NASA Composite Technologies for Launch Vehicles

Composites Materials and Manufacturing Technologies for Space Applications
Outline

• Why composites?

• Automated fiber placement (AFP)

• Composite Cryotank Technology Development (CCTD) Project

• Composites for large scale launch vehicles

• Concluding remarks
The National Aeronautics and Space Administration

Marshall supports three of the NASA Mission Areas:

- Human Exploration and Operations
- Space Technology
- Science
- Aeronautics Research
Composites Support NASA and the Nation

- All NASA Mission Directorates: Aeronautics Research, Human Exploration and Operations, Science, Space Technology
- Advanced Manufacturing National Initiative, and National Network for Manufacturing Innovation
- Other US Government Agencies: DOD, DARPA, DOE
- Identified in NASA Space Technology roadmap Technology Area 12 (Materials, Structures, Mechanical Systems & Manufacturing)
- Span multiple NASA Centers and disciplines
- Engage Industry and Research communities
Financial Value of Reducing Launch Vehicle Structure Weight*

Value of eliminating pounds of structural weight is based on the cost of putting those pounds in space, which depends on:

- Vehicle size
- Where the structure is on the vehicle
- Where the payload is going
- Launch market conditions/launch contract details
- Who makes the vehicle
- How many pounds are being eliminated

All of these factors vary but it's agreed that $/lb to orbit is significant.

### Average Price Per Pound to Orbit for Launch Vehicles

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>LEO Western</th>
<th>LEO Non-Western</th>
<th>GTO Western</th>
<th>GTO Non-Western</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>$8,445</td>
<td>$3,208</td>
<td>$18,841</td>
<td>N/A</td>
</tr>
<tr>
<td>Medium/Intermediate</td>
<td>$4,994</td>
<td>$2,407</td>
<td>$12,133</td>
<td>$9,843</td>
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<tr>
<td>Heavy</td>
<td>$4,440</td>
<td>$1,946</td>
<td>$17,032</td>
<td>$6,967</td>
</tr>
</tbody>
</table>

Futron Corporation Study, September 6, 2002

Canonical value often used: $10,000 per pound

*Mike Robinson Boeing
• Process developed in 1980’s
• Can apply either thermosets or thermoplastics, using prepreg materials in slit tape or tow forms
• Can perform fast, precise, accurate lamination on tooling, following preprogrammed paths
• Gaps, laps, twisted tows, fuzzballs, etc. are all par for the course
• Robotic mobility platforms are game changers, reducing entry cost by at least a factor of 2
Robot-based system allows multiple end effectors for assessing new composite materials, processes, structural concepts, manufacturing, and inspection techniques.

Proposed end effectors include (clockwise from top): machining, grid-stiffening, and continuous tow shearing capabilities.
Integrated Capabilities Across TRL* Range

* TRL = Technology Readiness Level

**TRL 1-3**

- Develop New Resins and Fibers
- Pre-Pregging of New Composite Materials

**TRL 4-6**

- Design and Fabrication of Advanced Structural Concepts

**TRL 7-9**

- Design, Build and Test Proto-flight Structures
- Post-Cure Characterization and NDE of Composites
- Manufacture Launch Vehicle Structures for NASA Missions

**Basic Research**

- LaRC

**Applications**

- MSFC

**Technology Maturation**
Design, build and test large prototype composite cryotanks for use on future launch vehicles

Two composite cryotanks (2.4-m and 5.5-m diam.) built using AFP, and tested at MSFC in 2014
CCTD Building Block Approach

**TRL Definitions**

**Basic Technology Research:**
- Level 1: Basic principles observed & reported
**Research to Prove Feasibility:**
- Level 2: Technology concept and/or application formulated
- Level 3: Analytical and experimental critical function and/or characteristic proof of concept
**Technology Development**
- Level 4: Component and/or breadboard validation in laboratory environment
**Technology Demonstration:**
- Level 5: Component and/or breadboard validation in relevant environment
- Level 6: System/subsystem model or prototype demonstration in a relevant environment
**Development:**
- Level 7: System prototype demonstration in a space environment
**System Test, Launch and Operations:**
- Level 8: Actual system completed and “flight qualified” through test and demonstration
- Level 9: Actual system “flight proven” through successful mission operations

• **MRL/TRL Advancement**
  - Prior to Project: 2-4 feasibility – technology development
  - After: 5-6 capability to model, design, manufacture and test subscale prototype hardware in a relevant environment demonstrated

• **Production Environment Demonstrations:**
  - Robotic automated fiber placement ~70% of structure
  - Multi-piece breakdown tool for one-piece pressure shell
  - Structurally efficient co-bonded and hot-bonded joints
CCTD Project Test Results 2.4m

6/25/2013:
- 135 psi achieved with tank filled with LH2
- 20 press./de-press. cycles between 20 psi & 100 psi conducted
- Permeation measurements conducted at multiple test conditions:

7/25/2015:
- 100 press./de-press. cycles between 20 psi & 135 psi conducted with LH2

Future:
- LH2 burst test at WSTF
Ground Test Program
1. Ambient Pressure
2. Cryogenic Pressure
3. Ambient Pressure & Mechanical
4. Cryogenic Cyclic Pressure

Ground Test Summary
✓ 83 pressure cycles
✓ 2 thermal cycles
✓ 2 max pressure cases
✓ 1 combined load cycle

Data Acquired
• Load/strain response
• Thermal response
• Laminate permeation rate
• Bolted joint performance
Micro cracks formed in thin plies primarily due to presence of porosity

To eliminate permeation
- Increase number of thin plies
- Reduce porosity
  - Autoclave cure
  - Improved OoA AFP processes

Autoclave cured panel extensive micro cracks post LH2 cycling in 5mil plies but no permeation
Risk Reduction Large Scale Structures

SLS block IB Upgrade (opportunities)

Design, build and test prototype composite skirts for future Space Launch System (SLS) upgrade

LaRC planning to build flat and curved panels for concepts, technology development and testing of structural joints

MSFC planning to build large curved panels for fabrication and testing of full-scale structural test article(s)
Assess possible accidental and fabrication induced damage threats
- For payload fairing blunt impact damage is the most likely type of accidental damage

Investigate effect of damage size with respect to structural scale
- Boundary conditions can affect the impact energy level necessary to produce a given size of damage.

Repair all detectable damage

Demonstrate through element and sub-component testing that under simulated flight loads the structure is insensitive to undetectable size damage

Test specimens were found to be insensitive to barely visible damage.
Concluding Remarks

• New robotic AFP platforms provide state-of-the-art composites capabilities for NASA Centers

• Flexible AFP system architecture allows development and implementation of advanced-capability end effectors

• AFP systems can support the full TRL spectrum from basic research to flight hardware

• With these AFP capabilities, LaRC and MSFC are well-positioned to support many NASA projects and programs