NASA Marshall Spaceflight Center: Materials and Manufacturing

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About Me

I'm from... Hazard

As in... The Dukes of Hazard?

B.S. Physics
M.S., Ph.D. Mechanical Engineering

Materials Engineer at United Launch Alliance (ULA)

currently aerospace engineer (Materials and Structures) at NASA Marshall Spaceflight Center
A Brief History of NASA MSFC

- **1945 Project Paperclip**
- **1950** German team moves to Redstone Arsenal to work for ABMA on development of Redstone Rocket
- **October 4, 1957** Sputnik launch
- **December 6, 1957** Vanguard explosion
- **January 31, 1958** Redstone Rocket puts Explorer I in orbit
A Brief History of NASA MSFC

1960 Eisenhower signs act creating civilian space agency

1960-1972 MSFC develops Saturn V

1973-1979 Skylab

1981-2011 Space Shuttle
A Brief History of NASA MSFC

1998- present  International Space Station

Space Launch System (SLS)

1990- present  Hubble Space Telescope

James Webb Space Telescope
NASA’s Four Core Mission Areas

- Science
- Space Technology
- Human Exploration and Operations
- Aeronautics
Human Spaceflight Architecture

Commercial support for ISS in low-Earth orbit

SLS for reaching new destinations beyond low-Earth orbit
Space Launch System (SLS)

- Initial lift capacity of 70 MT, evolvable to 130 MT
- Carries the Orion Multipurpose Crew Vehicle (MPCV)
- First flight of SLS in 2017
EFT1 Adapter

- First test flight of Orion in December 2014 on a Delta IV Heavy
- Re-entry speed of 25,000 MPH
- Adapter designed and manufactured at MSFC mates upper stage of Delta IV Heavy to Orion
Materials Engineering at NASA: An Overview
Materials Selection and Control

- Materials selection and control took on greater importance after Apollo 1 accident
- Material technical standards, selection criteria and controls were implemented
- All materials used in NASA spaceflight and ground support hardware must meet acceptance criteria based on intended use environment
Criticality of Materials Selection and Control

- **Apollo 1**: ignition source (uninsulated Ag-plated copper wire) + flammable materials (Velcro) + pure oxygen environment (16.7 psi)
- **Apollo 13**: oxygen tank 2 damaged by mishandling at NAA; during countdown demonstration test, technicians heat tank to drain it; thermostat welds shut and wiring is damaged; on-orbit damaged wiring starts a fire inside tank
- **Challenger**: failure to consider effects of temperature on O-ring/rubber elastomeric materials
- **Columbia**: foam on left bipod ramp detaches during launch and impacts TPS on left wing (RCC panel 8); during re-entry superheated air penetrates insulation and melts Al structure of left wing
Challenges of Materials Selection for Aerospace

- Materials must function in the extreme environments (natural or induced)
  - often necessitates development of new materials
- plastic deformation/yielding
- fatigue
- abrasion/wear
- corrosion
- thermal shock
- fracture
- melting
- impact
- buckling
- creep
- fluid compatibility
- space environmental effects
What materials are used for aerospace structures?

- Metals
  - Aluminum
  - Steel/stainless steel
  - Titanium
  - Magnesium
  - Superalloys
- Ceramics
- Plastics/Elastomers
- Composites
Example: Solar Sails

- solar sails exploit solar pressure to provide a means of propulsive energy
- sail material is typically a very thin (~micrometers) aluminum (or aluminized) film
  - Kapton, Mylar, Alumina
- sample material is CP1 polyimide
- material selection drivers for solar sails: degradation in space environment, weight, operating temperature range, fabrication (manufacturing), reflection and emissivity
- solar sail missions: IKAROS (JAXA, 2010), Sunjammer (January 2015), NEOScout, Lunar Flashlight
Example: Space Shuttle Tile

- Requirements:
  - Reusable thermal protection system
  - Ability to dissipate heat at 2200 F
  - LI-900, low-density surface insulation with silica glass fibers
  - 94% air by volume
  - Adhere to orbiter structure
Materials Selection Tools

- MAPTIS (Materials and Processes Technical Information System)
  - curated and maintained by NASA
  - provides materials design data, reference data, and requirements to NASA and NASA support contractors and partners

- Contains information on:
  - physical and structural properties
  - chemical compatibility
  - flammability
  - development data
  - thermal protection systems
  - space environmental effects
  - thermophysical and thermal data
Path to Process Certification

Characterize: SLM manufactured injector, mechanical property and microstructure test articles
Certify: CT Scan Nondestructive Inspection and Dimensional Verification
Institutionalize: Process Standards documentation for qualification/certification process
Path to Hardware Certification

- System Definition and Requirements
  - Definition document
  - Program requirements
  - NASA standards
  - Vendor tailored standards
  - Component specs
  - Vendor specs

- Design

- Verification Events
  - Design
    - Test
    - Analysis
    - Review process
      - RIDs, etc.
  - As-Built
    - Inspection
    - Acceptance Test
    - MRB

- Acceptance of Verification = Certification

Validation
Does part meet customer intent?
Advanced Manufacturing
Additive Manufacturing: Plastics

Additive manufacturing (AM) or 3D Printing (3DP) is the method of building parts layer by layer. Melt deposition fabrication builds the object out of plastic deposited by a wire-feed via the extruder head. The parts are ‘printed’ from 3-D CAD drawings loaded on the printer.

