National Aeronautics and Space Administration

A Lecture on Nanotechnology Applications For Aerospace

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UTRGV MENE Intermediate Nanotechnology Class

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With Contributions from

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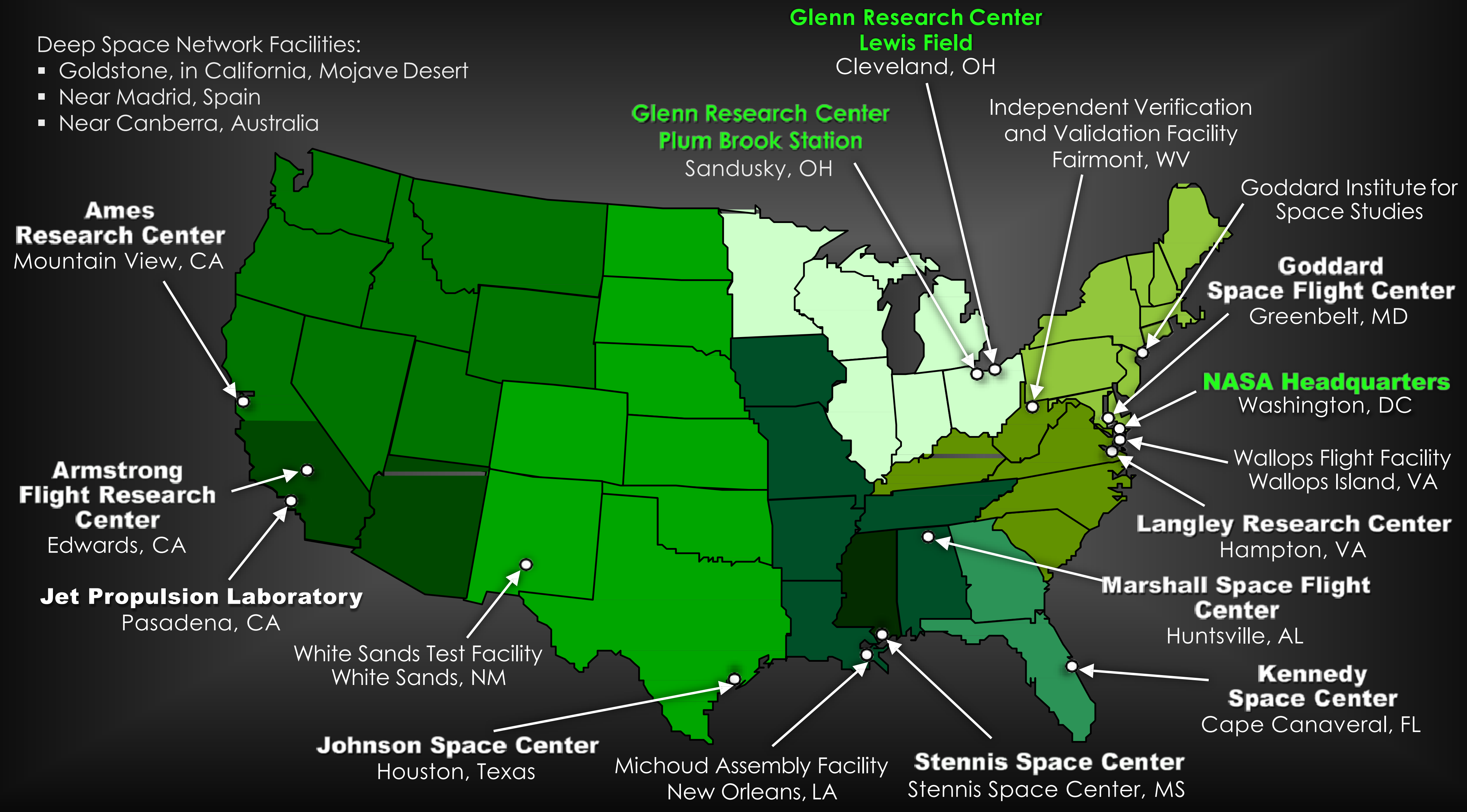
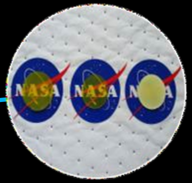
NASA Centers and Installations



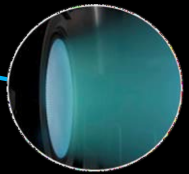
GRC Core Competencies

Power, Energy Storage and Conversion



Materials and Structures for Extreme Environments

Physical Sciences and Biomedical Technologies in Space



In-Space Propulsion and Cryogenic Fluids Management

Communications Technology and Development

Air-Breathing Propulsion

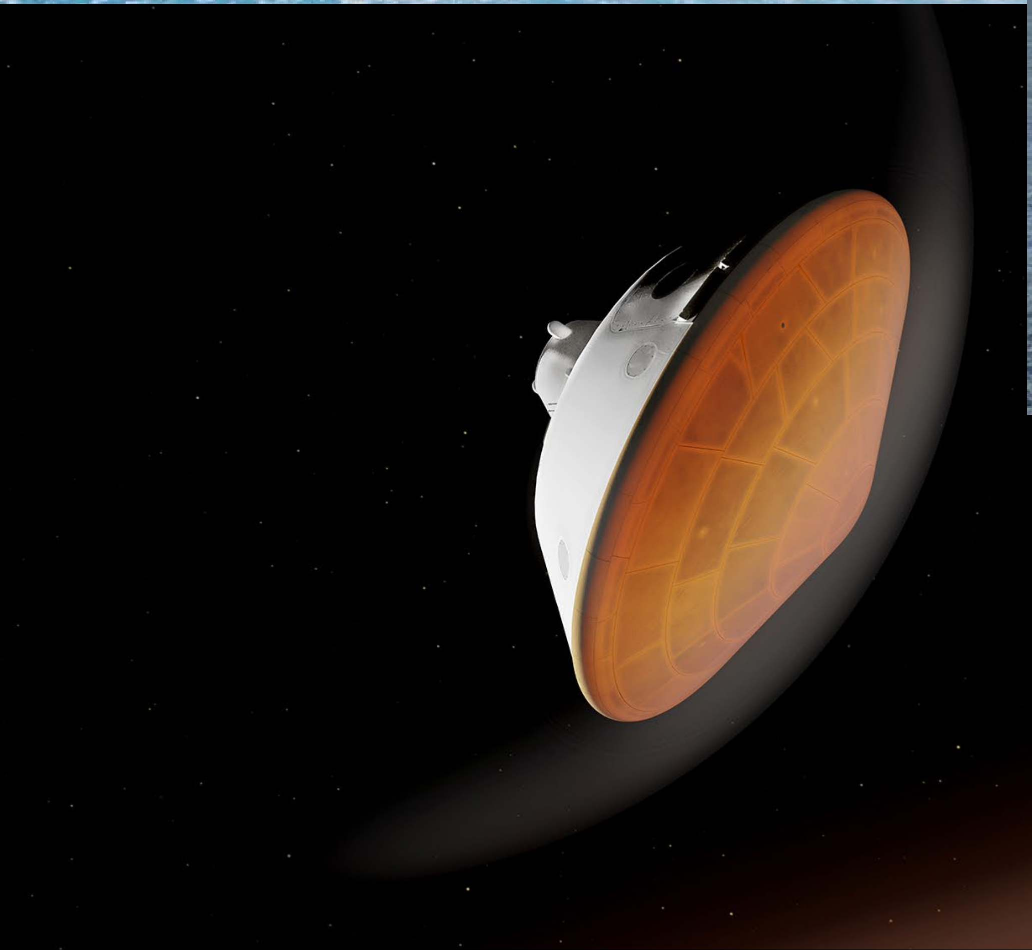
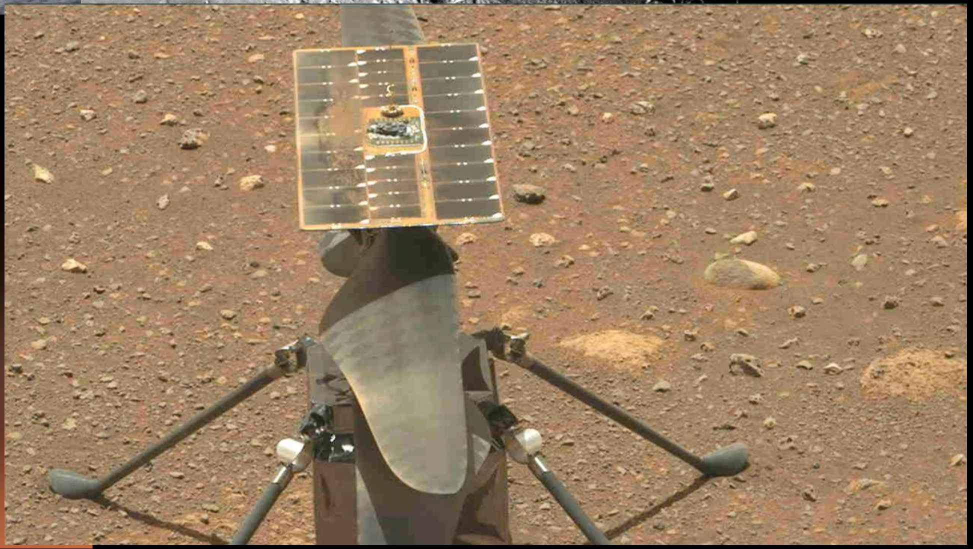
AEROSPACE CHALLENGES AND NANOTECHNOLOGY APPLICATIONS

