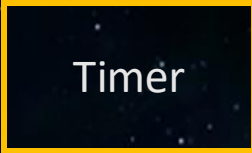




Space Technology Mission Directorate Game Changing Development Program

Mia Siochi | Superlightweight Aerospace Composites (SAC) | Annual Program Review | September 10-12, 2024

Superlightweight Aerospace Composites Overview



Needs Addressed by Project	
Stakeholder: Crosscutting	Demonstrate applications that can contribute to systems mass savings of $\geq 25\%$. Potential applications span across vehicle systems, communication, and thermal management in extreme environments.

Project Goals	
Goal #1	Maturation of CNT manufacturing production rates to yield commercial scale volumes of CNT reinforcement.
Goal #2	Development of optimal materials processing approaches to capitalize on the performance enhancements promised by this emerging reinforcement material.

KPP #	Parameter Name
1	CNT Reinforcement Specific Strength
2	Unidirectional CNT Composite Specific Strength
3	CNT Composite Fracture Toughness
4	CNT Manufacturing Rate
5	CNT Composite Transverse Strength

Superlightweight Aerospace Composites Overview



Timer

Project Objectives

Objective #1	Increase the spool length of high strength CNT.
Objective #2	Increase the manufacturing rate of high strength CNT.
Objective #3	Reduce iron catalyst content of CNT material.
Objective #4	Increase the specific strength and fracture toughness of CNT composites.
Objective #5	Increase the manufacturing readiness level (MRL) from 3 to 4 of composite fabrication techniques that enhance the inter-laminar properties of CNT composites to enable the maximum retention of the fiber mechanical properties.
Objective #6	Expand the set of mechanical properties for CNT composites beyond tensile properties to permit the broader consideration of aerospace applications.
Objective #7	Develop models and simulations that will inform the materials processing and manufacturability of CNT composite structures.
Objective #8	Conduct system analyses to illustrate systems mass savings in vehicles when project performance goals are attained.
Objective #9	Fabrication of prototype articles suitable for demonstration of manufacturability using CNT materials.

