Multidisciplinary Collaboration for Accelerated Aerospace Materials Development

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20 Years of Virginia Tech Macromolecules Innovation Institute Symposium
American Chemical Society Fall Meeting
August 21, 2024

Image Credit: NASA

NASA Missions

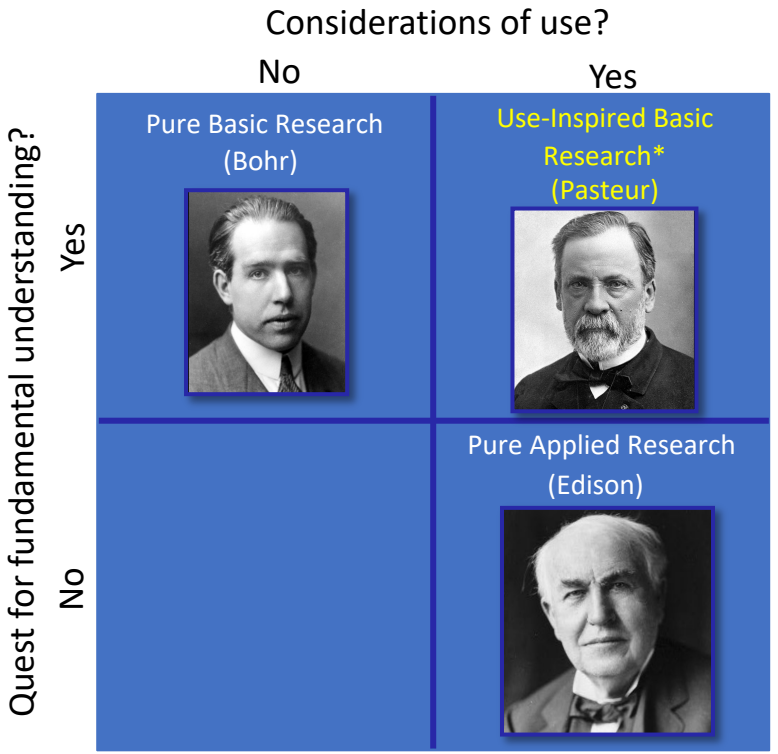
Image Credits: NASA

Polymer Materials Across NASA Missions

- Aeronautics
  - Environmentally Responsible Aviation (ERA)
  - Hi-Rate Composite Aircraft Manufacturing
- Space Technology for Exploration Systems
  - Lightweight Structures
  - Multifunctional Materials
  - In-Situ Resource Utilization

Use-Inspired Technology Development

- Use-driven fundamental research
- Considers systems level benefits
- From lab to demonstration



* Stokes, D. L., Pasteur's Quadrant: Basic Science and Technological Innovation, Washington, D. C.: Brookings Institution Press, 1997.
Photos are in the public domain.

Laminar Flow

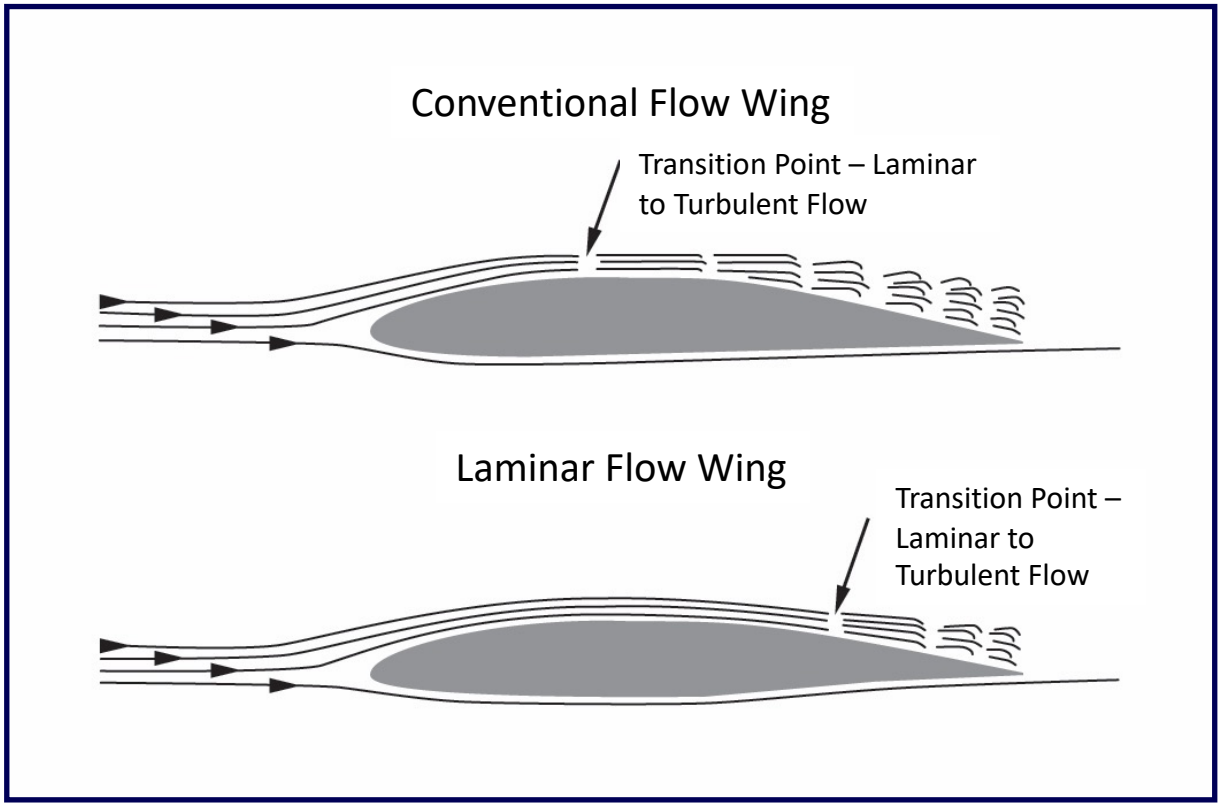
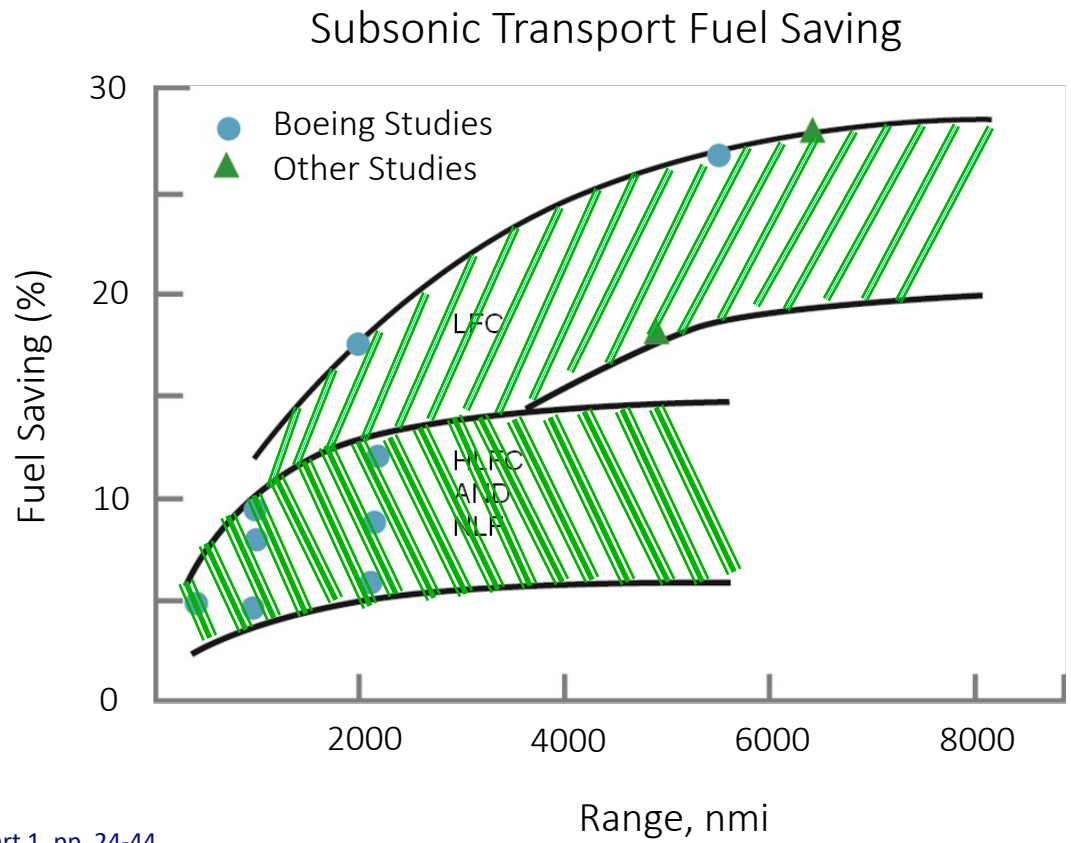


