National Aeronautics and
Space Administration

Space Technology Research Institutes 2016

Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures

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NASA Advisory Committee Meeting
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Problem

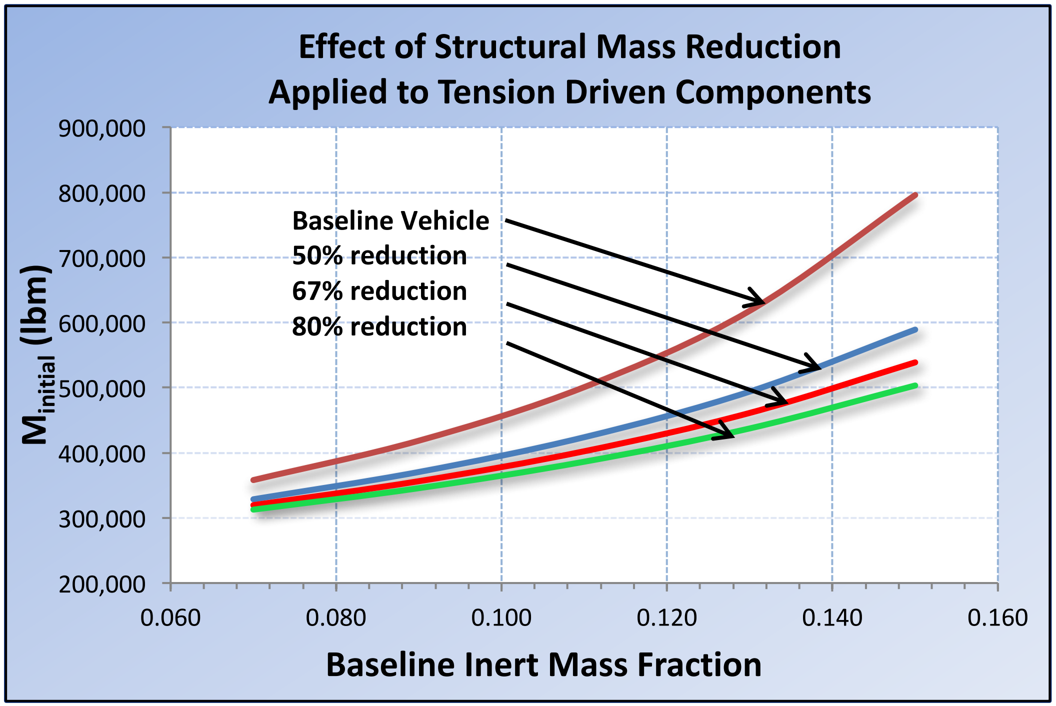
- Cost increases in proportion to the mass ratio
- Mass ratio increases linearly with the dry mass and exponentially with Δv
- Reducing structural mass reduces mission cost at constant payload or increases mission capability at constant cost

	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

* Order of magnitude estimates for mass ratios and costs.

