

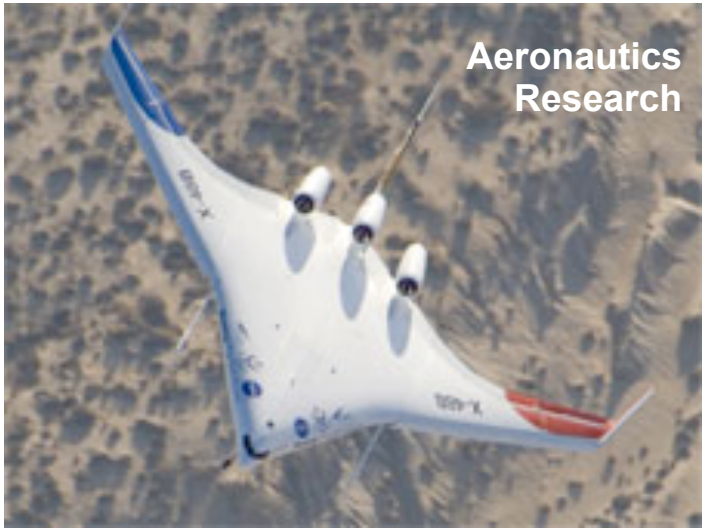
Nanotechnology for Aerospace Applications

Mia Siochi
NASA Langley Research Center
Hampton, VA

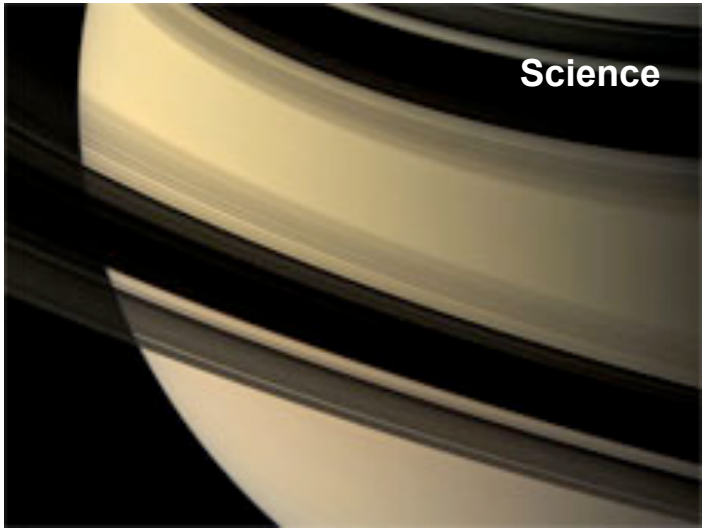
Big Ideas of Nanoscience & Nanotechnology
Fellows Institute
August 21, 2015

NASA Missions

Langley Research Center



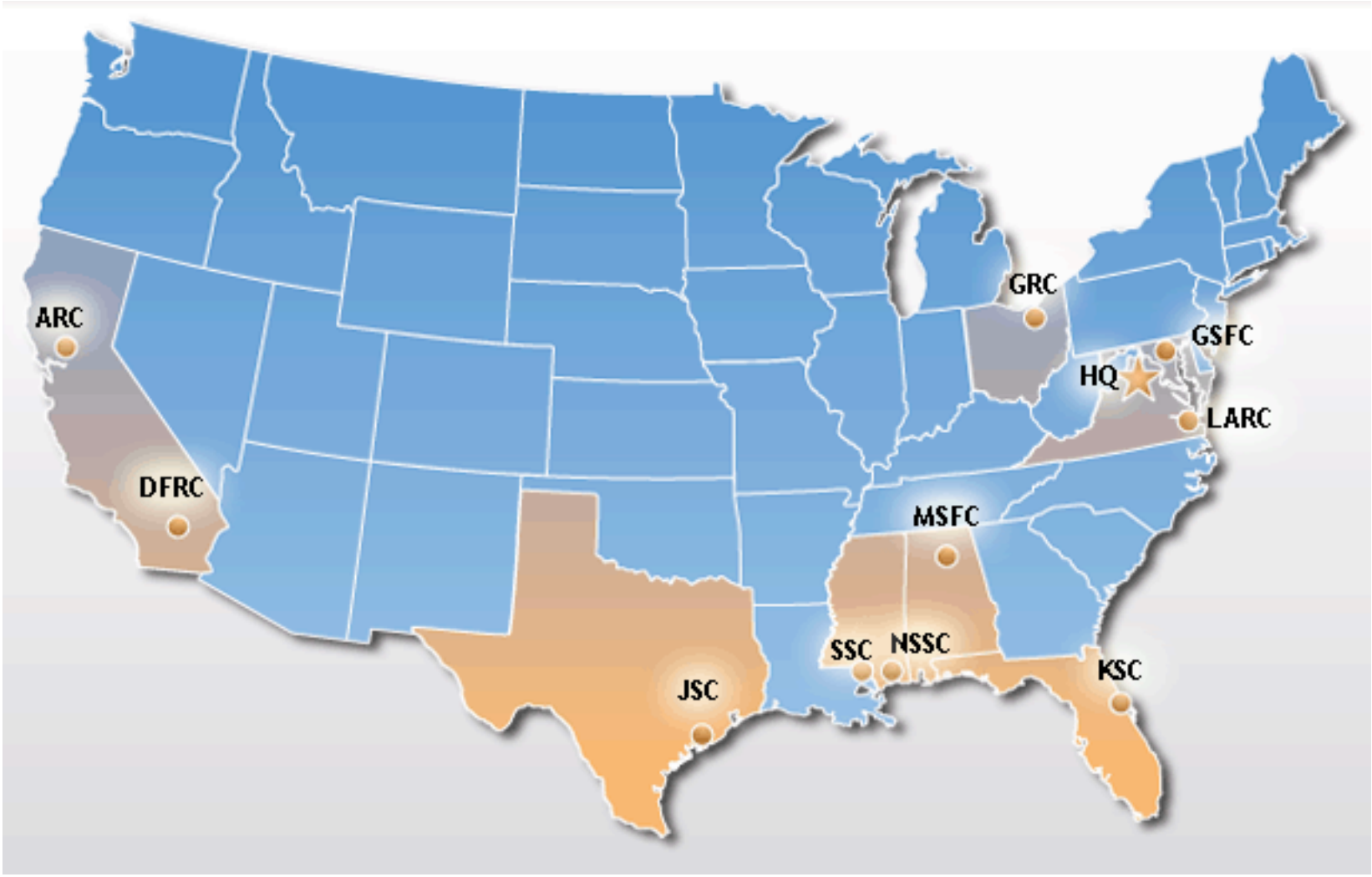




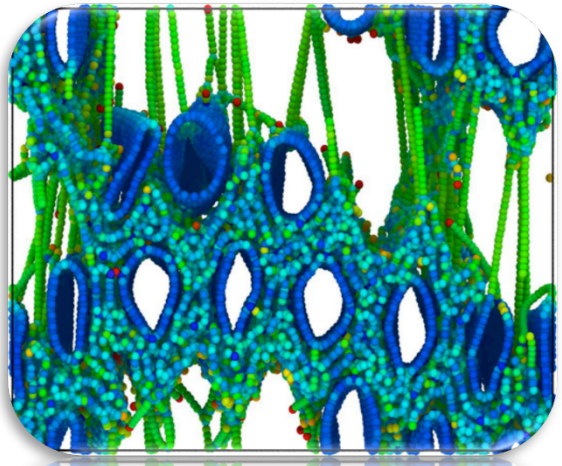


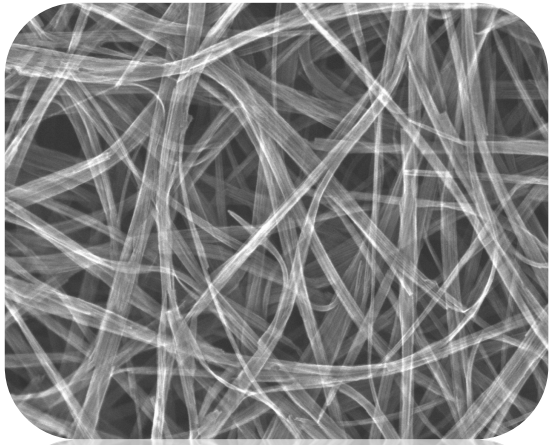
NASA Centers

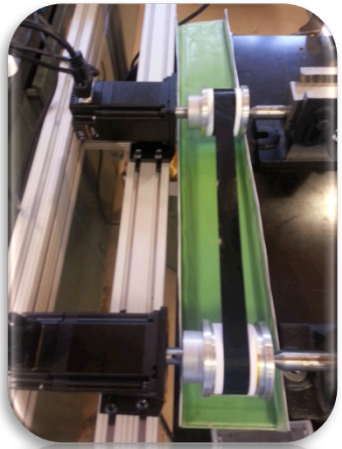
Langley Research Center



Structural Nanocomposites

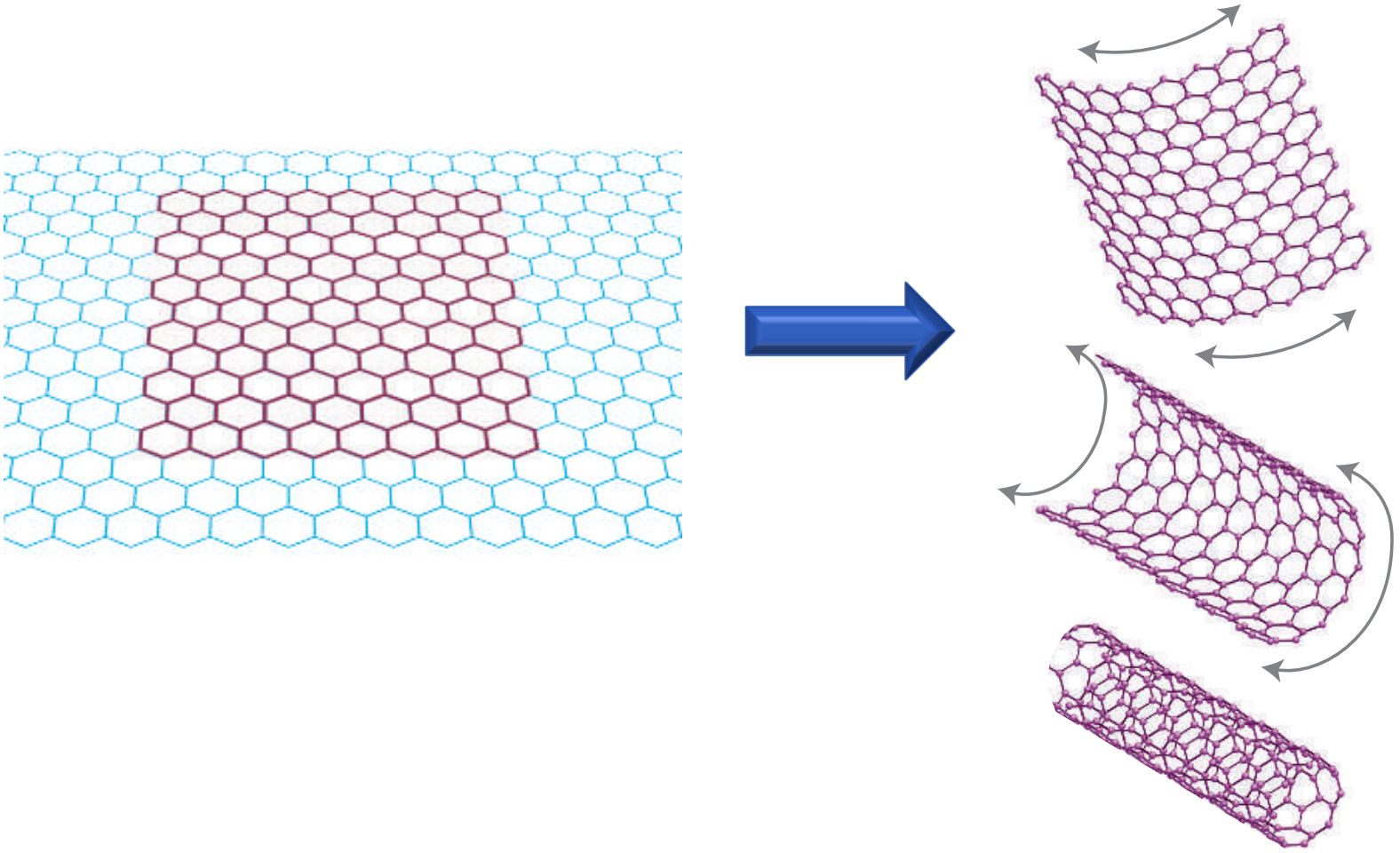






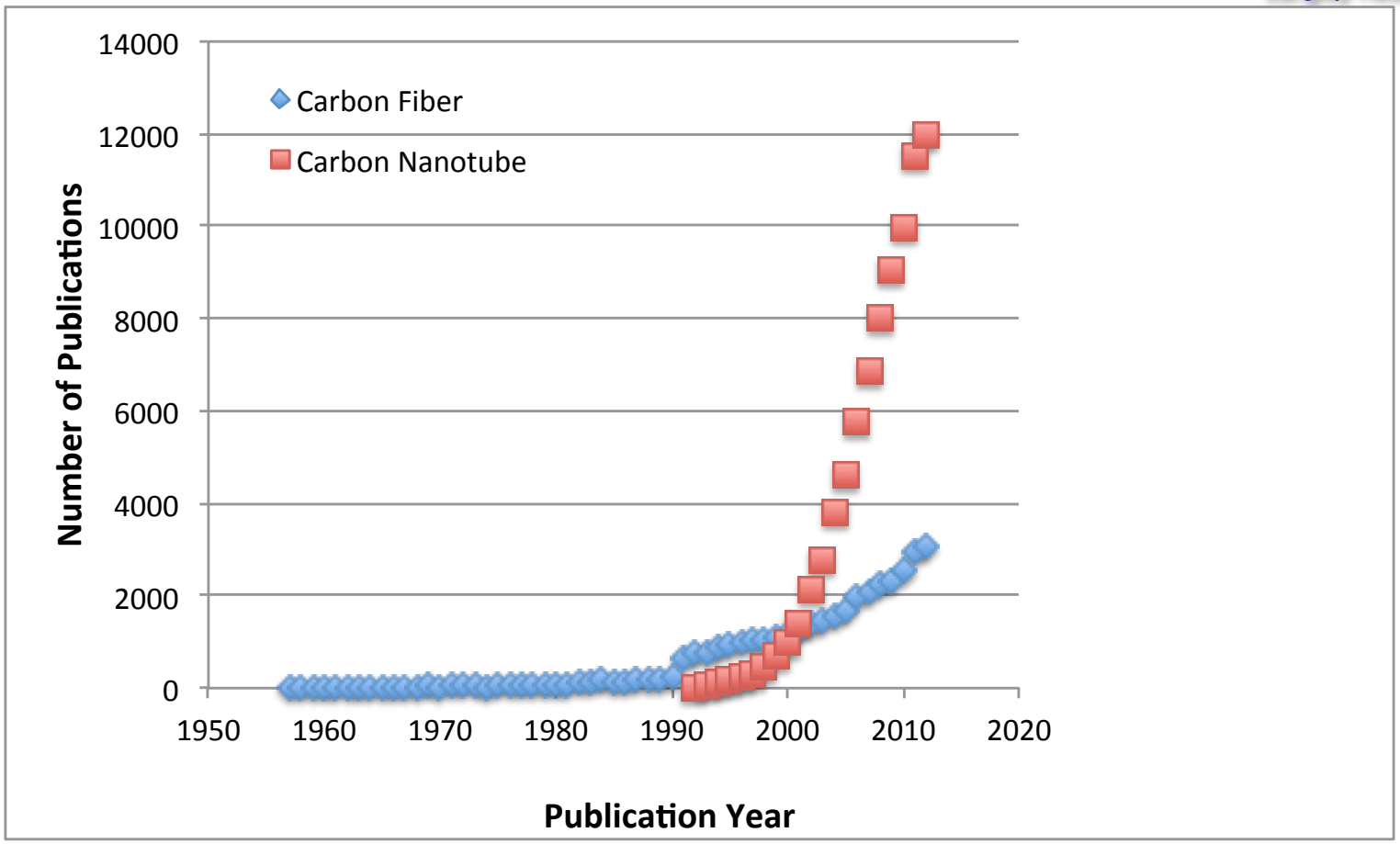


Carbon Nanotubes



Geim, A. K. and Novoselov, K. S., “The Rise of Graphene,” Nautre Materials, 6, 183-191, 2007.

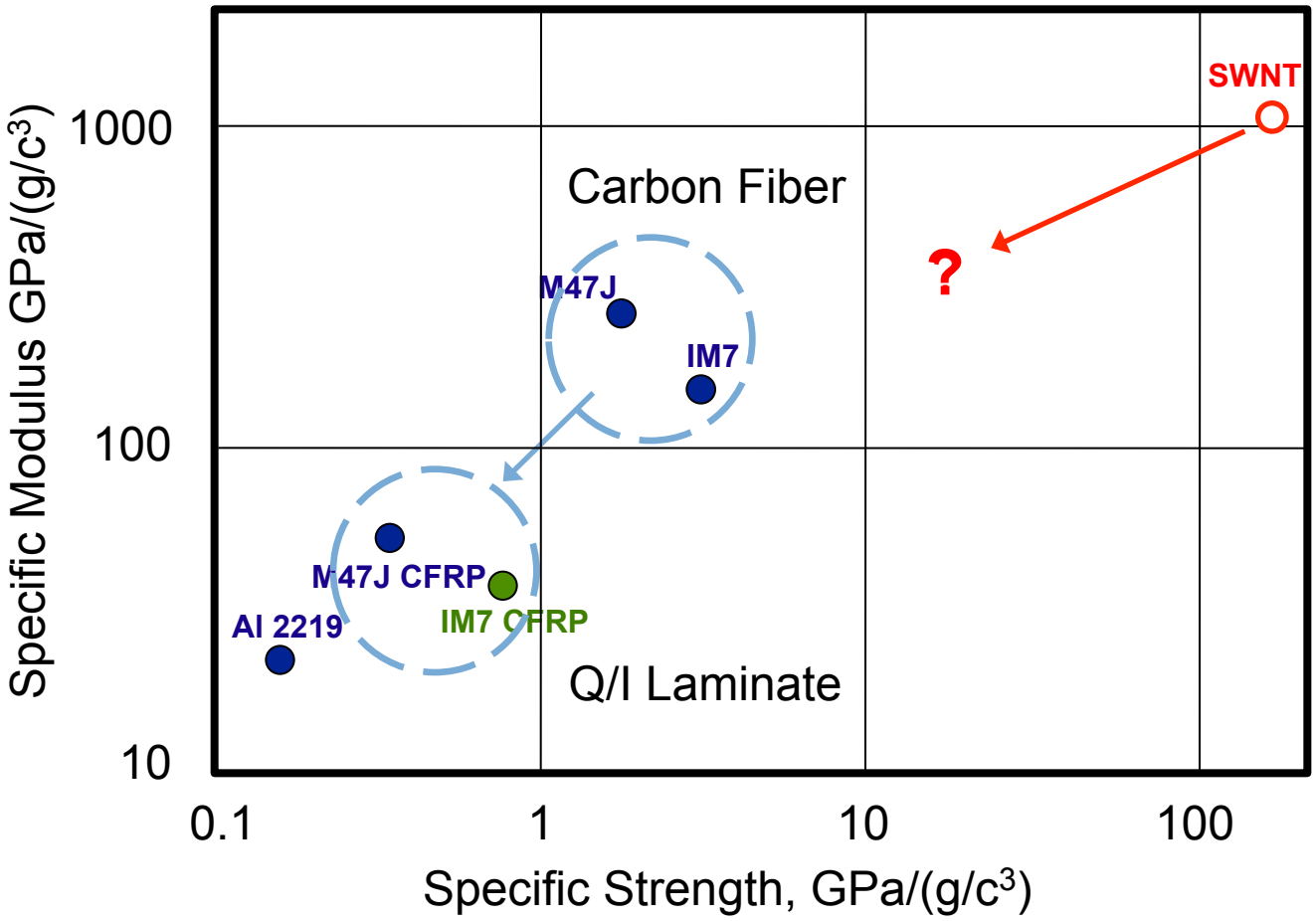
Comparison of CFRP and CNT Literature



- Compared to SOA lightweight structural materials (CFRP), there has been considerably greater attention paid to CNTs since its discovery in 1991.