Why is NASA Interested in Nanotechnology?

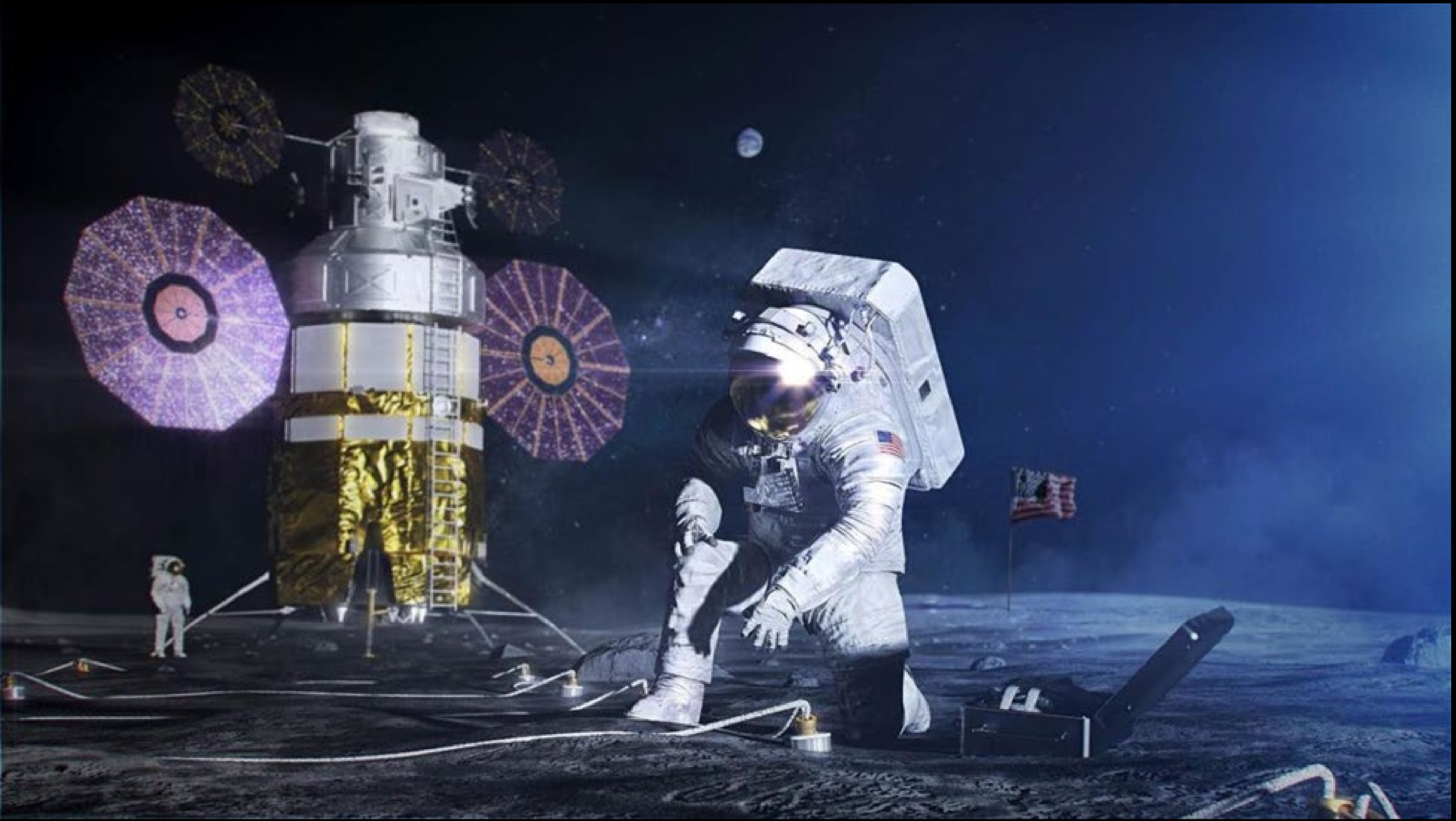
Aerospace technologies are extremely complex systems, that must defy gravitational forces. They must also survive extreme environments such as pressures, temperatures, vacuum, exposure to cosmic radiation. How can nanotechnology solve aerospace engineering problems?

Extreme Environments
What would you feel in these environments?



Nanotechnology Applications



- Nanotechnology is a tool to develop better:

  - Materials
  - Sensors
  - Water and air purification and remediation
  - Power generation, transmission and storage

In Situ Resource Utillization (ISRU)

ISRU involves any hardware or operation that harnesses and utilizes 'in-situ' resources to create products and services for robotic and human exploration

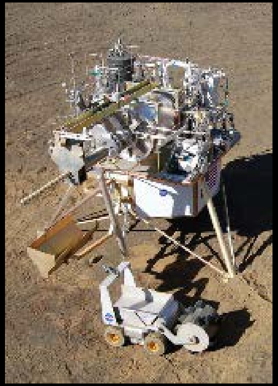
Resource Assessment (Prospecting)

sampling, sniffing, analyzing species

Resource Acquisition

abrasive environment, low-pressure gases

Resource Processing/ Consumable Production



Chemical processing plant

In Situ Energy

Generation and storage of electrical, thermal, and chemical energy

In Situ Manufacturing

Processing in-situ feedstock into parts

In Situ Construction

changing properties of loose in-situ materials into consolidated structural materials

Nanotechnology and ISRU

Nanomaterial catalysts or catalyst substrates for increased active area in

Sabatier catalyst material after vibration testing

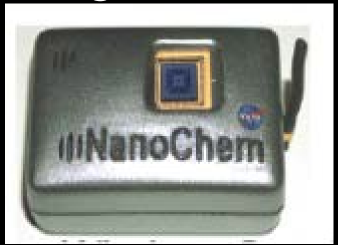
Improved or self-healing coatings and electronics for excavation and construction equipment dealing with abrasive materials

Insulation material for hot (reactors) and cold (cryo tanks) components in the not-quite-a- vacuum environment on Mars

RASSOR excavator delivering regolith

Flexible Aerogel Insulation

Nanosensors for prospecting, hazard detection, and health management



(L) CNT “Electronic Nose”; (R) Nanochemsensor flown on ISS

Nano sorption materials to increase mass adsorbed to mass adsorbent ratio for Mars atmosphere acquisition or during gas separation steps.

