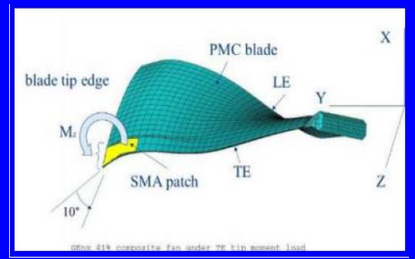
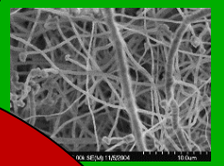
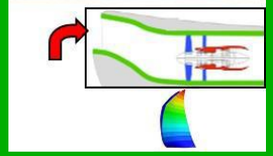
Polymeric Materials for Aerospace Power and Propulsion

Multi-functional Materials

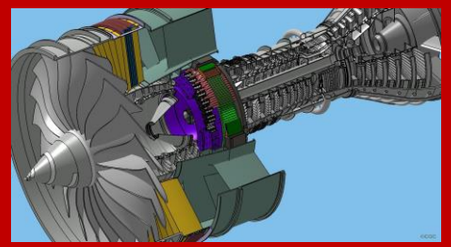


Lightweight Structures

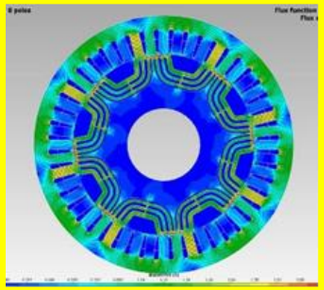




Propulsion



Computational-modeling



Thermal Management

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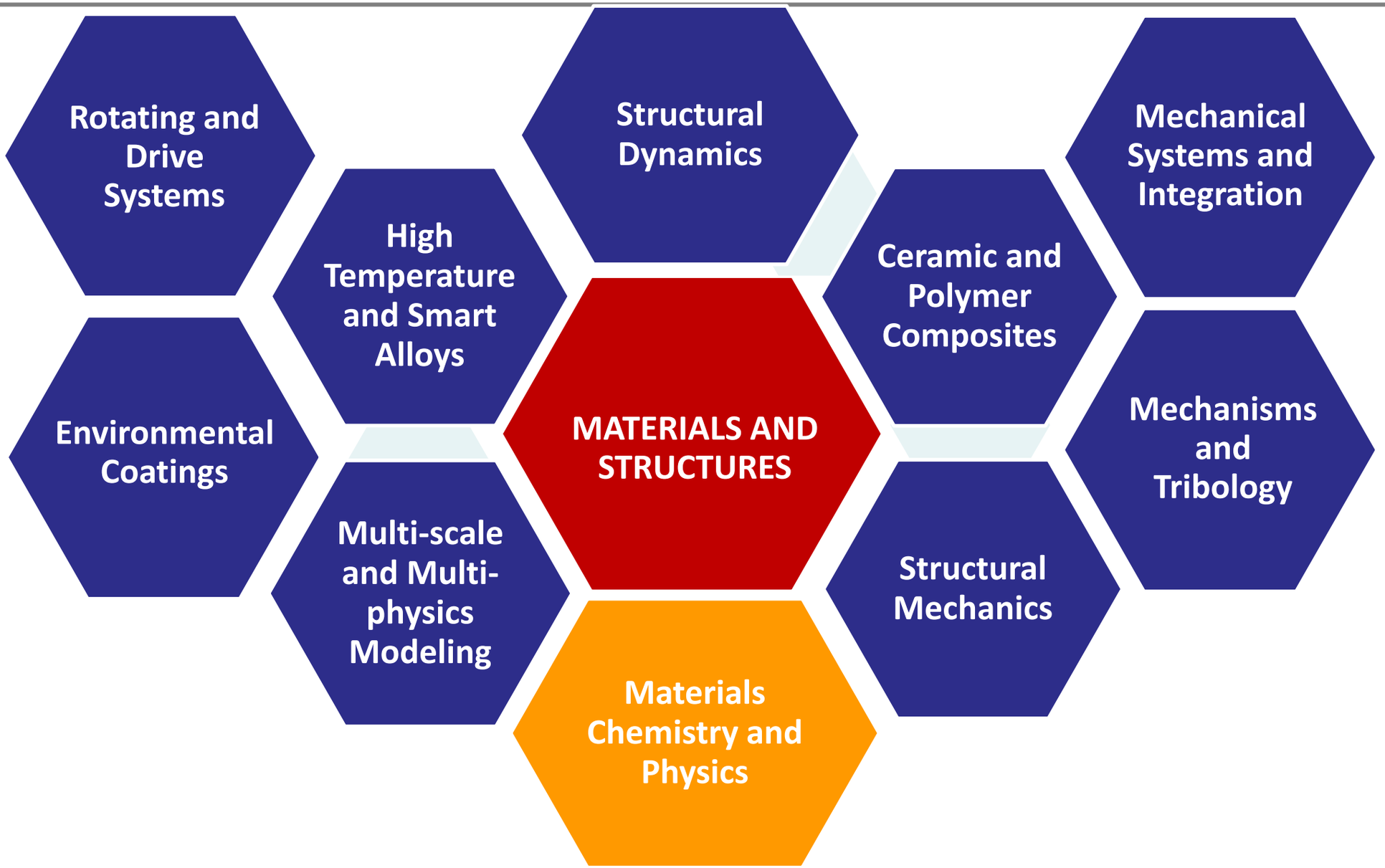
Materials and Structures Division



What can be considered as an extreme environment?