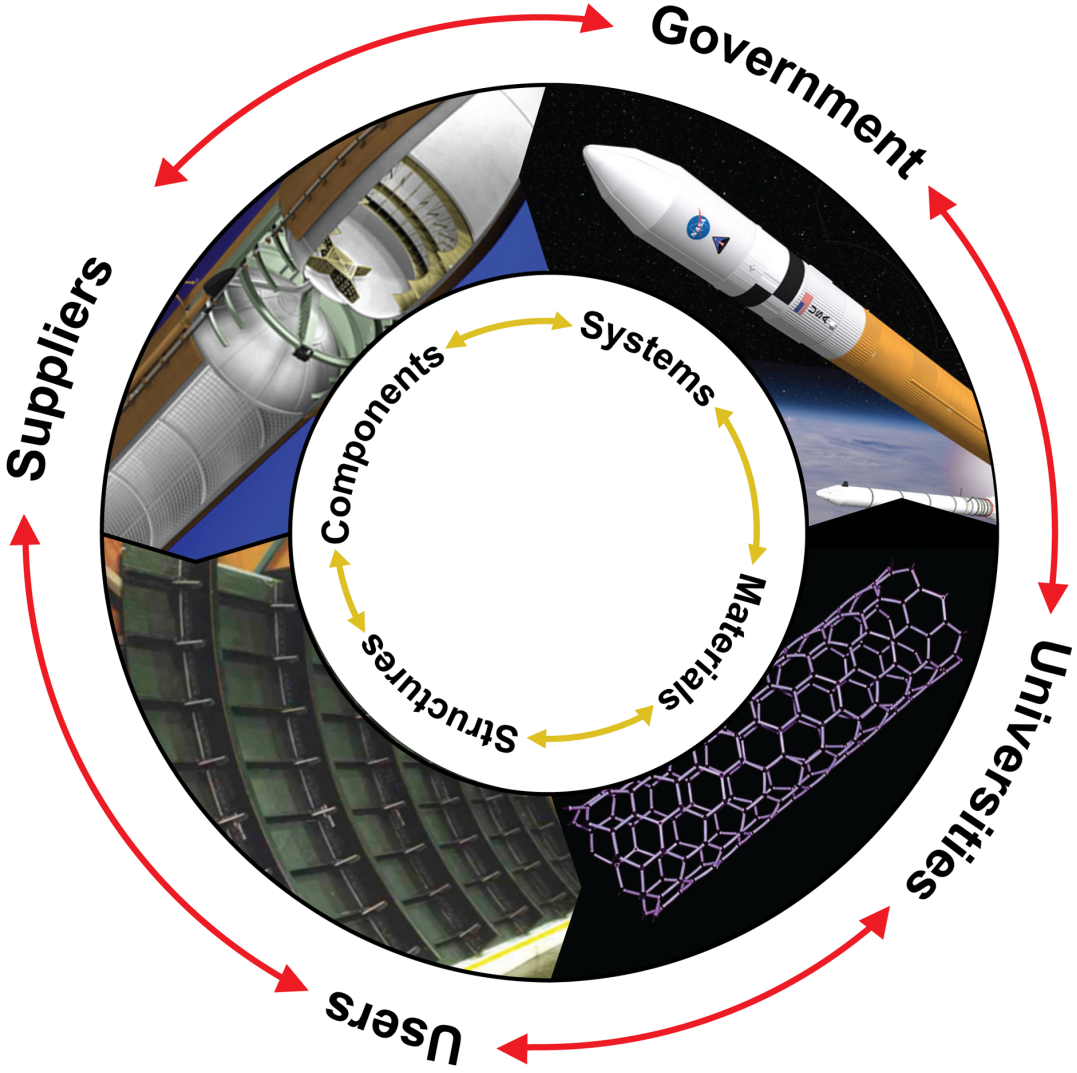
Statistics derived from Web of Science data, Siochi, April 2013.

Why Carbon Nanotubes?



Harris, Shuart, Gray, NASA TM 211664, 2002

Accelerate Technology Maturation with Multidisciplinary Approach



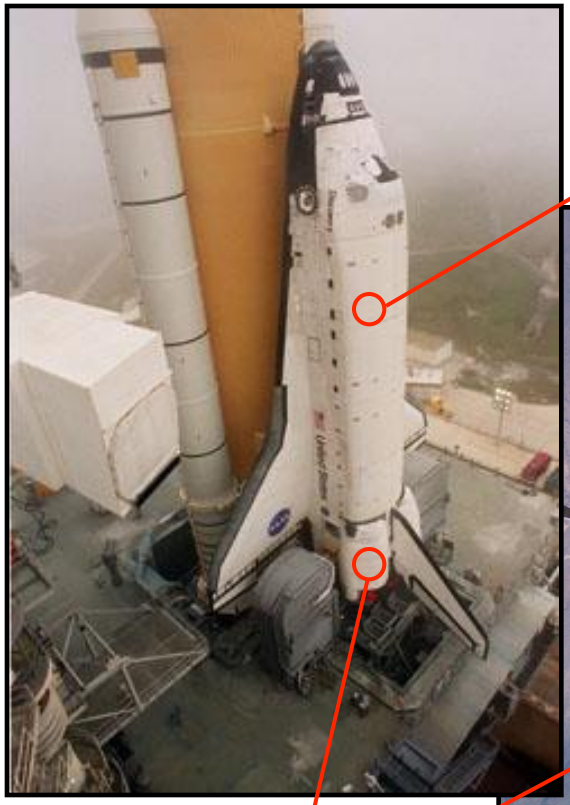
Competition – Carbon Fiber Composites

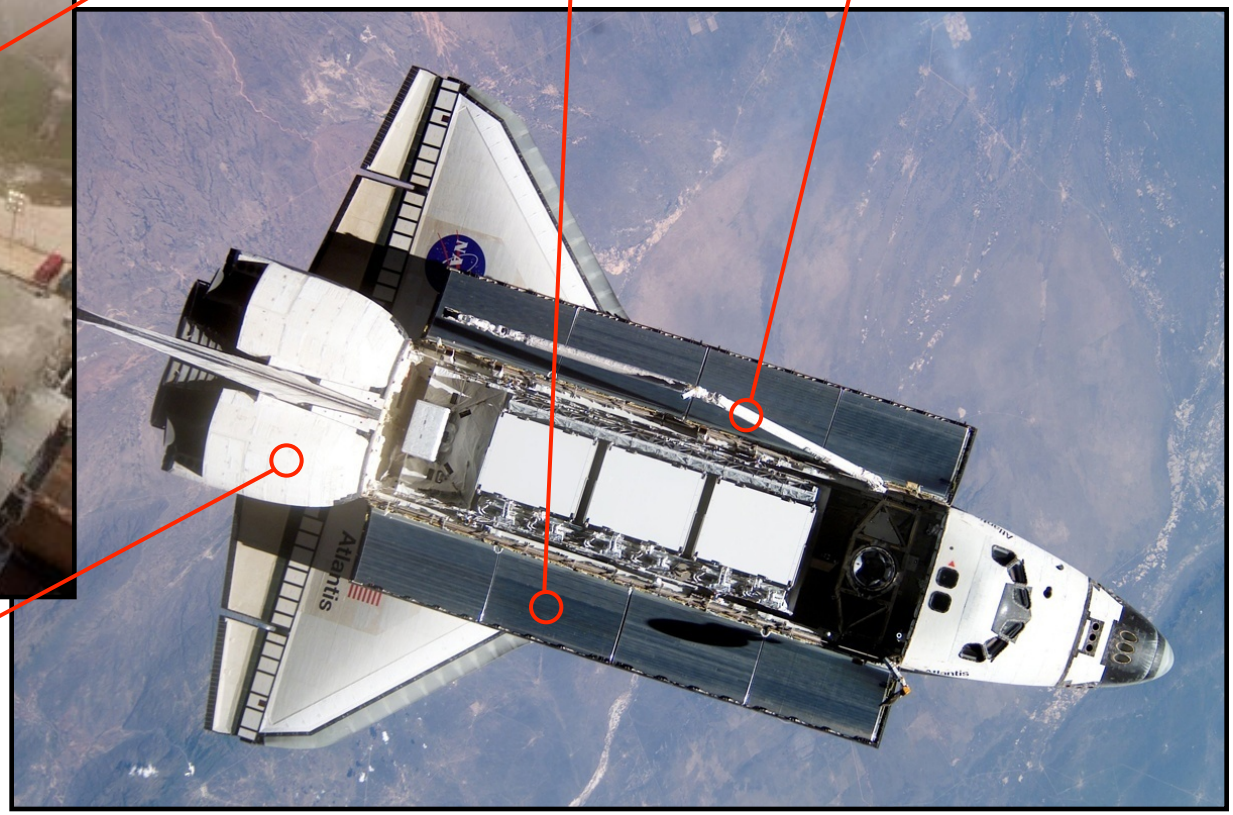
Langley Research Center



Early Composite Technology Adopter

Langley Research Center

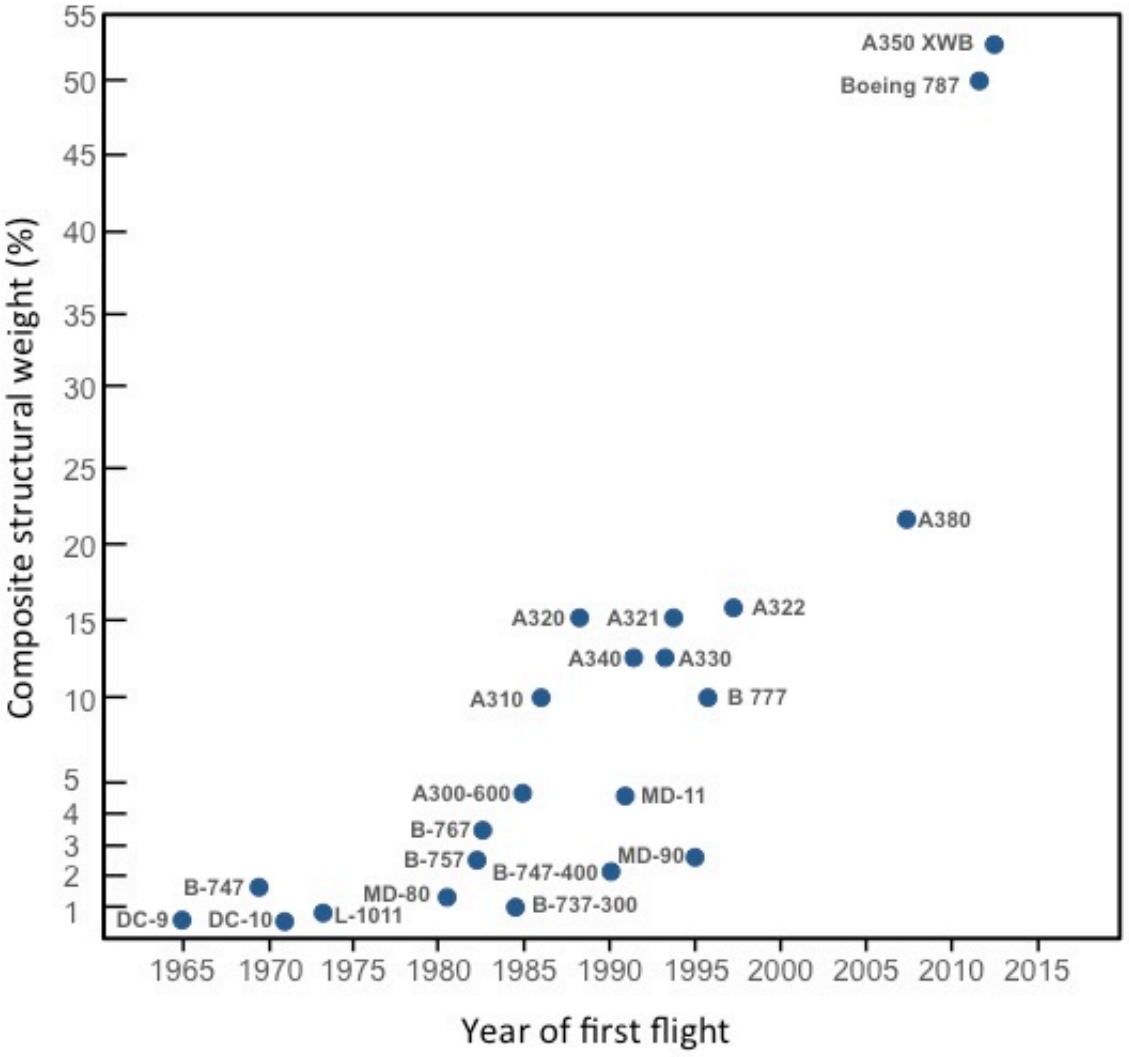




STS orbiter payload bay doors were the largest composite structure ever designed and built circa late 1970's. First flight in 1981

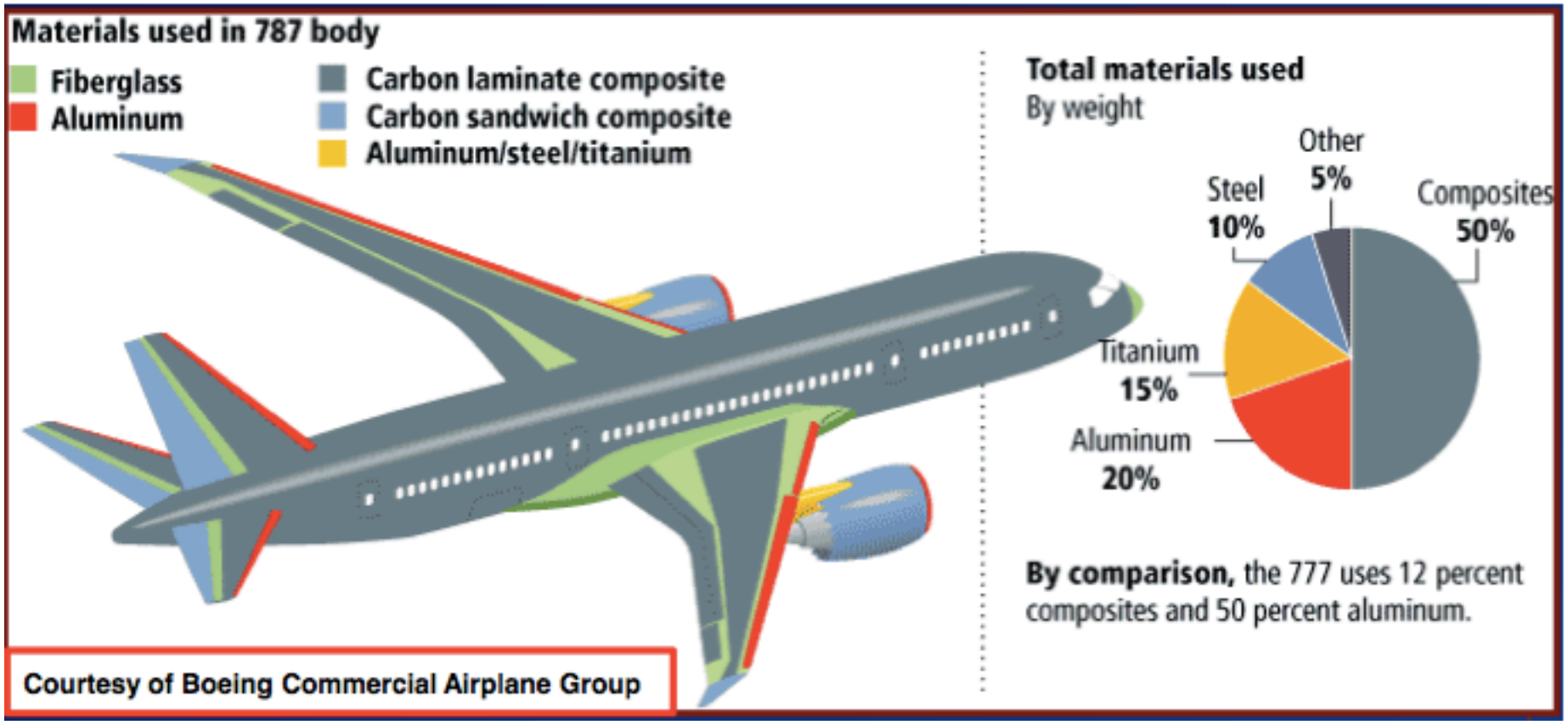
Dr. Charlie Harris, Future of Materials, Aviation Unleashed, October, 2010.