G. Gordon, AIAA SPACE 2007, paper 6278.

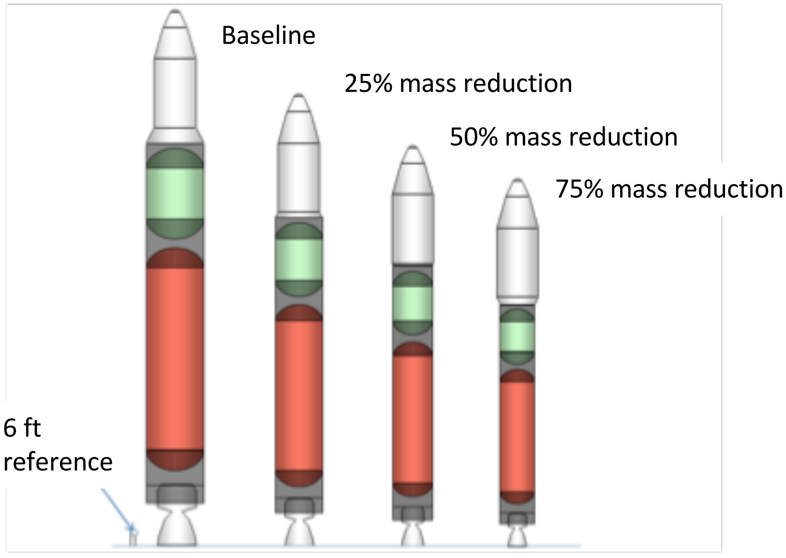
Setting Goals using Systems Analysis



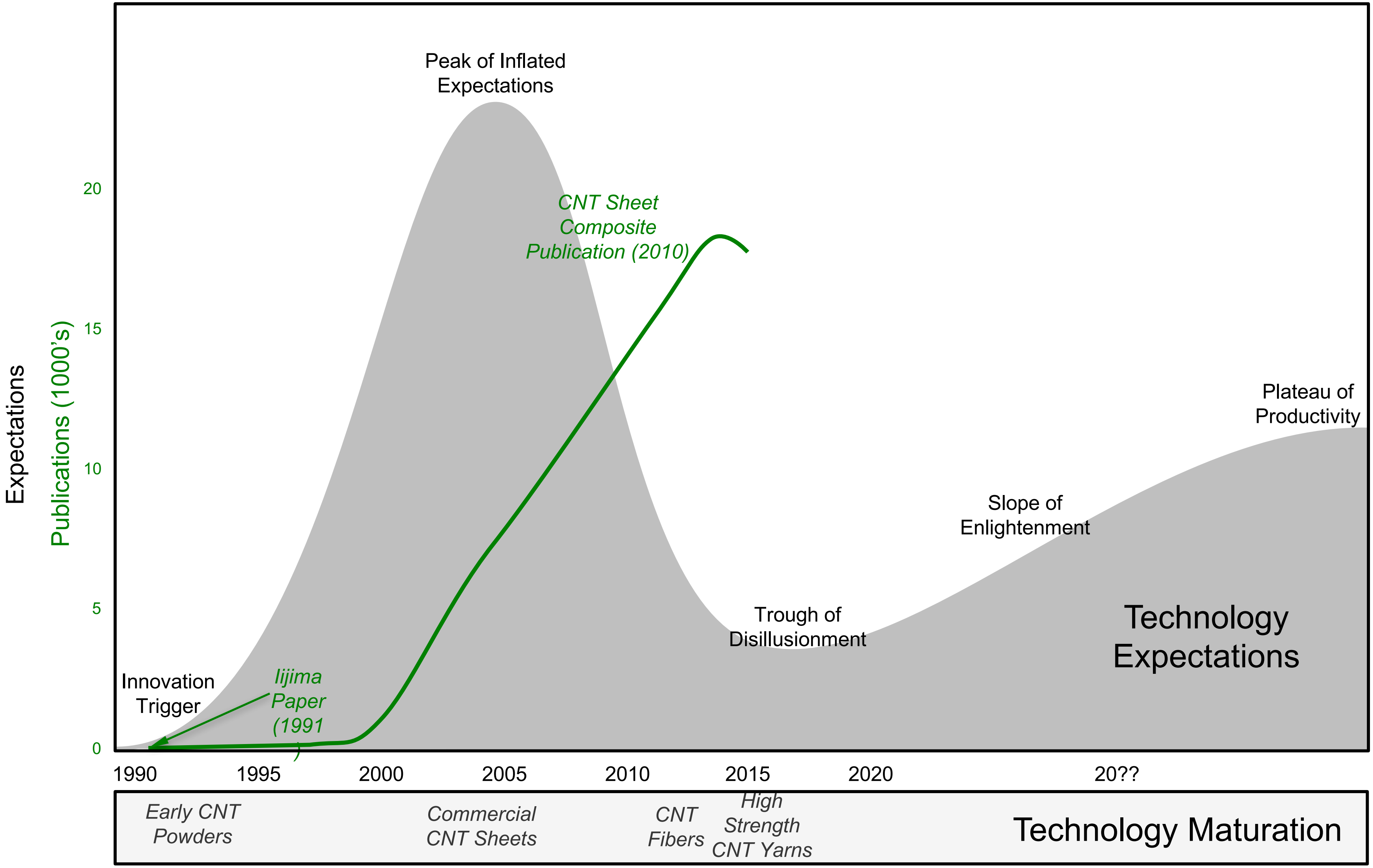
Result: Increasing material specific strength by 2x could reduce Gross Lift Off Weight ($M_{initial}$) by 25% (over 200,000 lbs)!