“3D print, you will.”
When a tool on the space station breaks, astronauts must often wait months for a replacement. 

3-D printer on board the space station would enable astronauts to print replacement parts within hours; enhanced safety for crewed operations.

Could also enable the manufacturing of small satellites (nanosats) on orbit.

NASA is partnering with Made in Space, Inc. to develop and fly a 3-D printer to the space station in fall 2014.
Additive Manufacturing: Metals

- Propulsion components manufactured using Selective Laser Machining (SLM) atomized metal powder fused by laser
  - Inconel, Titanium
- Hot fire testing and burst testing for validation
- Immense potential to reduce cost and development life cycle for propulsion systems
- Uncertainty in how additively manufactured parts compare to conventionally manufactured counterparts
- Development of certification path and standards
Microgravity Materials Science: 
Materials Joining

- Space structures are increasingly susceptible to MMOD and collisions with other hardware – current risk is low, but could be catastrophic
- Welding would enable a rapid repair capability and versatile means of on-orbit assembly
- Offers advantages over mechanical fasteners and adhesives:
  - reduced weight
  - improved mechanical properties
  - reduced stress concentrations
  - increased rigidity
## A Brief History of In-Space Welding

<table>
<thead>
<tr>
<th>Year</th>
<th>Activity</th>
<th>Country</th>
<th>Process</th>
<th>Vehicle</th>
<th>Images</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1969</td>
<td>Vulcan, Self-contained experiment</td>
<td>Russia</td>
<td>EB, Arc</td>
<td>Soyuz 6</td>
<td><img src="image1.png" alt="Image" /></td>
<td>First demonstration of on-orbit welding.</td>
</tr>
<tr>
<td>1989</td>
<td>On-orbit Electron Beam Welding Experiment Definition</td>
<td>US (MSFC/Martin Marietta)</td>
<td>EB</td>
<td>Ground Demo only</td>
<td><img src="image4.png" alt="Image" /></td>
<td>Demonstrated on-orbit repair concept, weld schedule, and 2219-T87 metallurgy utilizing beam deflection.</td>
</tr>
<tr>
<td>1990s</td>
<td>International Space Welding Experiment</td>
<td>US (MSFC)/Ukraine (Paten Weld Institute)</td>
<td>EB</td>
<td>Space Shuttle (Not Flown)</td>
<td><img src="image5.png" alt="Image" /></td>
<td>Demonstrated safety challenges associated with manual EVA welding.</td>
</tr>
<tr>
<td>1995</td>
<td>Versatile Space Welding System Phase II SBIR</td>
<td>US (MSFC/Electric Propulsion Lab)</td>
<td>Arc</td>
<td>Ground Demo Only</td>
<td><img src="image6.png" alt="Image" /></td>
<td>Developed Hollow Cathode Arc Weld System</td>
</tr>
</tbody>
</table>
Friction Stir Welding

- Friction stir welding
  - new welding process that does not melt the material
  - produces high-strength, defect-free joints
  - completely robotic process
  - used for almost all launch vehicle primary structures and habitable modules
    - ULA, SpaceX, Orbital
  - largest vertical weld tool ever constructed for SLS barrel panel welds at MAF
- Material samples mounted externally on the Kibo module (JAXA) of the ISS
- Samples are exposed to the space environment for up to two years, then downmassed for testing and analysis
- Experiments evaluate material degradation in the space environment
  - atomic O₂
  - UV radiation
ISS Open Data Portal

-Current initiative in compliance with presidential directive to make science data from International Space Station open-source
-Global access to cutting edge research data
-Increased products, patents, and publications
-Accelerate path from idea to research to products
Advanced Manufacturing Roadmap

ISS Platform
- In-space Fab & Repair Plastics Demonstration via 3D Printing in Zero-G
- Qualification/Inspection of On-orbit Parts using Optical Scanner
- Printable SmallSat Technologies
- On-orbit Plastic Feedstock Recycling Demonstration
- In-space Metals Manufacturing Process Demonstration

Earth-based Platform
- Certification & Inspection of Parts Produced In-space
- In-space Metals Fabrication Independent Assessment & NASA Systems Trade Study

Earth-based Platform (cont.)
- Printable Electronics & Spacecraft
- Self-Replicating/Repairing Machines
- In-situ Feedstock Development & Test: See Asteroid Platform

Planetary Surfaces Platform
- In-situ Feedstock Test Beds and Reduced Gravity Flights Which Directly Support Technology Advancements for Asteroid Manufacturing as well as Future Deep Space Missions.
  - Additive Construction
  - Regolith Materials Development & Test
  - Synthetic Biology: Engineer and Characterize Bio-Feedstock Materials & Processes

Deep Space Missions