Composites in Commercial Transport Aircraft (2010)

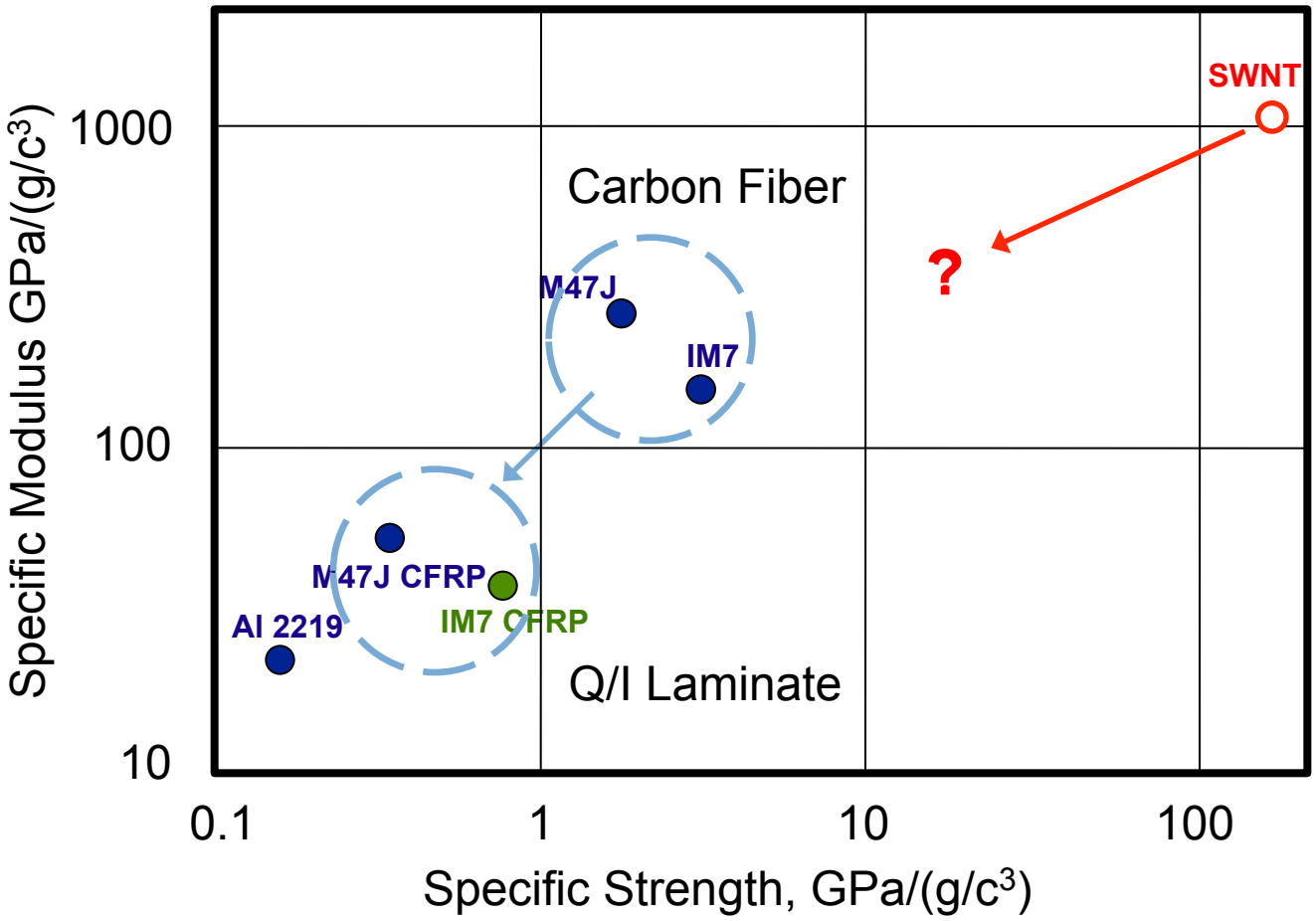


Dr. Charlie Harris, Future of Materials, Aviation Unleashed, October, 2010

Boeing 787

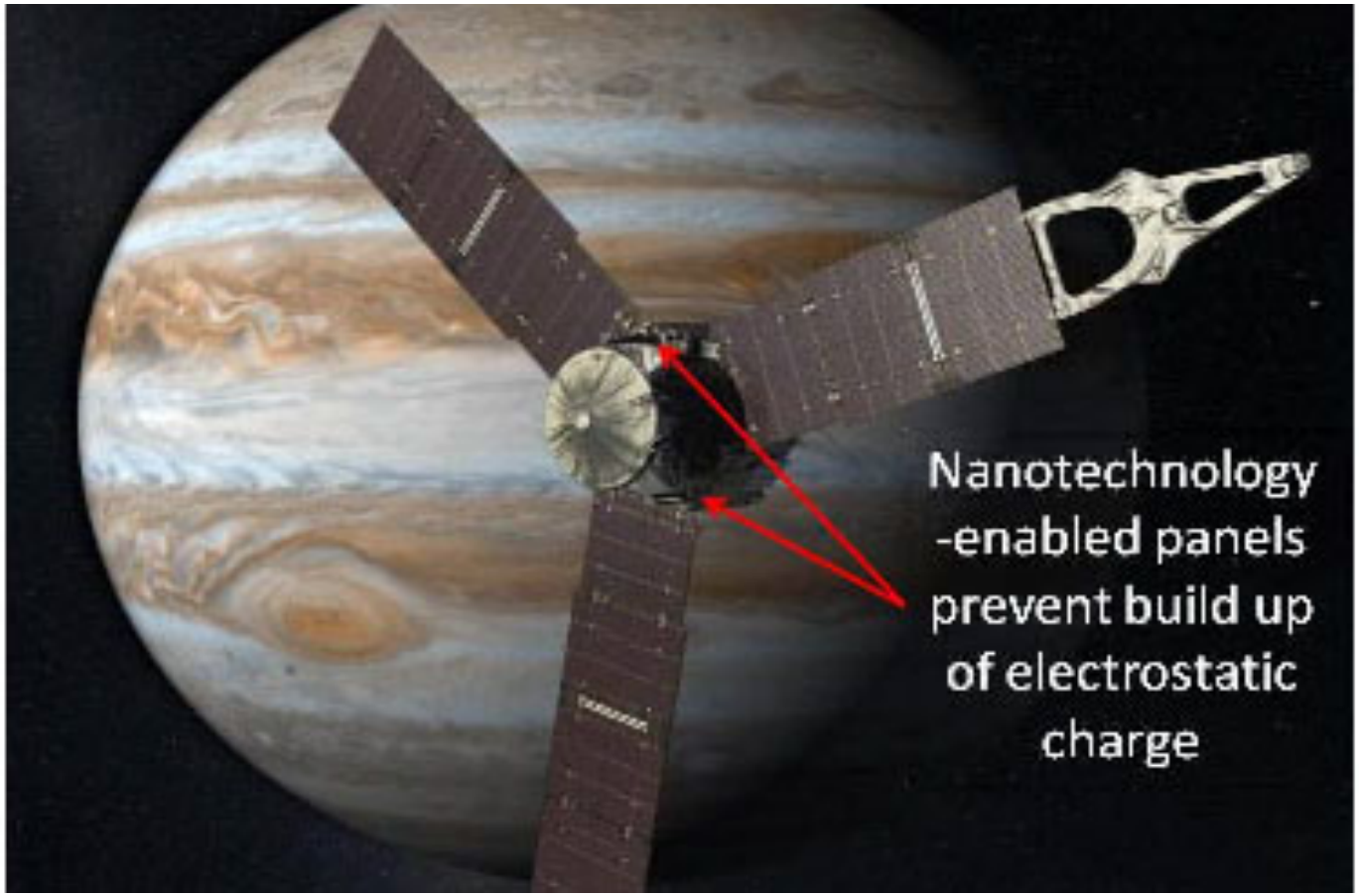

Materials used in 787 body
Fiberglass
Aluminum
Carbon laminate composite
Carbon sandwich composite
Aluminum/steel/titanium
Courtesy of Boeing Commercial Airplane Group
Total materials used
By weight
Other
5%
Steel
10%
Composites
50%
Titanium
15%
Aluminum
20%
By comparison, the 777 uses 12 percent composites and 50 percent aluminum.

Why Carbon Nanotubes?



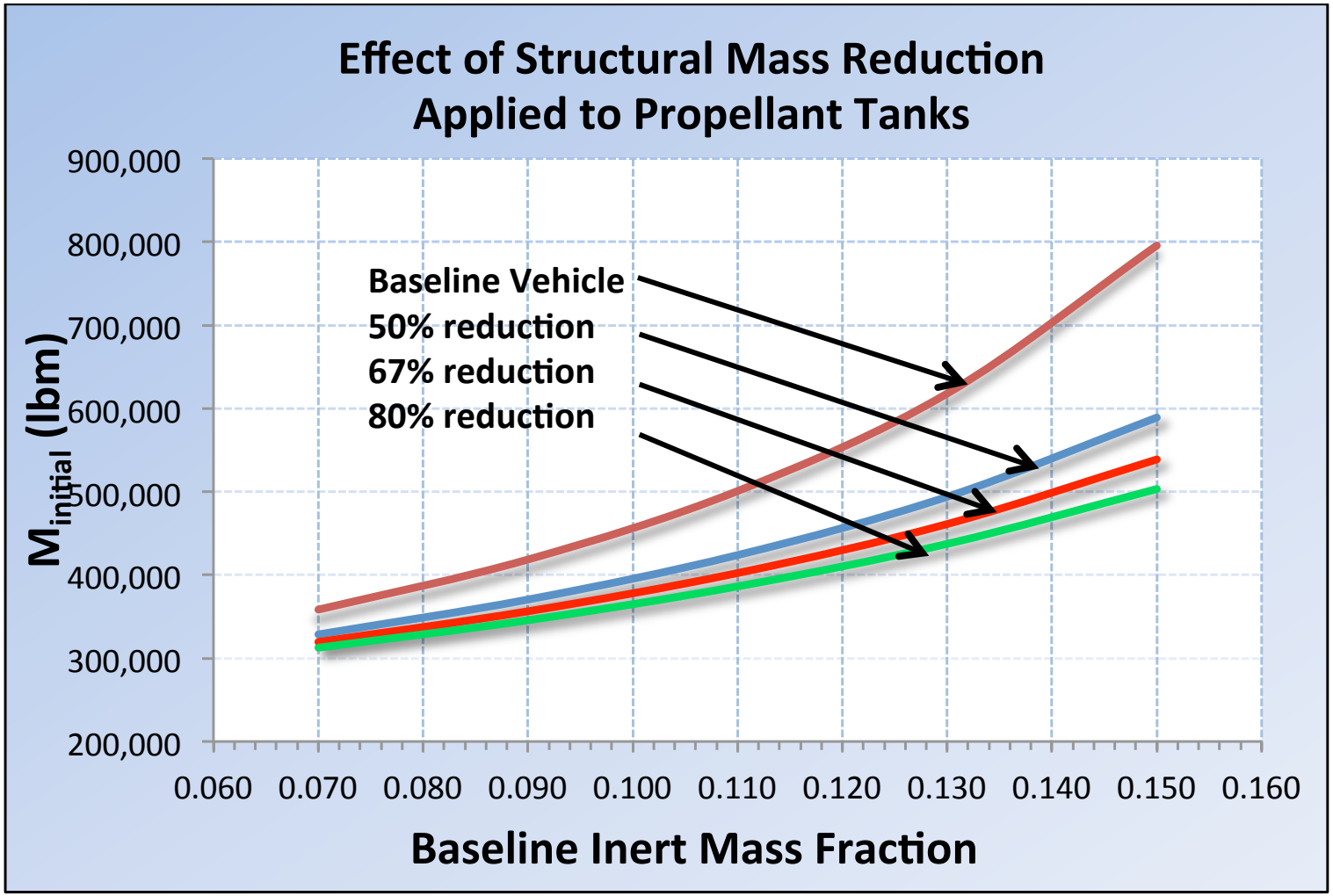
Harris, Shuart, Gray, NASA TM 211664, 2002

Juno Spacecraft - 2011

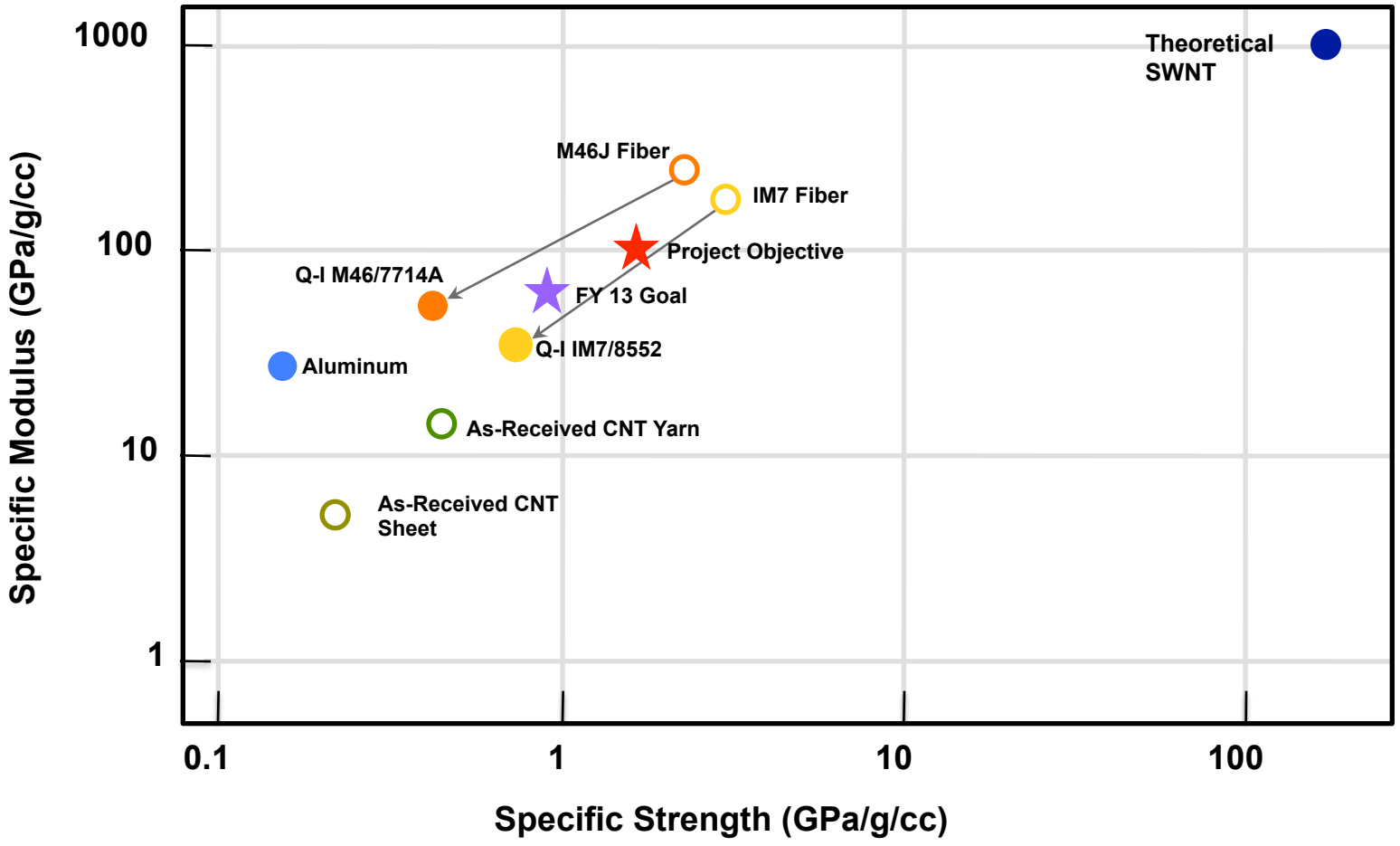


Nanotechnology Headed to Jupiter, http://www.nano.gov/slideshow-archive

Potential System Weight Savings

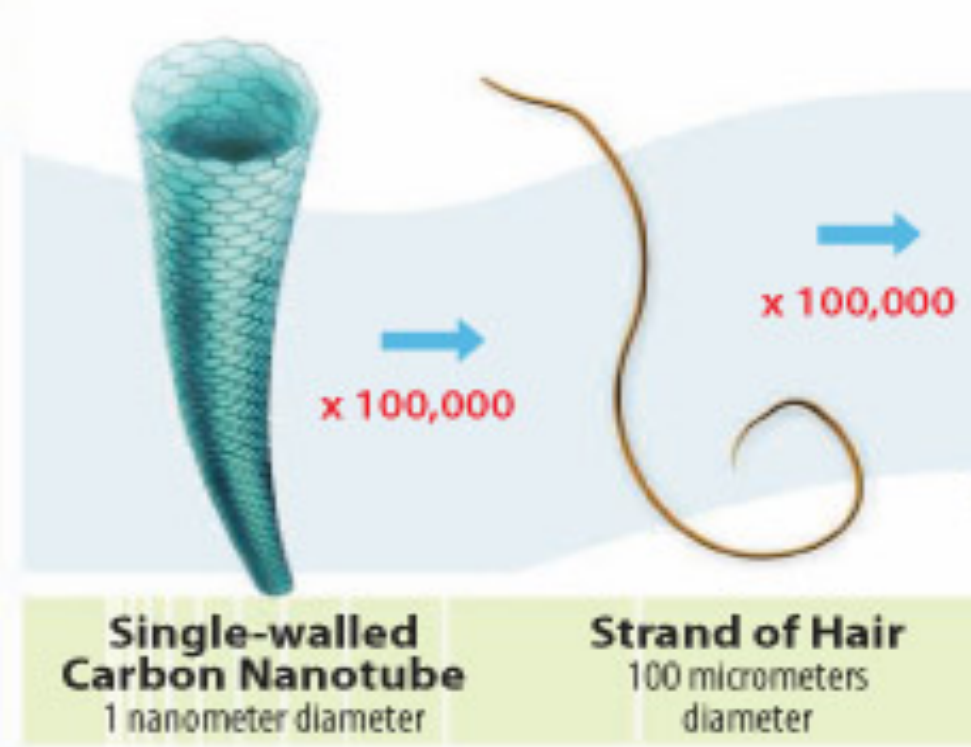


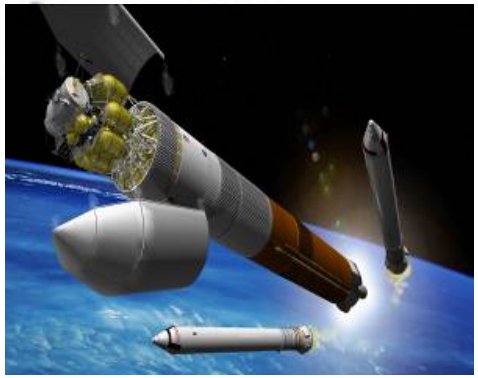
Nano to Macro Challenge



- Available materials have starting mechanical properties inferior to other SOA materials.