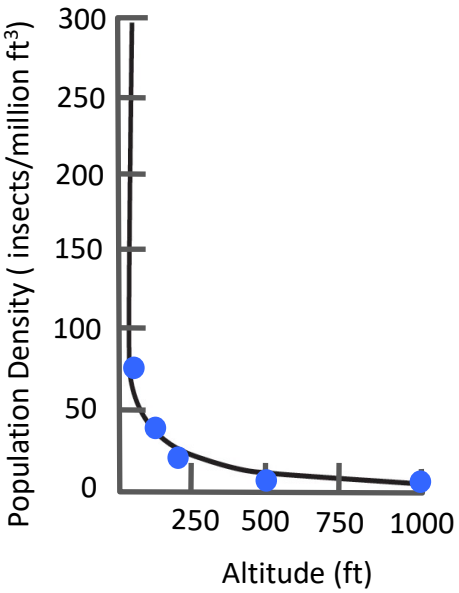
Image Credits: NASA

Motivation for Laminar Flow Control



Kirchner, M.E. NASA CP-2487, 1987, Part 1, pp. 24-44.

Objective



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC97–44358–2 Date: December 29, 1997 Photo By: Tony Landis

DC–8 Airborne Laboratory arrival at NASA Dryden

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED04–0056–71 Date: March 6, 2004 Photo By: Jim Ross

NASA's DC–8 flying laboratory takes off from Juan Santamaria International Airport in San Jose, Costa Rica, on NASA's AirSAR 2004 campaign.

To design an engineered surface that prevents insect residue adhesion under take-off and landing conditions.

Bragg, M.G. and Maresh, J.L. AIAA Paper no. 84-2170, 1984.