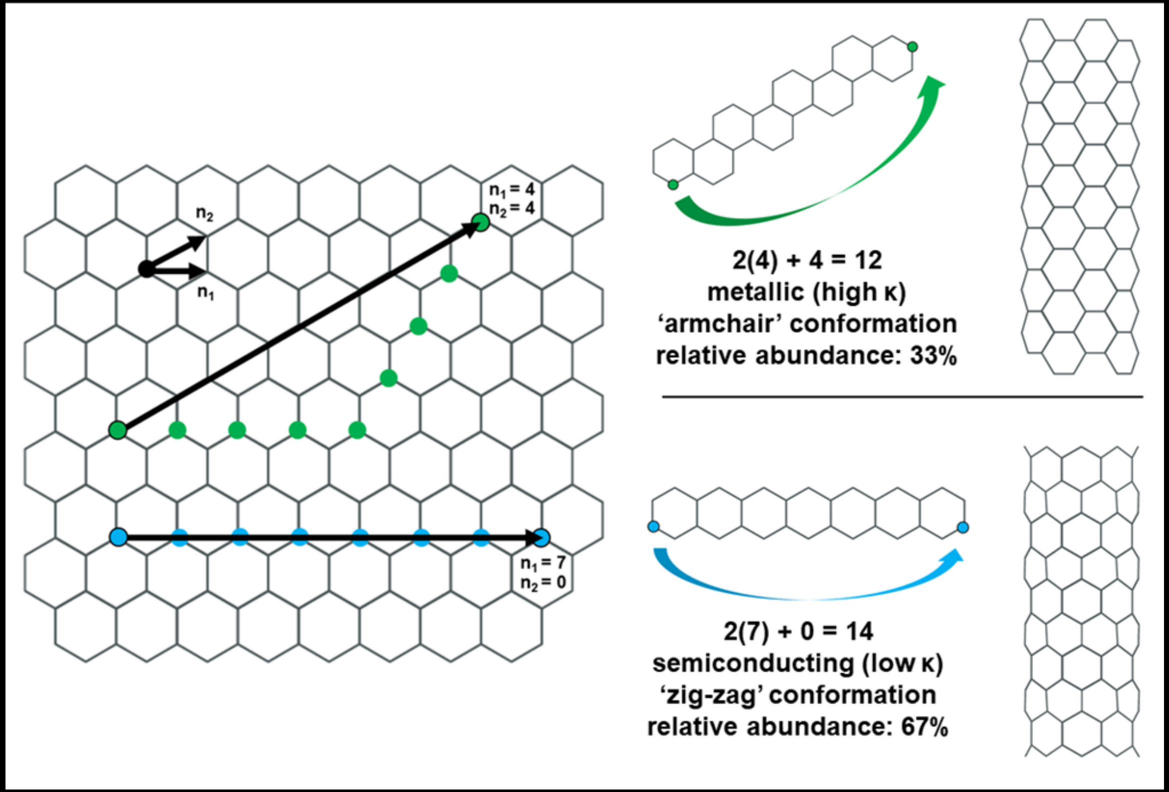
Sorption pump prototype unit

Carbon Nanotubes CNT

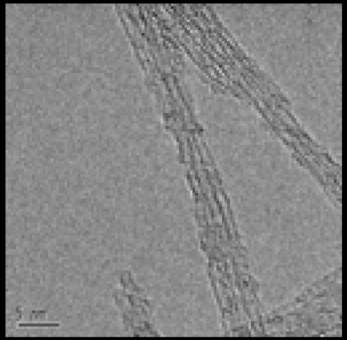
NANOTECHNOLOGY SOLUTIONS

Carbon Nanotubes, CNT

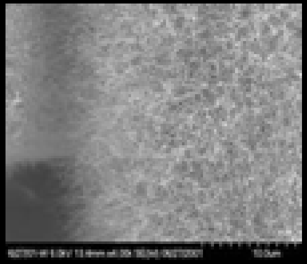
- Excitement: Single CNT material properties out perform steel in strength, copper in electrical conductivity & diamond in thermal conductivity
- Reality: Properties degrade in assemblies of CNT
- Challenge for wiring is to improve properties of assemblies of CNT—wires, yarns



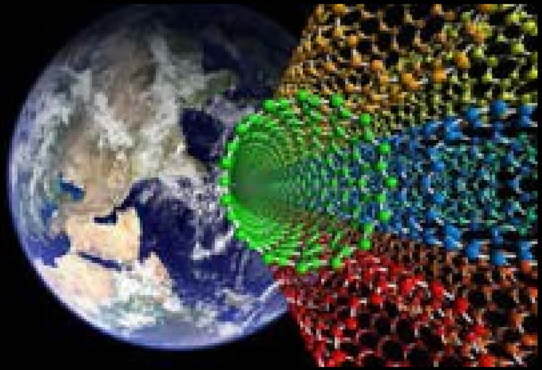
Lightweight, Multifunctional Materials- Carbon Nanotubes



Purified Single Wall Carbon Nanotubes



Nanotube Modified Substrates



- Carbon Nanotube Space Elevator

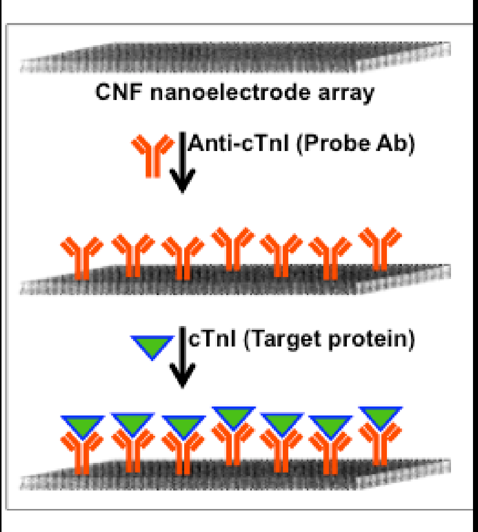
- Carbon nanotubes (CNTs) have remarkable properties-
  - > Specific strength 150X that of conventional carbon fibers, 100X aluminum
  - > Elongation 10X that of conventional carbon fibers
  - > Electrical and thermal conductivities ~10X that of high conductivity carbon fibers
- Because of these properties, carbon nanotubes have been proposed for disruptive applications such as a space elevator cable. Is this Possible????
- Widespread use of CNTs in aerospace hampered by inability to uniformly and reliably disperse them into polymers and other matrix materials

National Academies Quadrennial Review of the NNI

Real Applications
Nanosensors for Chemical/Biological Detection

- Low mass and volume, low power demand, high sensitivity/selectivity sensors for the detection of chemical and biological species for human and robotic exploration

- Sensor concepts under development include portable CNT sensors for leak detection (left) and functionalized carbon nanofiber sensors for detect of cardiac disease biomarkers (right).