Nano to Macro Scaling of Properties







Aerospace Vehicles
10s of meters

Technology insertion in a structural application remains elusive

Adopted from National Nanotechnology Initiative (www.nano.gov)

Barriers for Technology Insertion – Application Side



- **Displacing SOA**
  - Performance
  - Risk
  - Cost
- **Knowledgeability**
  - Objective assessment of emerging technology capabilities
  - Established design paradigms
- **Nano to macro**
  - Addressing heterogeneous system integration issues
  - Preserving nanoscale benefits

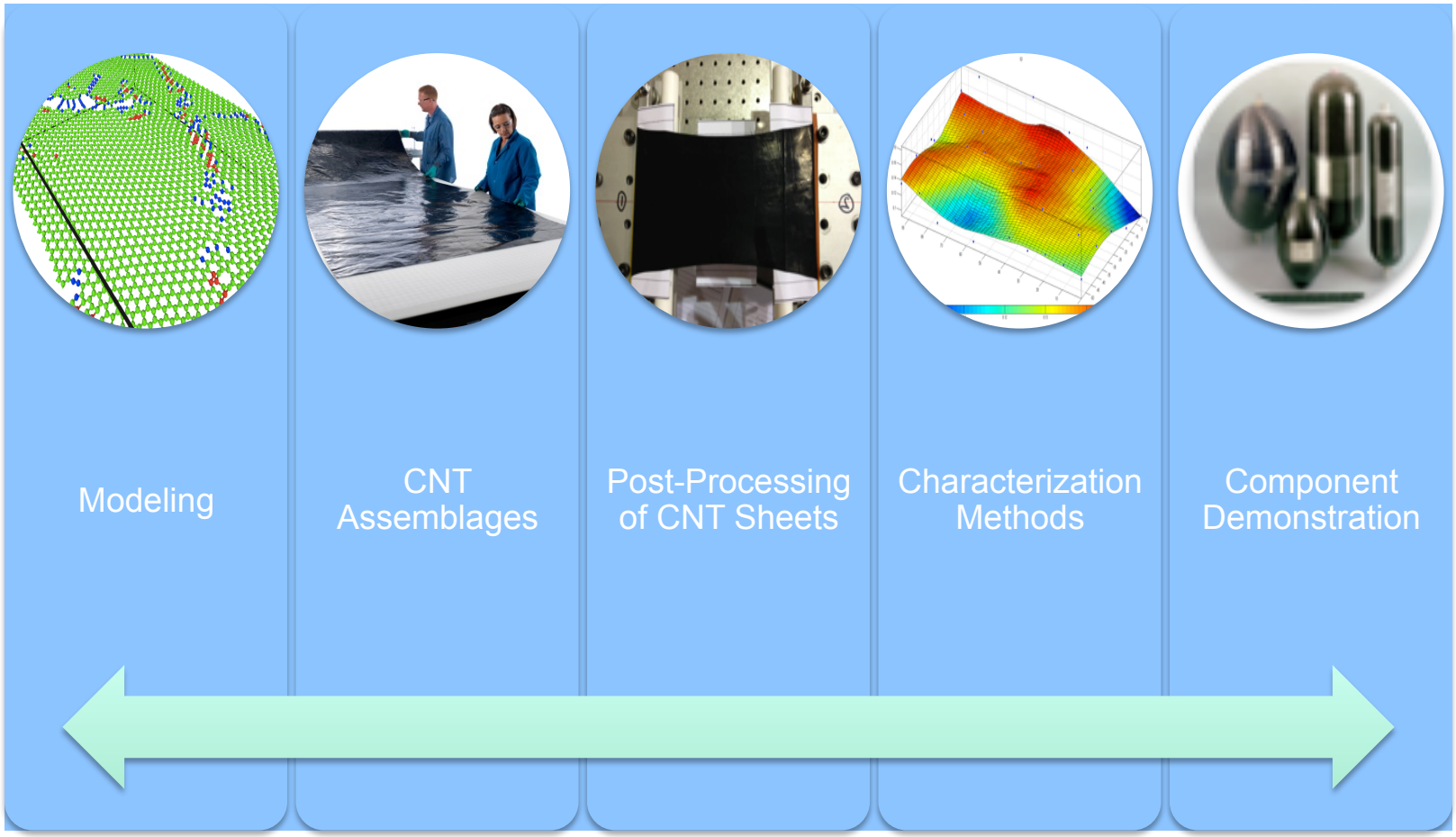
Barriers for Technology Insertion – Supply Side



- **Scale-up to large quantities**
  - Commercially viable processes to produce large volume of material
  - CNTs should be available in assemblages that lend themselves to the fabrication of structural components
- **Quality of material**
  - Development of reliable, reproducible and controlled carbon nanotube synthesis process on a large scale
  - Development of the above processes for CNT assemblages that have the necessary properties to meet aerospace requirements

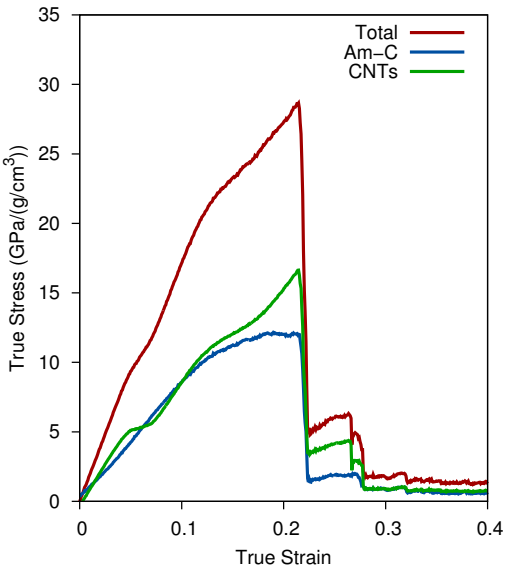
Nanotechnology Project Spans Modeling to Component Demo

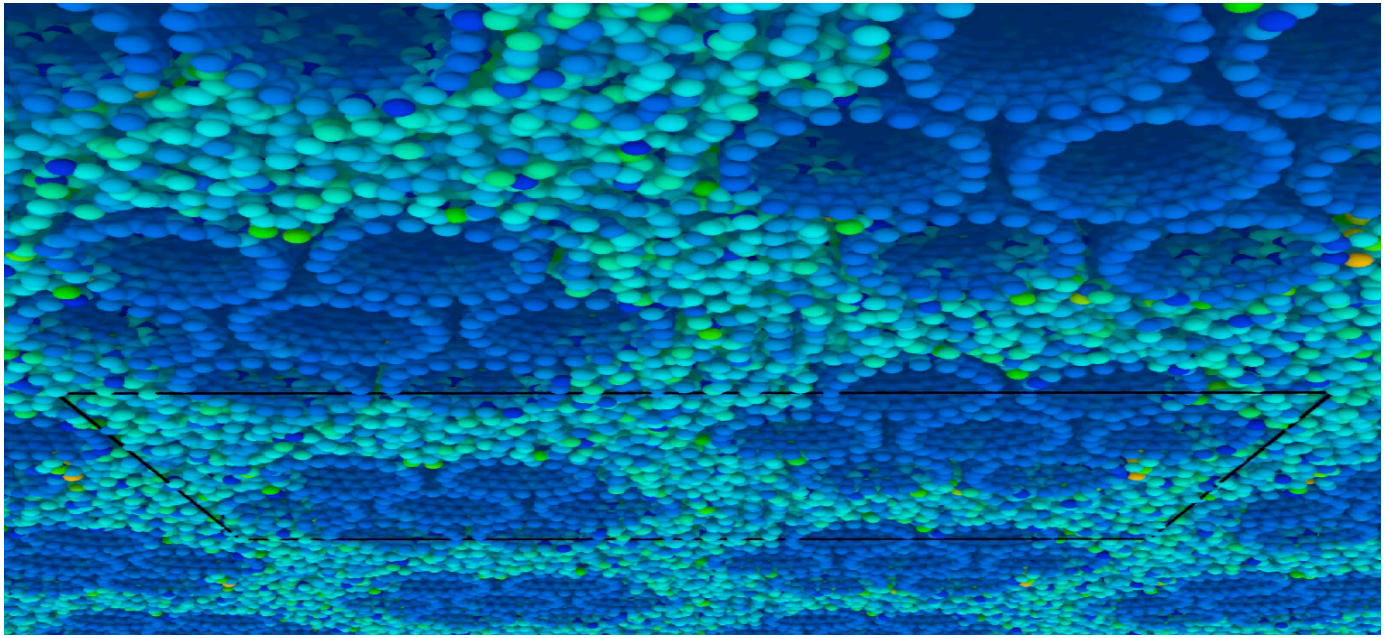
Langley Research Center



Project has adopted a comprehensive approach involving modeling, materials development, testing and characterization, and component level demonstration to accelerate materials development and mission transition

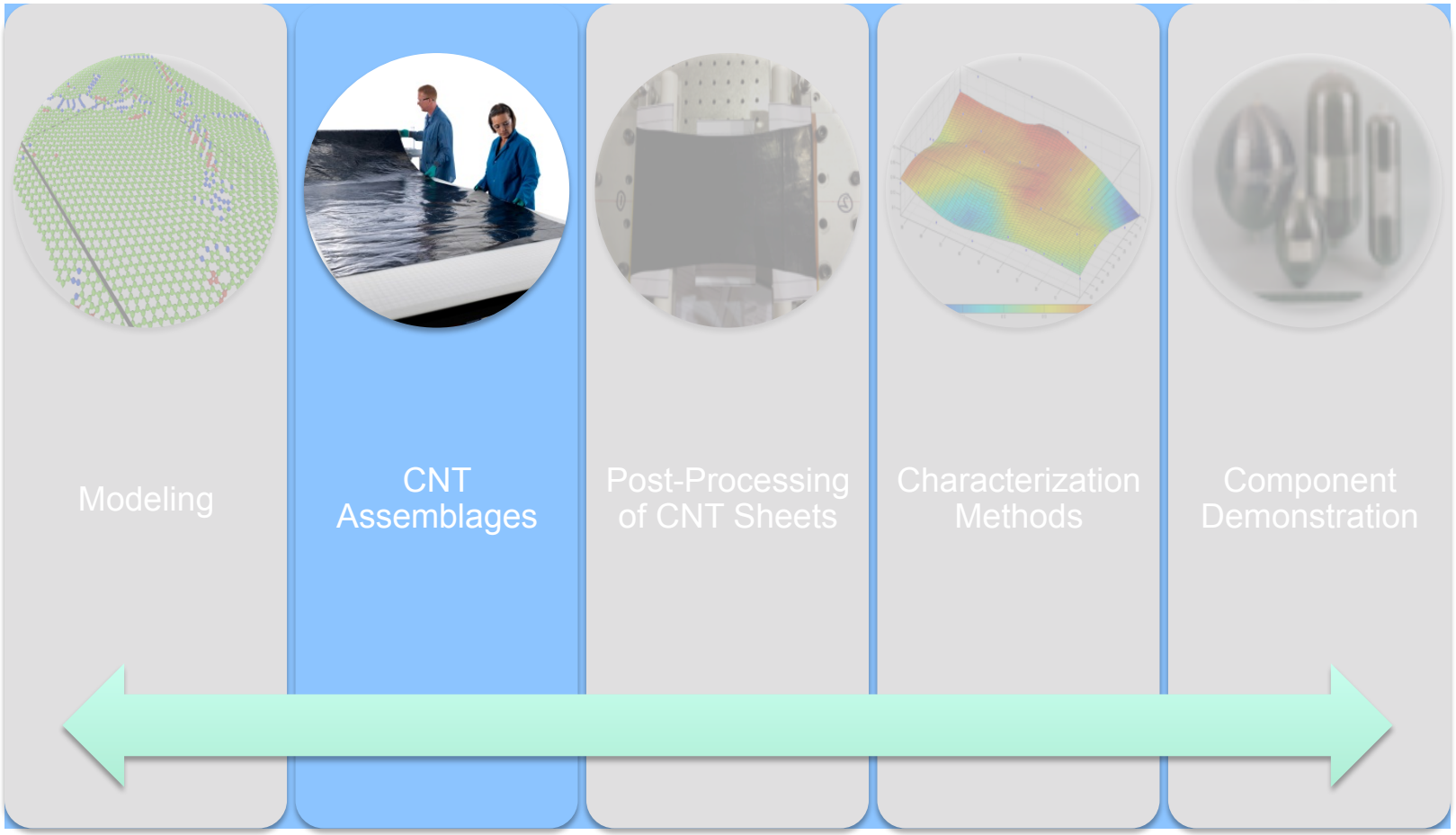
Bundle Failure





Nanotechnology Project Spans Modeling to Component Demo

Langley Research Center



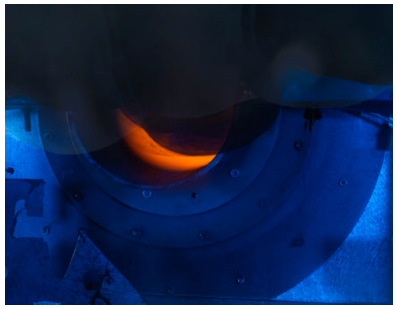
Project has adopted a comprehensive approach involving modeling, materials development, testing and characterization, and component level demonstration to accelerate materials development and mission transition