Observations

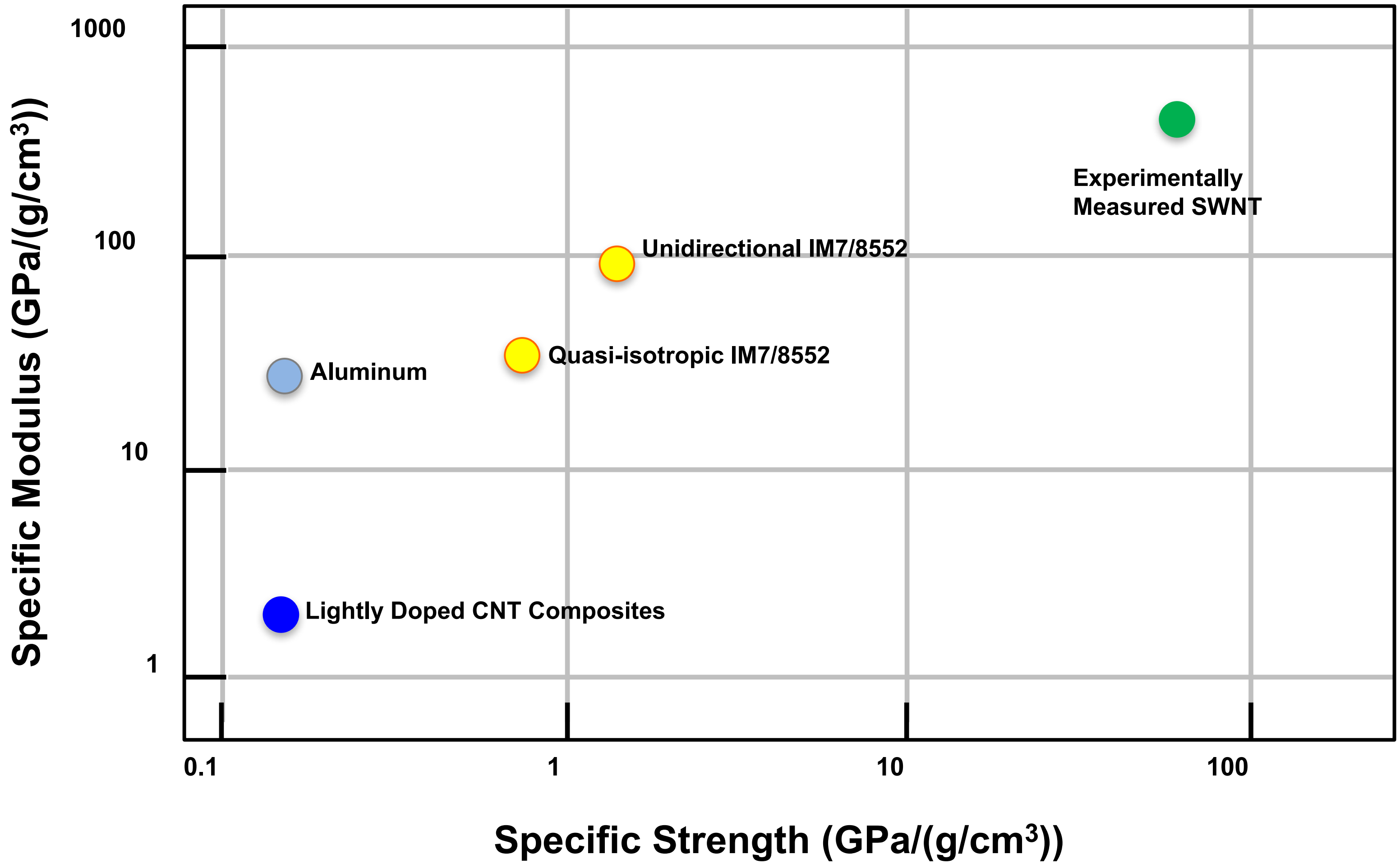
- Baseline mass fractions typical of existing rockets
- Weight savings applied to tension driven structures only, others could benefit



