Non-Autoclave (Prepreg) Manufacturing Technology

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.Jointly accomplished by a Boeing Led Team and the U.S. Government under the guidance of the Air Force
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Acknowledgements

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Phase 1 Program Objectives

- Demonstrate a readiness level of 3 in 18 months for a 200°F oven cure (vacuum pressure only), 350°F post cure epoxy prepreg system (250 deg F use, medium tough) for structure co-bonded or secondarily attached.
  - **Material**
  - **Process**
  - **Tooling**
  - **Equipment**
  - **Key Features, Design Guidelines**
  - **Full Size – Dissection and engineering evaluation (example)**
- Demonstrate a technology readiness level of 4 in 30 months (7 of 8 criteria fulfilled on MRL of 6*)
  - **Transition Process to Fabricators**
  - **Full Size**
  - ***Develop Transition to Application***

*Defense Science Board Report, 2006, Appendix H: Manufacturing Readiness Levels
http://www.acq.osd.mil/dsb/reports/2006-02_Mantech_Final.pdf

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Addressing Technical Challenges to Enable Disruptive, Pervasive Use of Non-Autoclave Manufacturing

- Autoclave Type of Properties With a Initial Cure Temperature of 200°F with Vacuum Pressure Only and a Free Standing Post Cure @ 350°F
- Large, Void Free Components
- Material Family for Monolithic, Co-cured, Co-bonded Unitized and Sandwich Structures
- Structural Life >5K Hours
- Reduced Cost/Span Time Tooling Family for Use in 10-25 Units
- Processing and Tooling to Match Production

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Material Comparisons

	Material		Blue=Tests by Boeing	
Properties	1st Generation Non-Autoclave	2nd Generation Non-Autoclave	Target for 3rd Generation Non-Autoclave (X5320) Candidate C actuals	Current Autoclave
Wet Tg (°F)		250	300 329 (DMA)	300
-65F Filled Hole Tension (ksi)		60	60	60
220F/Wet Open Hole Compression (ksi)	21	30	41 38	41
Interlaminar Tension (ksi)		2.9	3.5	3.5
220F/Wet Pin Bearing (ksi)	52	75	85 113	85
Cure Temp (°F)	180	180	200	350
Out Time (days)	5	30	30 15	30
% Porosity	4	<1	<1	<1
Structural/Production Application	Prototype Secondary and Primary	Prototype Secondary and Primary; Production Secondary	Production & Prototype Primary/Secondary	Production Primary
Compression Strength after Impact (ksi)	18	18	25	25
Fiber Compatibility	High Strength	High Strength; Intermediate Modulus	High Strength; Intermediate Modulus; Possibly High Modulus	High Strength; Intermediate Modulus
Tooling	Simple; Inexpensive	Simple; Moderate Expense	Simple; Moderate Expense	Complex; Expensive

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Program Approach

Z, T, hats, honeycomb, syncore,
Thick, large, ramps, complex contour

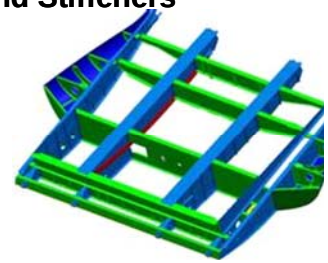
Equipment studies – ovens, vacuum pumps

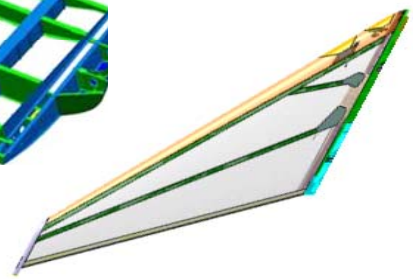
Freezer life
Processing variations – ramp rate,
Temperature, vacuum, debulk, damming, cure and post cure

Cross-ply, quasi-isotropic panels
15 and 30 day out time discriminator panels
Rabbet panel

Composite Design Options

- Individual Monolithic Skins and Stiffeners (I's, C's and/or Z's) Secondarily Attached
- Sandwich Skins and Stiffeners (I's, C's and/or Z's) Secondarily Attached
- Cocured/Cobonded Hat Stiffened Skins and Stiffeners (I's, C's and/or Z's) Secondarily Attached
- Unitized Skin and Stiffeners





TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6
Initial Material & Processing Guidelines and Properties	Processing /Manufacturing and Material Optimization and Limits	Part Configuration Limits	• Full Size Demo Parts @ Fab Companies • Draft Specs & Guidelines	Transition Candidate Subcomponent Evaluation	Technology Transition Candidate Demonstration
Phase I				Phase II	

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Program Schedule

17 July 2007 – Agreement Signed

17 March 2008 – Material Selection Milestone, X5320 resin

9 September 2008 – Industry Review

- Q5 Report – Draft Material Specification, Tool Design Guidelines
- Q6 Report – Summarize MRL 3, Draft Process Specification, Design Guidelines

