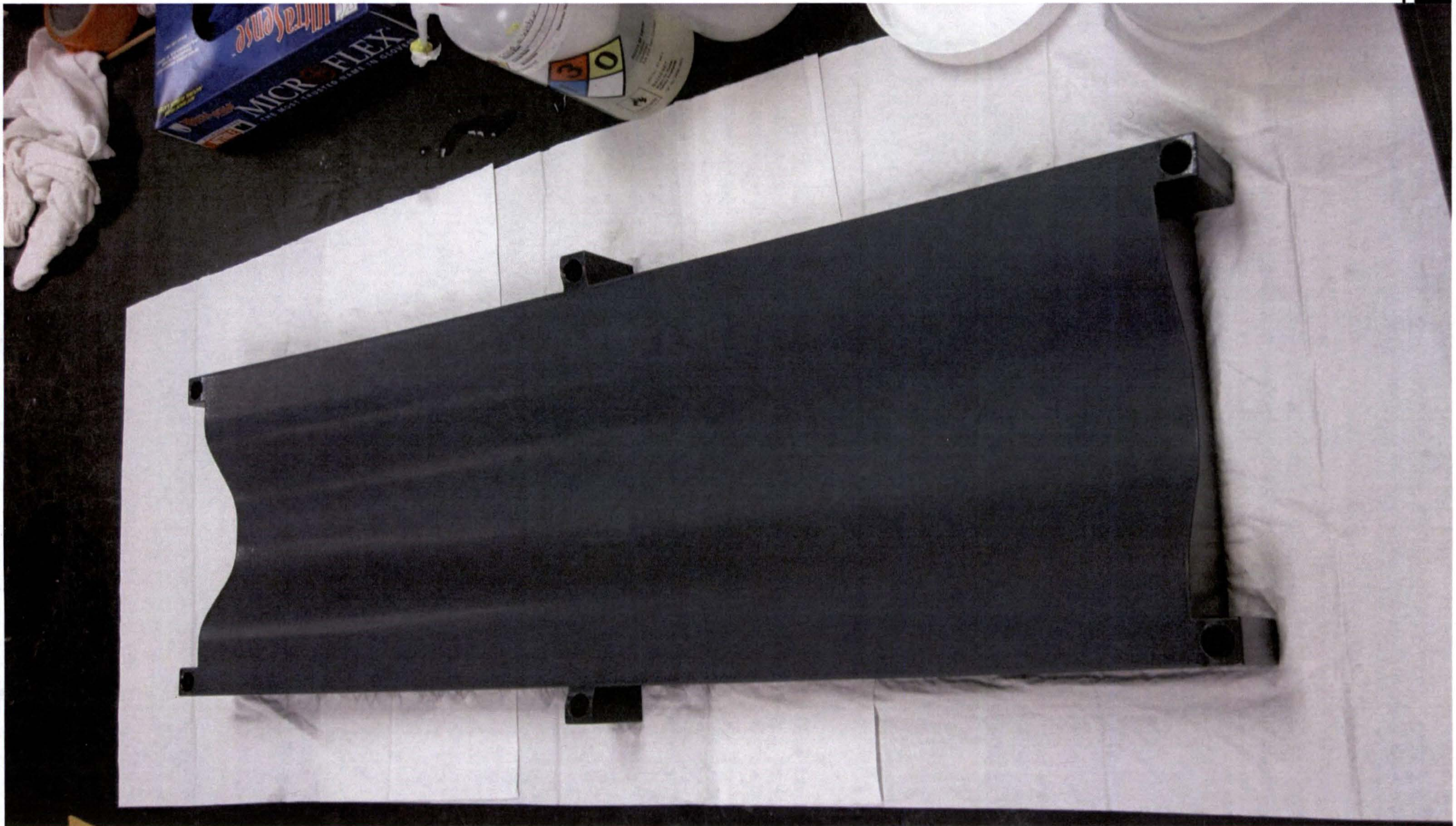
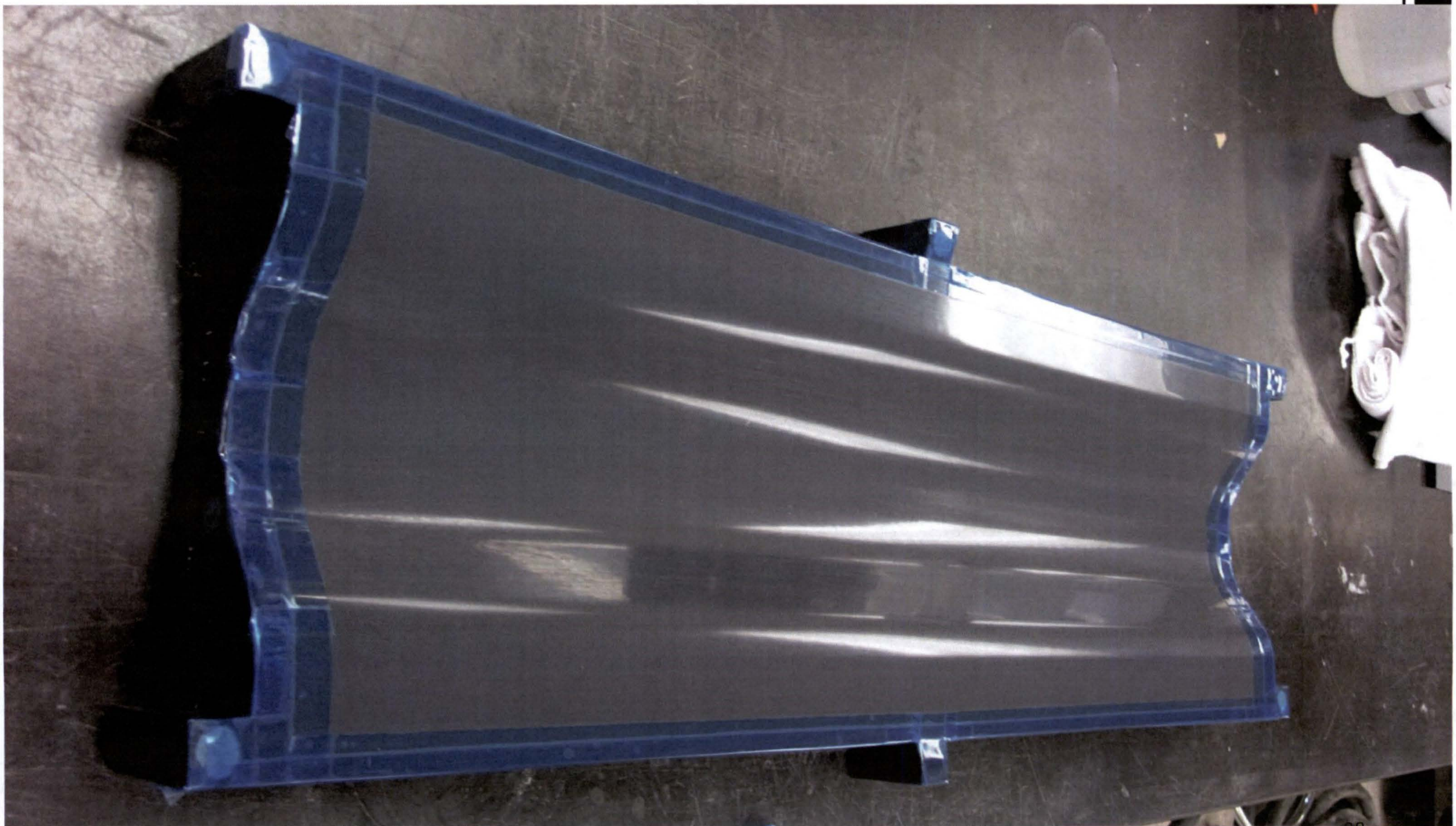