Influence of Surface Characteristics on Insect Residue Adhesion

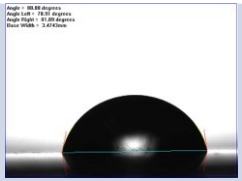
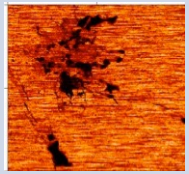
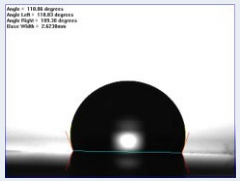
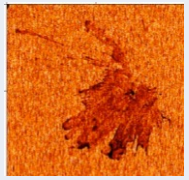
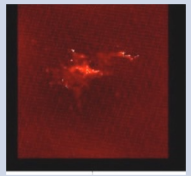
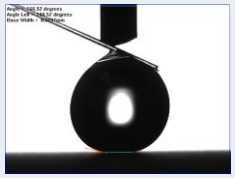
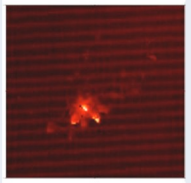
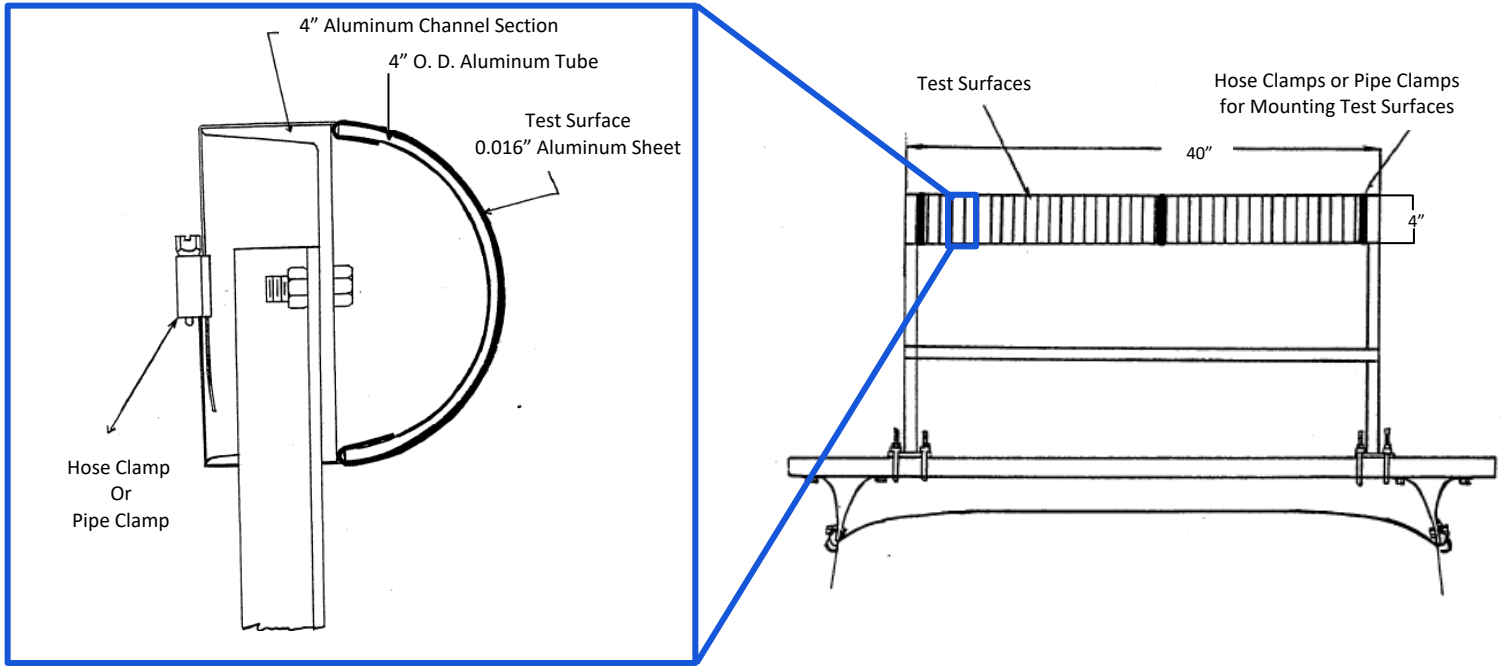
Surface	Contact Angle	Residue Area
Aluminum Control		
Hydrophobic Coating		
Laser Patterned		
Coated Laser Patterned		