Superlightweight Aerospace Composites

Team Members



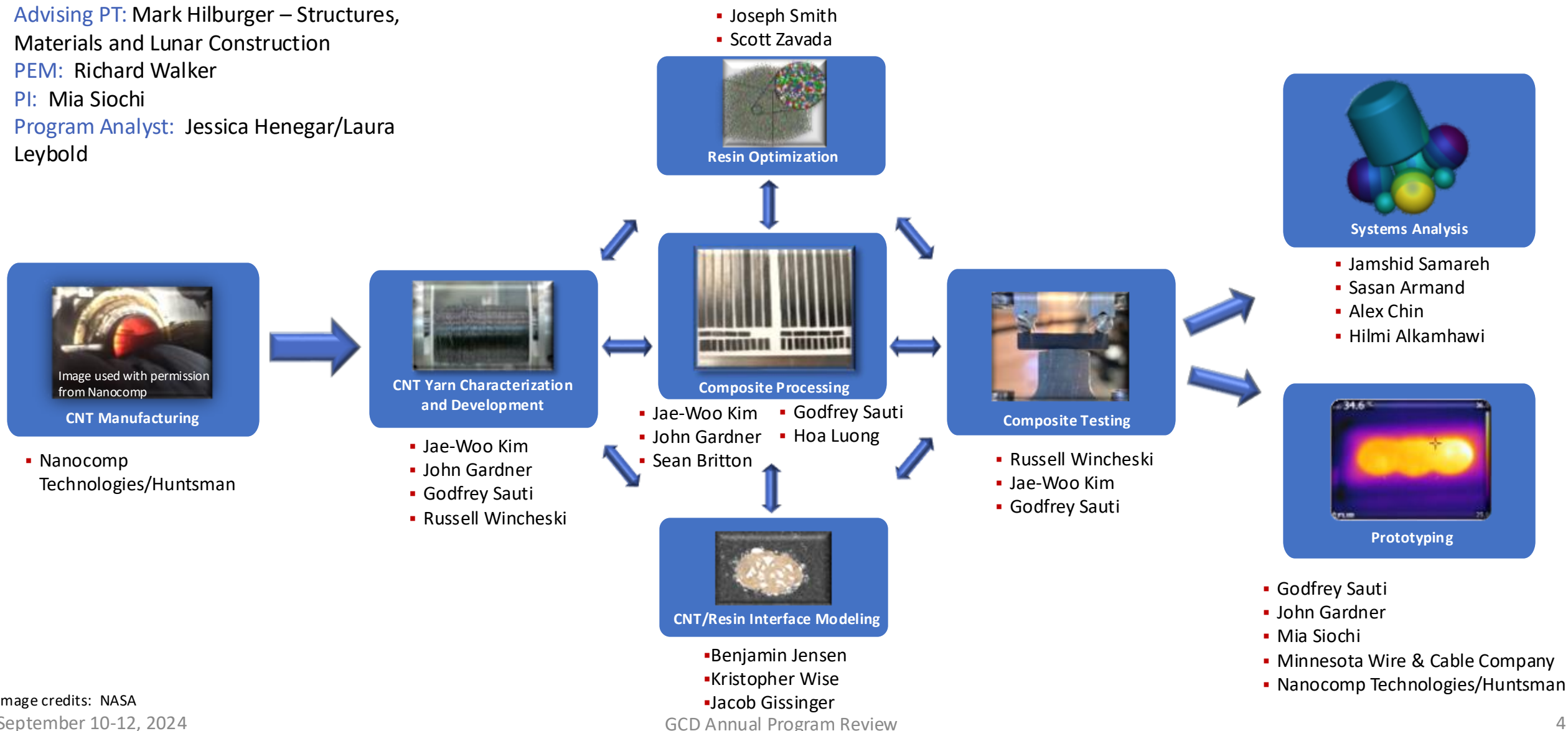
Timer

Advising PT: Mark Hilburger – Structures, Materials and Lunar Construction

PEM: Richard Walker

PI: Mia Siochi

Program Analyst: Jessica Henegar/Laura Leybold



Technical Progress

Large Scale CNT Yarn Manufacturing



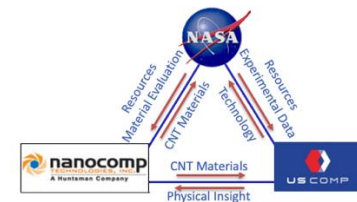
Timer

Objectives 1 and 2
KPP 1 and 4



Image used with permission from Nanocomp

- CNT production/day has increased by 2-3x the rate possible last year.
- Scaled up manufacturing system is producing high strength material approaching those possible on optimized small reactor.



Economical large-scale manufacturing of high strength yarn enables technology infusion.

Technical Progress

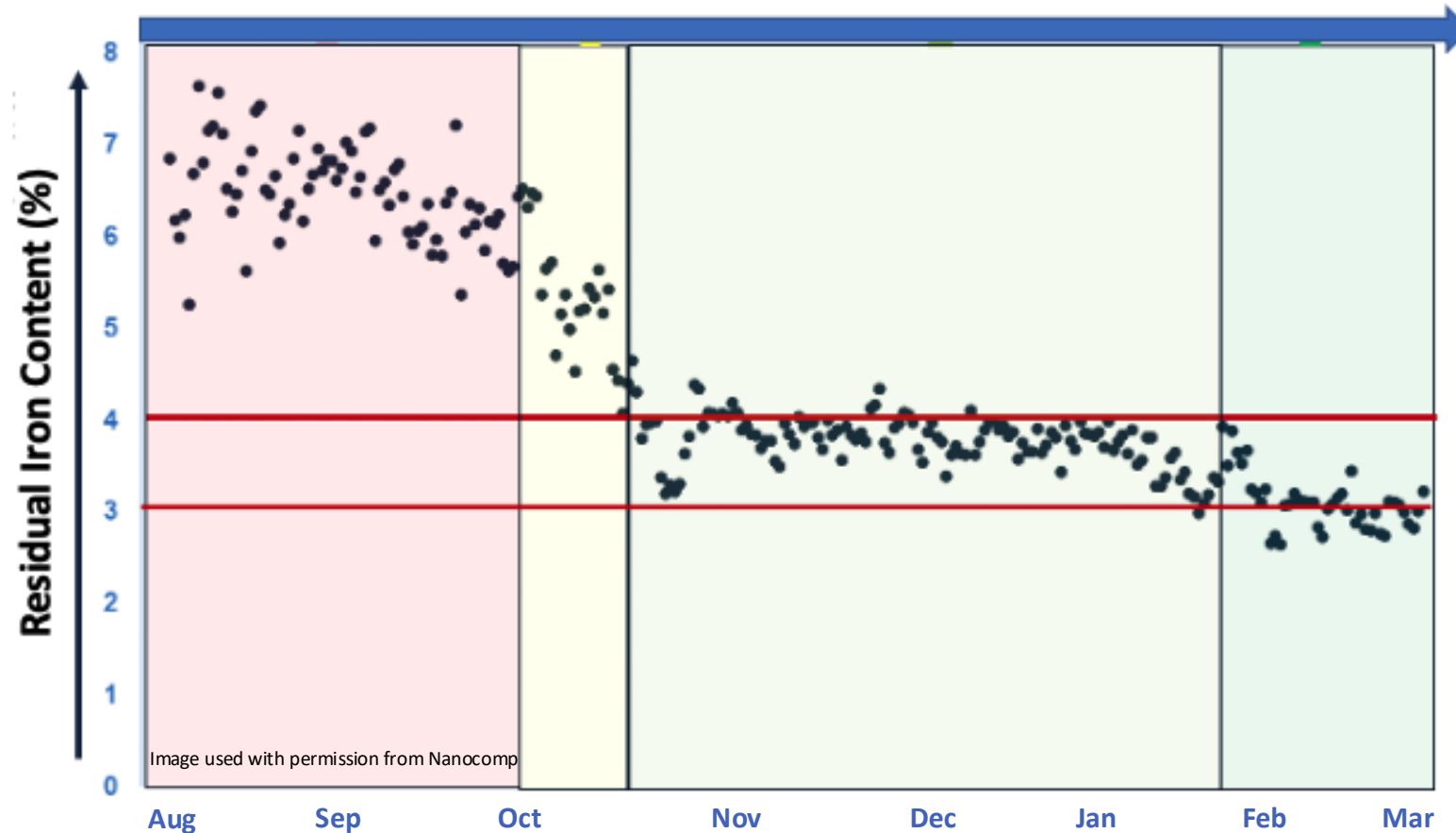
Large Scale Low Iron CNT Yarn Manufacturing