Aerocover Mold Prep – Before Mold Release



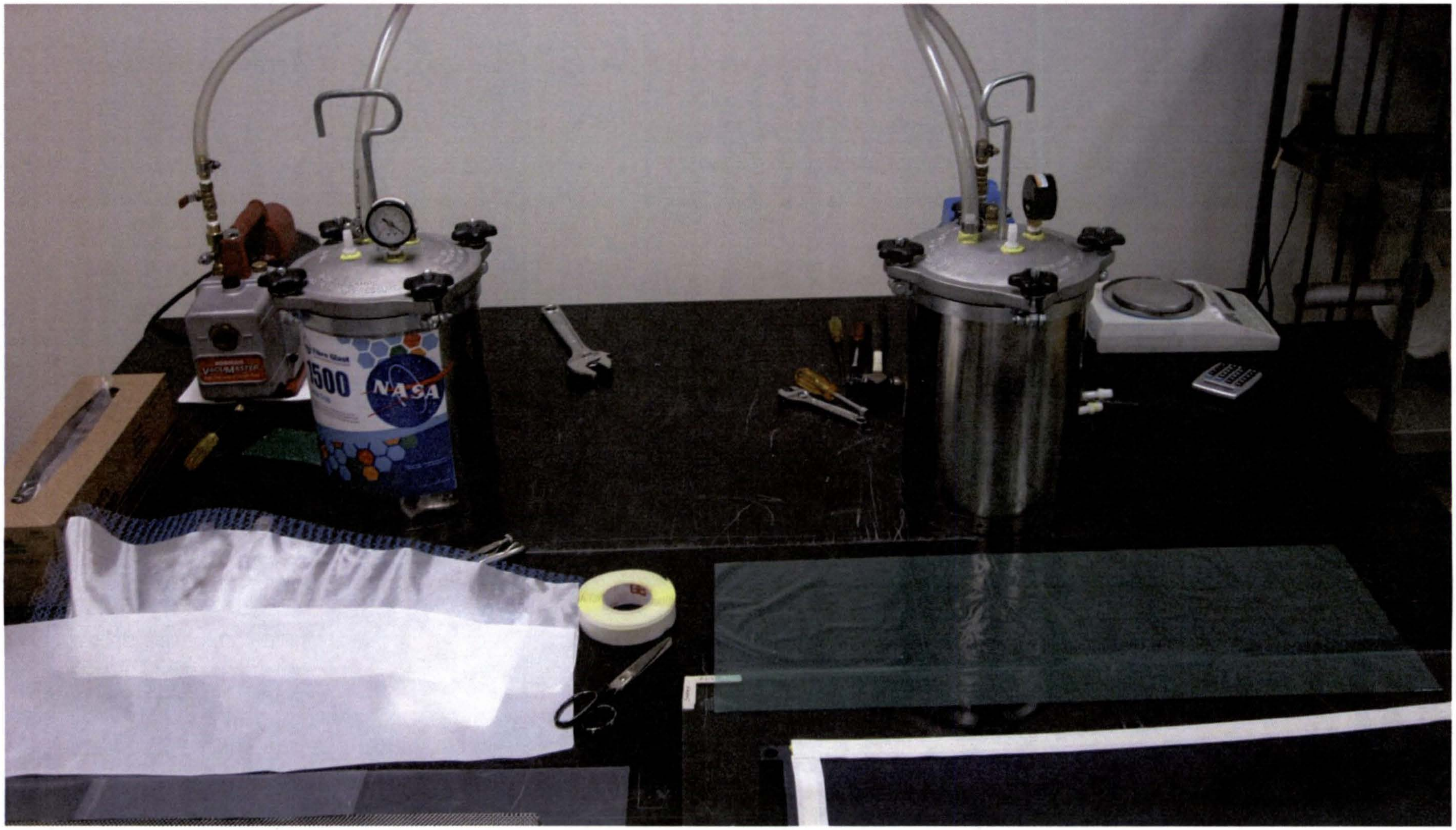
Aerocover Mold Prep – After Mold Release



Composite Aerocover Overview

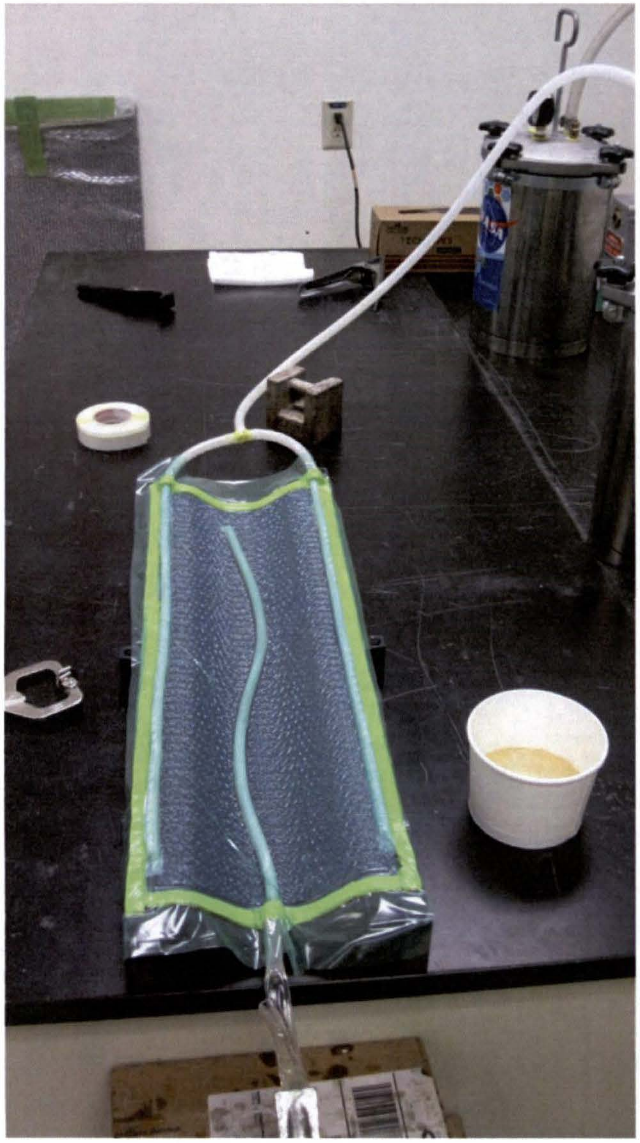
- **Manufacture** of flat laminates for mechanical testing:
  - Vacuum infusion
- **Manufacture** of aerocover shield:
  - Wet lay-up
    - Favored method
  - Vacuum infusion
    - Vinyl tube left positive on the part
    - Not yielding enough resin for quality part