Materials State-of-the-Art

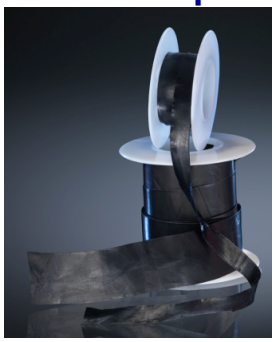
Nanocomp Technologies - SBIR

Langley Research Center

Non-Woven Textile



CNT Tape



CNT Yarn

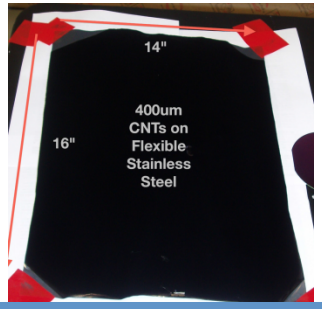


CNT Sheet

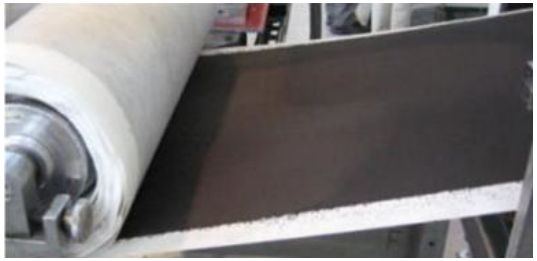


General Nano - SBIR

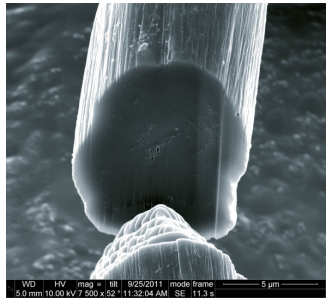
Vertical Arrays

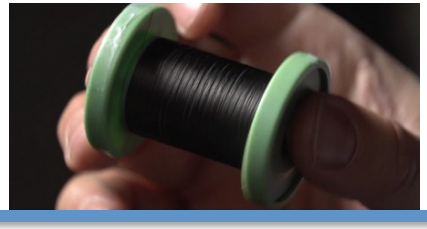


CNT Sheet



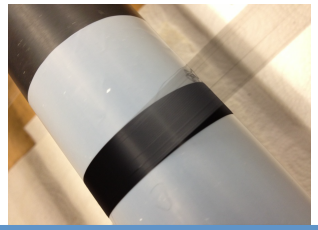
Rice University – AFOSR MOU



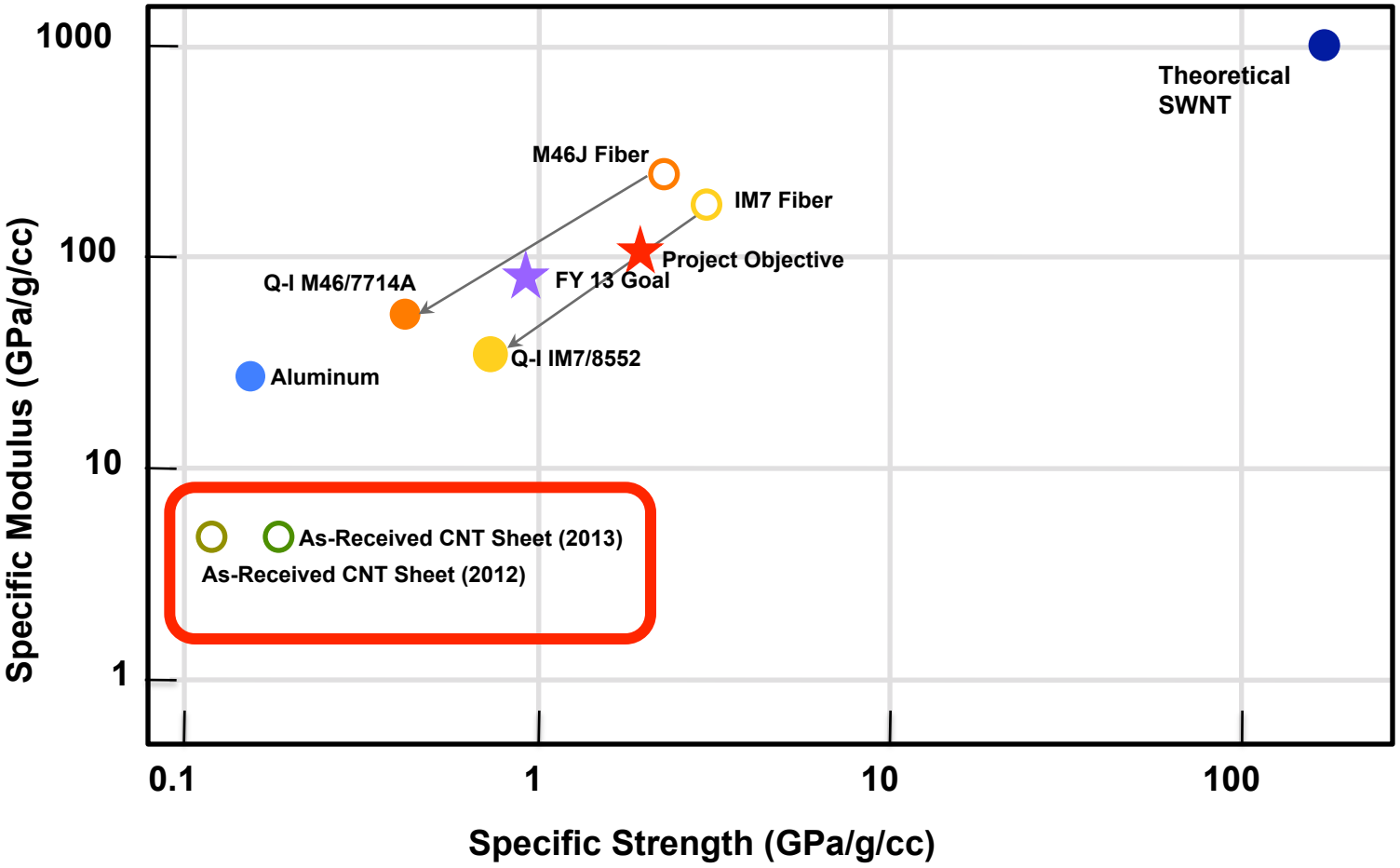


University of Cincinnati – Cooperative Agreement



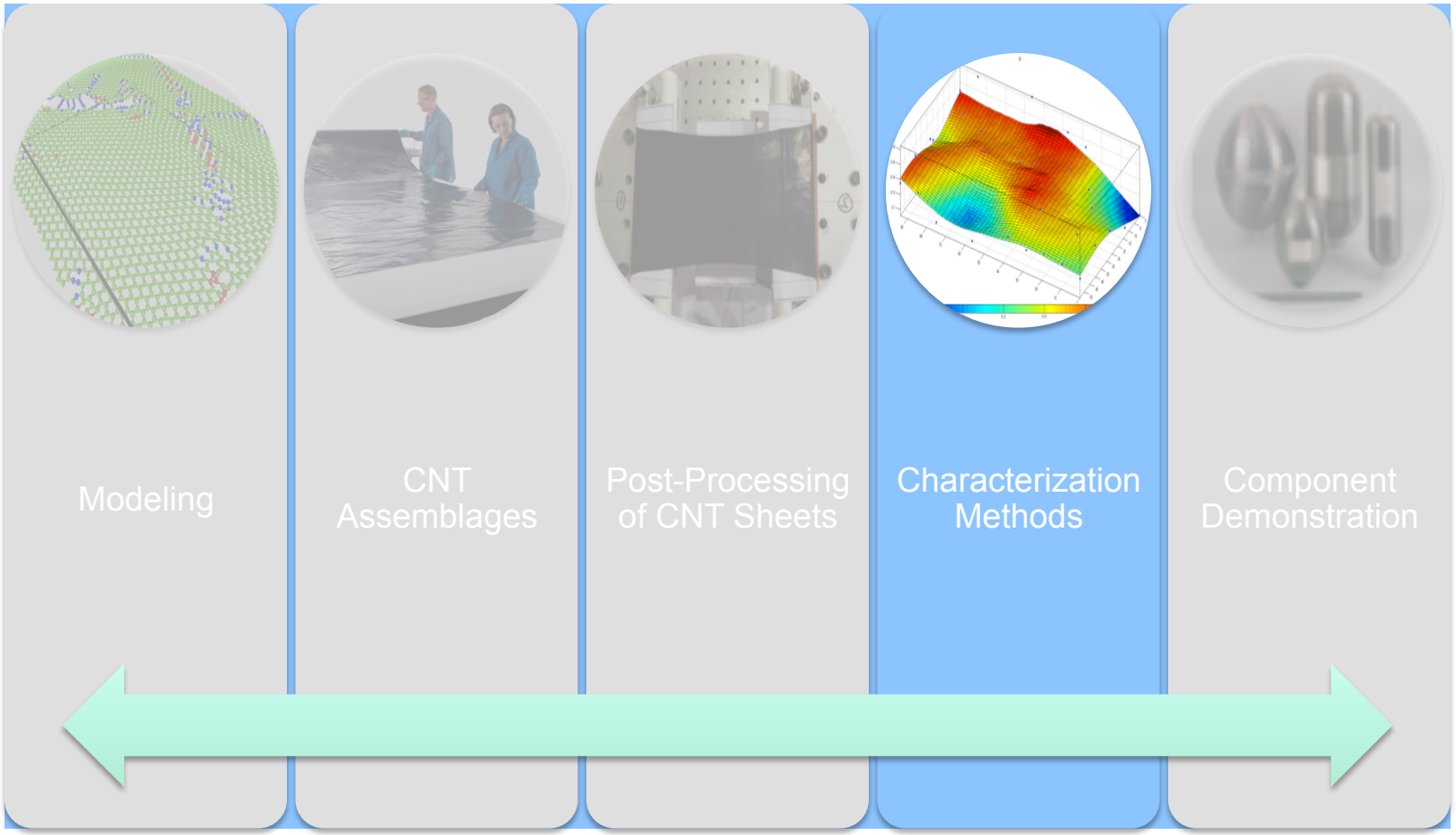


Properties of As-Received Materials



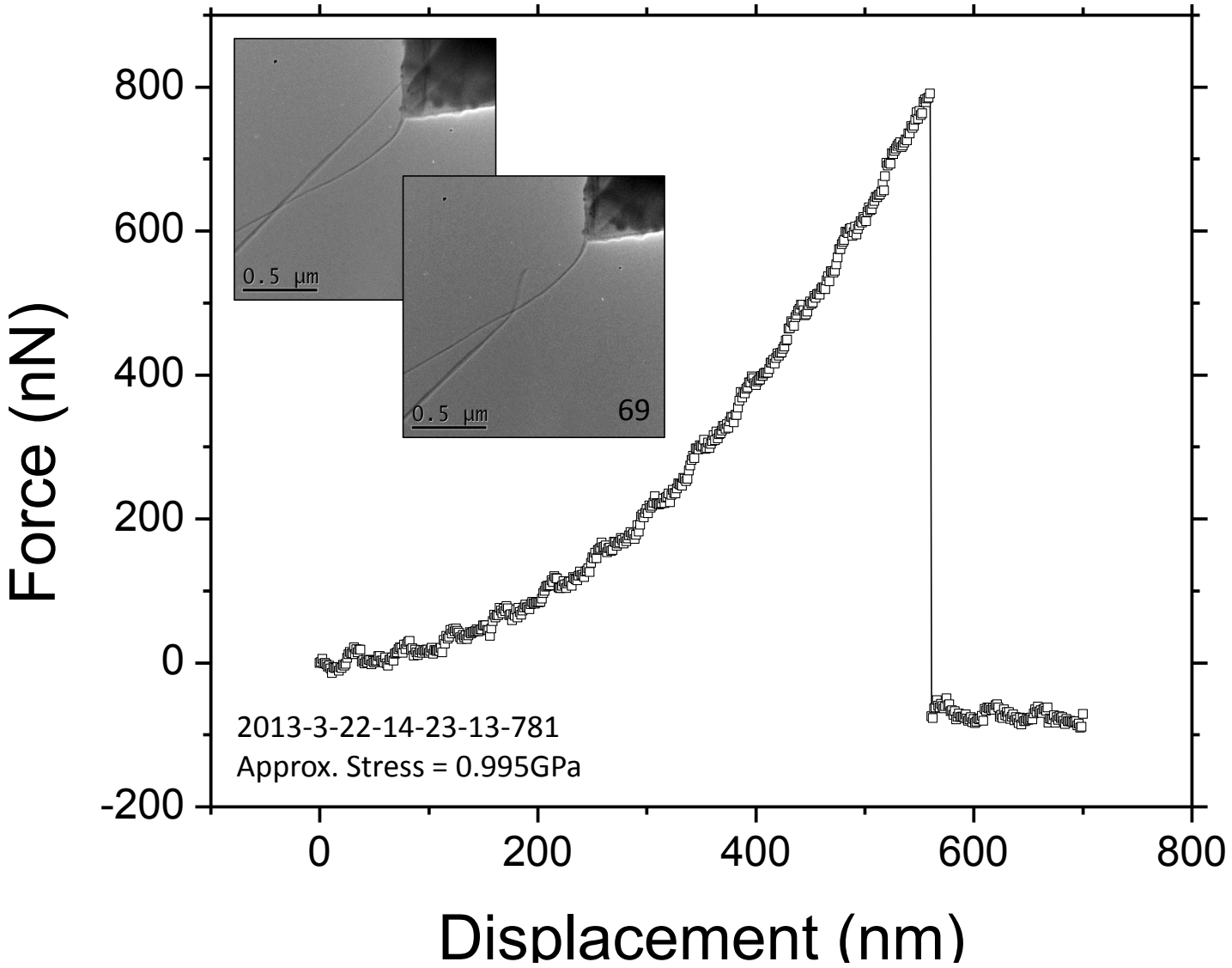
Nanotechnology Project Spans Modeling to Component Demo

Langley Research Center



Project has adopted a comprehensive approach involving modeling, materials development, testing and characterization, and component level demonstration to accelerate materials development and mission transition

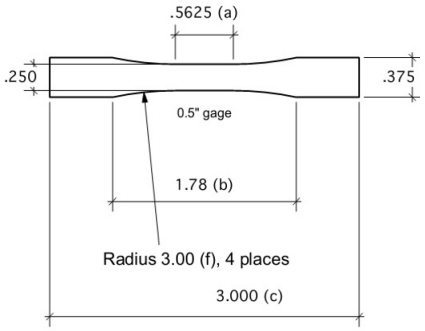
Testing of Nanomaterials



CNT Composite Tensile Testing

Objective:

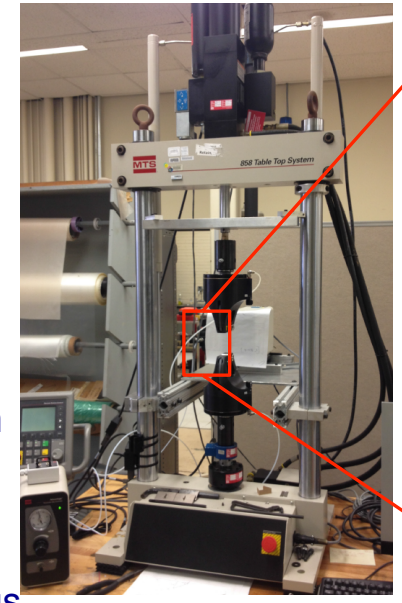
- Develop a reliable method for measuring tensile strength and stiffness of scaled-up CNT composites

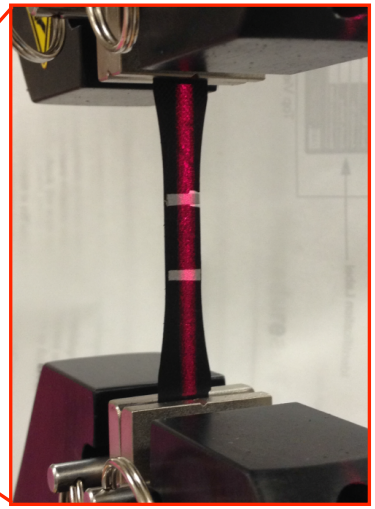




Issues:

- Strain measurement
  - Specimens relatively flimsy and small - cannot use extensometers or strain gages
- Cross-sectional area measurement
  - Difficult to reliably measure thickness
- Definition of stiffness
  - The response of most specimens tested to-date is highly non-linear

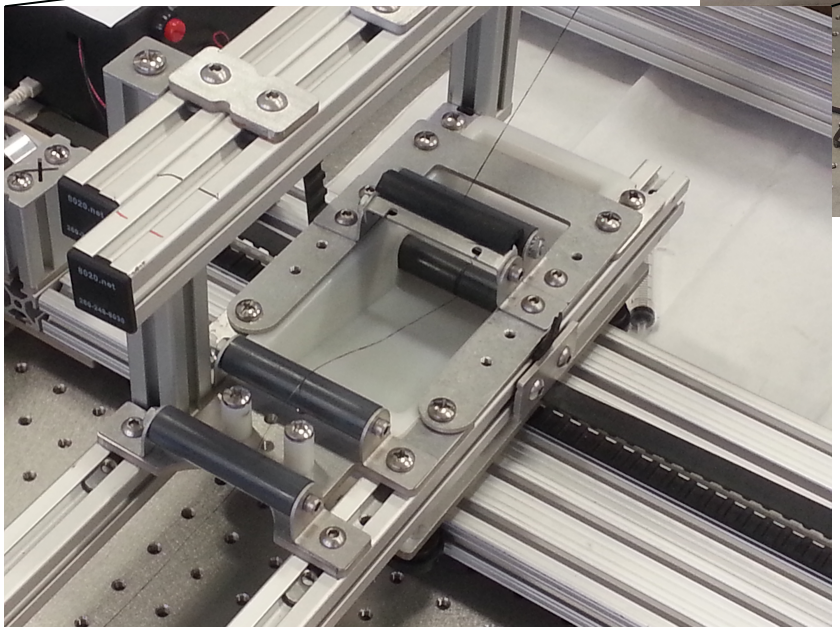


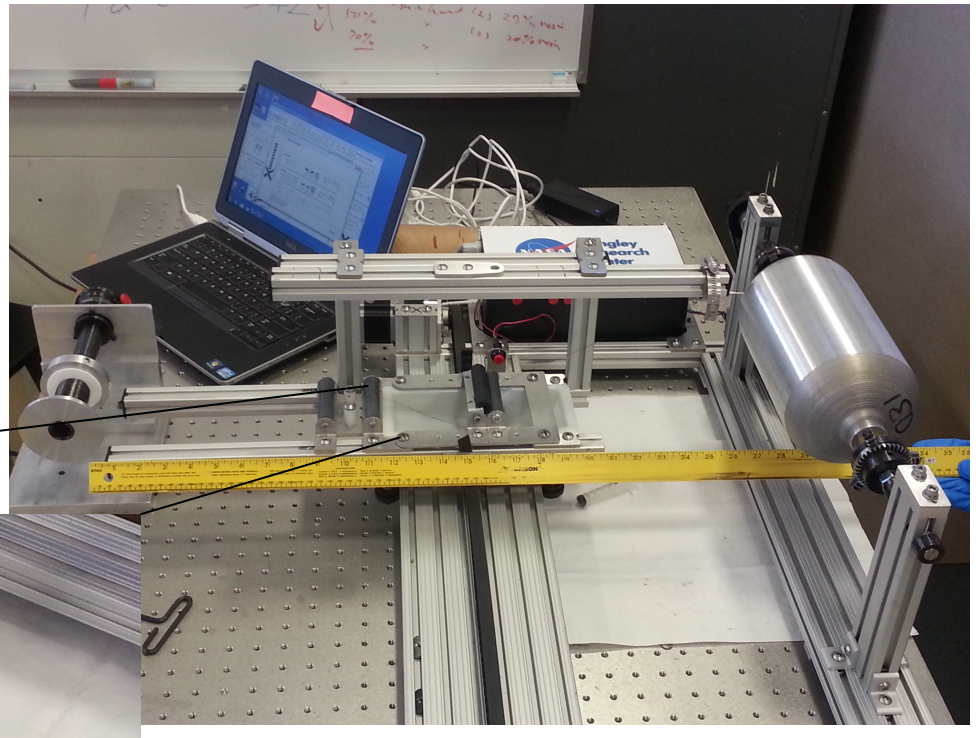


Approach:

- Utilize the modified ASTM D-638 test method
  - 3.0” long dog-bone specimen with 0.25” wide gage section
  - Measure strain using a non-contact laser extensometer
  - Compute specific strength and stiffness
  - Define consistent range for computing the “elastic” modulus