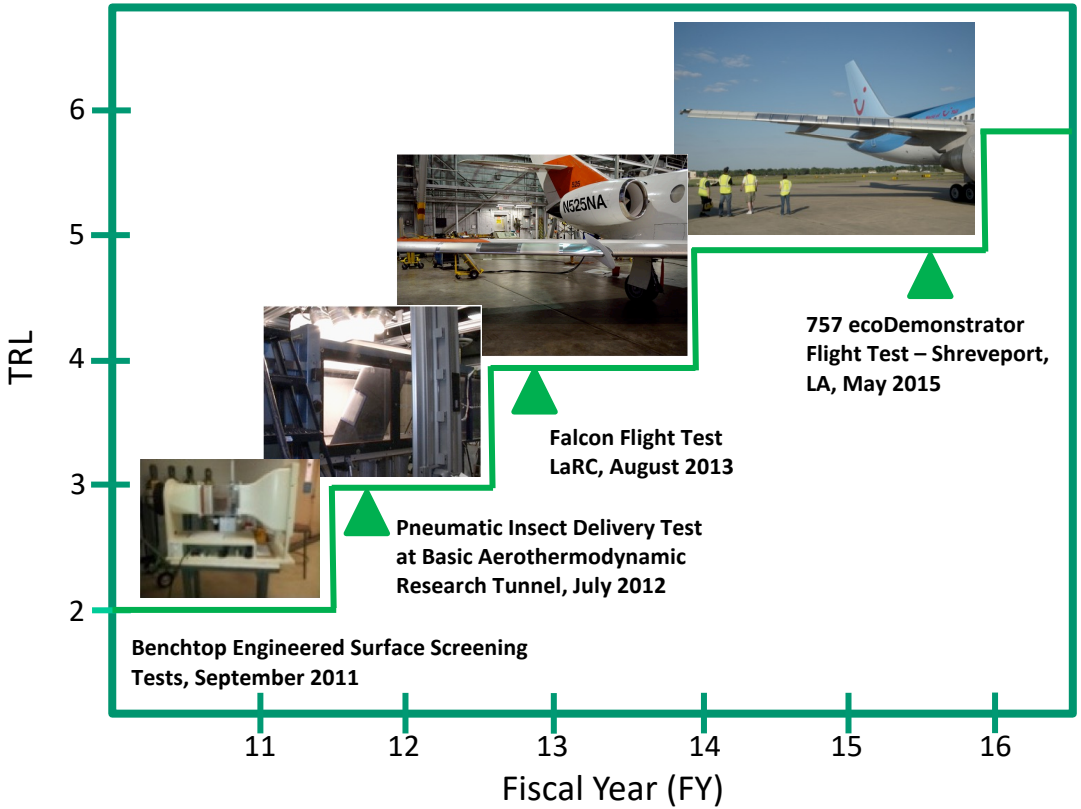
Image Credits: NASA

Ground Testing



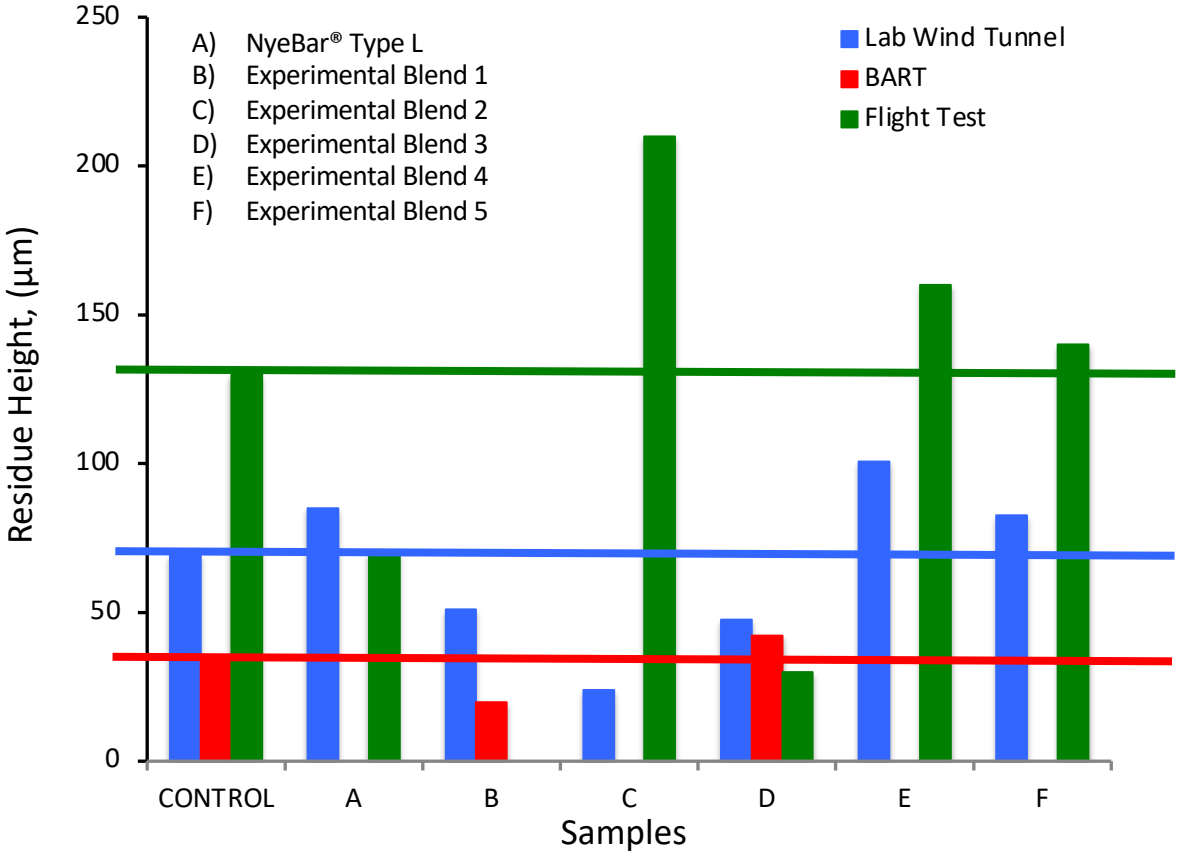
Eiss, N. S., Wightman, J. P., Gilliam, D. R., and Siochi, E. J., NASA CR176231, 1986, pp. 59, 61.

Technology Maturation Roadmap for Coatings



Coating technology fits within ERA's goals of 8% drag reduction for airframe technology

Summary of Test Results

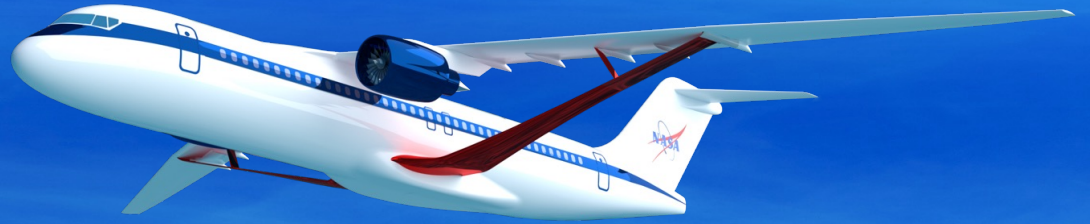


Polymer Materials Across NASA Missions

- Aeronautics
  - Environmentally Responsible Aviation
  - Hi-Rate Composite Aircraft Manufacturing
- Space Technology for Exploration Systems
  - Lightweight Structures
  - Multifunctional Materials
  - In-Situ Resource Utilization

Hi-Rate Composite Aircraft Manufacturing

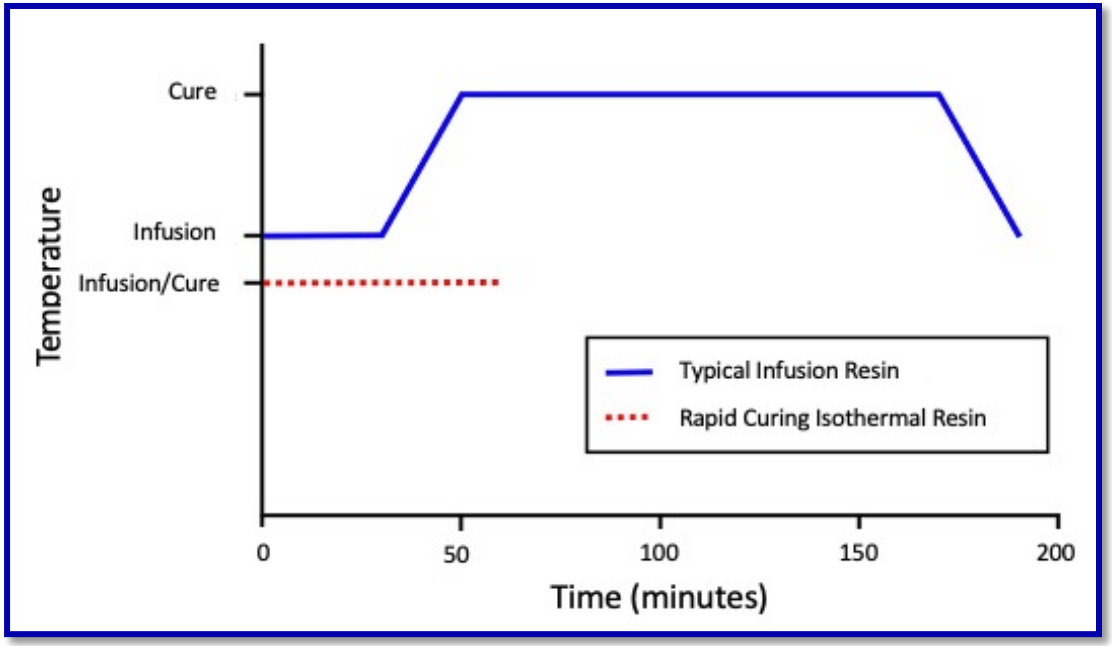
Objective: 4x to 6x increase in composite aircraft production rate



- Market Outlook for Single Aisle Aircraft
- More than 40,000 deliveries by 2040
- Historic aircraft production rates per month
  - Metallic: 60
  - Composite: 10-14
- Target production rate of 80 per month