- **Aeronautics**
  - **Vibrations**: Noise, airflow
  - **Impact**: Birdstrike
  - **Thermal**: Aircraft engines
  - **Weather**: Icing

Ice accumulation on engine

Image credit: NASA

- **Space**
  - Atmosphere
  - Radiation (solar, cosmic)
  - Extreme temperatures (hot and cryogenic)
  - High impact (micro-meteoroids)
  - Heat from atmospheric entry/ reentry

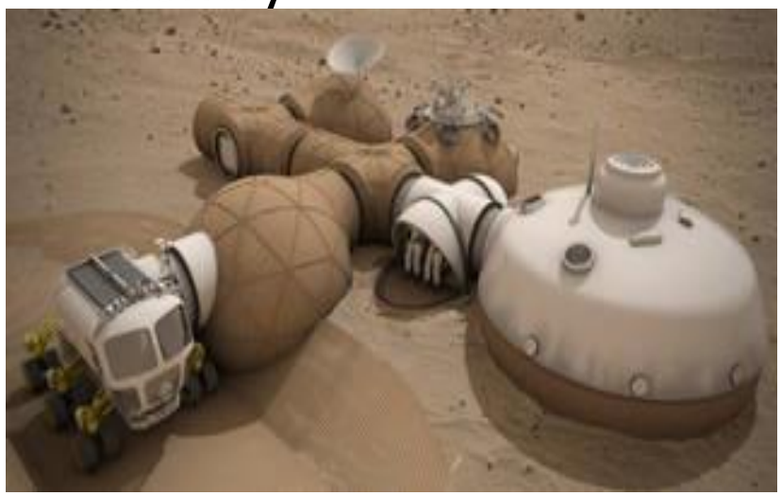


Image credit: NASA

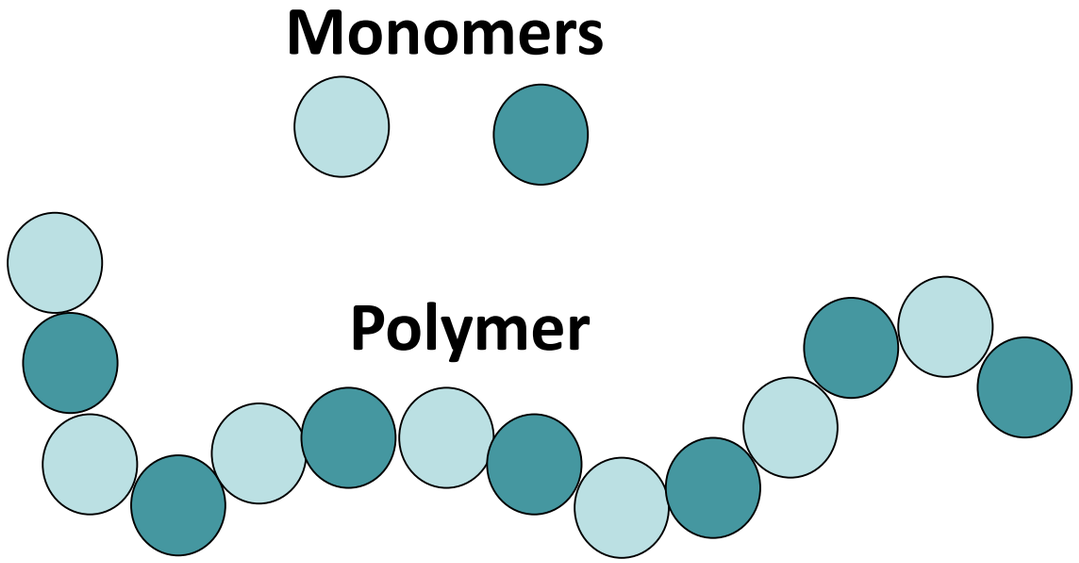
Examples of Needs and Challenges in Aeronautics and Space

- **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???

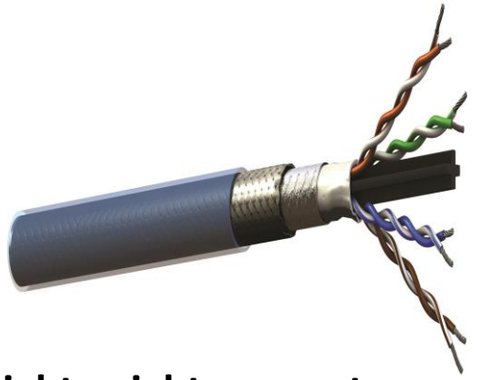
- **BUT FIRST…**
  - What is a polymer?
    - Large molecule made of repeat units
    - Examples: plastic bags, adhesives, fibers, building materials, paint, foams, films
- **Benefits**
  - Lightweight
  - Versatility
- **Impact**
  - Vehicular mass reduction
  - Enhanced efficiency
- Challenges: Operating temperature and processing constraints



Materials for High Power Density Electric Motor

- **Benefits**:
  - Fuel Savings
  - Noise Reduction
  - Carbon and Nox Reduction

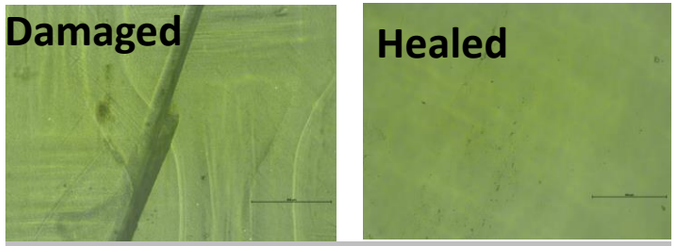
- **Electrical Insulation Development**
  - Goal: Better thermal management
  - Thermally conductive electrical insulation needed to optimize engine performance in hybrid electric motors
  - Electrical insulators are typically polymers (thermal conductivity: ~0.1 – 0.2 W/mK)