Timer

Colors Represent Significant Process Change

Objectives 2 and 3
KPP 1 and 4



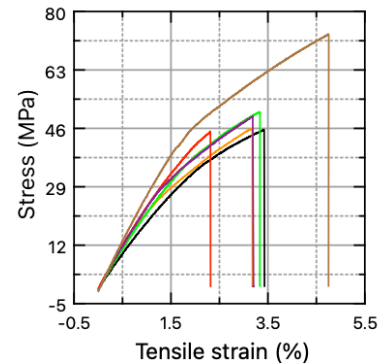
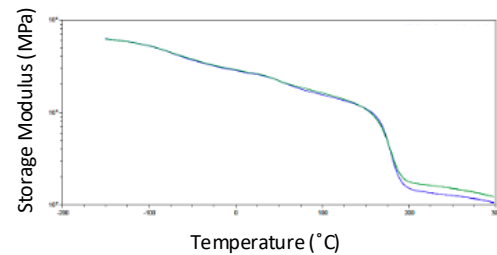
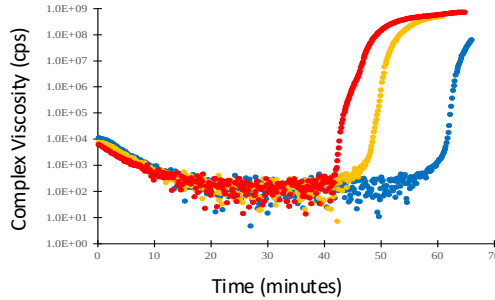
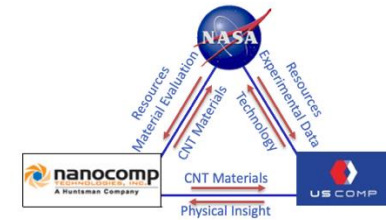
- Significant process changes enabled significant reduction in residual iron content in CNT yarns.

Lower iron-containing high strength yarn broadens technology infusion potential.

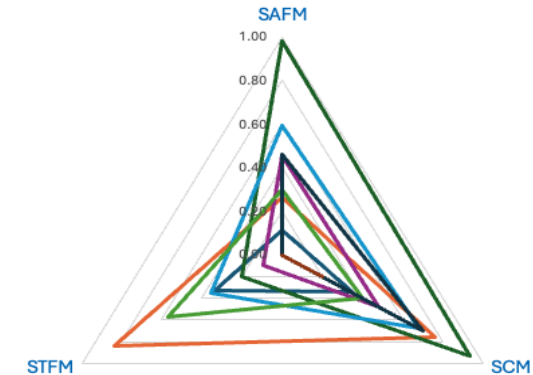
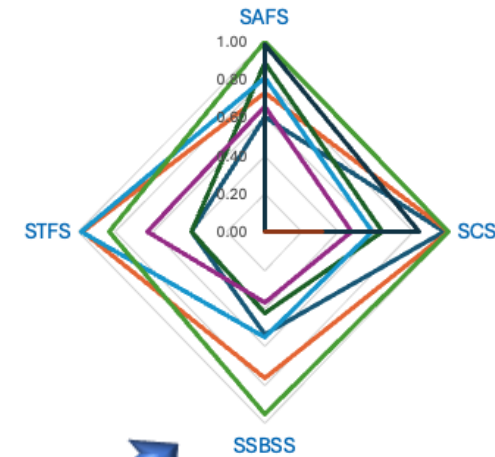
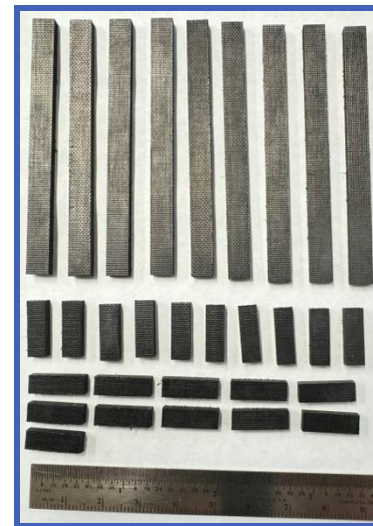
Technical Progress

CNT Mechanical Properties

Objectives 4, 5 and 6
KPP 2, 3 and 5



Resin cure studies were conducted to inform CNT composite processing.