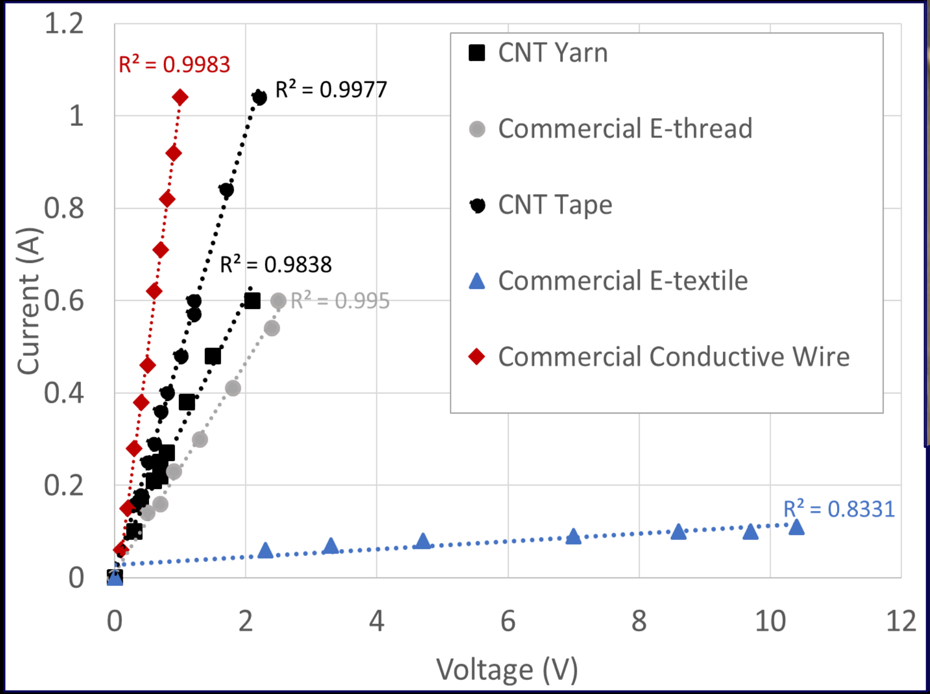


Real Applications
Durable Electrically Conductive Textiles CNT (E-textiles)

- **Potential applications for e-textiles in aerospace**
  - Spacesuits
  - Sensors
  - Inflatables
  - Blankets
  - Health monitors

- **Challenges with e-textiles and wires**
  - Flexibility
  - Durability
  - Reliability
  - Manufacturing challenges
  - Reparability

Solution: Use CNT yarns to develop lightweight, flexible, and durable e-textiles

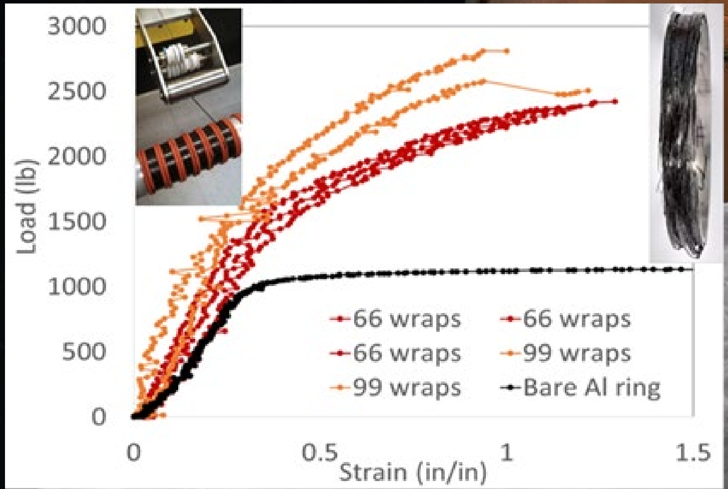


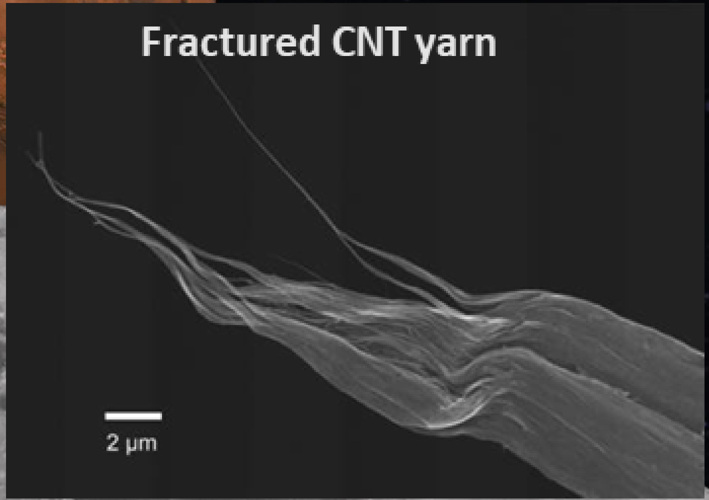
IR thermal image of preliminary heating pad construction: Heat distribution dependency on CNT stitch spacing

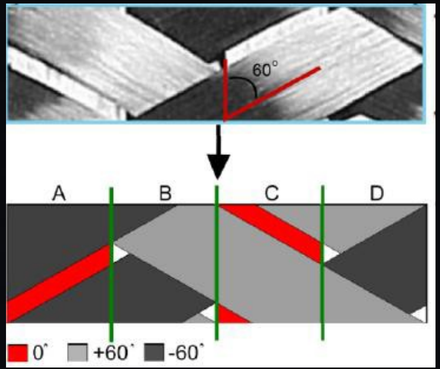
Nano-Structural Applications

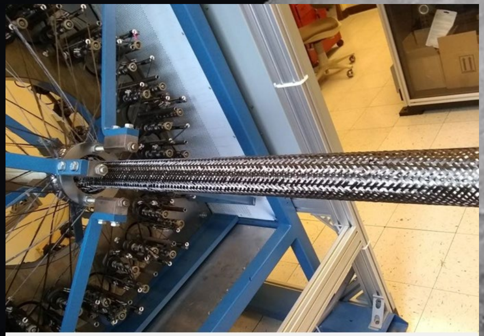
Application: Composite Overwrap Pressure Vessel s (COPV) tanks used in cold gas thruster systems.

Goal: Develop carbon nanotube (CNT) reinforced composites with 1.5 to 2x's specific strength of conventional carbon fiber composites.

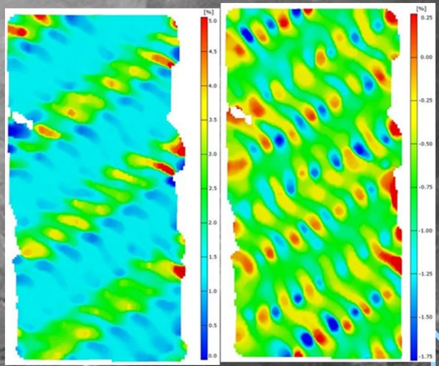








Carbon fiber – CNT Yarn Triaxial Braided Tube



Nanocomposite overwrap tank

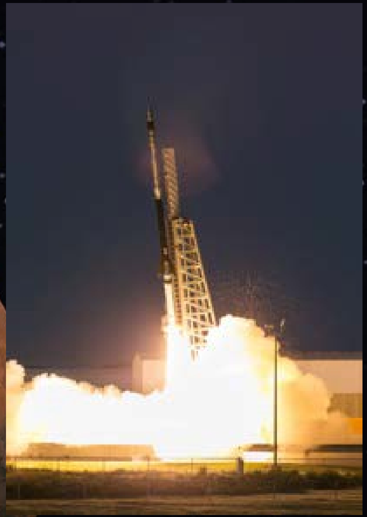
1st Ever Demonstration of CNT Composites in Aerospace ***Structures***

Carbon Nanotube (CNT) Fiber

nanocomp TECHNOLOGIES, INC.