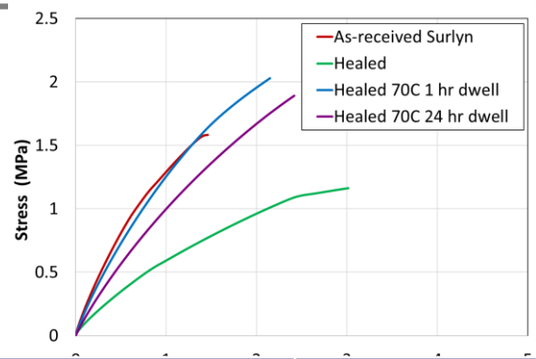
Lightweight power transmission system

Smart Materials

State-of-the-art insulation prone to damage and pre-mature failure



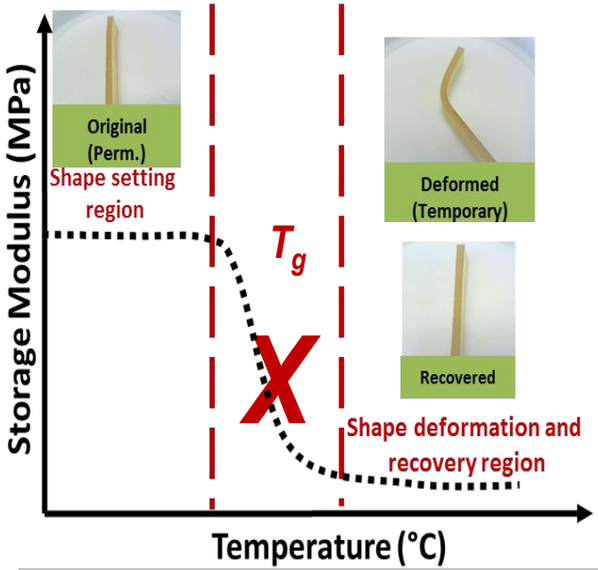
Self-healing electrical insulation

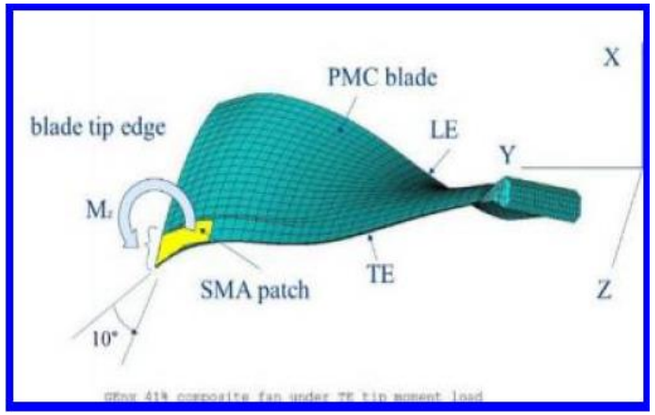


Repairable materials for easy maintenance

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

	Ionomer	Damaged Ionomer	Healed Ionomer
Average Breakdown Voltage (kV)	16.8 ± 1.09	~9.7	~15.7





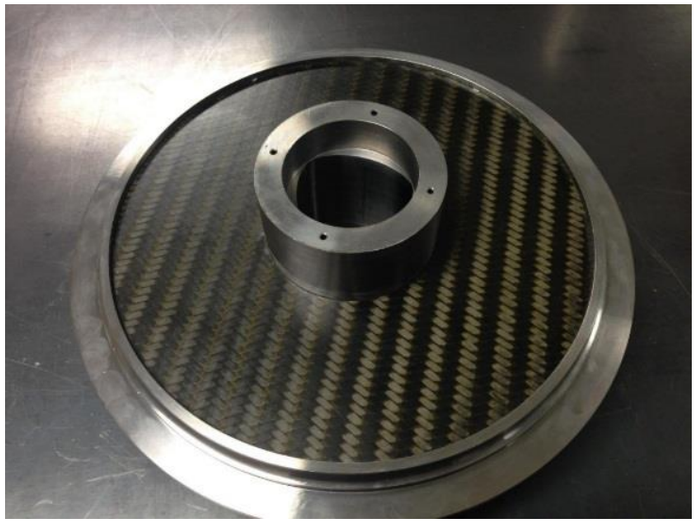
Min, J., Williams, T. et al, AIAA 2016-1501

Shape-morphing polymers and composites

Image credit: NASA

Lightweight Structures: Polymer Matrix Composites

- **Polymer matrix composites (PMCs)**
  - Used in both structural applications and components
  - Can be molded into complex shapes
  - Lightweight, high strength-to-stiffness

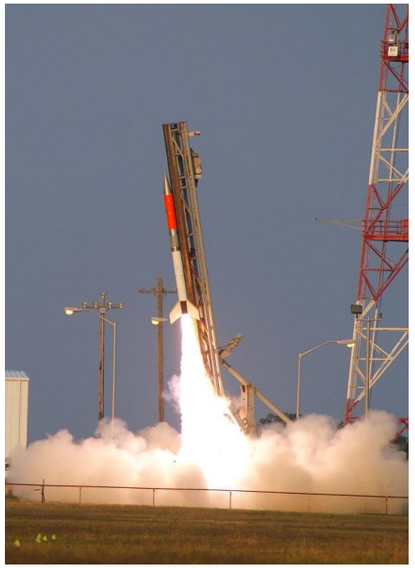


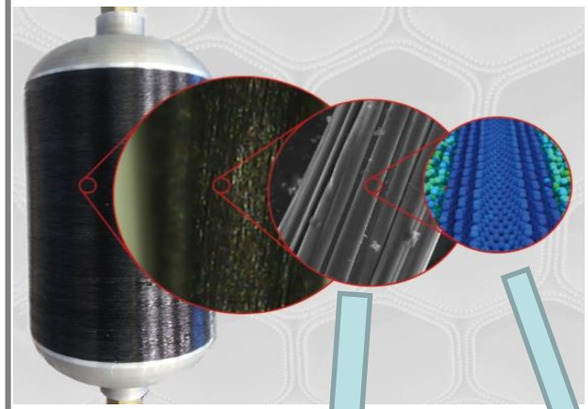
Lightweight Structures: Nanocomposites

Composite overwrap pressure vessels (COPVs)

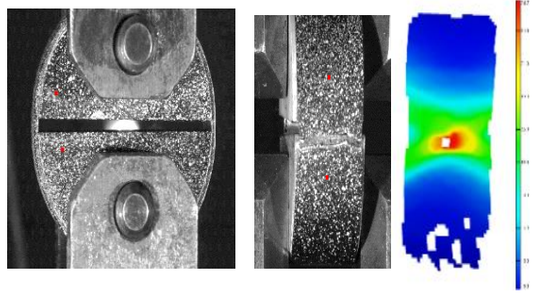
- **Application:** Simulate COPV tanks in cold gas thruster systems
- **Goals:**
  - Develop carbon nanotube (CNT) reinforced composites with 1.5 to 2x's specific strength of conventional carbon fiber composites
  - Improve strength of bulk CNT sheets, tapes, and yarns through processing and post-processing methods
  - Validate materials by design, fabrication, ground and flight testing of nanocomposite overwrap pressure vessel
- **Impact:**