SAFS: specific axial flexural strength
SCS: specific compression strength
SSBSS: specific short beam shear strength
STFS: specific transverse flexural strength
SAFM: specific axial flexural modulus
SCM: specific compression modulus
STFM: specific transverse flexural modulus

Technical Progress

CNT Mechanical Properties



Timer

- Composite process development has yielded expanded set of CNT composite mechanical properties in the transverse direction that are better than baseline carbon fiber composites.
- Processing improvements continue to evolve to improve compressive properties. Latest set of samples are being cut for testing.
- CNT composite fiber process is being patented, and technology transfer efforts are underway.

Objectives 4, 5 and 6
KPP 2, 3 and 5

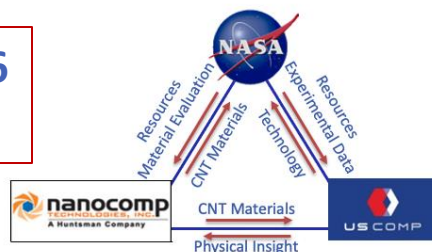
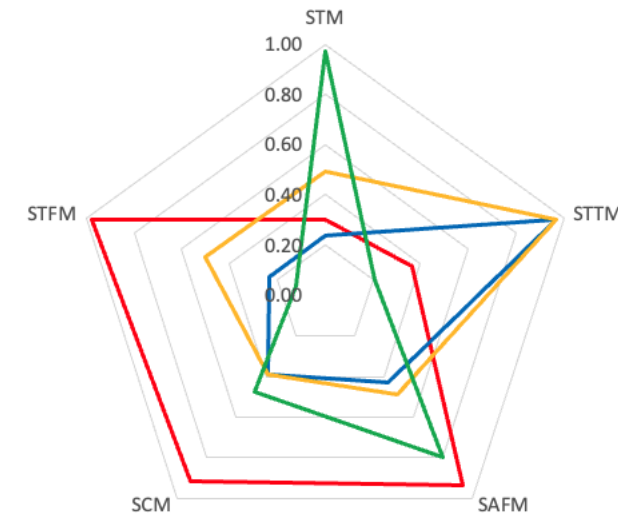
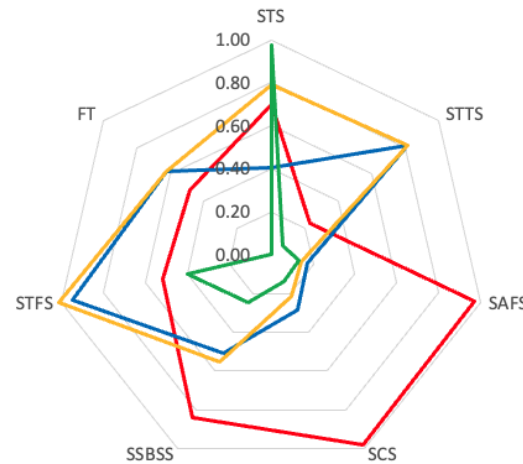


Image credits: NASA



- Unidirectional Carbon Fiber Composite
- Unidirectional Baseline CNT Composite
- Unidirectional Experimental CNT Composite – 2023
- Unidirectional Experimental CNT Composite – 2024

STS: specific tensile strength
STTS: specific transverse tensile strength
SAFS: specific axial flexural strength
SCS: specific compression strength
SSBSS: specific short beam shear strength
STFS: specific transverse flexural strength
FT: Mode I fracture toughness

STM: specific tensile modulus
STTM: specific transverse tensile modulus
SAFM: specific axial flexural modulus
SCM: specific compression modulus
STFM: specific transverse flexural modulus

Expanding CNT composite mechanical properties is necessary to inform infusion paths.

Technical Progress

Systems Benefits Analysis

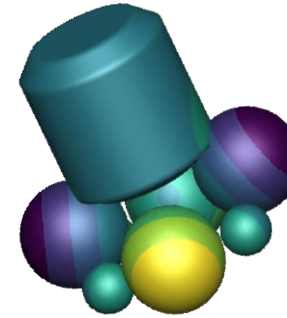


Timer

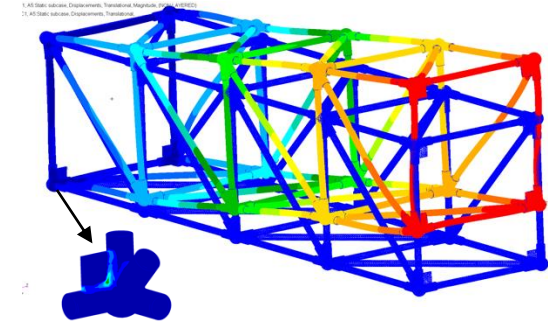
Objectives 8 and 9
KPP 2, 3 and 5

- Developed an analysis model with appropriate parameters for advanced material assessment.
- Quantified the benefits of using carbon nanotubes (CNT) for a generic lunar ascent vehicle.
 - Benefits include enabling stiffer secondary load bearing structures, which could lower the vehicle mass and/or improve risk posture.
 - Benefits of using CNT for a generic truss structure concept were demonstrated by systems modeling.
 - Developed generic 4-, 8-, and 12-bay truss models.
- Identified NASA missions with significant secondary non-pressurized elements that could benefit from CNT.
- Initiated the development of a test model for a generic 4-bay truss structure.
 - Selected a truss that is representative of structures ranging from Commercial Lunar Payload Services (CLPS) landers to large integrated truss structure (ITS) like Artemis Gateway ITS.