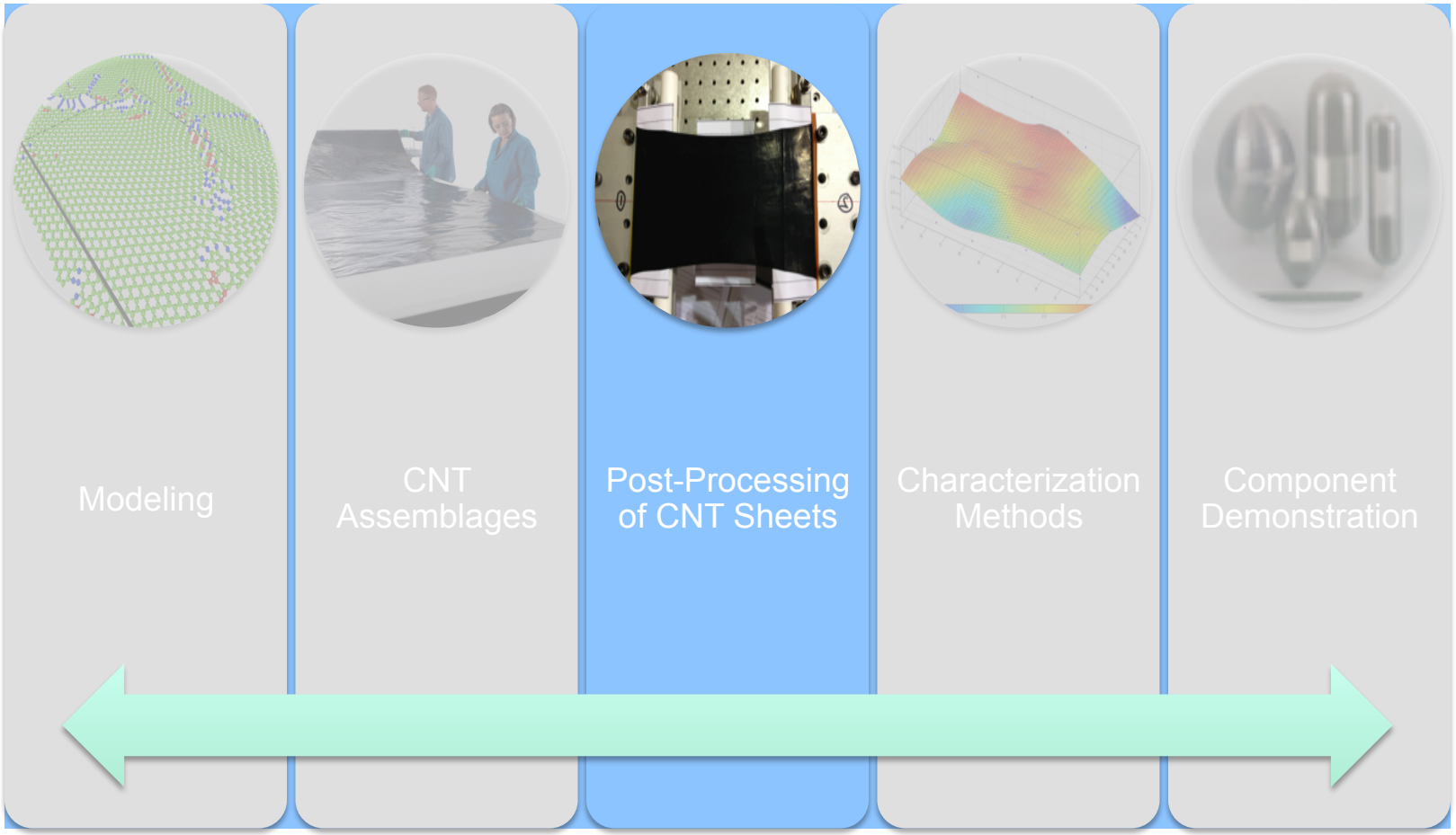
Continuous Winder – Dry or Wet Winding





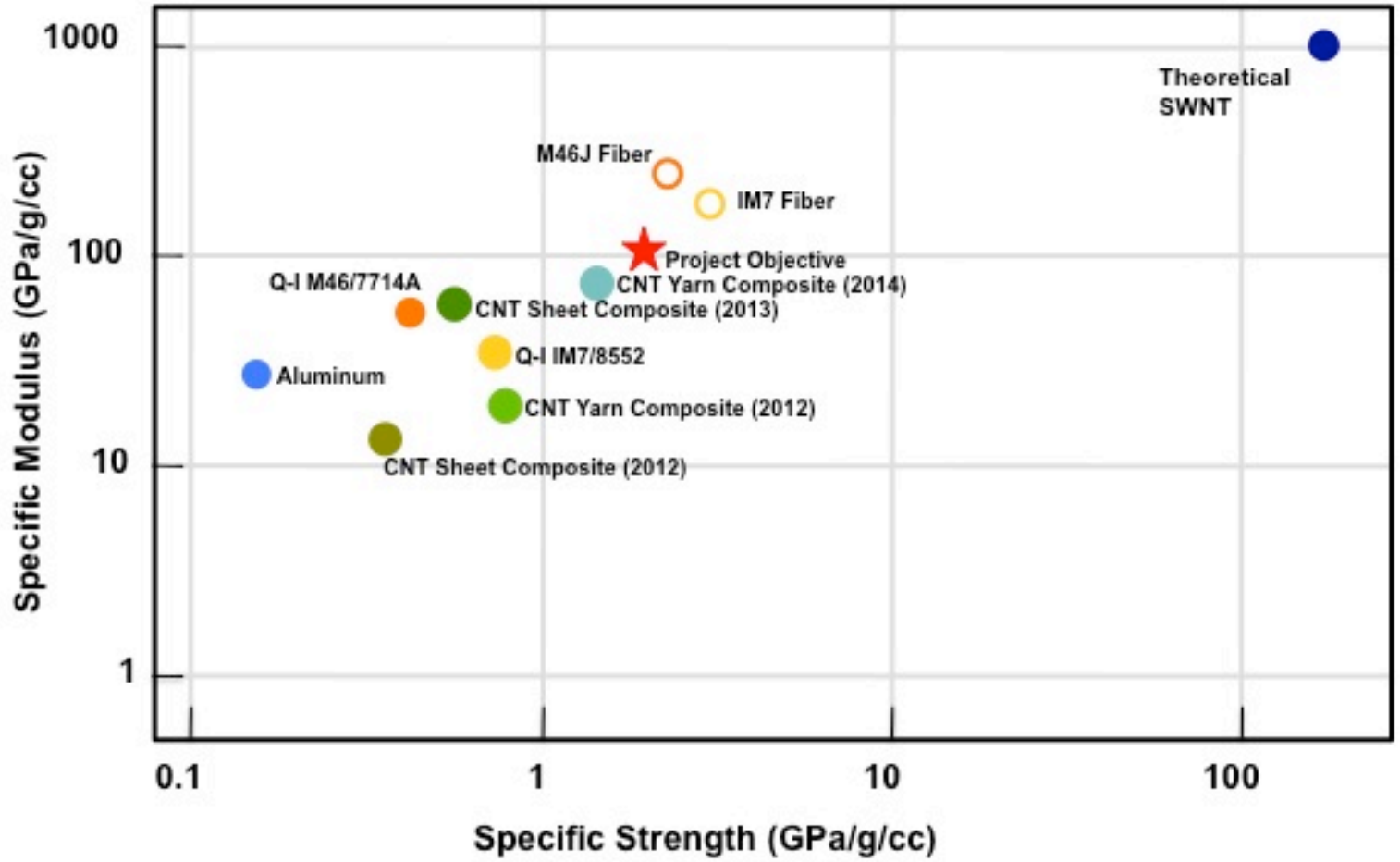
Langley Research Center

Nanotechnology Project Spans Modeling to Component Demo

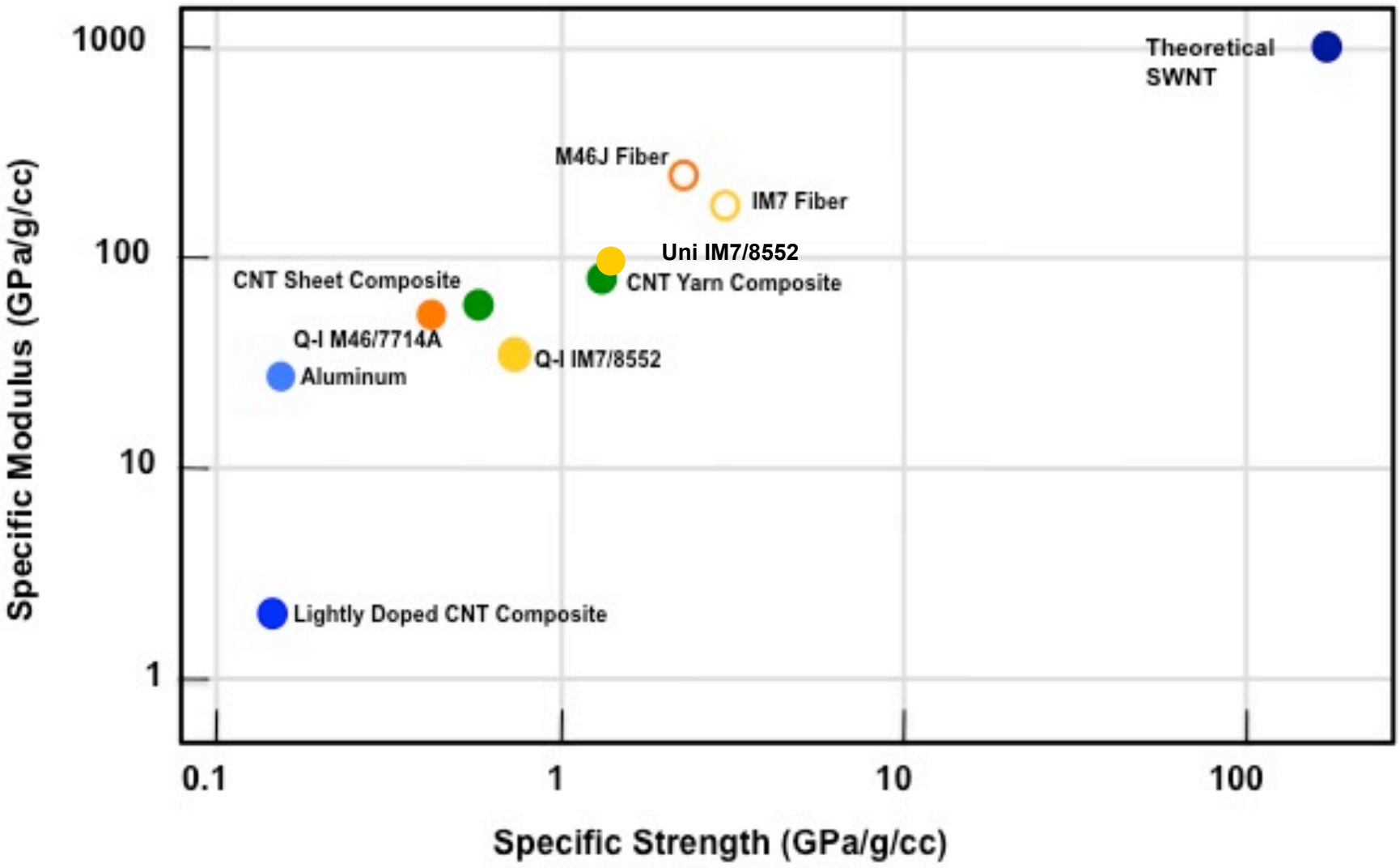


Project has adopted a comprehensive approach involving modeling, materials development, testing and characterization, and component level demonstration to accelerate materials development and mission transition

Status – End of FY 14

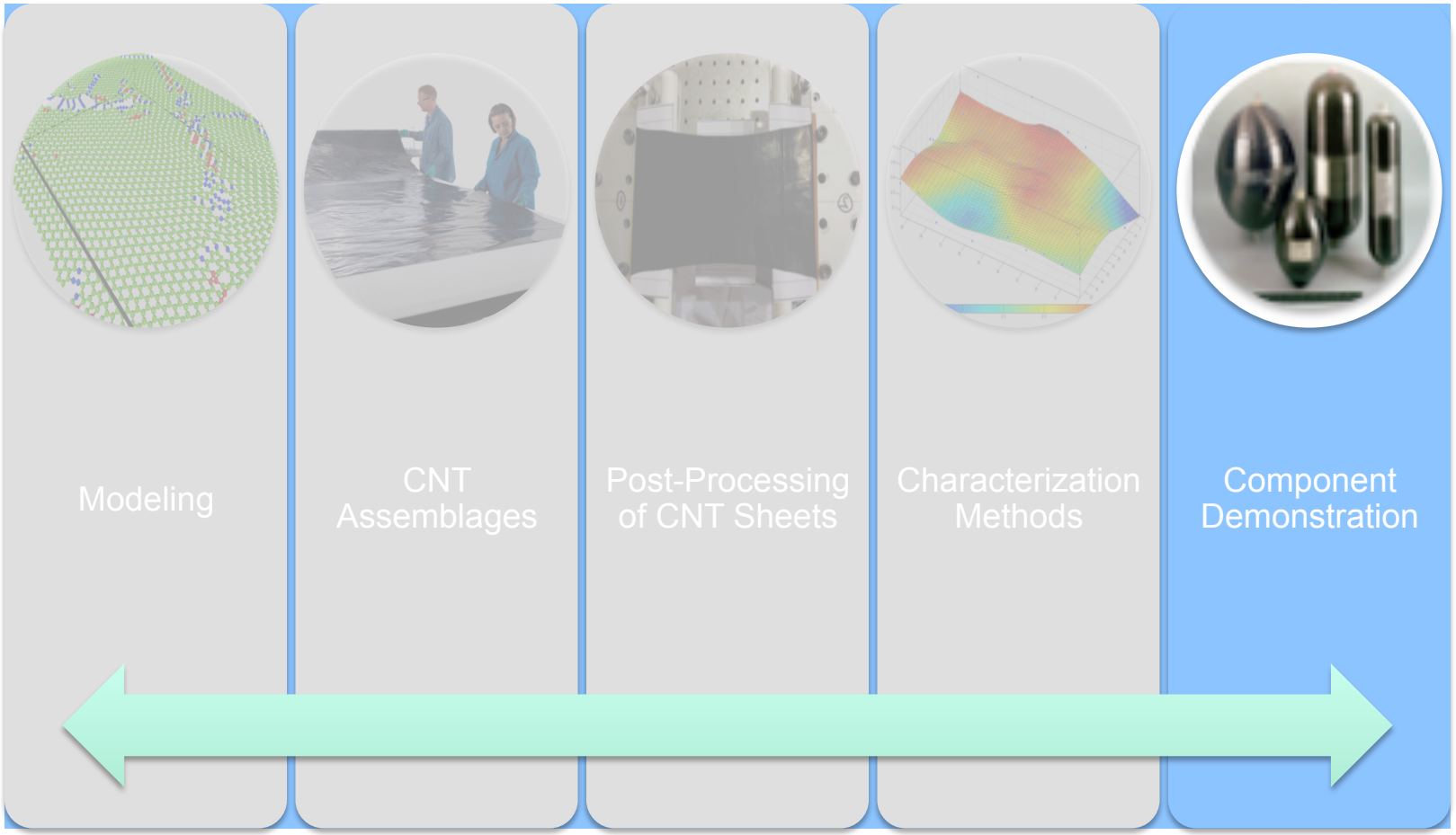


How is Structural Nano Different?



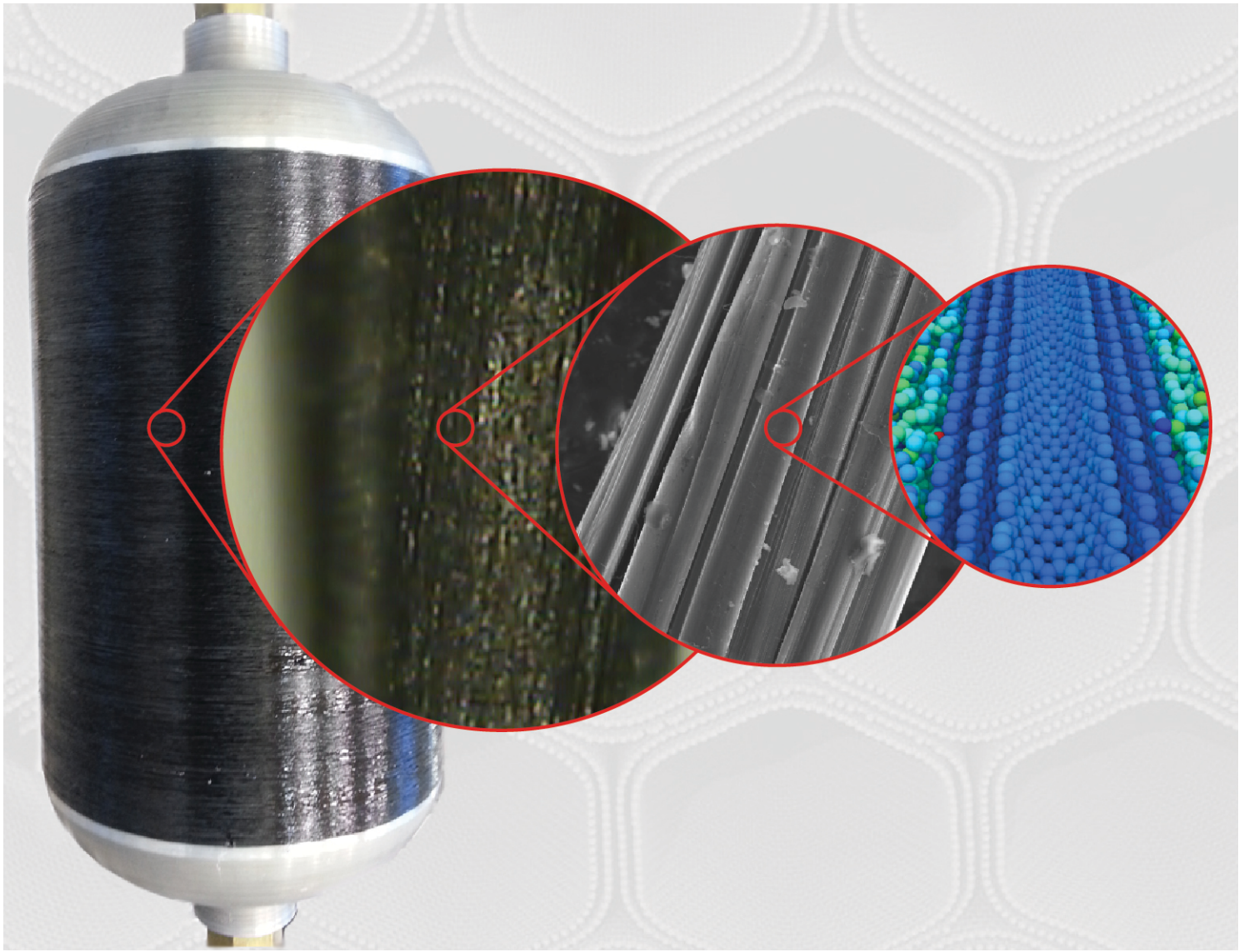
Nanotechnology Project Spans Modeling to Component Demo

Langley Research Center



Project has adopted a comprehensive approach involving modeling, materials development, testing and characterization, and component level demonstration to accelerate materials development and mission transition

Accelerated Technology Maturation



Sounding Rocket Demo



Engineered Surfaces for Mitigation of Insect Residue Adhesion

Emilie J. Siochi[1], Christopher J. Wohl[1], Joseph G. Smith Jr. [1], John M. Gardner[2], Ronald K. Penner[3], John W. Connell[1]

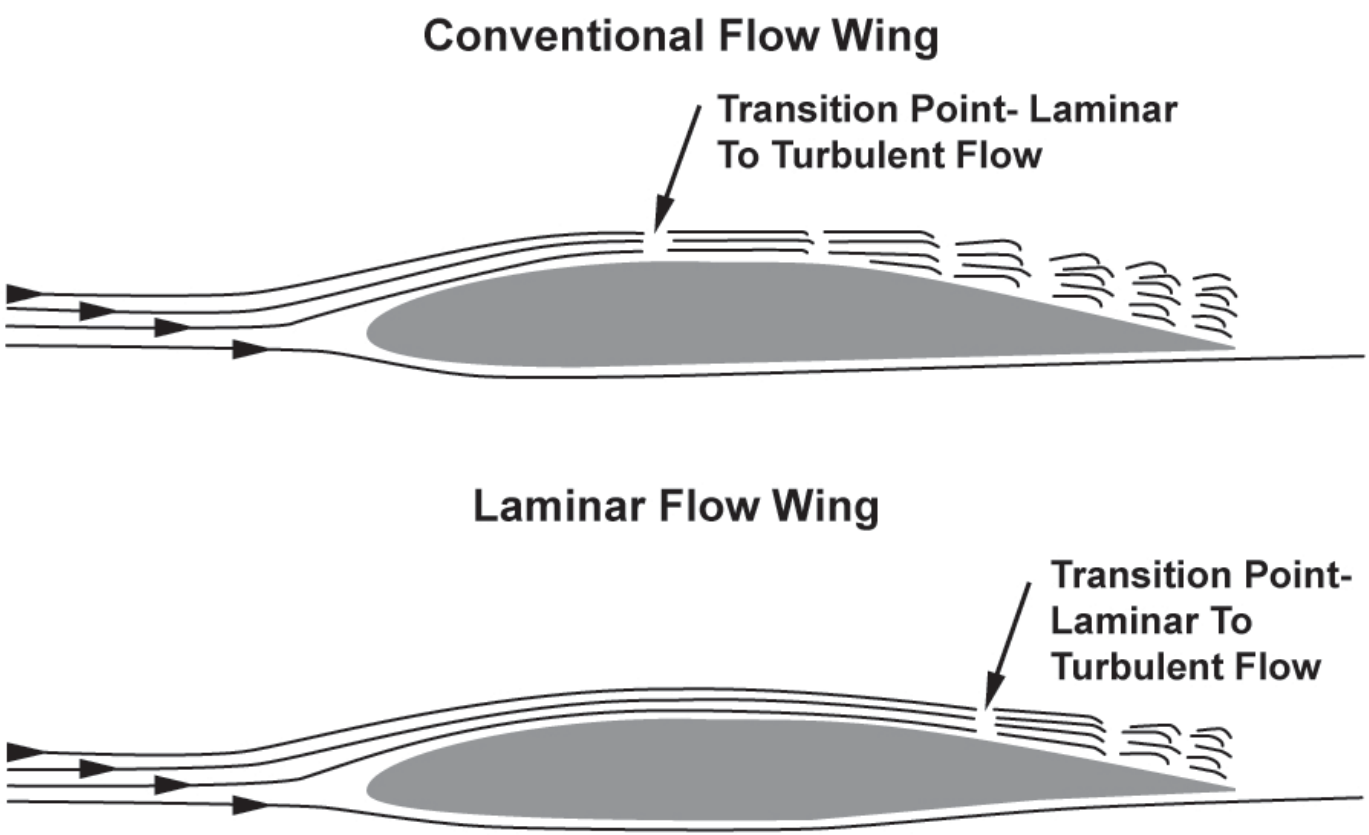
[1]NASA Langley Research Center, Hampton, VA 23681
[2]National Institute of Aerospace, Hampton, VA 23666
[3]Science and Technology Corporation, Hampton, VA 23666