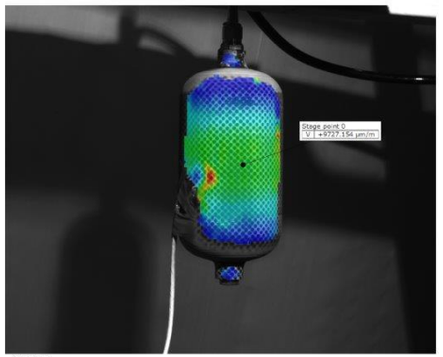
Implementation of high strength, lightweight nanocomposites could lead to significant mass savings

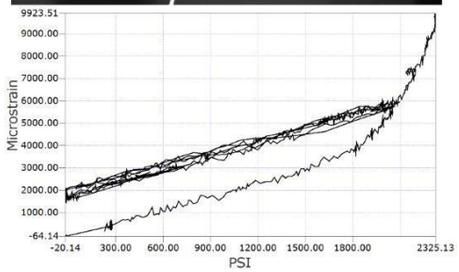


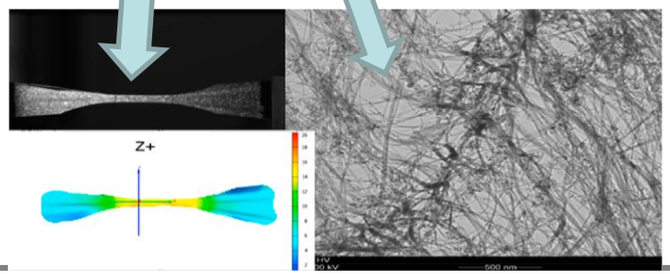


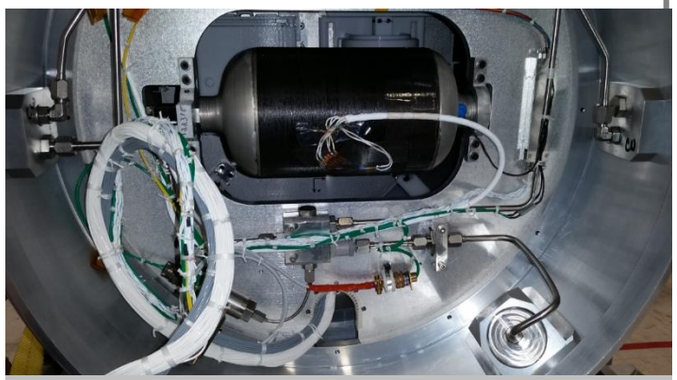
Split D-ring Mechanical Testing





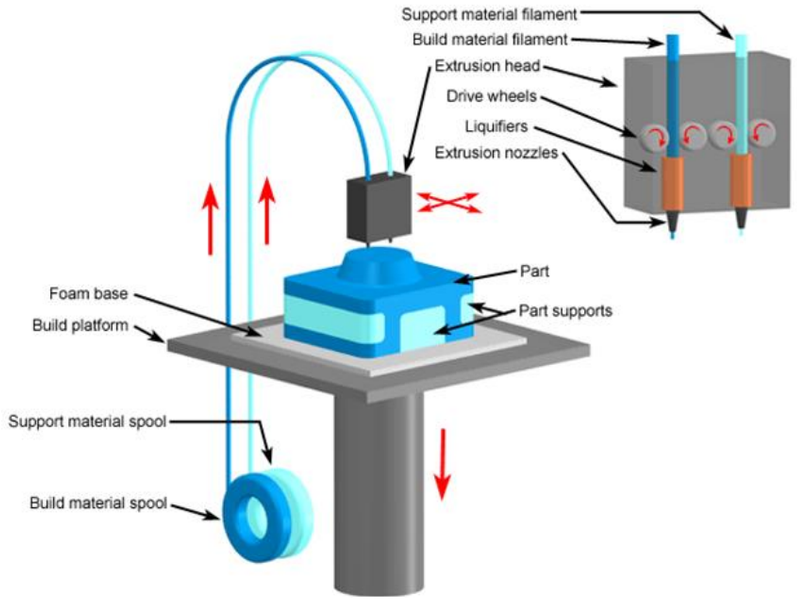




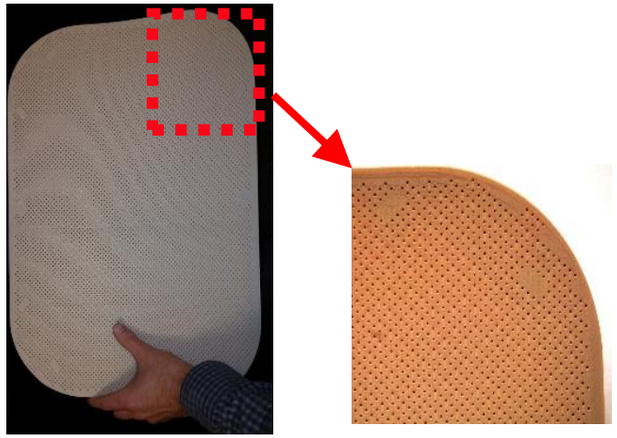


Lightweight structures

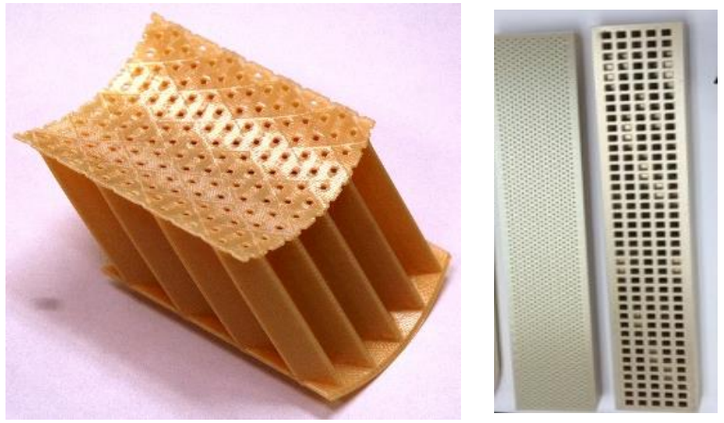
Lightweight Structures through Additive Manufacturing