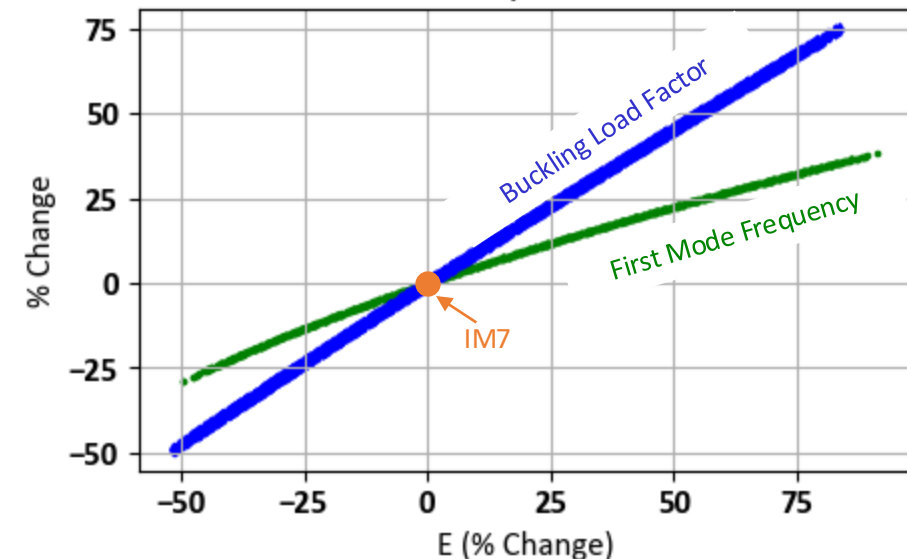
Generic Lunar
Ascent Vehicle



Generic Truss Structure



4-Bay Truss



Spacecraft Truss Element Prototyping

Objectives 8 and 9
KPP 2, 3 and 5

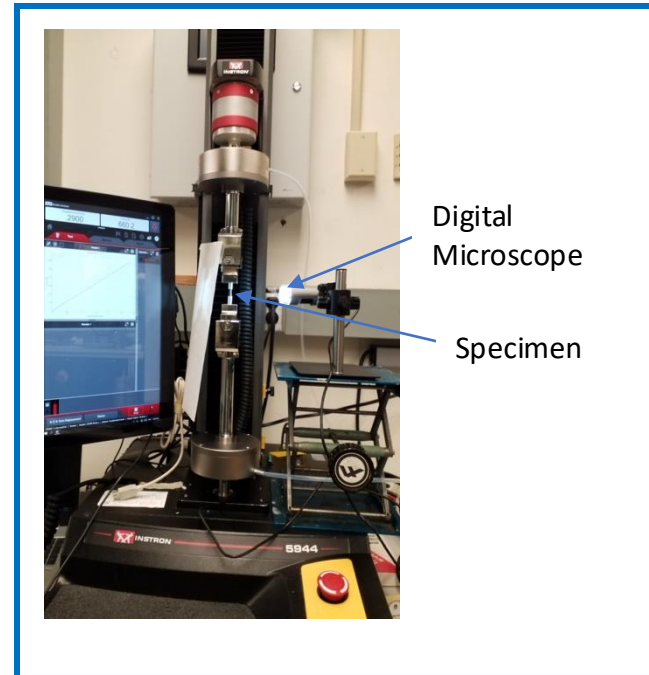
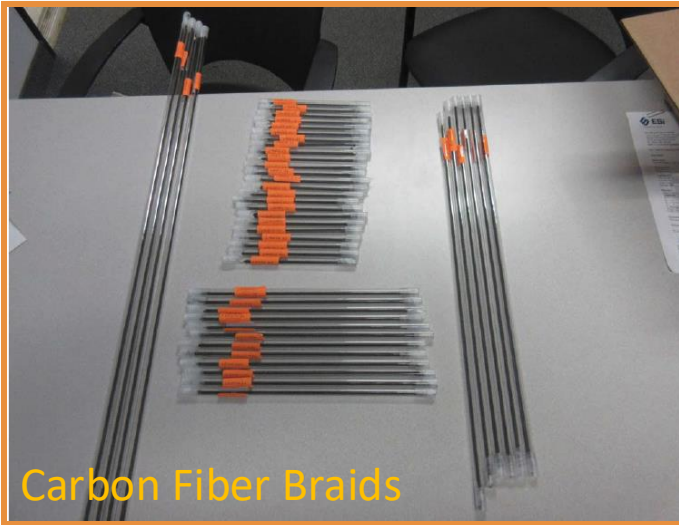


- Systems modeling conducted as part of the project showed that there are benefits from higher stiffness composites made from CNT preforms relative to carbon fiber preforms.
- Model is in the process of being validated using plastic piping and 3D printed joints.
- Benefits predicted will also be validated by the fabrication and testing of truss elements made with carbon fiber and CNT reinforcement.
- Phase 3 SBIR awarded to produce 24" braided preforms that are 1" in diameter to represent truss elements ubiquitous in spacecraft was completed.
- Composite truss elements will be fabricated and tested.

