Polymeric Materials for Aerospace Power and Propulsion

Multi-functional Materials

Lightweight Structures

Computational-modeling

Propulsion

Thermal Management

Tiffany S. Williams, Ph.D.
Materials Chemistry and Physics Branch
NASA Glenn Research Center
tiffany.s.williams@nasa.gov
• **Aeronautics**
  - **Vibrations**: Noise, airflow
  - **Impact**: Birdstrike
  - **Thermal**: Aircraft engines
  - **Weather**: Icing

• **Space**
  - **Atmosphere**
  - **Radiation** (solar, cosmic)
  - **Extreme temperatures** (hot and cryogenic)
  - **High impact** (micro-meteoroids)
  - **Heat from atmospheric entry/reentry**
Examples of Needs and Challenges in Aeronautics and Space

• **System Challenges in Aeronautics**
  – Efficiency (power, cost)
  – Mass and noise reduction

• **Needs**
  – Thermal management
  – Higher strength and stiffness lightweight composites
  – High temperature, toughened composites
  – Multi-functionality
    • Morphing structures
    • Electrically conductive composites

• **System Challenges in Space**
  – Mass and volume reduction
  – Degradation in harsh space environments

• **Needs**
  – Lightweight materials and structures
  – Materials and structures that can perform reliably in extreme environments
  – Multi-functionality
    • Radiation protection
    • Impact resistant
    • Smart materials
Why Polymers???

• BUT FIRST...
  – What is a polymer?
    • Large molecule made of repeat units
    • Examples: plastic bags, adhesives, fibers, building materials, paint, foams, films

• Benefits
  – Lightweight
  – Versatility

• Impact
  – Vehicular mass reduction
  – Enhanced efficiency

• Challenges: Operating temperature and processing constraints
Materials for High Power Density Electric Motor

• **Benefits:**
  – Fuel Savings
  – Noise Reduction
  – Carbon and Nox Reduction

• **Electrical Insulation Development**
  • **Goal:** Better thermal management
  • Thermally conductive electrical insulation needed to optimize engine performance in hybrid electric motors
  • Electrical insulators are typically polymers (thermal conductivity: ~0.1 – 0.2 W/mK)
Smart Materials

State-of-the-art insulation prone to damage and premature failure

Self-healing electrical insulation

Repairable materials for easy maintenance

Ionomeric copolymers achieved ~93% recovery in dielectric strength after healing. Over 85% recovery in mechanical strength.

<table>
<thead>
<tr>
<th></th>
<th>Ionomer</th>
<th>Damaged Ionomer</th>
<th>Healed Ionomer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Breakdown Voltage (kV)</td>
<td>16.8 ± 1.09</td>
<td>~9.7</td>
<td>~15.7</td>
</tr>
</tbody>
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Shape-morphing polymers and composites

Min, J., Williams, T. et al, AIAA 2016-1501

Image credit: NASA
Polymer matrix composites (PMCs)
- Used in both structural applications and components
- Can be molded into complex shapes
- Lightweight, high strength-to-stiffness
Lightweight Structures: Nanocomposites

Composite overwrap pressure vessels (COPVs)

- **Application:** Simulate COPV tanks in cold gas thruster systems
- **Goals:**
  - Develop carbon nanotube (CNT) reinforced composites with 1.5 to 2x’s specific strength of conventional carbon fiber composites
  - Improve strength of bulk CNT sheets, tapes, and yarns through processing and post-processing methods
  - Validate materials by design, fabrication, ground and flight testing of nanocomposite overwrap pressure vessel
- **Impact:**
  Implementation of high strength, lightweight nanocomposites could lead to significant mass savings
Lightweight Structures through Additive Manufacturing

Fused Deposition Modeling Process

• Feasibility Assessment: 3D print structures made of high temperature thermoplastics and composites

• Additive manufacturing beneficial for printing intricate shapes difficult to make using conventional processes

Chuang, K., NASA/TM—2015-218749
Lightweight Thermal Insulation: Polyimide Aerogels

*Sol* → *Gel* → *Aerogel*

Highly porous solid with pore sizes 10-40 nm.
Better insulating properties than fiberglass under ambient pressure

Flexible polyimide aerogels

Antenna substrates

Inflatable aerodynamic decelerators

Cryotank Insulation

Insulation for EVA suits and habitats

![Density vs. Modulus Graph](image)

- PMDA/DMBZ
- 6FDA/PMDA/DMBZ
- BPDA/DMBZ
- BPDA/ODA
Lightweight Thermal Insulation: High Temperature Inorganic Aerogel Composites

Aerogel bonds to fibers; unlike commercial materials, particles do not spall. Aerogel/fiber bond achieved by heat treatment of alumina paper to remove all binders prior to sol impregnation.

APA-2/ aerogel composite

Density of 0.14 g/cm³, lighter than other high temperature insulators (0.3428g/cm³)

Aerogel can be treated to be hydrophobic
Multi-functional Materials and Structures

Incorporate multi-functionality for mass reduction and increased efficiency

Multi-functional structure with energy storage capability

Flexible, impact resistant fabrics pioneered at the Univ. of Delaware

Cubic SiO₂ nanoparticles

Kevlar fabric

Impact-resistant shear thickening fluid-embedded textiles for deep-space habitat shell

Variable stiffness, impact-resistant habitat Shell

Hybrid fabrics can enable integration of functional fibers into traditional reinforcement

Hybrid triaxial braid development
What Can We Learn from Nature?

Quiet Flight – Owls

Acoustic absorption – Natural Fibers

Flight Take-off Concepts (Urban Air Mobility) – Flock of birds

Autonomous Repair – Plant regeneration

Habitat Inspiration?

Silk bagworm crawling out of cocoon

Old Wasps Nest

Survival in extreme environments – Tardigrades

Silk Bagworm Cocoons on Shrub

Photo credit: Jim Nemet, Cleveland Metroparks Zoo

https://asknature.org/strategy/cryptobiosis-protects-from-extremes/#jp-carousel-7249

Interior view of praying mantis’s cocoon (after eggs hatched)
NASA Glenn’s Biomimicry Group – V.I.N.E.

**Mission:** With inspiration from nature and natural systems as its driving framework, V.I.N.E. seeks to help solve NASA’s biggest challenges – in collaboration with experts from academia, industry, and other government agencies.

Source for nature-inspired ideas

[www.asknature.org](http://www.asknature.org)
Materials Processing Facilities

Fiber Braiding

Prepreg Development

Nanofiber Development

Thin Film Casting

Filament Winding

Composites Processing
Questions?