Image Credit: NASA

Rapid Curing Infusion Resins



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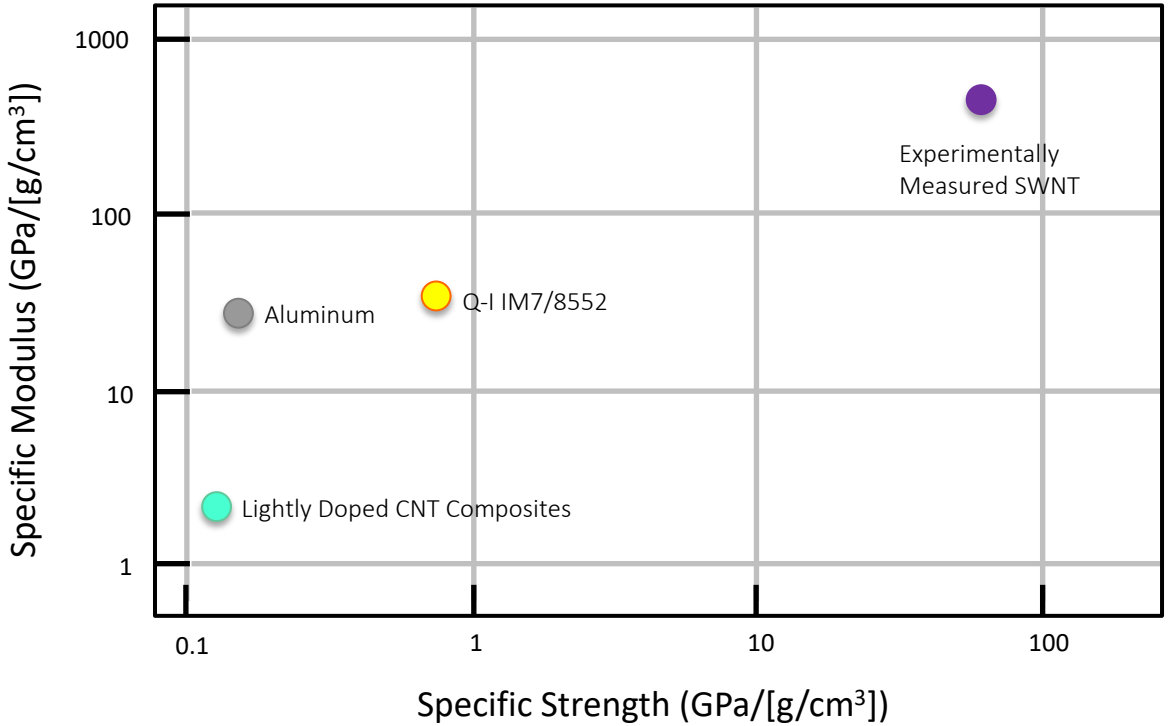
Summary of the Problem

- Cost increases in proportion to the mass ratio.
- Mass ratio increases linearly with the dry mass and exponentially with $\Delta\upsilon$.
- Reducing structural mass reduces mission cost at constant payload or increases mission capability at constant cost.

	Mass Ratio*	Cost per pound*
Low Earth Orbit	20	$4,000
Earth to Moon	200	$40,000
To Moon, Return to Earth	500	$100,000
Earth to Mars	500	$100,000
To Mars, Return to Earth	5000	$1,000,000

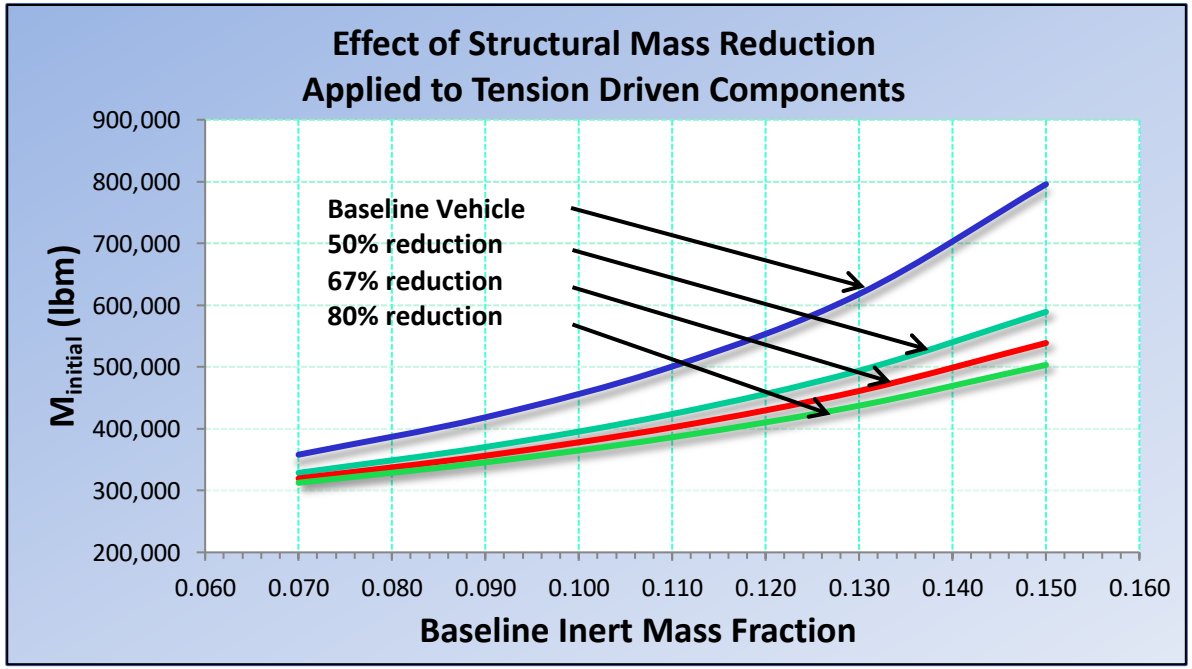
*Gordon, G. D., AIAA SPACE 2007, paper 6278.

Outcomes



- Representative data point from Siochi, E. J. et al., MRS Bulletin, **40**, 829-835, 2015.