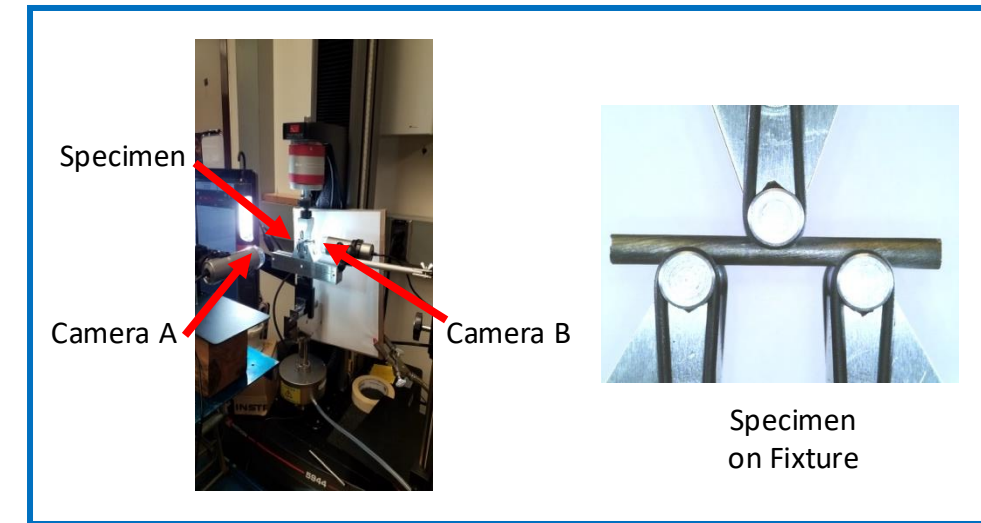
Technical Progress Prototype Fabrication