Acknowledgements

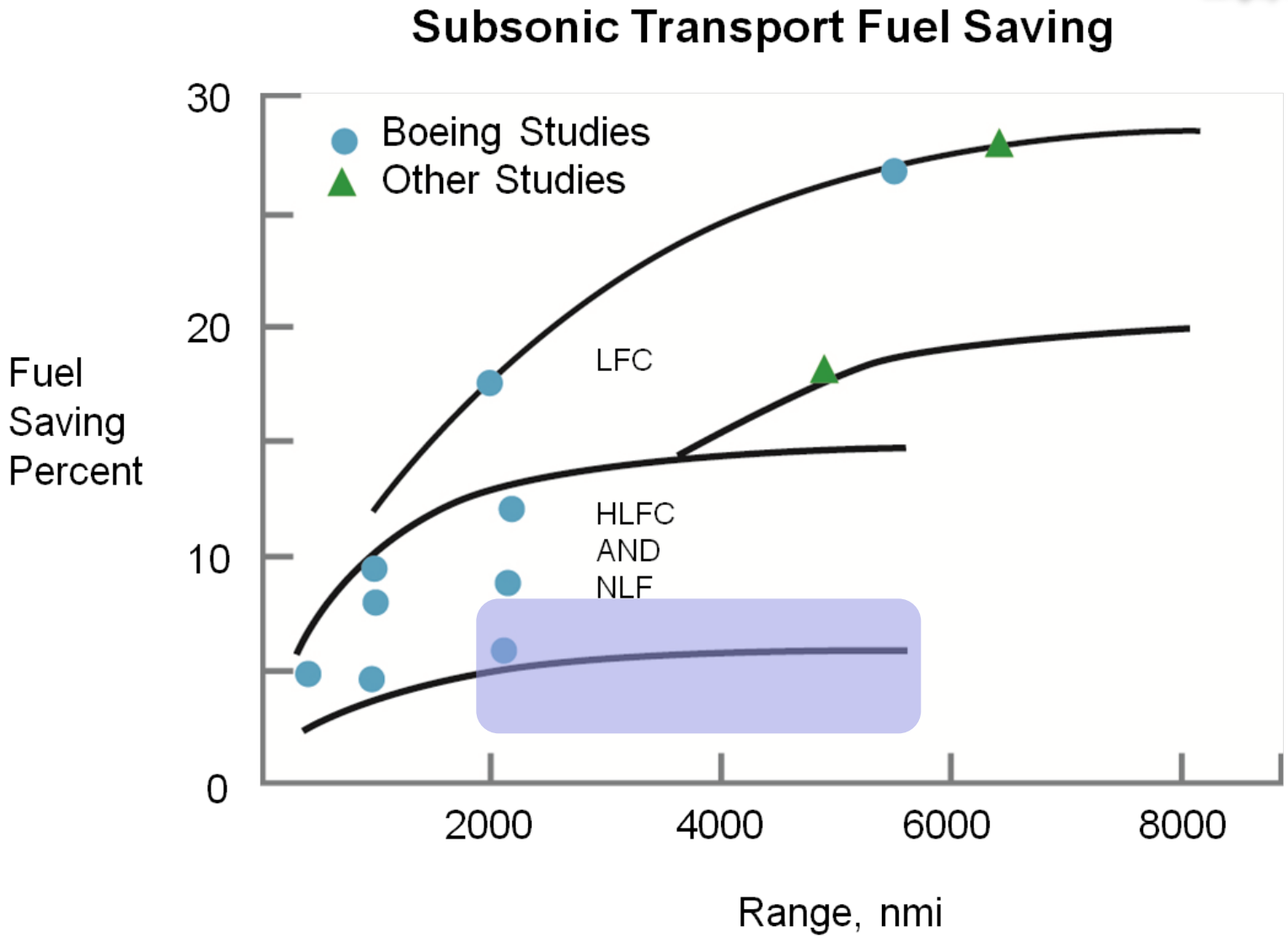


- **BART Studies:**
  - Dan Neuhart, Marlyn Andino, Donald Day, Paul Bagby, Michael Leonetti
- **Camarillo Flight Tests:**
  - Northrop Grumman: Anne Bender, Chris Harris, Andrea Korntheuer, Barry Hawkins
  - Scaled Composites: Ben Harvey, Mark “Forger” Stuckey, Phillip Grassa, John Marion
  - AFRL: Gary Dale, Nate Decker
- **Other Support:**
  - John Hopkins, LaRC: Laser Ablation Panel Fabrication
- **Scientific Discussion:**
  - Rudy King, Tony Washburn

Laminar Flow



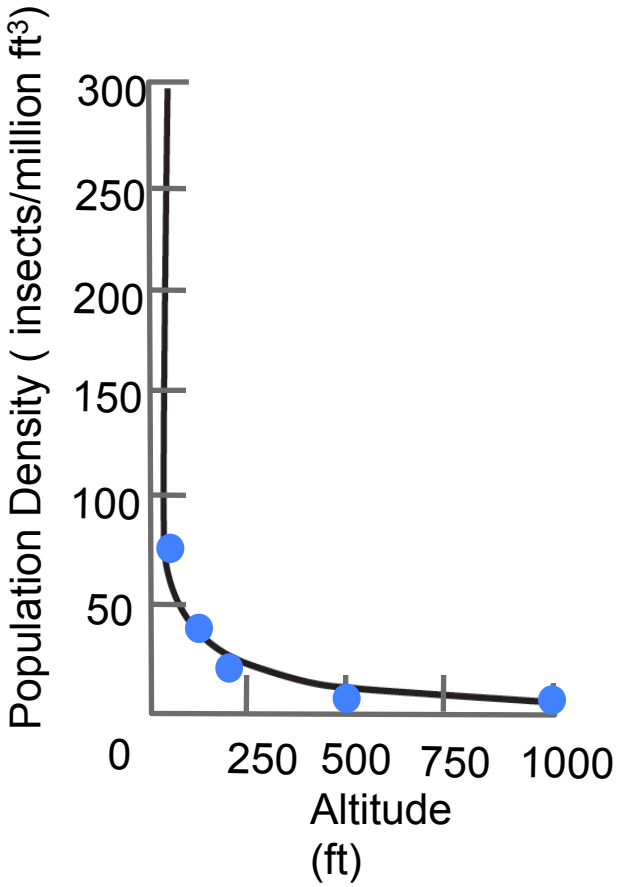
Motivation for Laminar Flow Control



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

Objective

Langley Research Center





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

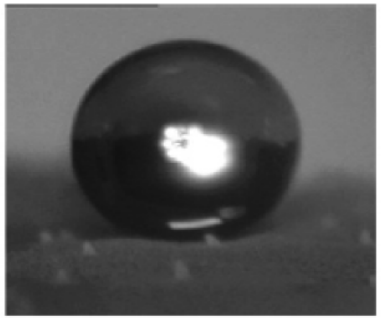
NASA's DC-8 flying laboratory takes off from Juan Santamaria International Airport in San Jose, Costa Rica, on NASA's AirSAR 2004 campaign.

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.

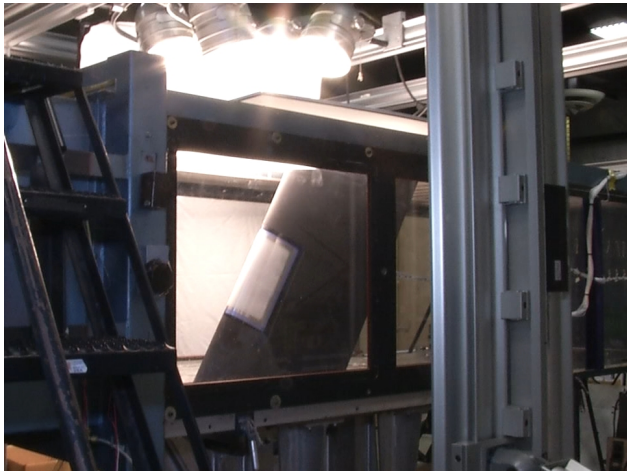
Evaluation of Engineered Surfaces

Langley Research Center



Screen commercial and experimental materials using contact angle goniometry.





Downselect promising coatings for wind tunnel testing.



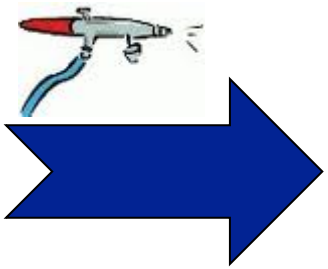
Flight test candidate coatings down-selected from wind tunnel tests.

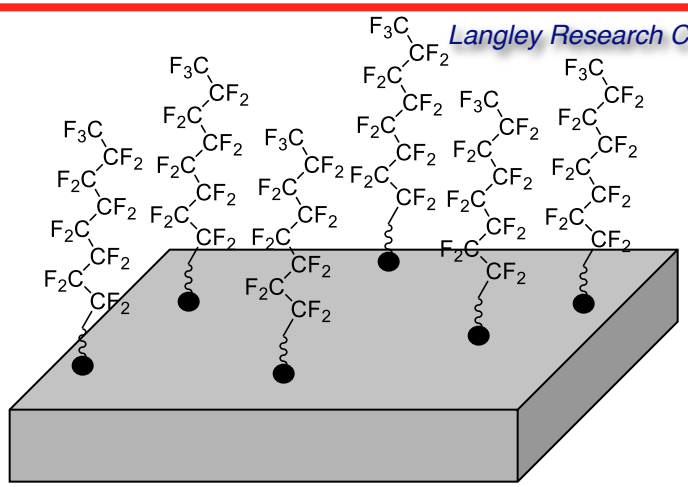
Engineered Surfaces

Langley Research Center

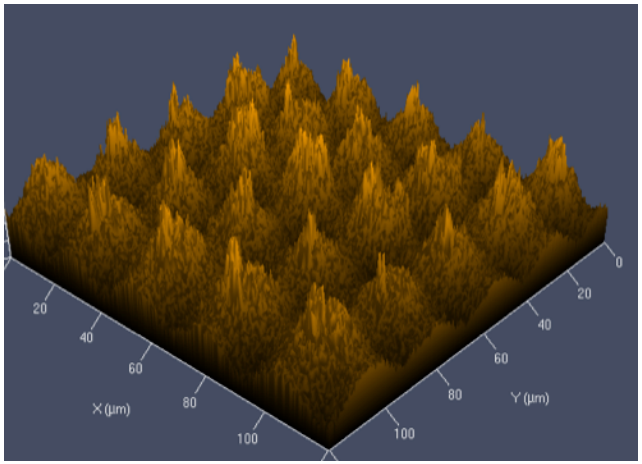


Aluminum Substrate

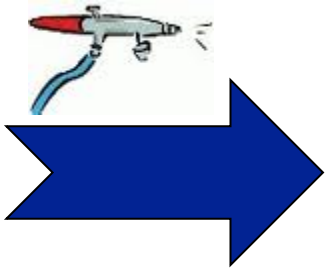


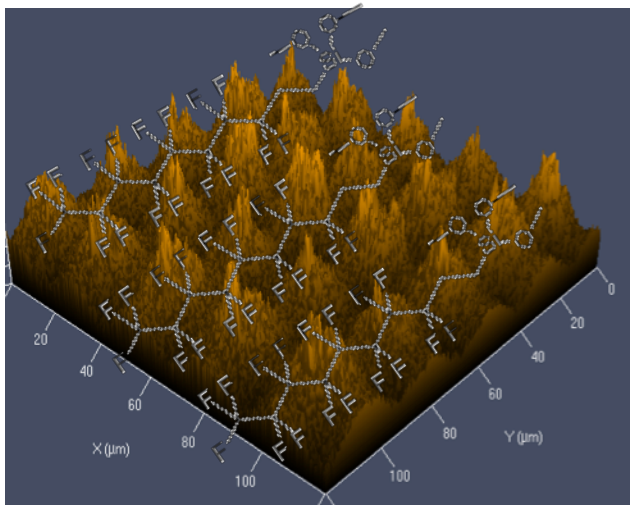


Low Surface Energy Aluminum Substrate



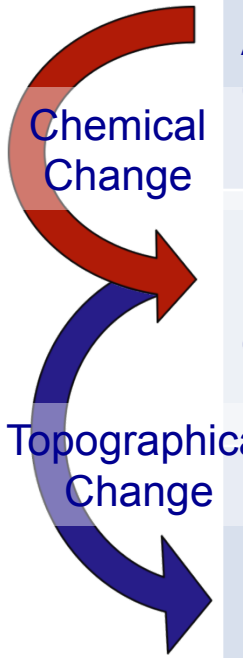
Laser Ablated Aluminum Substrate

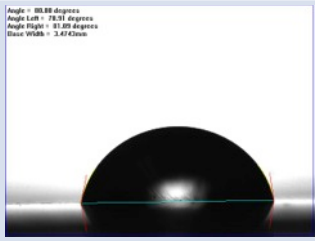
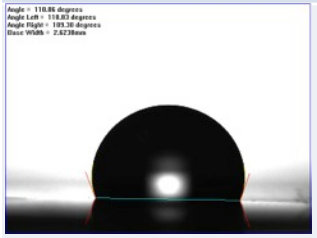
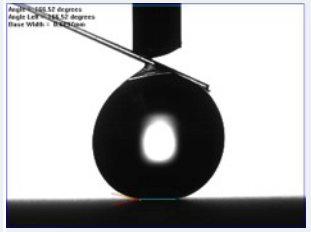




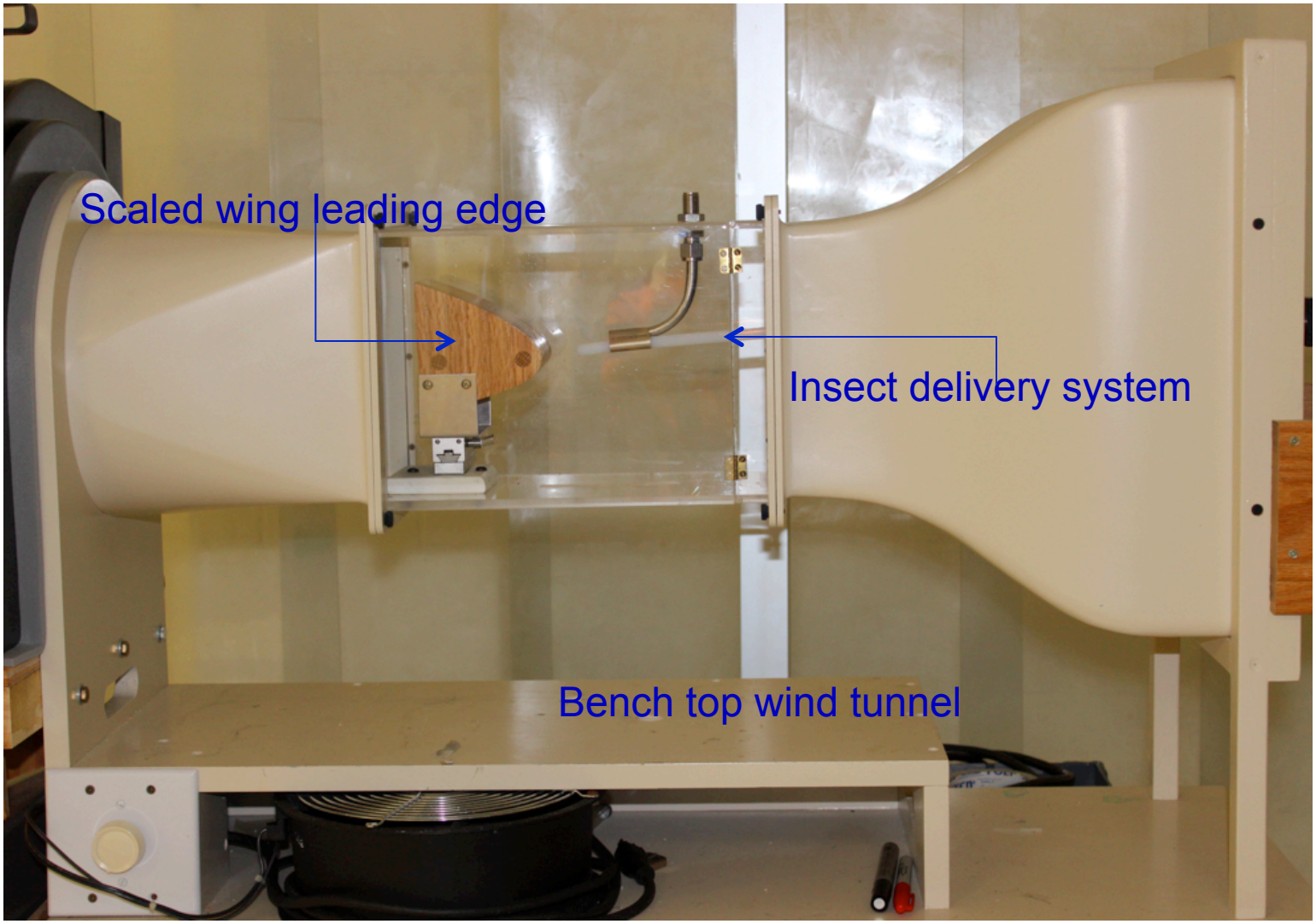
Coated Laser Ablated Aluminum Substrate

Influence of Surface Characteristics on Surface Energy



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

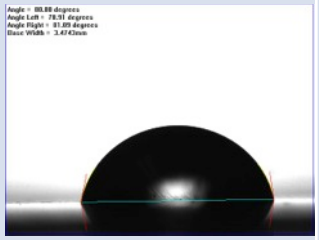
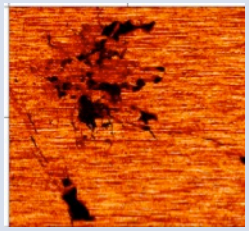
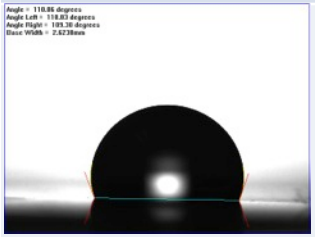
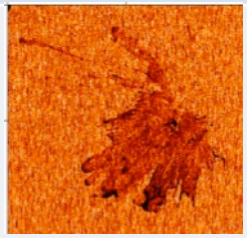
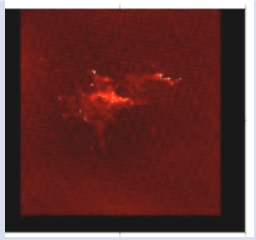
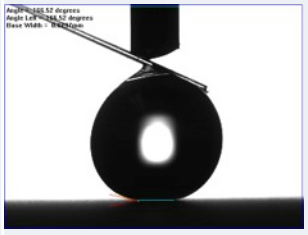
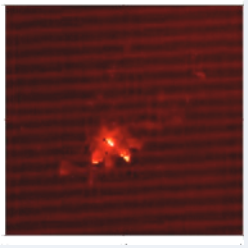
Lab Scale Bug Gun