Setting Goals Using Systems Analysis



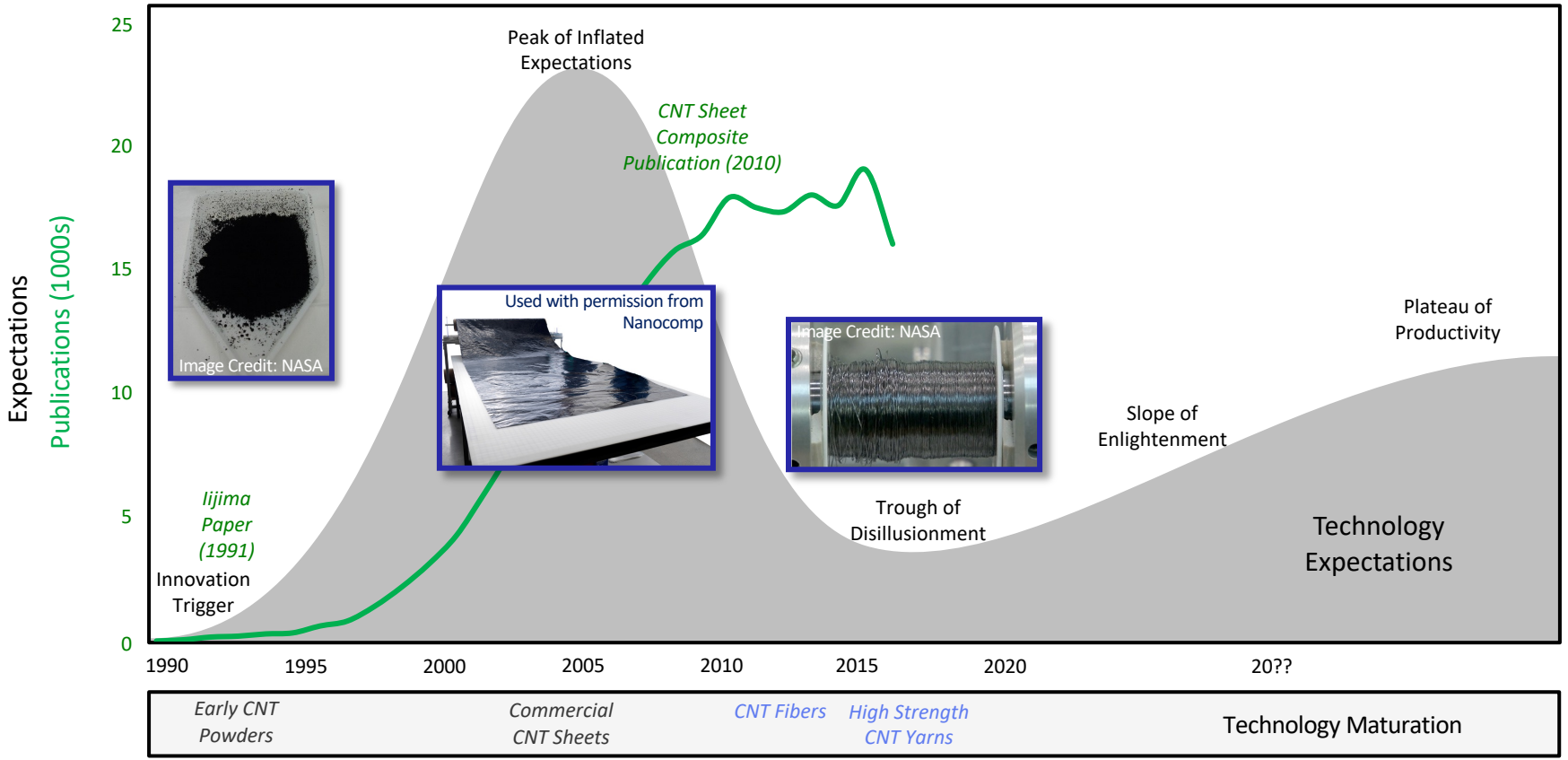
- A 2x to 3x improvement in specific mechanical properties will permit substantial mass reduction in structural and non-structural components.

McMillan, M., White Paper, March, 2013.

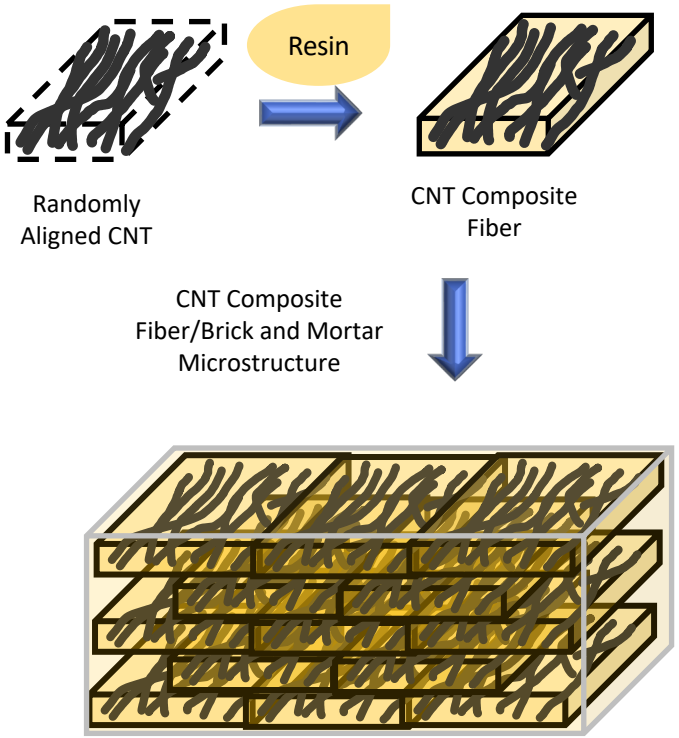
State-of-the-Art Lightweight Structural Material

6 ft x 10 ft PETI-5/IM7 Skin Stringer Panel from High-Speed Research (HSR) Program