Filament Winding of Composite Overwrap Pressure Vessel (COPV)

COPV Installed in Sounding Rocket Cold Gas Thruster System

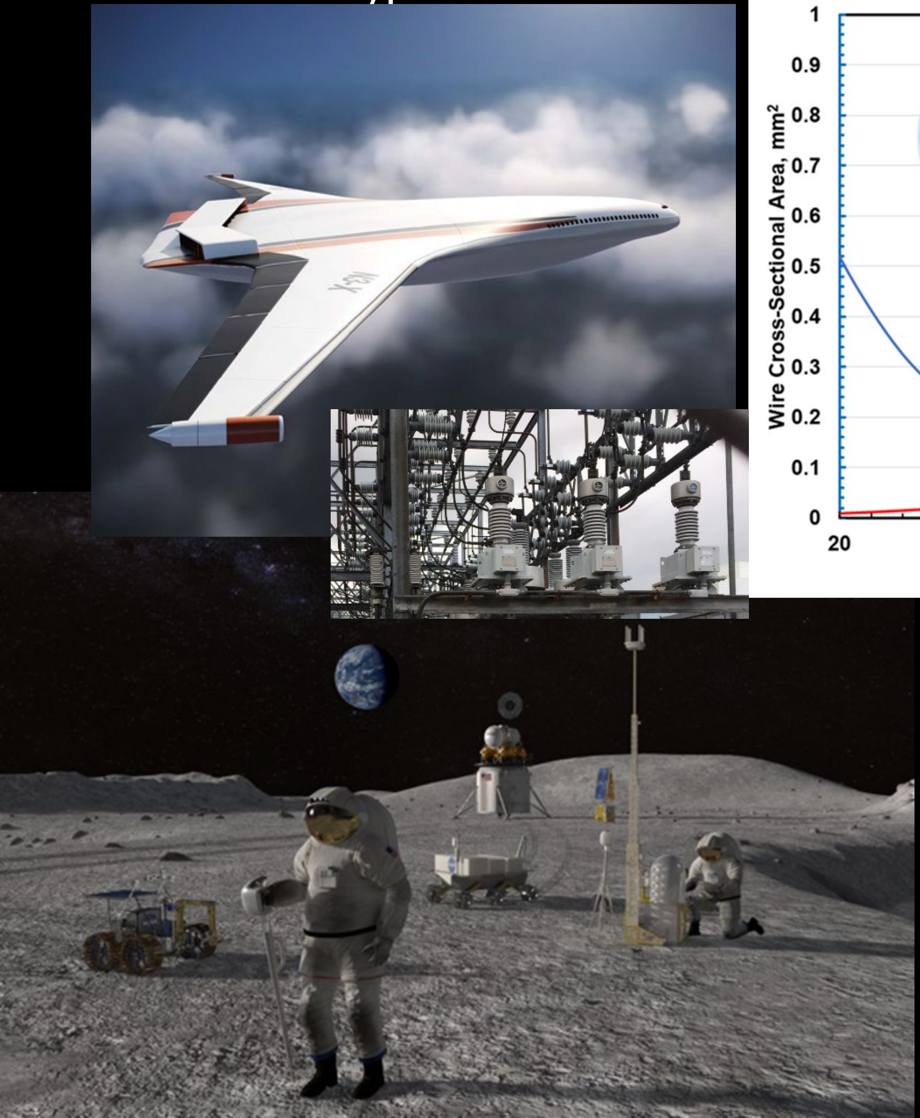


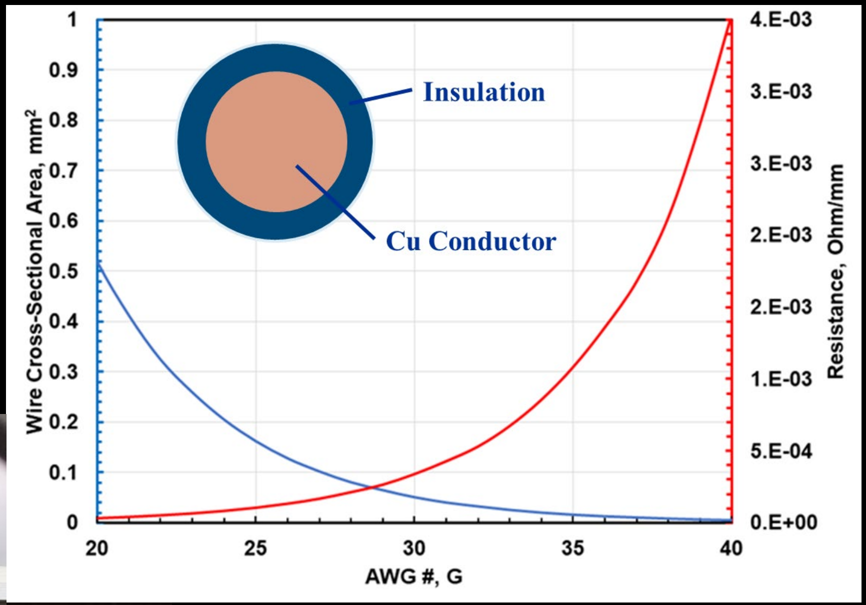
Successful Flight Test on May 16, 2017

- Significantly improved the mechanical properties of CNT fibers and fiber reinforced composites – specific tensile strength on par with standard aerospace composites
- Developed flight heritage for CNT composites
- Further work is needed to develop composites that more fully exploit the unique

Lighter-Weight Conductor Cables are Needed for Aerospace Electrical Propulsions and Planetary Missions

N3-X Prototype Turboelectric





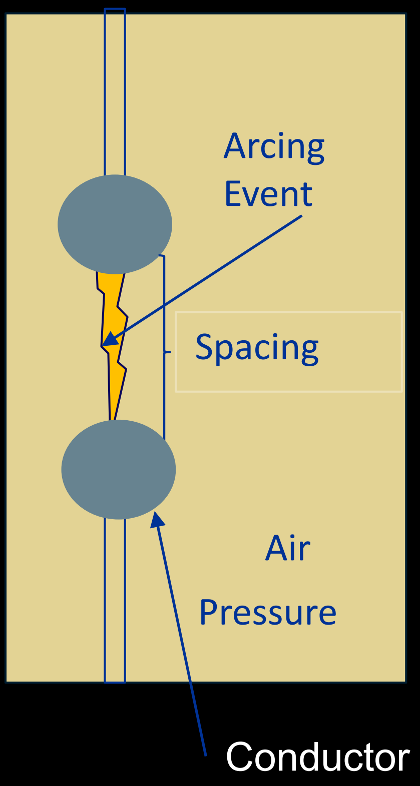
Why ?
Let's Think About….

- What are the potential problems?
- Does the solution create a new challenge?

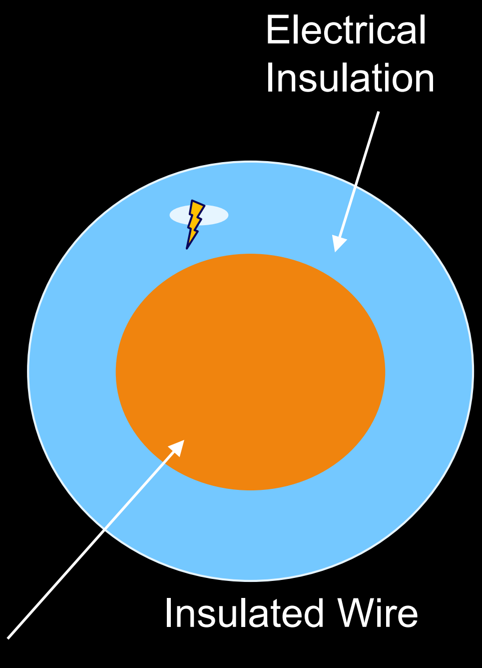
Example: Electric Propulsion is heavy due all the electric systems.
We can lightweight the conductor by increasing the voltage , V.
V= I (current) X R (resistance)
What can go wrong? →We need more insulation.