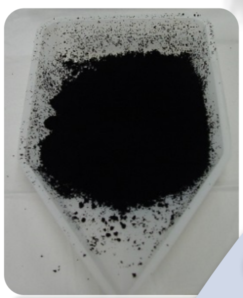
Carbon Nanotube (CNT) Gartner Hype Cycle



Nano to Macro Challenge



Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures



CNT Powder

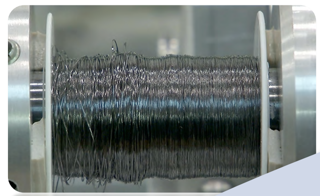
1991-Early 2000s

- Early national investments in CNT research
- NASA interest in structural properties
- Powder form CNT unable to enhance mechanical properties to compete with state of the art structural materials

CNT Sheets

2004

- CNT sheets first became available
- Manufacturing maturation heavily supported by DoD, including Title III funding
- Property enhancements were focused on electrical properties
- CNT sheets for electrostatic charge dissipation were used on Juno which launched in 2011



High Strength CNT Yarn

2015

- NASA Game Changing Development Program supported efforts in structural CNT resulted in mechanical property improvements to commercially available CNT yarn for composite application
- NASA's internal efforts supported 500% increase in specific strength and 1600% increase in specific modulus of CNT composites over 3 years despite non-optimal CNT composites
- CNT composites at tipping point, needing better understanding of mechanisms for load transfer to continue improvements in mechanical properties

Ultra High Strength Composite Panel

2022

- 5-year Space Technology Research Institute (STRI) funding expected to yield fundamental understanding of CNT composite mechanical properties to reach panel level properties that will enable systems level mass reduction
- Materials Genome Initiative accelerated panel properties development required by STRI will yield both models to enhance understanding of CNT composites and continued maturation of CNT materials manufacturing
- Vision for STRI includes complementary internal NASA efforts to assure timely integration of this technology in systems architecture concepts

Computationally Accelerated Materials Development for Ultra High Strength Lightweight Structures

Topic Focus
Ultra high strength lightweight structural material enabled by Materials Genome Initiative (MGI) computational guidance

Distinctive Features of Topic
- MGI approach that spans entire materials development cycle
- Requires demonstration article with challenging property targets at the end of performance period
- Panel properties specified are at least double that of state of the art carbon fiber composite properties
- Properties defined with systems guidance on overall payoff in mass reduction for aerospace systems

Computational Guidance Spans Materials Development Cycle
- Application-guided structural materials design – predictive modeling of material properties including load transfer mechanisms that will influence material and structure design
- Computationally guided design, synthesis, and processing to enable macroscale fabrication of ultra high strength composite
- Accelerated testing and evaluation of material properties to inform iterative advancement of materials design, synthesis, and processing

NASA Contribution to Emerging Materials Technology Development
- Provide the mission pull to define relevant material properties that make insertion into NASA missions plausible
- Leverage DoD investments in electrically conductive materials to enable the advancement of high strength materials with broad commercial implications for aerospace
- Theoretical understanding of ultra high strength CNT structures that complements internally funded advancements in prototyping and structural design of advanced high strength composite structures