Fused Deposition Modeling Process



Engine access door



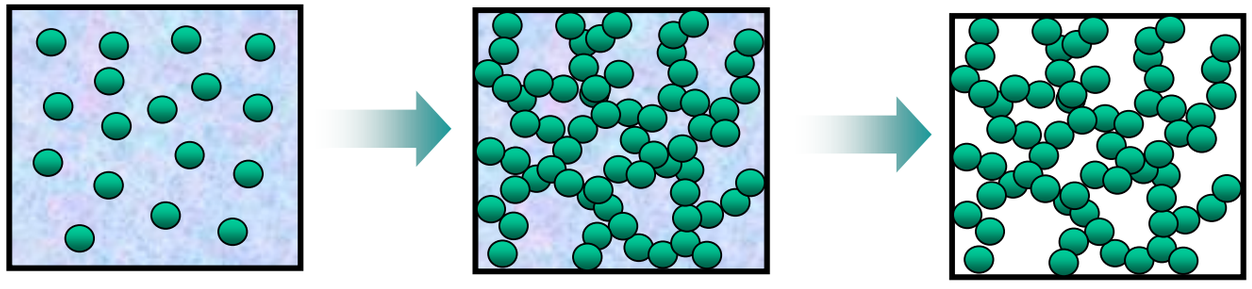
Acoustic liner and components

- 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

Composite vanes

Chuang, K., NASA/TM—2015-218749

Lightweight Thermal Insulation: Polyimide Aerogels

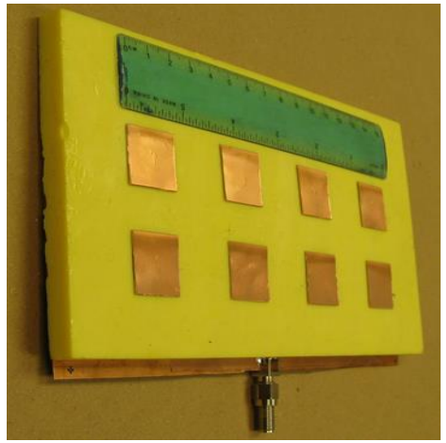


Sol *Gel* *Aerogel*

Highly porous solid with pore sizes 10-40 nm.

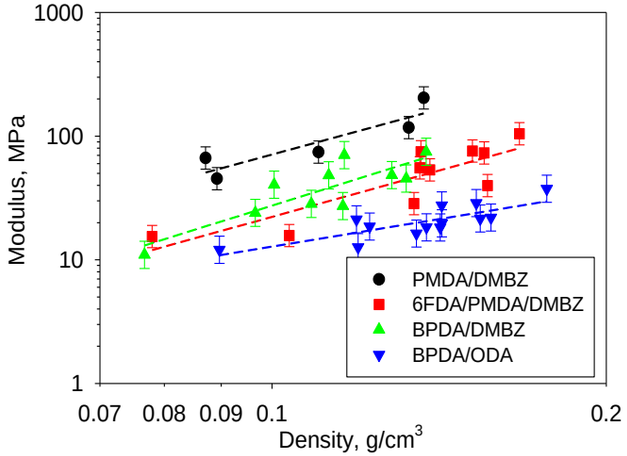
Better insulating properties than fiberglass under ambient pressure