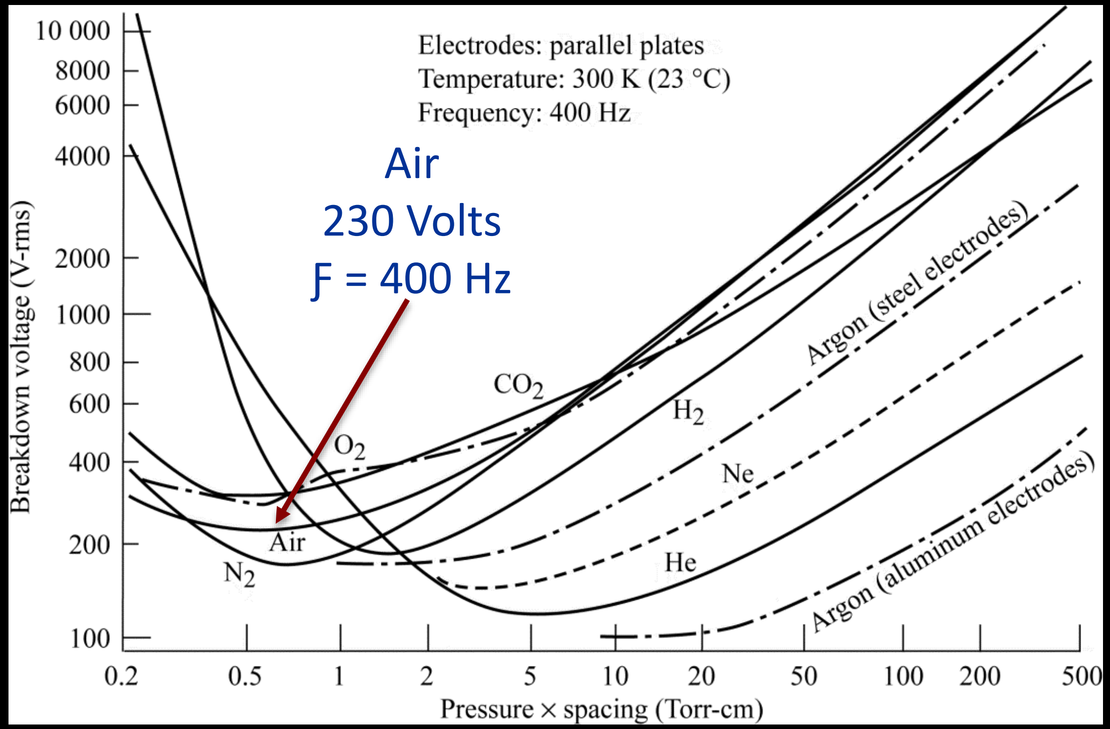
Power $P = I \times V = R \times I^2 = V^2 / R$

Technical Challenges: Partial Discharge and Corona



Partial discharge in void





Breakdown Voltage of Several Gases as a Function of *pd* at Room Temperature

The minimum voltage for electrical discharge between two metal conductors at ***high altitude*** will occur at ~ 327 V. ***At 400 Hz the minimum voltage drops to 230 V for breakdown to occur***. Additionally, voids, defects and contaminants in electrical insulation can experience intensified local discharge called partial discharge.

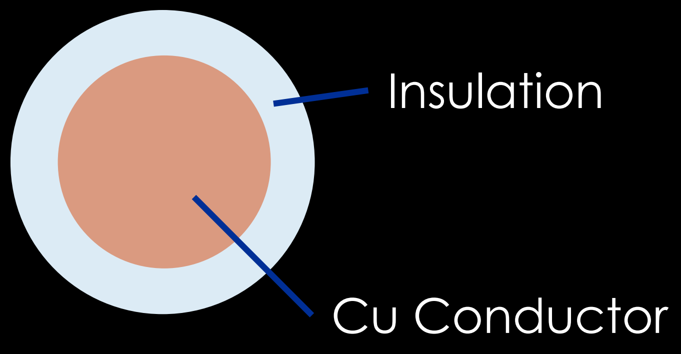
Chart Reference: NASA-HDBK-4007 W/CHANGE 3

Taking A Low Power Idea and Researching a High Power Idea with CNT/Cu Composite Design

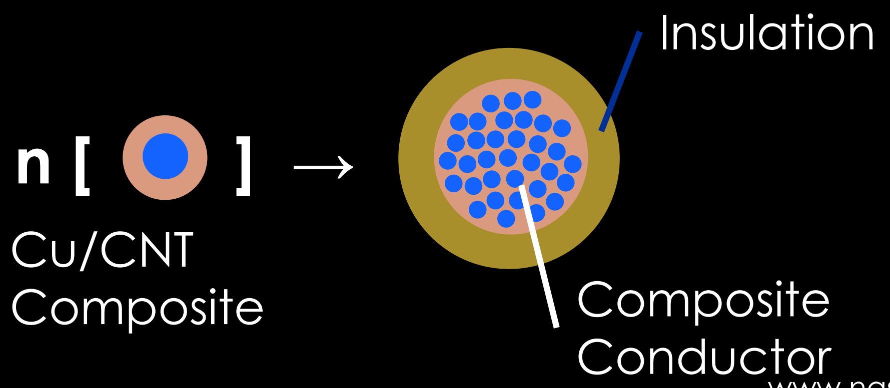
	Copper	Carbon Nanotube (CNT) Yarn
Electrical Conductivity (κ, S/m)	5.8×10^7	*1.3×10^6
Tensile Strength (σ, MPa)	200	1500

Key Feature	(σ_{TS}, MPa)	Electrical Conductivity (κ)
Electroless plating [2]	-	90% IACS
Self-fueled electrodeposition [3]	500-650	51% IACS
Super-aligned CNTs [4]	287	46.8 MS/m
Cu-Ti alloy matrix [5]	362 *σ_{YS}	93% IACS
SPS composites, not aligned [6]	275	93% IACS
Higher ampacity [4,7]	-	46-47 MS/m

Now



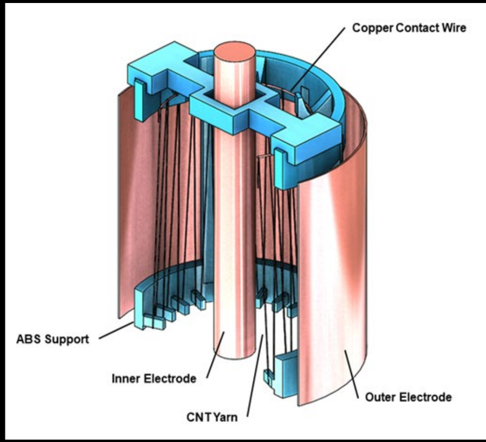
Future

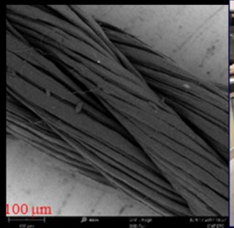


National Aeronautics and Space Administration

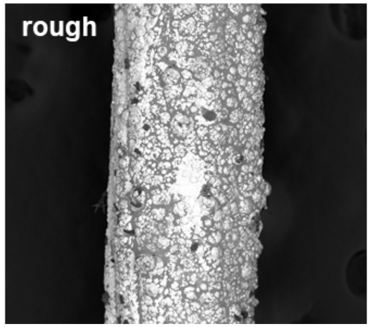
Lightweight High Voltage Composite CNT-Cu Conductor