Timer



Tensile Test of Composite Bars



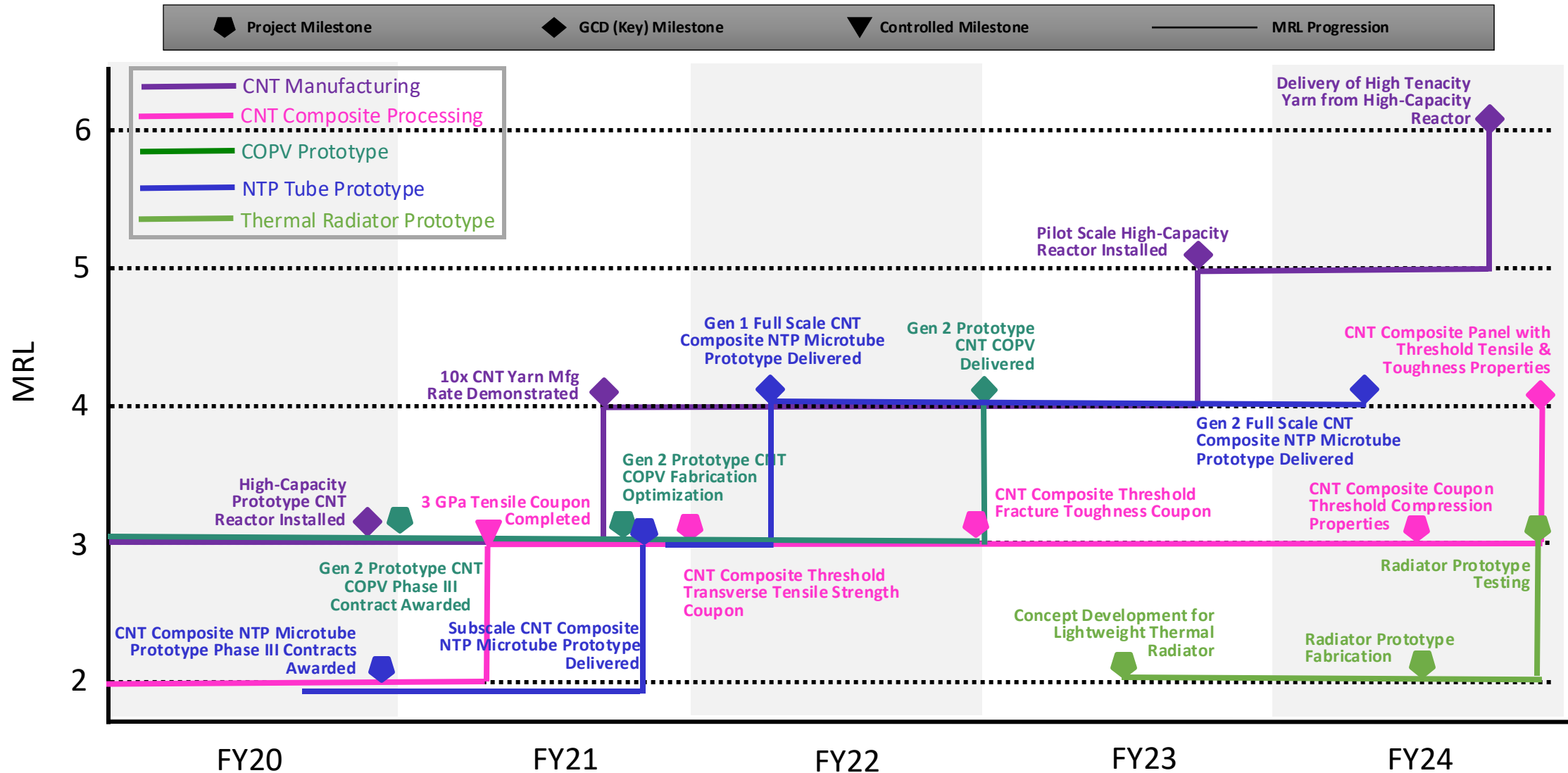
Short Beam Shear Test of Composite Bars

- Test methods tailored to geometry of composite tube were developed.
- Several CNT composite tubes were tested to evaluate fabrication method.

Superlightweight Aerospace Composites Lifecycle Milestone/Maturity Schedule



Timer



Superlightweight Aerospace Composites Transition/Infusion Status



Timer

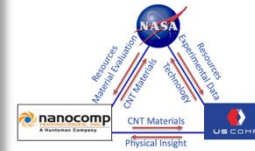
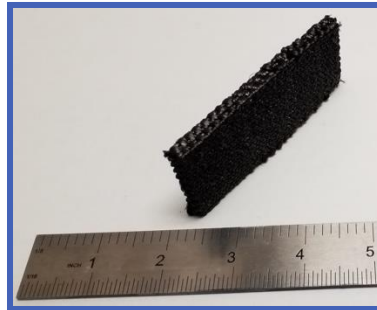


20 feet of 28
AWG CNT
Twisted Pair
Data Cable



20 feet of 28
AWG COTS
Twisted Pair
Data Cable

- In process of being qualified as data cable by other government agencies
- Benefits are mass savings over state of the art cables
- CNT does not cold weld compared to copper



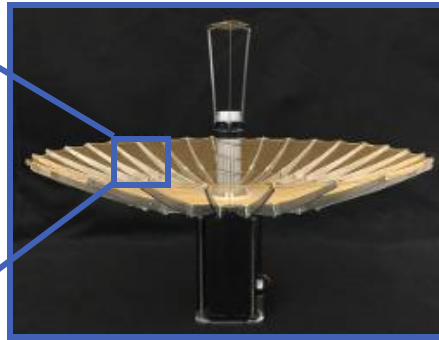
- Topologically optimized 3D woven CNT reinforced composite for space vehicle component.



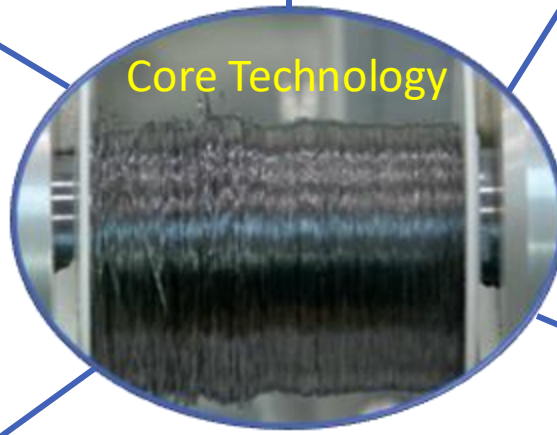
- Exploring benefits of fabricating composites for extreme environments such as carbon/carbon composites



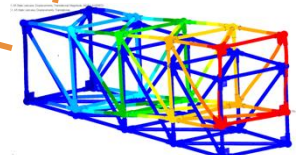
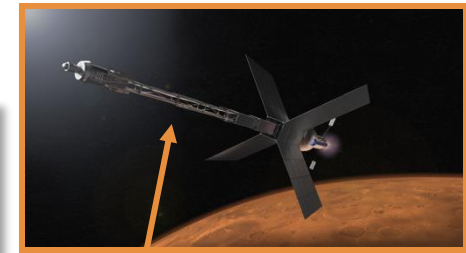
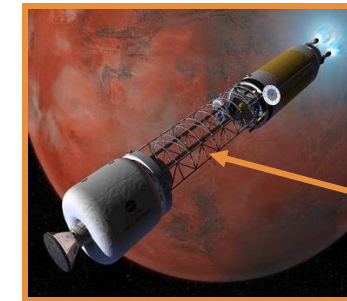
Knitted CNT



- Previously investigated as a deployable antenna
- Substitute for gold coated molybdenum
- Manufacturing scale-up enabled required cost reduction



High Strength CNT Yarn



- Mechanical properties enhanced and systems analyses indicated benefits for truss structure elements
- In process of validating systems analysis models with prototype truss element fabrication and testing