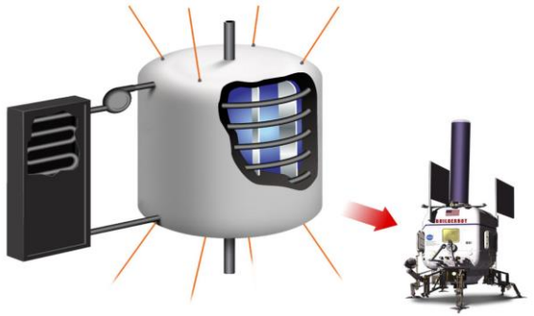
Inflatable aerodynamic decelerators



Antenna substrates

Flexible polyimide aerogels

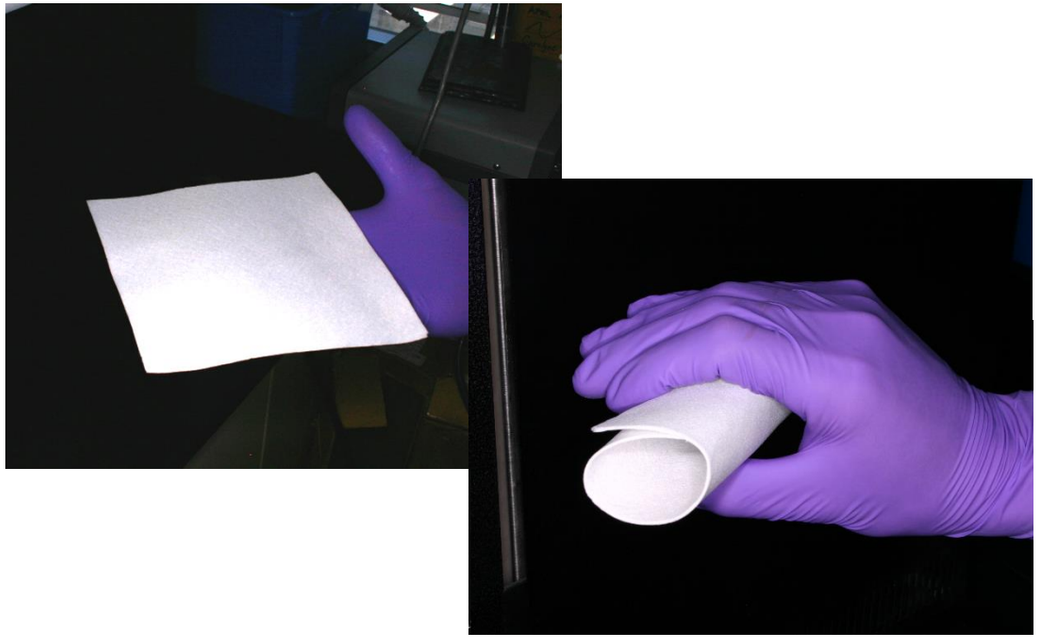




Cryotank Insulation

Insulation for EVA suits and habitats

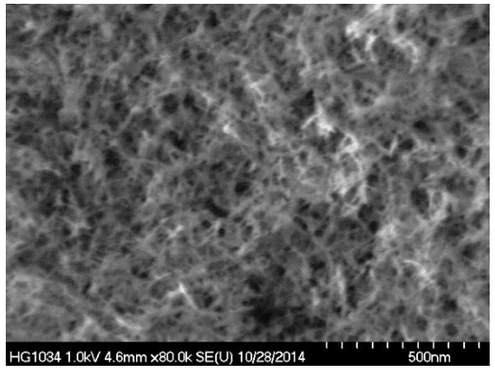
Lightweight Thermal Insulation: High Temperature Inorganic Aerogel Composites



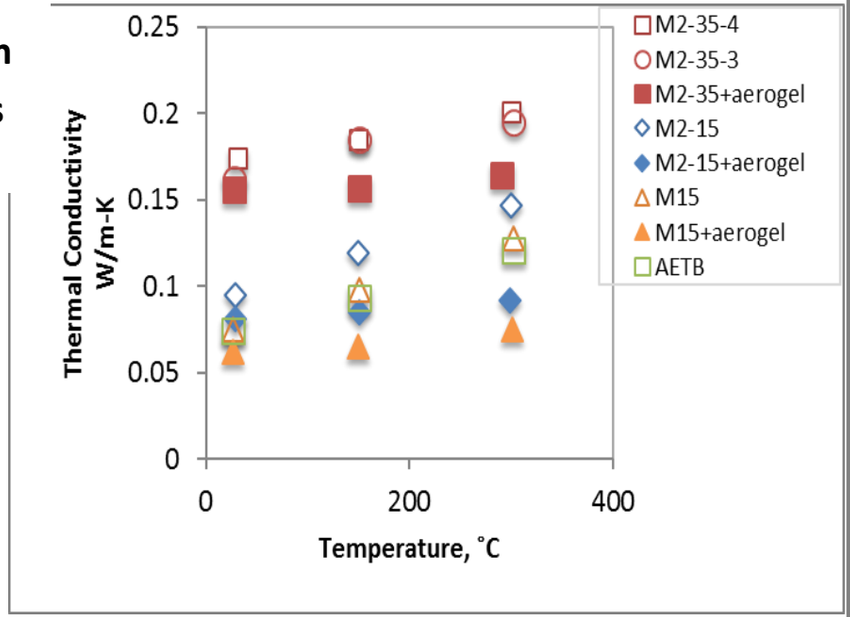
High temperature aerogel composite insulation

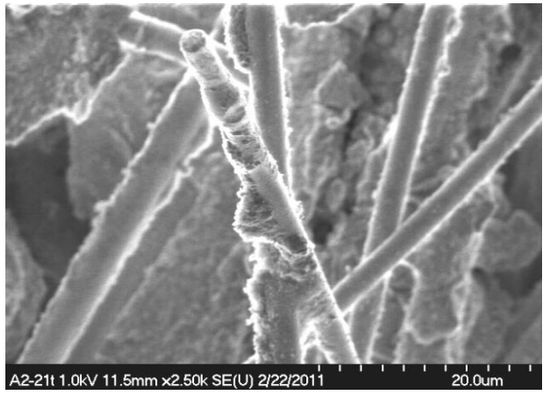
APA-2/ aerogel composite

Density of 0.14 g/cm^3, lighter than other high temperature insulators (0.3428g/cm^3)



375 m^2/g



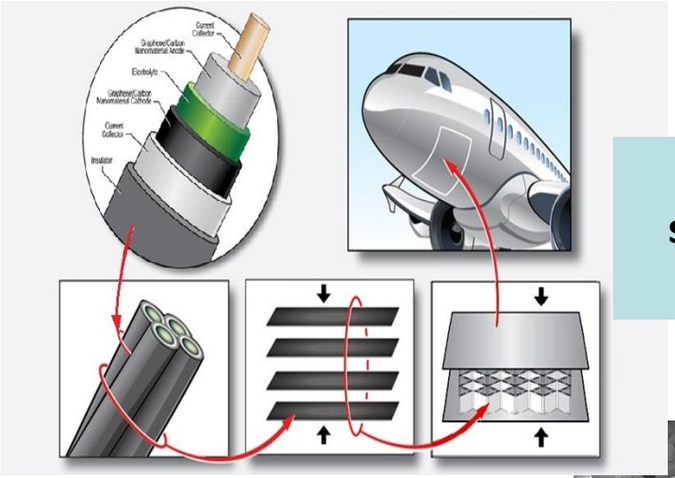


Aerogel bonds to fibers; unlike commercial materials, particles do not spall. Aerogel/fiber bond achieved by heat treatment of alumina paper to remove all binders prior to sol impregnation.

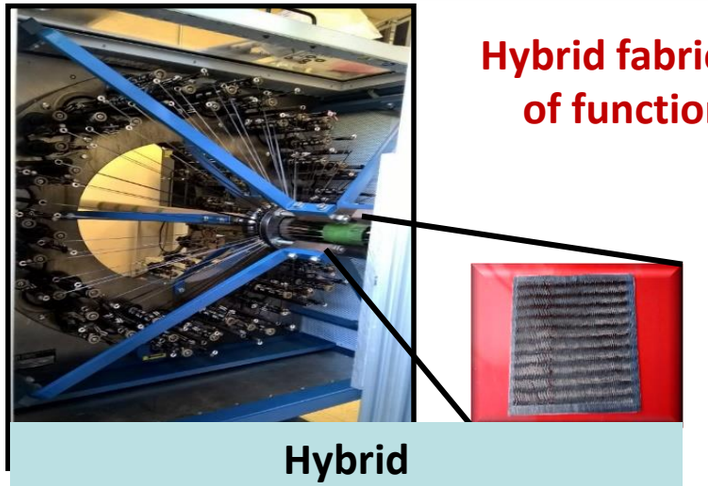
Aerogel can be treated to be hydrophobic