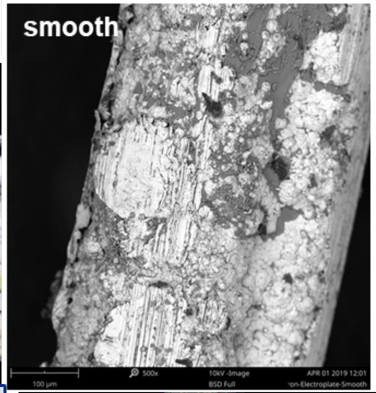
1. Electroplating

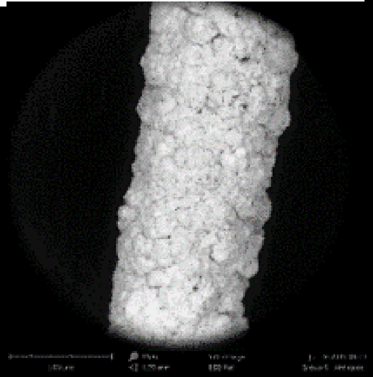




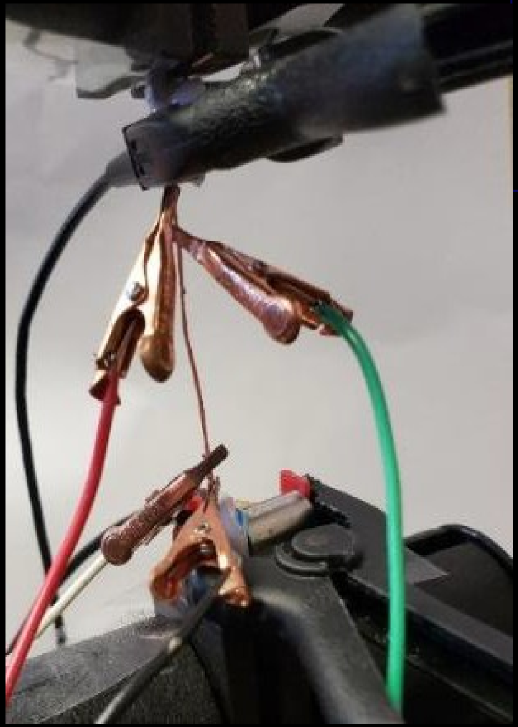
2. Drawing



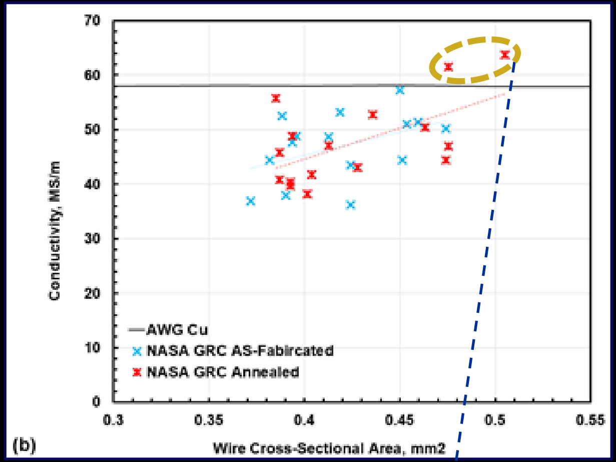




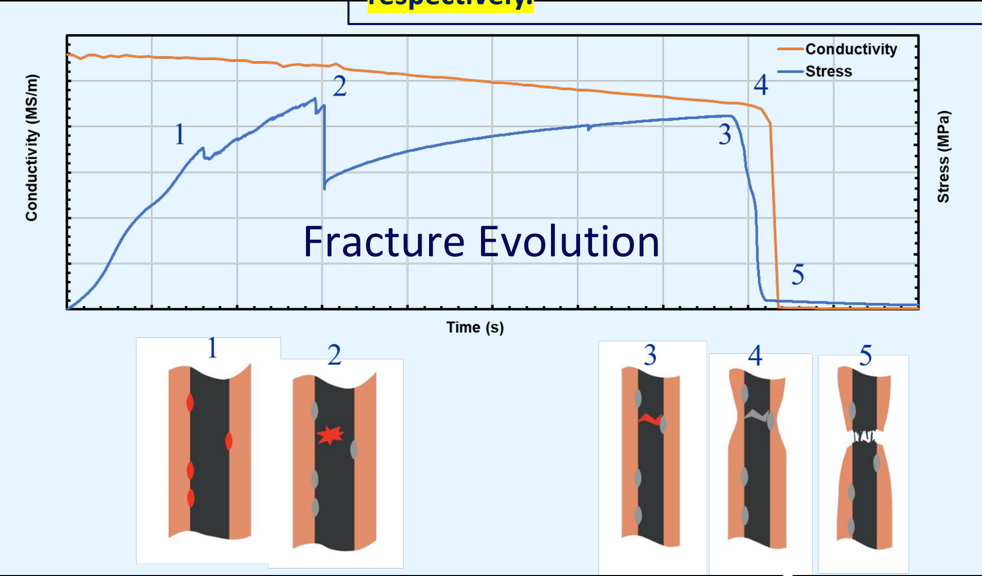
Correlate electrical and mechanical behaviors via 4-probe electrical resistance (ER) and acoustic emission (AE) monitoring



CNT-Cu composite provides opportunity to further reduce cable weight while maintain most of the electrical conductivity of the conductor and increase strength.



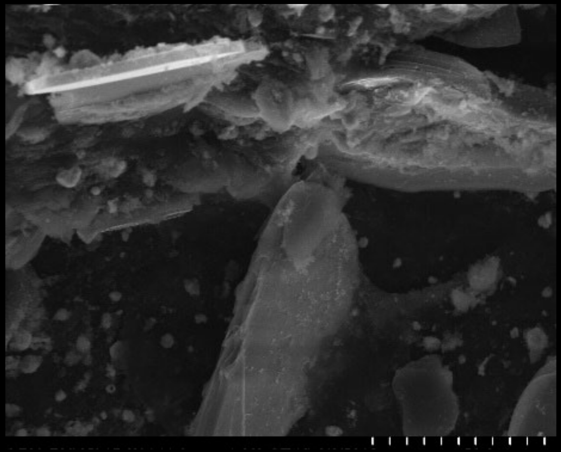
Batch 5 conductivities were greater than both theoretical predictions and pure annealed Cu by 9.8 and 4.8 percent, respectively.



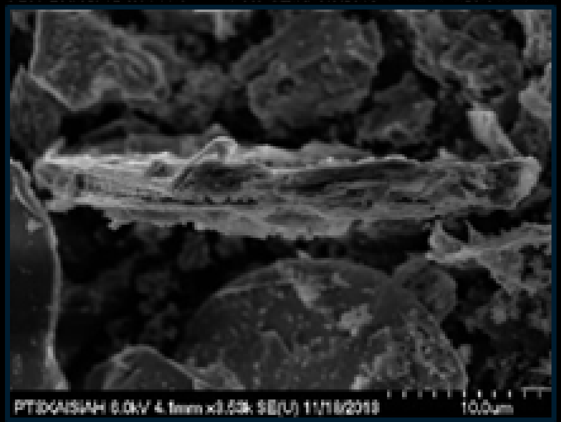
BORON NITRIDE NANO MATERIALS

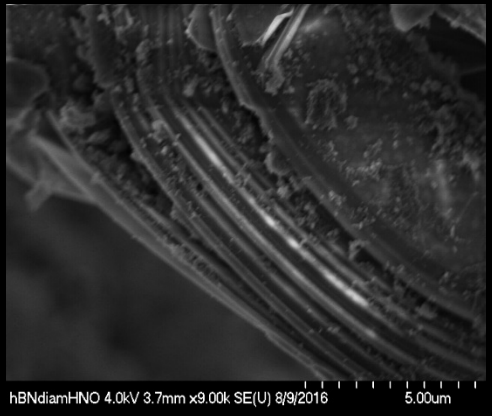
Why Boron Nitride?