Composite Aerocover Overview



Composite Aerocover Overview

Aerodynamic Cover / First Attempt



[0,90,+45,-45] [Adhesive] [Pyrogel] [Adhesive] [-45,+45, 90, 0]

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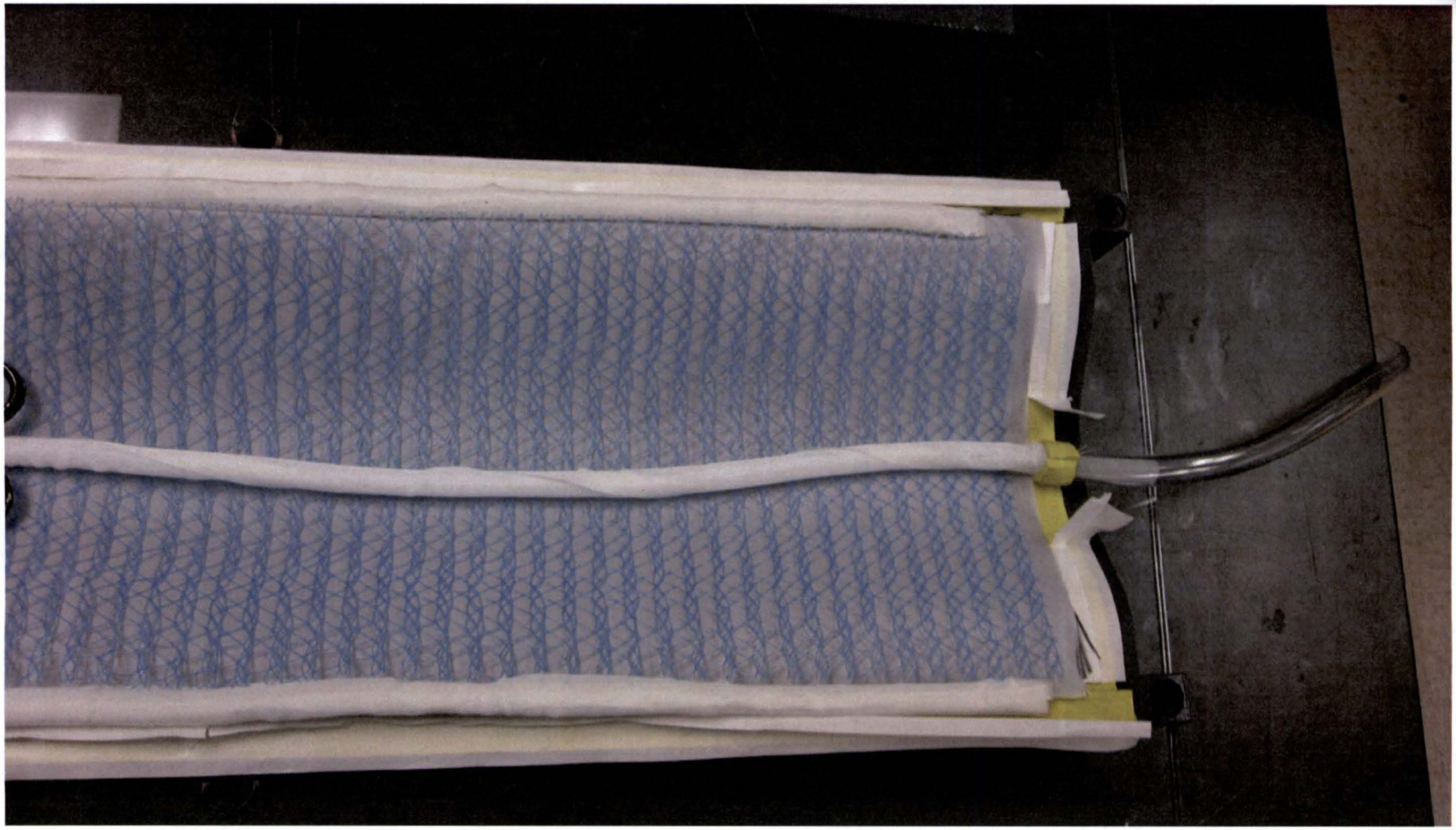
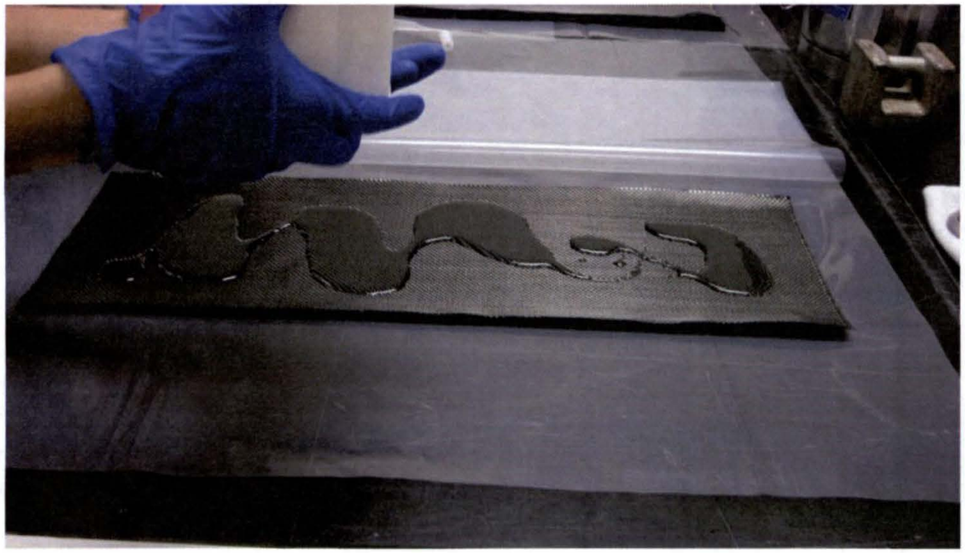
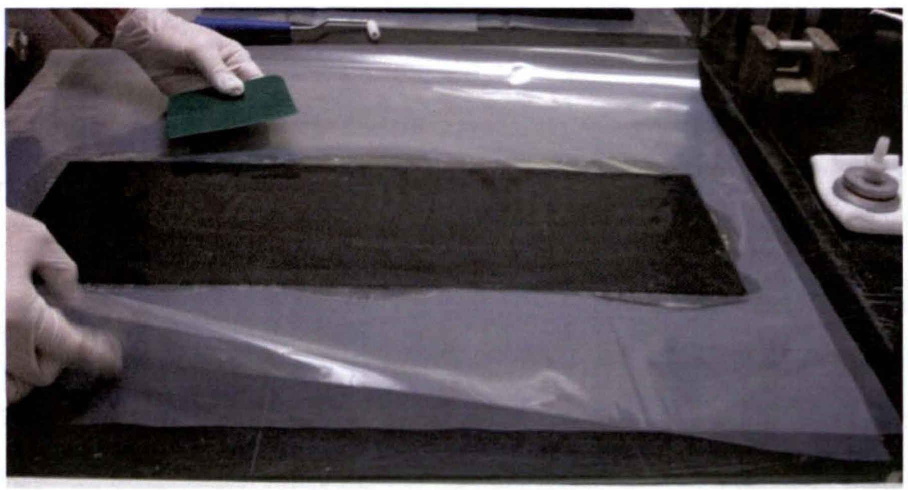
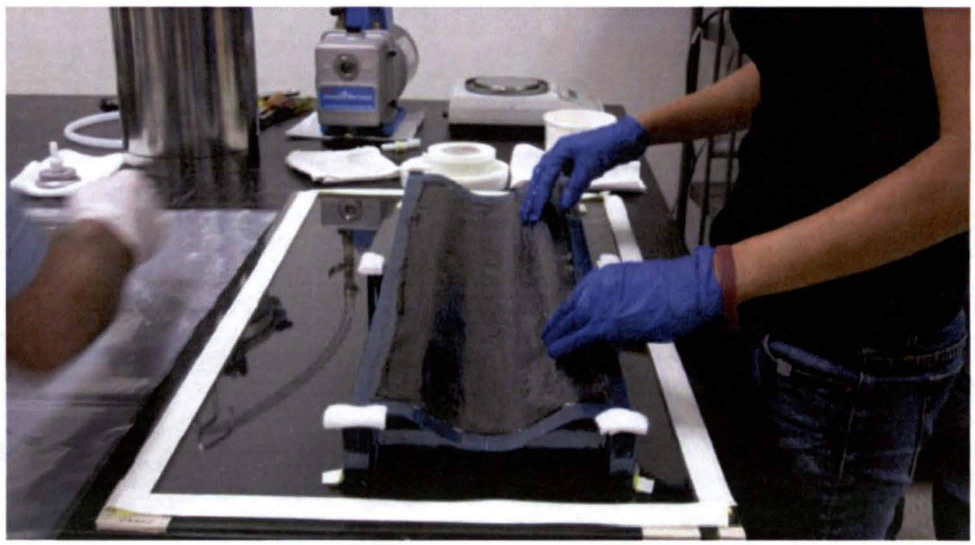