Superlightweight Aerospace Composites

Assessment Summary



Timer

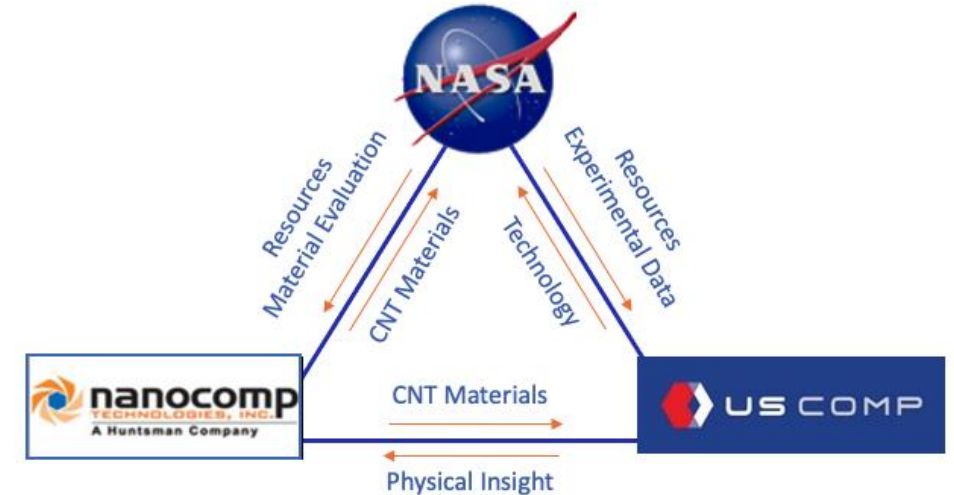
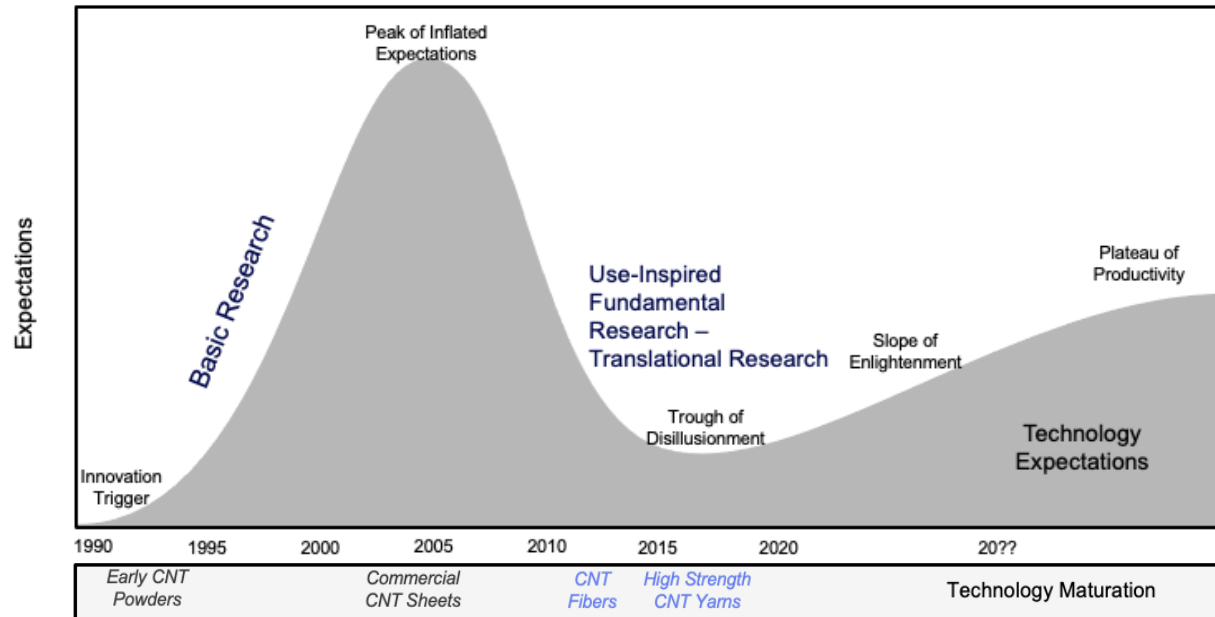
Project Name	Performance				Comments
	C	S	T	P	
Annual					Technical – No issues Cost – No issues Schedule – No issues Programmatic – No issues

	Oct	Nov	Dec	Jan	Feb	MYR	Apr	May	Jun	Jul	Aug	APR
C												
S												
T												
P												

Schedule delay for completion of compression mechanical property milestone in May was due to equipment issues that slowed down process development work. Equipment issues were resolved and a change request to push milestone out was approved.

Summary

TechMat Capability End State for Scope of the Project



- Manufacturing maturation of high strength CNT is anticipated to advance from MRL 3 at the project inception to MRL 6 at the end of the project.
- Application dependent use of high strength CNT will advance from MRL 2 at the project inception to MRL 4 at the end of the project.

NASA mission needs serve as technology pull to guide accelerated maturation of emerging technologies.