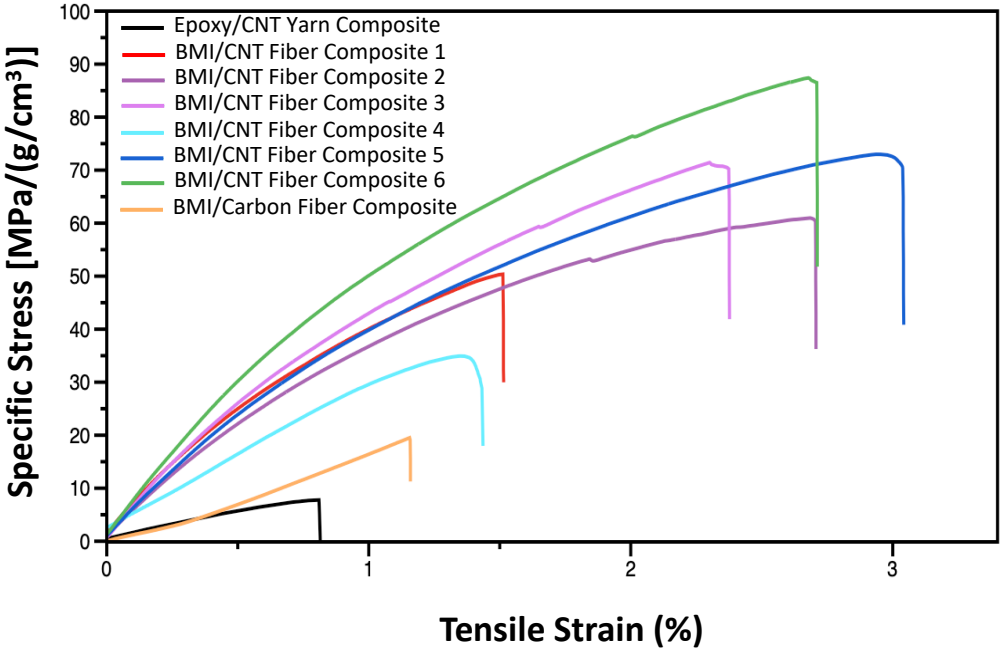
Use-Driven Technology Maturation



Multiscale Hierarchical CNT Composite Fabrication

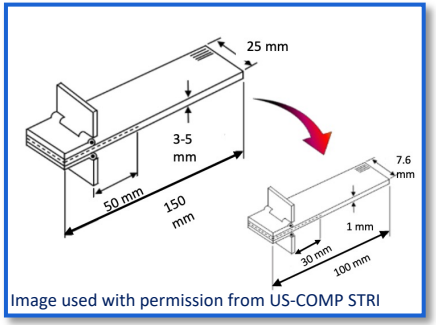


Transverse Tensile Test Results



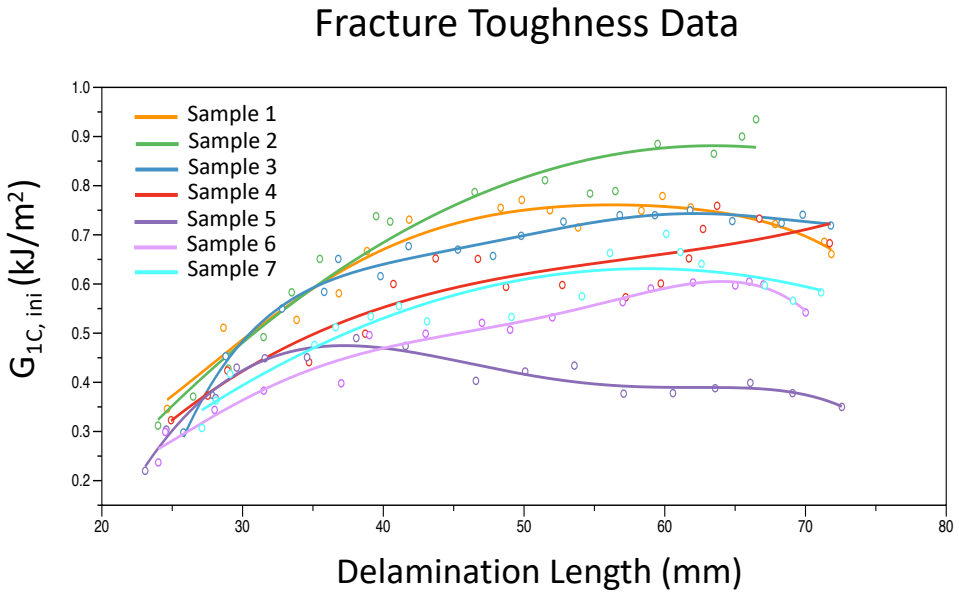
Kim, J-W., et al., *Composites Part A*, **167**, 107449, 2023.

CNT Composite Fracture Toughness



Based on ASTM D5528
Double Cantilever Beam (DCB) Test

CNT Composite DCB Samples



Kim, J-W., et al., *Composites Part A*, **167**, 107449, 2023.

Systems Defined Goal Provides Common Objective

NASA Centers
- LaRC

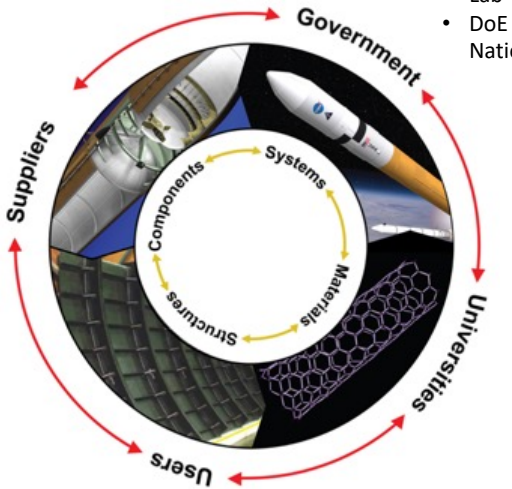
Public/Private Partnerships
- Northrup Grumman
- University of Dayton Research Institute/State of Ohio

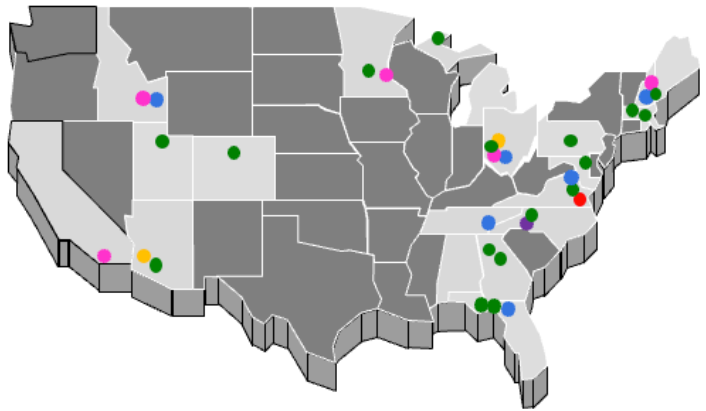
OGA Leveraging
- AFOSR
- AFRL – ManTech Program
- DoD
- DoE - ARPA-E
- DoE – Idaho National Lab
- DoE – Oak Ridge National Lab

Small Business
- Textum, Inc.

SBIR/STTR
- Nanocomp
- Cornerstone Research Group
- Minnesota Wire & Cable
- Applied Composites

STRI
- Florida State U
- MIT
- VCU
- Ga Tech
- Penn State U
- FL A&M U
- Solvay
- Textum
- Michigan Tech
- U of Utah
- U of Colorado
- Johns Hopkins
- U of Minnesota
- Columbia University
- Nanocomp
- Northrop Grumman





Incentivize multidisciplinary partnerships to accelerate maturation of an emerging material ecosystem.