Multi-functional Materials and Structures

Incorporate multi-functionality for mass reduction and increased efficiency



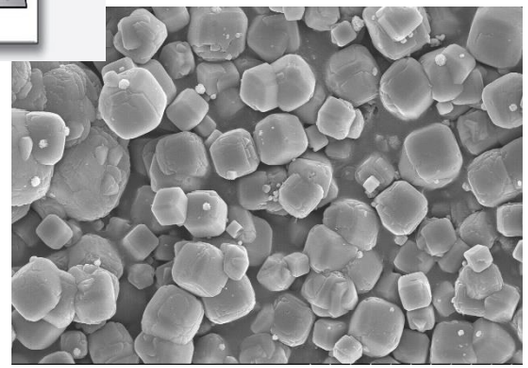
Multi-functional structure with energy storage capability



Hybrid triaxial braid development

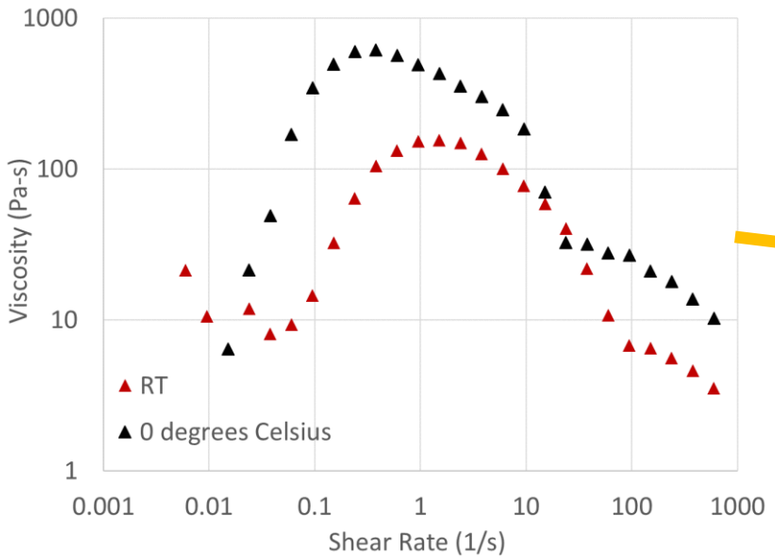
Hybrid fabrics can enable integration of functional fibers into traditional reinforcement

Micro-meteoroid Damage



Cubic SiO_2 nanoparticles

Kevlar fabric



Variable stiffness, impact-resistant habitat Shell

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

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

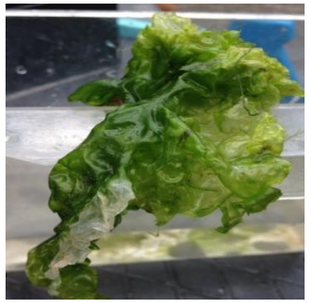
What Can We Learn from Nature?

Quiet Flight – Owls

Photo credit: Jim Nemet, Cleveland Metroparks Zoo

Acoustic absorption – Natural Fibers

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



Autonomous Repair – Plant regeneration

Habitat Inspiration?

Silk Bagworm Cocoons on Shrub

Silk bagworm crawling out of cocoon

Old Wasps Nest

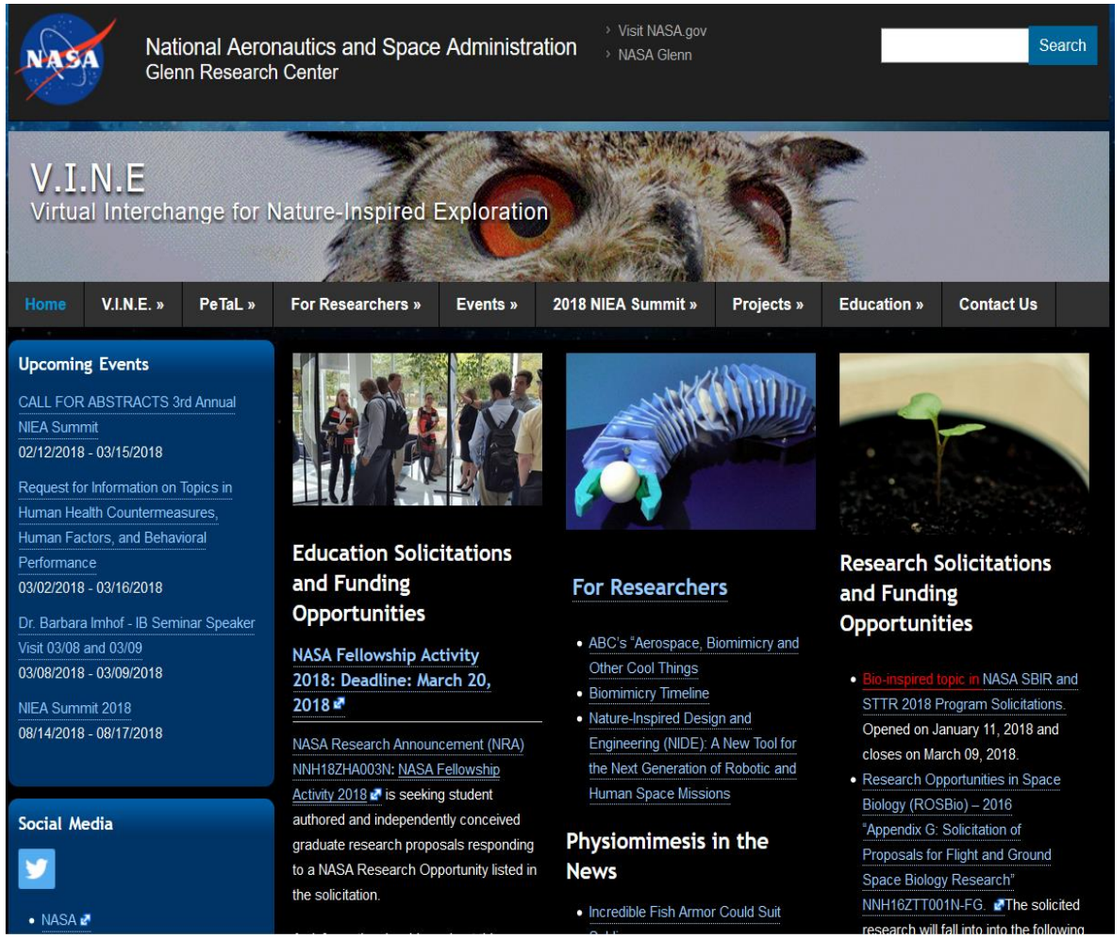
Survival in extreme environments – Tardigrades

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.