Composite Aerocover Overview







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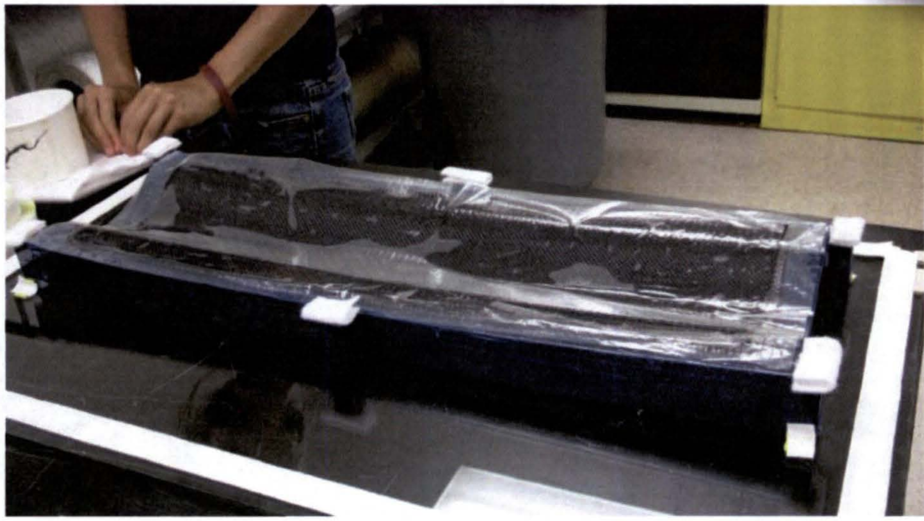