Image Credit: NASA

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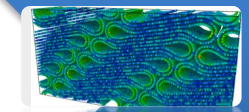
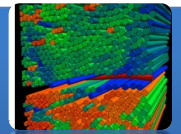
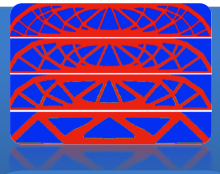
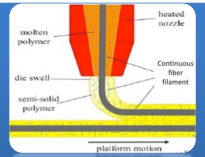
Multidisciplinary Teaming to Accelerate Technology Maturation

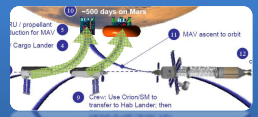

Atomistic Modeling

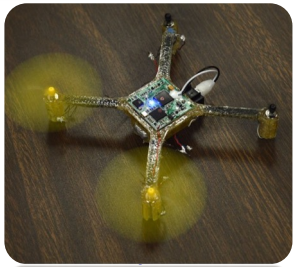

Mechanics of Materials Modeling

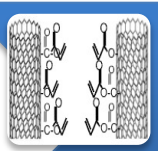

Topological Optimization

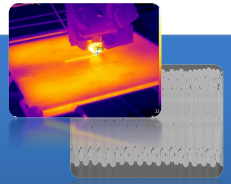


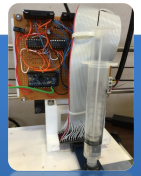
Process Modeling

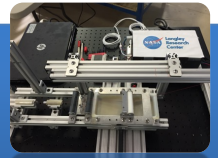

Systems Analysis

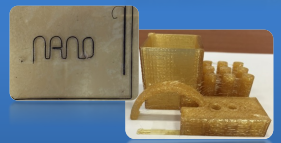

Nanostructured Multifunctional Component


Chemistry


Materials Characterization

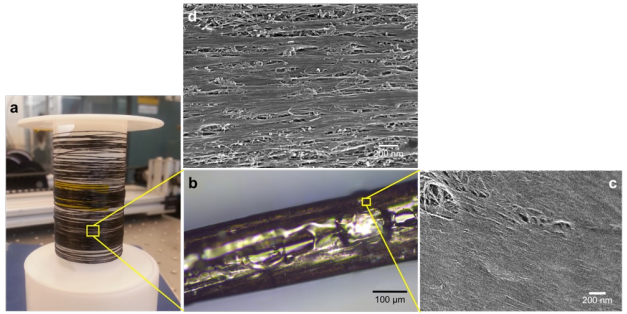

Sensor Fab and Characterization

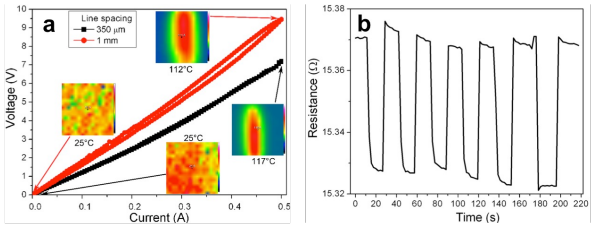

Composite Processing

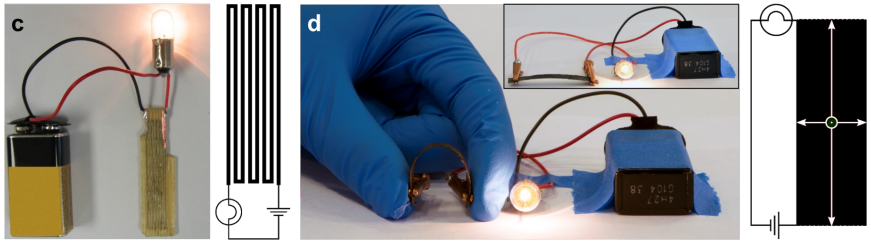


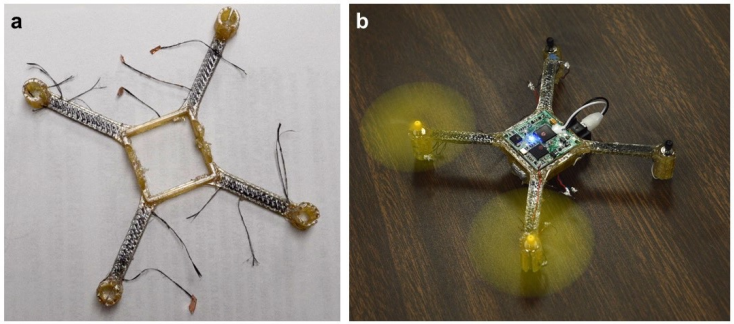
3d Printing

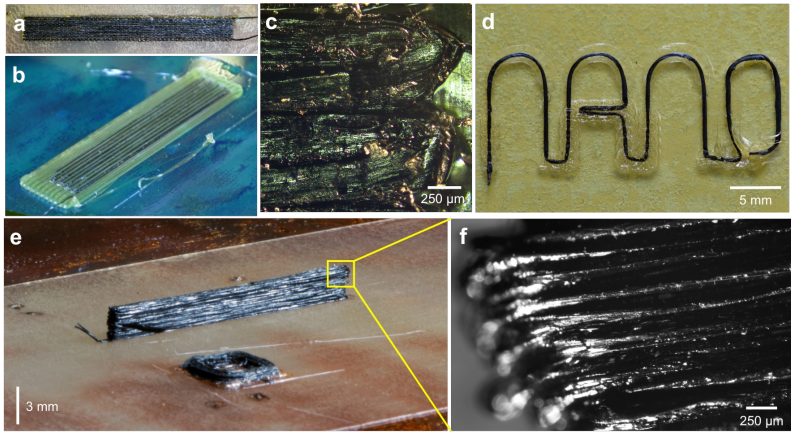
Prototyping for Accelerated Technology Development











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In-Situ Resource Utilization

Image Credit: NASA

Acknowledgements

Computational Modeling

- Kristopher Wise
- Benjamin Jensen

Polymer Synthesis

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- John Connell
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- John Gardner
- Jae-Woo Kim

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Characterization and Testing

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- Michelle Shanahan
- Ronald Penner
- Paul Bagby
- Godfrey Sauti
- Russell Wincheski

Flow Physics

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- Jenna Eppink
- Rudolph King
- Dan Neuhart
- Anthony Washburn

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