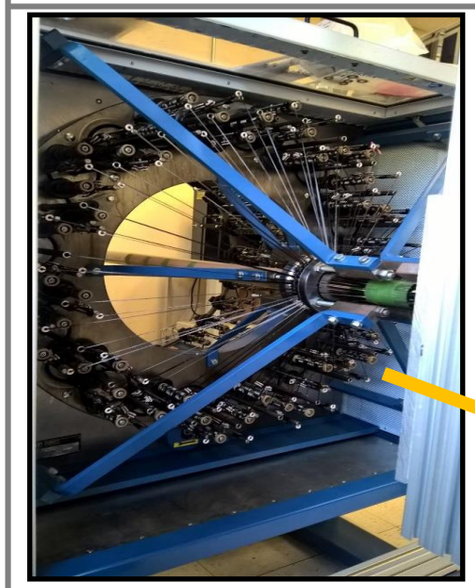


Cluster	Catalyst
Big Data, Artificial Intelligence, Machine Learning, Sensors, Robotics	Schilling / Trease / Robinson
Synthetic Biology, Artificial Evolution and Human Persistence in Space	Alexander / Maurer
Multi-functional Materials, Structures, Processing	Williams / Maurer
Hybrid and Alternative Manufacturing	Reyes
Information, Communication, Education	Brown / Eggermont
Systemology	Nagel / Mcnamera / Hearn
Energy Conversion, Power, Propulsion and Mobility	Peshek
ISRU	Trunek

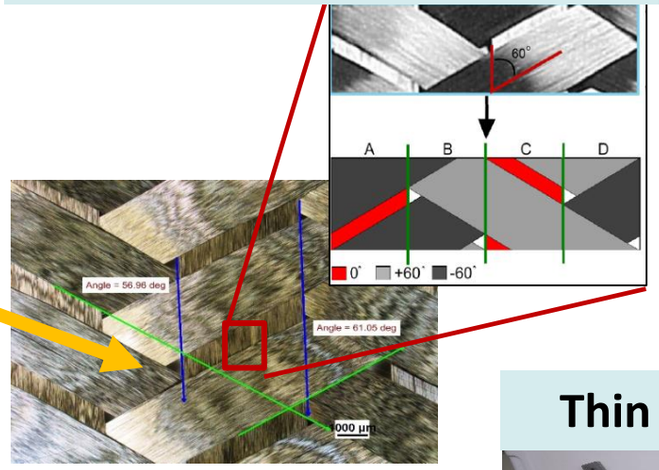
https://www.grc.nasa.gov/vine/

Source for nature-inspired ideas
www.asknature.org

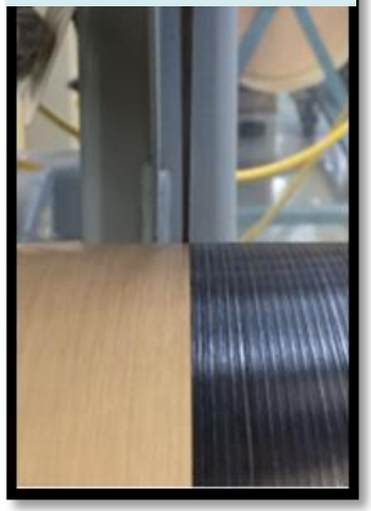
Materials Processing Facilities



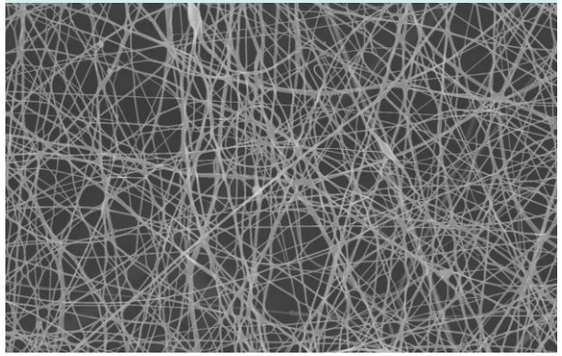
Fiber Braiding



Prepreg Development

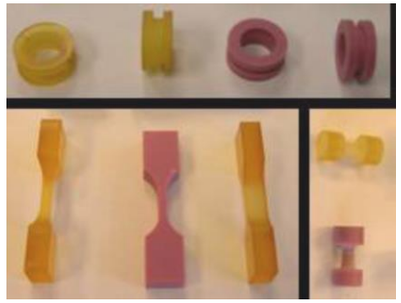


Nanofiber Development

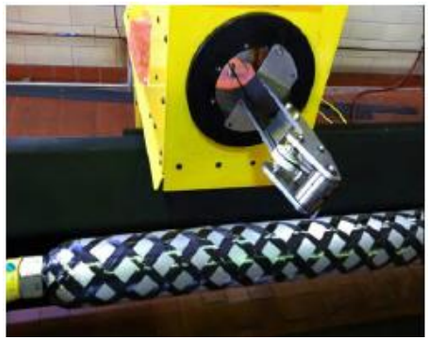


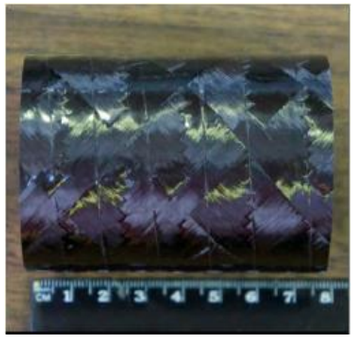
Thin Film Casting

Composites Processing



Filament Winding





Kohlman, L, NASA/TM –2014-216635

Questions?