Influence of Surface Characteristics on Insect Residue Adhesion

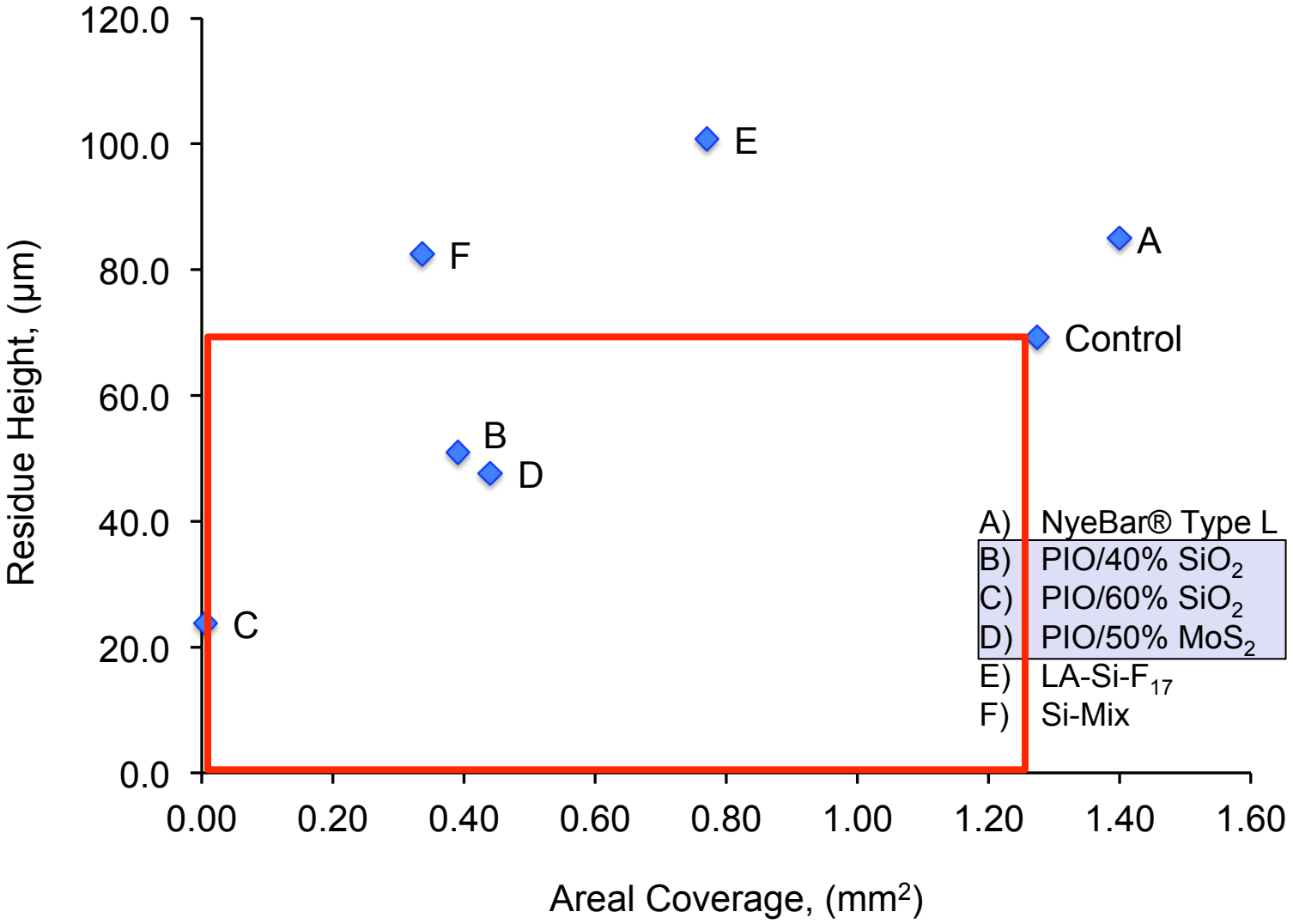


Langley Research Center

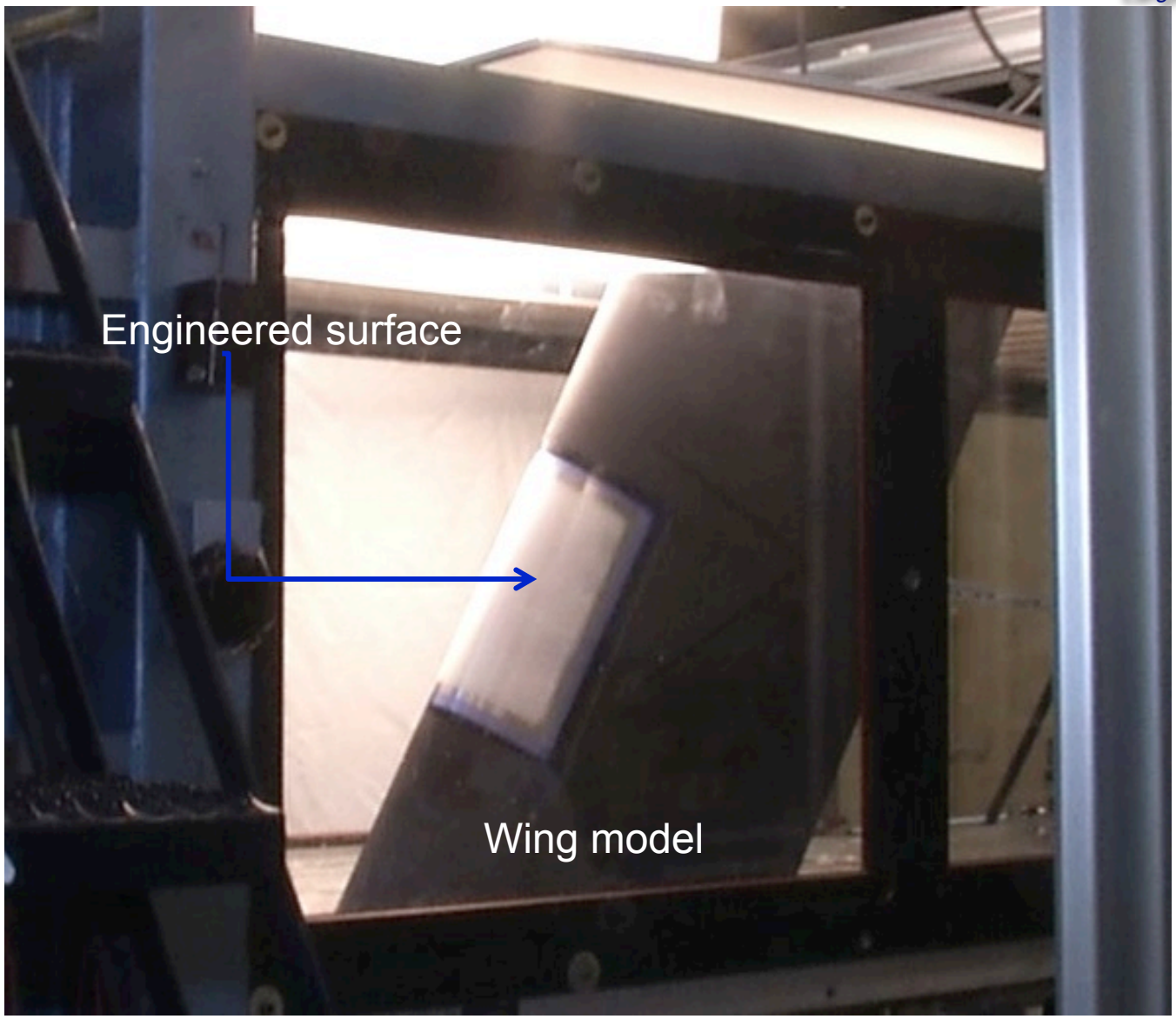
Surface	Contact Angle	Residue Area	Areal Coverage (mm^2)	Residue Height (μm)
Aluminum Control			1.38 ± 0.49	70 ± 4
Hydrophobic Coating			0.71 ± 0.30	66 ± 4
Laser Patterned			1.22 ± 0.10	66 ± 5
Coated Laser Patterned			0.45	62

Lab Scale Fruit Fly Test Results

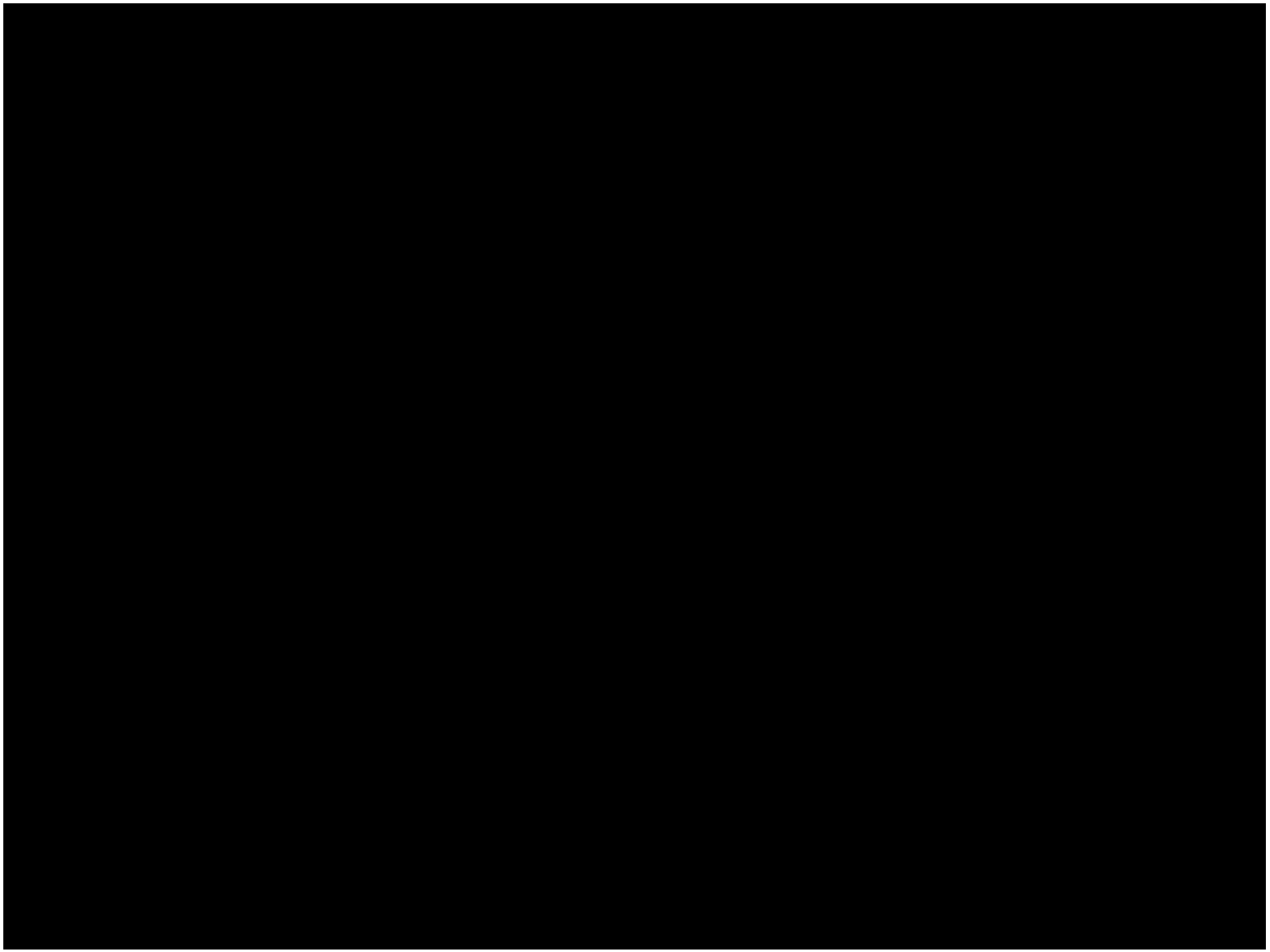
Langley Research Center



Model for BART Insect Adhesion Tests



BART Video Excerpt

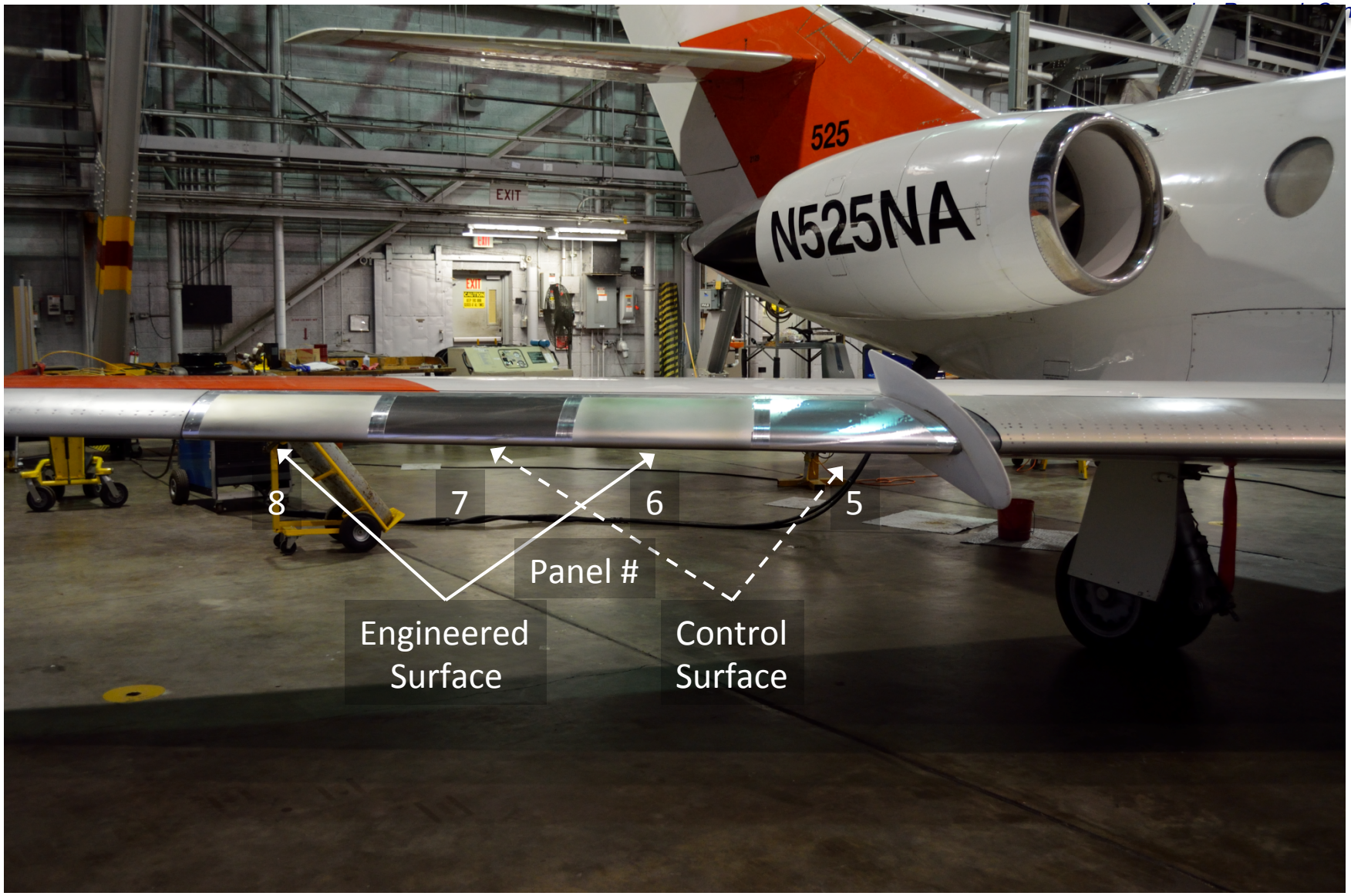


Falcon Flight Testing

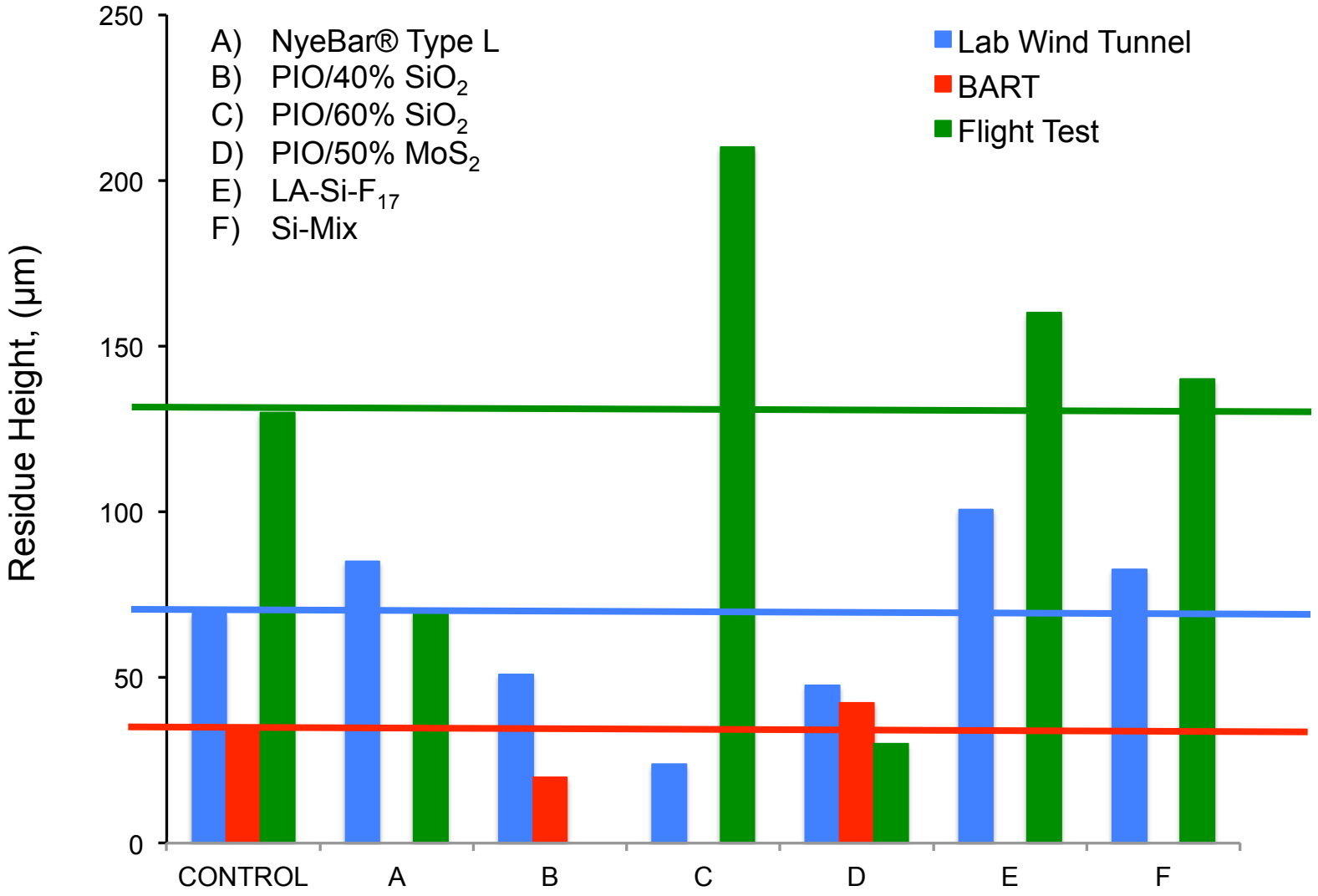




Falcon Flight Testing



Summary of Test Results



EcoDemonstrator for 2015 Flight Testing



EcoDemonstrator for 2015 Flight Testing






Thank You