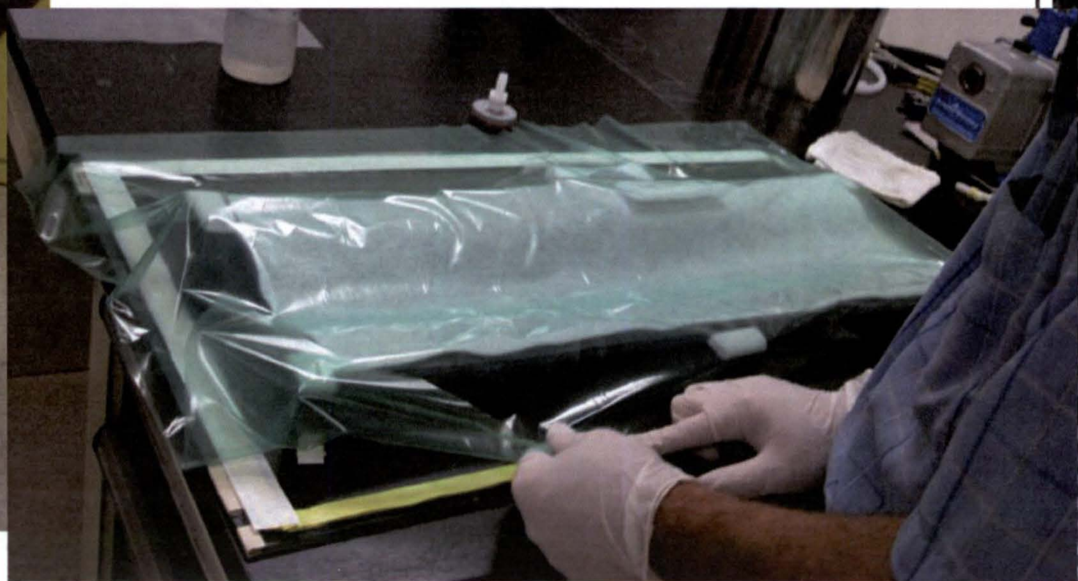

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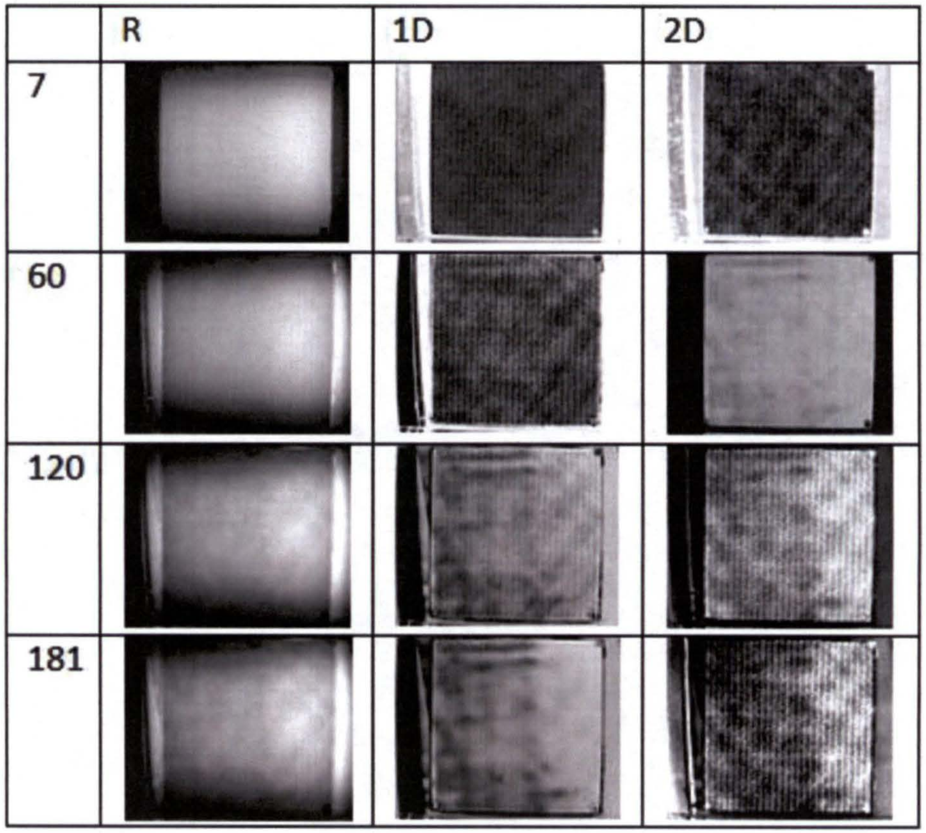
- Non Destructive Testing
  - Flash thermography imaging of the front and back side of each composite panel.
  - Uses a heat source to heat the composite part that is being inspected. As the composite part is cooled down, an infrared camera monitors the temperature distribution across the surface. The infrared camera is paired with digital processing equipment to indicate defects in the part.
  - TWI Flash Thermography System. Provided: temperature (R data), rate of temperature change in time (1D Data), and the rate of the rate of temperature change in time (2D data).



Composite Aerocover Overview

- Void Content Analysis
  - *ASTM D 2734-90: Void Content Analysis: Standard Test Methods for Void Content of Reinforced Plastics*
  - *Should be less than 1%*

$$T = 100/(R/D + r/d) \quad (1)$$

$$V = 100(T_d - M_d)/T_d \quad (2)$$

Where:

T = Theoretical density

R = Resin in composite, weight %

D = Density of composite

r = reinforcement in composite, weight %

d = density of reinforcement

V = Void content, volume %

T_d = Theoretical Composite density

M_d = Measured composite density

Table 1- Void Content Analysis

Void Content, Volume %					
3k [0, 45, 90, -45]s		**3k [-45, 90, 45, 0]**		**3k [0, 45, 90, -45]**	
Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
1.12	3.14	12.04	9.87	10.39	12.67

Composite Aerocover Overview

Table 3 - ASTM C 297/C 297M - 04 Data

Specimen Label	Load at Tensile Strength (Pound Force - lbf)	Tensile stress at Tensile Strength (Pounds Per Square Inch - psi)	Layup Scheme
A-1	65.5	16.4	#12, 8-ply, [0,45,90,-45]s with Aerogel felt
A-3	66.9	16.7	#12, 8-ply, [0,45,90,-45]s with Aerogel felt
A-3	69.7	17.4	#12, 8-ply, [0,45,90,-45]s with Aerogel felt
A-4	53.2	13.3	#12, 8-ply, [0,45,90,-45]s with Aerogel felt
A-5	58.1	14.5	#12, 8-ply, [0,45,90,-45]s with Aerogel felt
Average	**62.68**	**15.66**	**8-ply [0,45,90,-45]s Aerogel, Axiom, Aeropoxy**
B-1	71.6	17.9	4-ply, [0,45,90,-45] with Aerogel felt
B-2	83.4	20.8	4-ply, [0,45,90,-45] with Aerogel felt
C-2	43.1	10.8	4-ply, [0,45,90,-45] with Aerogel felt
B-3	85.7	21.4	4-ply, [0,45,90,-45] with Aerogel felt
B-4	72.2	18	4-ply, [0,45,90,-45] with Aerogel felt
B-5	82.6	20.6	4-ply, [0,45,90,-45] with Aerogel felt
C-4	55.1	13.8	4-ply, [0,45,90,-45] with Aerogel felt
C-5	50.6	12.6	4-ply, [0,45,90,-45] with Aerogel felt
C-1	24.7	6.2	4-ply, [0,45,90,-45] with Aerogel felt
C-3	15.9	4	4-ply, [0,45,90,-45] with Aerogel felt
Average	**58.5**	**14.6**	**4-ply [0,45,90,-45] Aerogel, Axiom, Aeropoxy**
Average (C-1, C-3 removed)	**68.0**	**17.0**	**4-ply [0,45,90,-45] Aerogel, Axiom, Aeropoxy**