NASA Space Technology Research Institute

University of Utah

Michigan Tech University

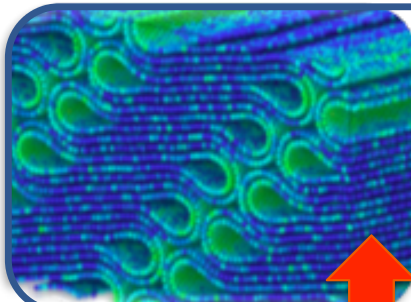
Florida State University

Massachusetts Institute of Technology

Pennsylvania State University

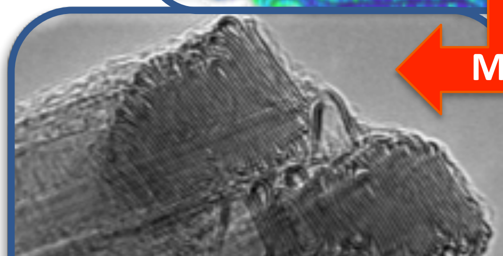
Virginia Commonwealth University

University of Minnesota

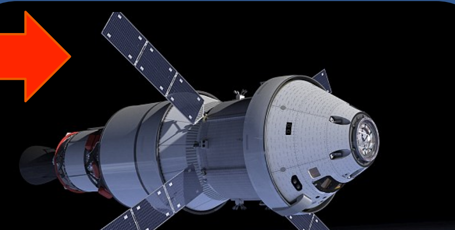


Computational tools
- Multiscale simulation
- Topology optimization

MGI



Experimental tools
- Multiscale characterization
- Panel-level mechanical tests



Digital data for design
- Structure-property relationships
- Mechanical property database

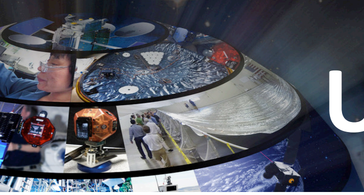
Georgia Tech

University of Colorado

Florida A&M University

Johns Hopkins University

https://www.nasa.gov/press-release/nasa-selects-proposals-for-first-ever-space-technology-research-institutes



US-COMP Organizational Structure

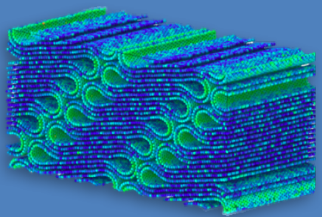
Technical Advisory Board (TAB)

Leadership Team

Simulation & Design Team (SDT)

Team lead: Greg Odegard

- **Force field development**
- **Atomistic/molecular modeling**
- **Meso-scale modeling**
- **Continuum modeling**



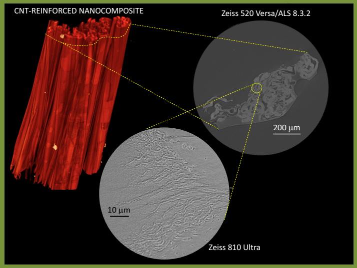
Testing feedback & model validation

Material structure

Testing & Characterization Team (TCT)

Team lead: Mike Czabaj

- **Materials characterization**
- **Mechanical testing**
- **Thermal and electrical testing**



Optimized material design

Synthesis feedback

Validation

Characterization

Prototypes

Structure data

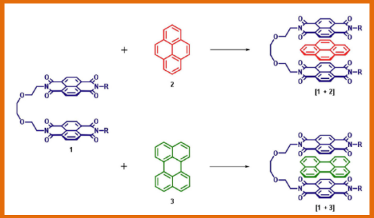
Quality feedback

Test panels

Material Synthesis Team (MST)

Team lead: John Hart

- **Ultra-dense CNT structures**
- **CNT/polymer interfaces**



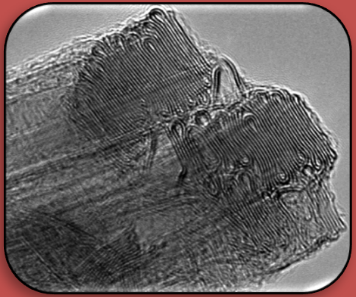
Manufacture feedback

Material prototypes

Material Manufacturing Team (MMT)