17 March 2009 – Cut up report/summary - demonstration article(s)

- Q7 Report – Tooling Replication, Part Dissection, Test Results, Fatigue Analysis
- Q8 Report – Summarize status to MRL 4

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X5320 Specifications

- **MMS 5063** "INTERMEDIATE MODULUS CARBON FIBER REINFORCED TOUGHENED EPOXY PREPREG, ATMOSPHERIC PRESSURE CURING”
- **MMS 5064** "CARBON FIBER REINFORCED TOUGHENED EPOXY PREPREG, ATMOSPHERIC PRESSURE CURING”
- **MMS 5065** "QUARTZ FIBER REINFORCED TOUGHENED EPOXY PREPREG, ATMOSPHERIC PRESSURE CURING”
- **MMS 5066** "FIBERGLASS REINFORCED TOUGHENED EPOXY PREPREG, ATMOSPHERIC PRESSURE CURING”
- **PS14450** “ATMOSPHERIC PRESSURE CURING TOUGHENED EPOXY LAMINATES AND SANDWICH STRUCTURES; FABRICATION AND ACCEPTANCE OF"

Specs shown are Boeing-specific; we are also considering industry standards (SAE AMS specs or equivalent).

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Science Based Processing

Characterizations
- Resin Kinetics
  - Dynamic and Isothermal DSC
- Resin Viscosity
  - Dynamic and Isothermal RDS
- Fiber Bed Permeability and Elasticity
- 3 Point DMA (Resin and Prepreg)
  - Modulus Development
  - CTE
  - Shrinkage
  - Tg

Characterizations
- Oven Temperature
  - Thermocouple readings
- Air Velocity
  - Air flow meters
- Heat Transfer Capability
- Vacuum System Capability
  - Pumps
  - Atmospheric conditions
- Tool Mass
- Tool Thermal Capabilities

Modeling and Simulation
- COMPRO
- CACC/ASCOM

Processing/Manufacturing Uses
- Property Development with Cure and Post Cure
  - Tg
  - Resin Flow
  - Degree of Cure
- Tooling Spring-in Compensation
- Exotherm
- Thick-Thin Cure Compatibility
- Tooling/Oven/Resin Cure Compatibility
- Cure Compatibility With Multiple Part Material Types
- Temperature and Pressure Gradients

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Tooling Replication

Selected tooling used for fabrication will be demonstrated to show acceptable repeated use for 10-25 units. Thermal cycling will include temperatures greater than the material processing temperatures (chosen to account for variability and still show robustness).

Brake Formed Polycarbonate

Hybrid Concept with Surface Master™905 M LS

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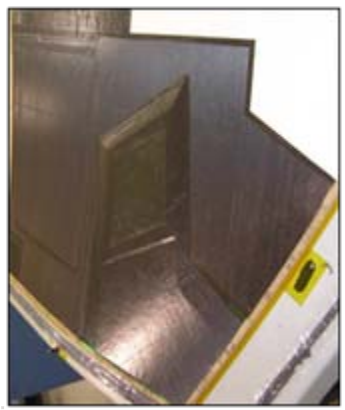
Feature Dissection

Part(s) of representative scale will be used to verify that representative key features can be acceptably produced with the materials, processes, and tools of this program via:

- Dissection and photomicrographic evaluation
- Limited static testing of features, and
- Engineering evaluation of fatigue on critical details

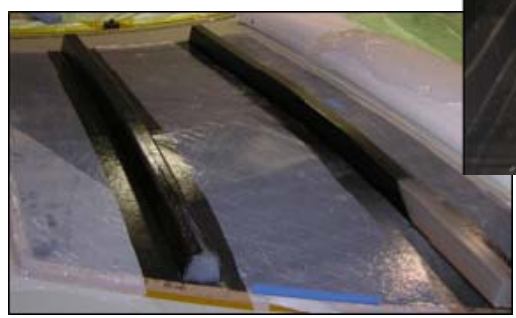
The 20 month demonstration article was fabricated by Boeing. Additional articles will be fabricated by subcontracted fabricators.

3 ft x 5 ft Stiffened Skin



Rabbet Detail

Hats and Blades



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Upcoming Presentations/Meetings

- 2008 Fall Society for the Advancement of Material and Process Engineering (SAMPE), September 2008 in Memphis, TN – Manufacturing and Processing Advances 2A, 2:00 pm, Room L5

- 3’ x 5’ X5320 Co-Cured Stiffened Skin will be on display in the U.S. Air Force AFRL/RX exhibit space (323) until 4PM Wednesday.

- Defense Manufacturing Conference 1-4 December 2008,
  - Composite Processing and Fabrication Session, Wednesday, 3 December, at 2:00 pm.

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Discussion/Feedback

- Material characteristics
- Material product forms
- Industry Material Specifications – interest, approaches
- Processing constraints, desires
- Database considerations
- Tooling approaches, concerns
- Equipment requirements – ovens, vacuum sources, other heat sources
- Challenging part features for producibility evaluations/scale
- Applications and related constraints/issues
- Variability, robustness
- Further interest?

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