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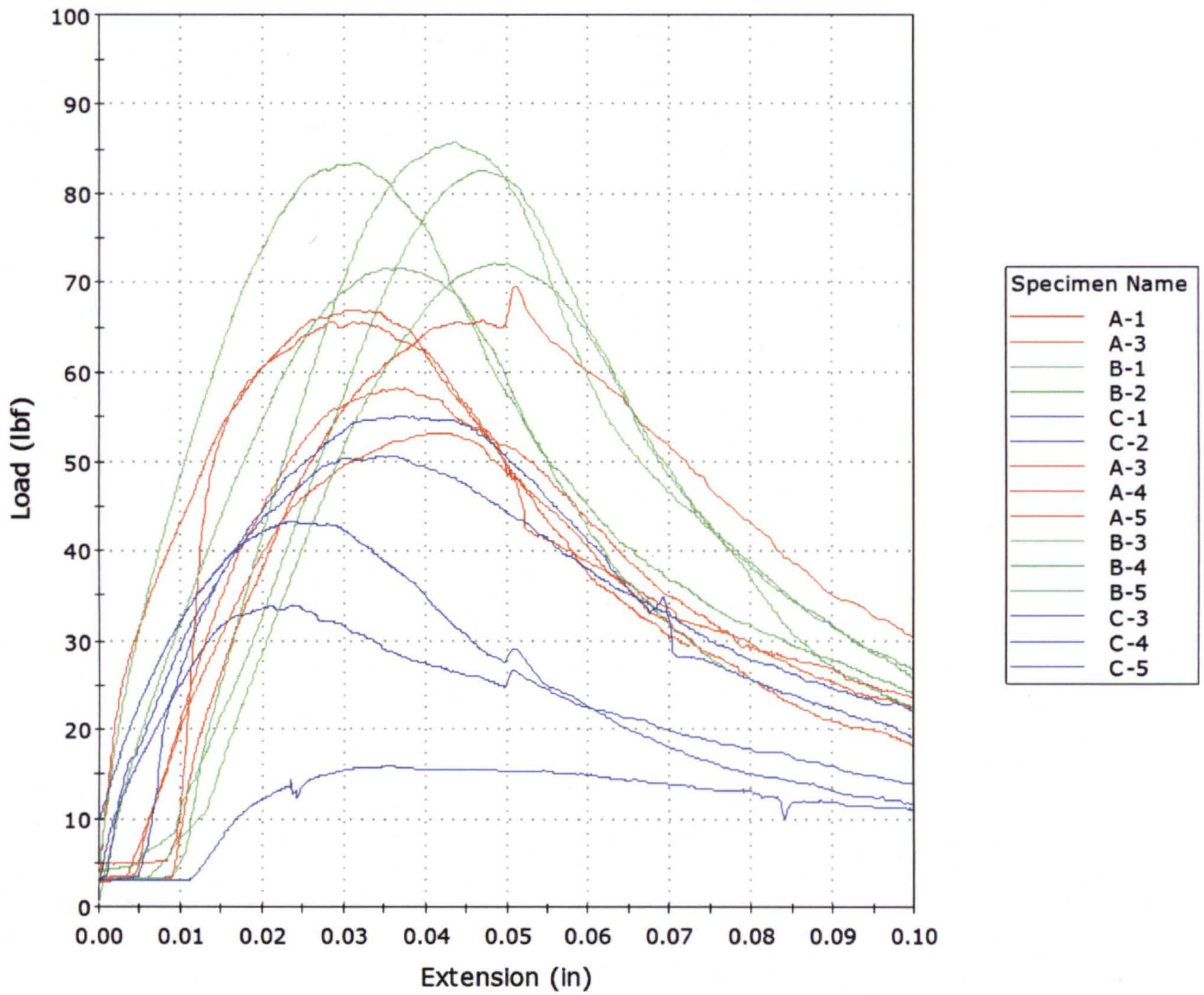

References

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