- **BN Good Insulation Properties**
  - Constant wide band gap above 5.2 eV
  - On BN nanotube, it's independent of diameter, chirality or number of tubular walls
- **High Thermal Conductivity**
  - Thermal Conductivity of 600 $W(m°K)^{-1}$
  - Larger thermal conductivity than CNTs
  - Ability to dissipate heat in nano-electrics
- **Chemically and Thermally Stable**
  - Hydrophobic
  - Chemical stability
  - Oxidation in air above 1100 °C
- **Fiber form brings continuity of properties on composites**



h-BNNS

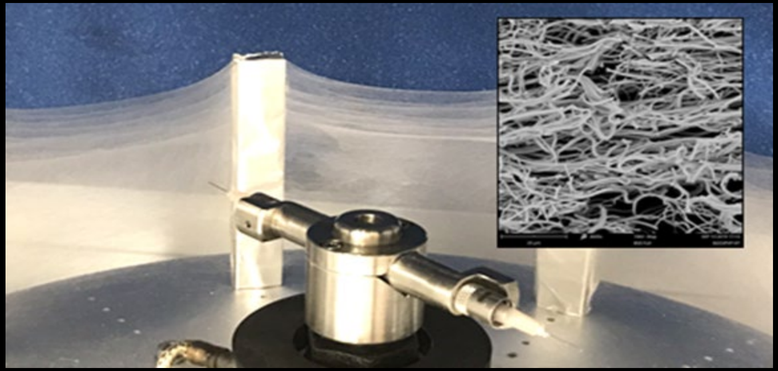




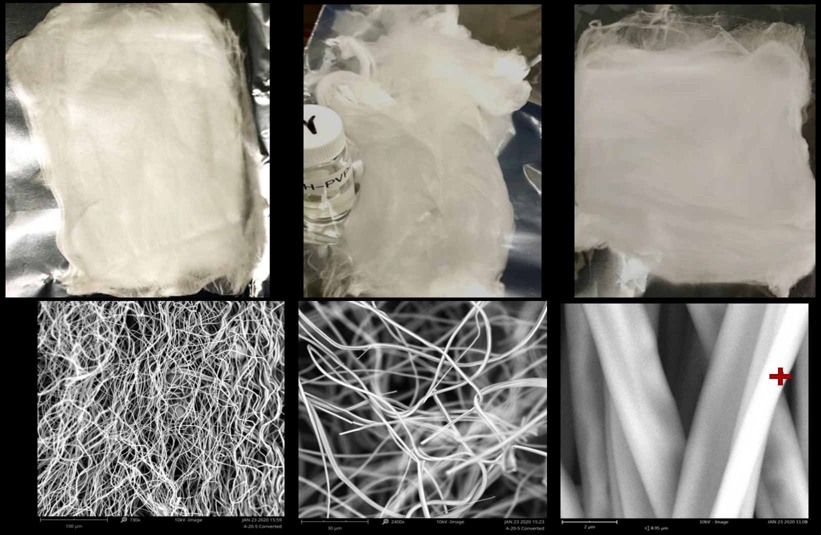
Multifunctional Properties for Different Applications

Polymer Derived h-BN Nanofibers

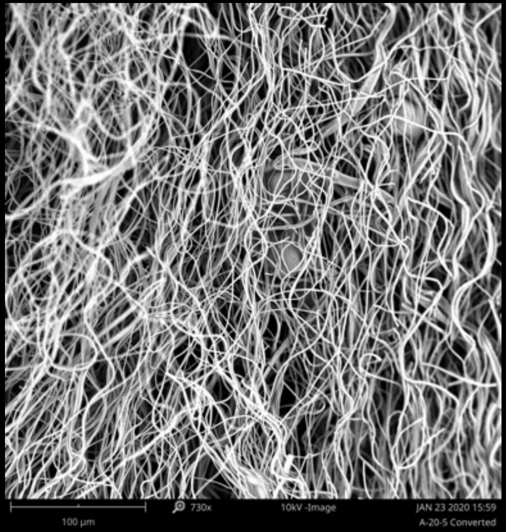
1. Solution Spinning

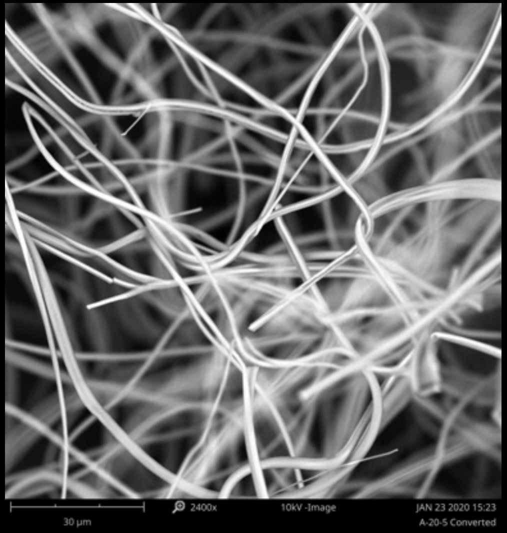


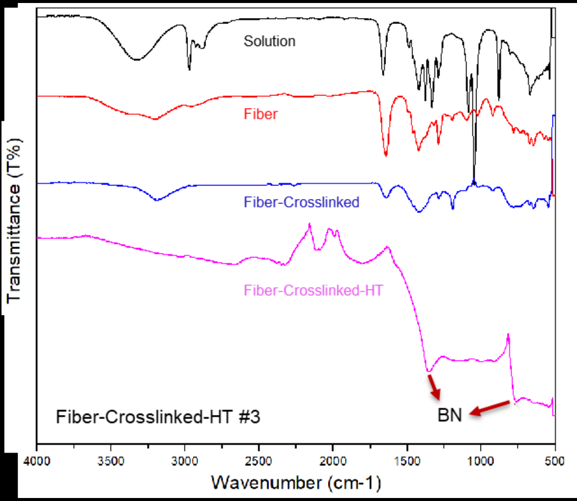
2. Fiber Mats

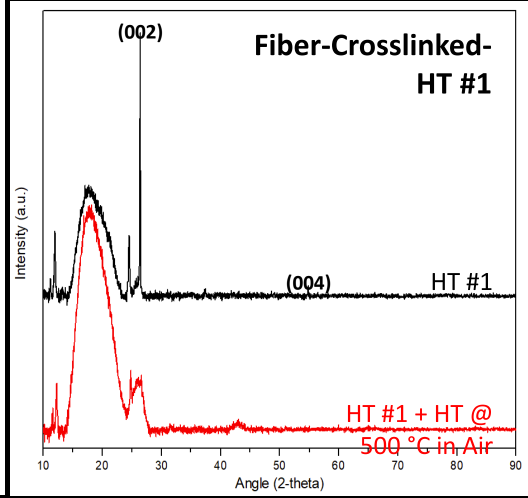


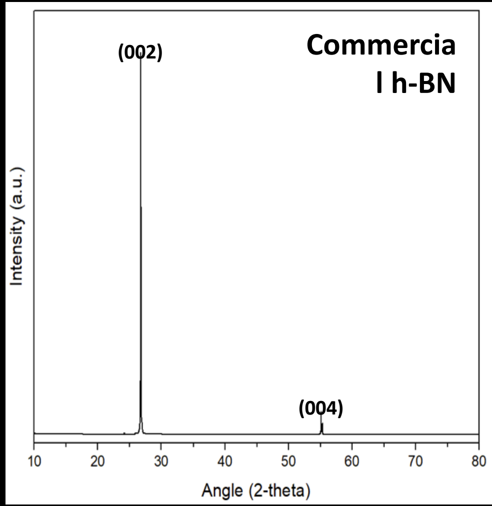
3. Ceramic











Development of h-BN nanofibers for aerospace applications in systems exposed to extreme environments

Lecture Summary:
Nanotechnology can solve aerospace challenges by light-weighting technology and reducing cost. Always consider the environment of operation.

Innovation with this in mine:

- Earth Environment
- Space Environment
- Destination Environment
- Operational Environment
- Manufacturing
- Product Life
- Payload Costs

NASA Careers:
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Type NASA in the search window.

NASA Fellowships:
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NASA Internships:
https://intern.nasa.gov/

Thank you!