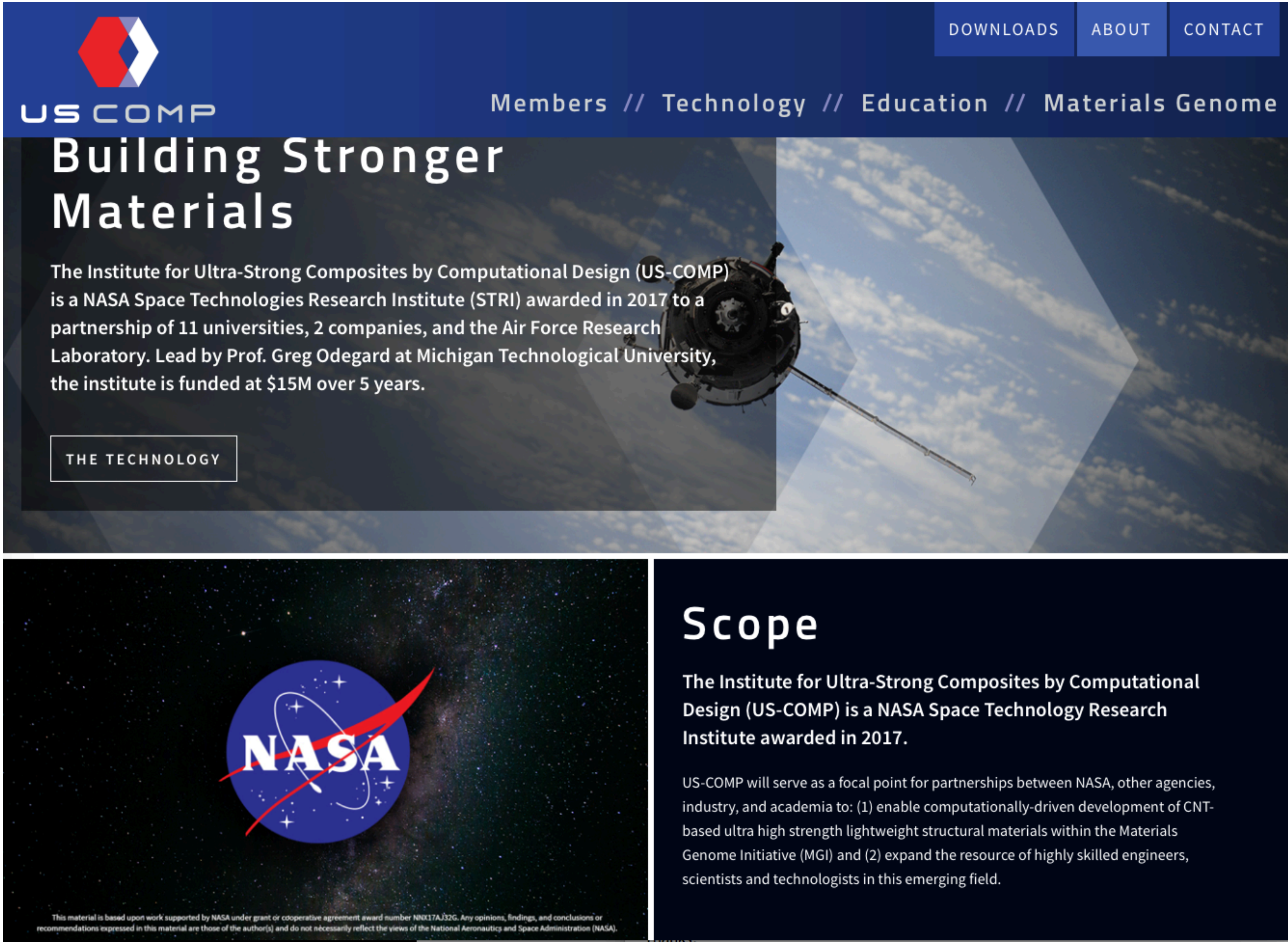
Team lead: Richard Liang

- **Manufacturing scale-up**
- **Materials characterization**



US-COMP Website

http://us-comp.com



Thank You

"For a successful technology, reality must take precedence over public relations, for nature cannot be fooled."

Richard Feynman, Rogers Commission Report on the Challenger Crash