TiiMS
TEXAS INSTITUTE FOR INTELLIGENT BIO-NANO MATERIALS AND STRUCTURES FOR AEROSPACE VEHICLES
A NASA University Research, Engineering and Technology Institute (URETI)

Multifunctional Bio-Nano Materials and Structures Technologies for Aeronautics and Space Exploration

Dimitris C. Lagoudas
Institute Director

Daniel C. Davis
Director of Operations

Texas Institute for Intelligent Bio-Nano Materials and Structures for Aerospace Vehicles
Texas A&M University
College Station, TX 77843-3409

- Funded by the National Aeronautics and Space Administration
- Administered by the Texas Engineering Experiement Station
- A collaborative effort among: Prairie View A&M University | Rice University | Texas A&M University | | Texas Southern University | University of Houston | University of Texas - Arlington

UREТIs

Bio-Inspired Design and Processing of Multi-Functional Nano-Composites (BIMat)

- Design and modeling of hierarchically structured materials capable of bio-sensing catalysis and self-healing

- **Princeton**
- UCSB
- Northwestern
- U of NC
- Nat'l Inst. Aerospace

Institute for Nanoelectronics and Computing (INAC)

- Develop fundamental knowledge and enabling technologies in: ultradense memory, ultraperformance devices, integrated sensors, and adaptive systems

- **Purdue**
- Yale
- Northwestern
- U of Fl
- Cornell
- UCSD
- Texas A&M

Institute for Intelligent Bio-Nano Materials and Structures for Aerospace Vehicles (TiiMS)

- Basic and applied research in the integration of sensing, computing, actuation and communication in smart materials

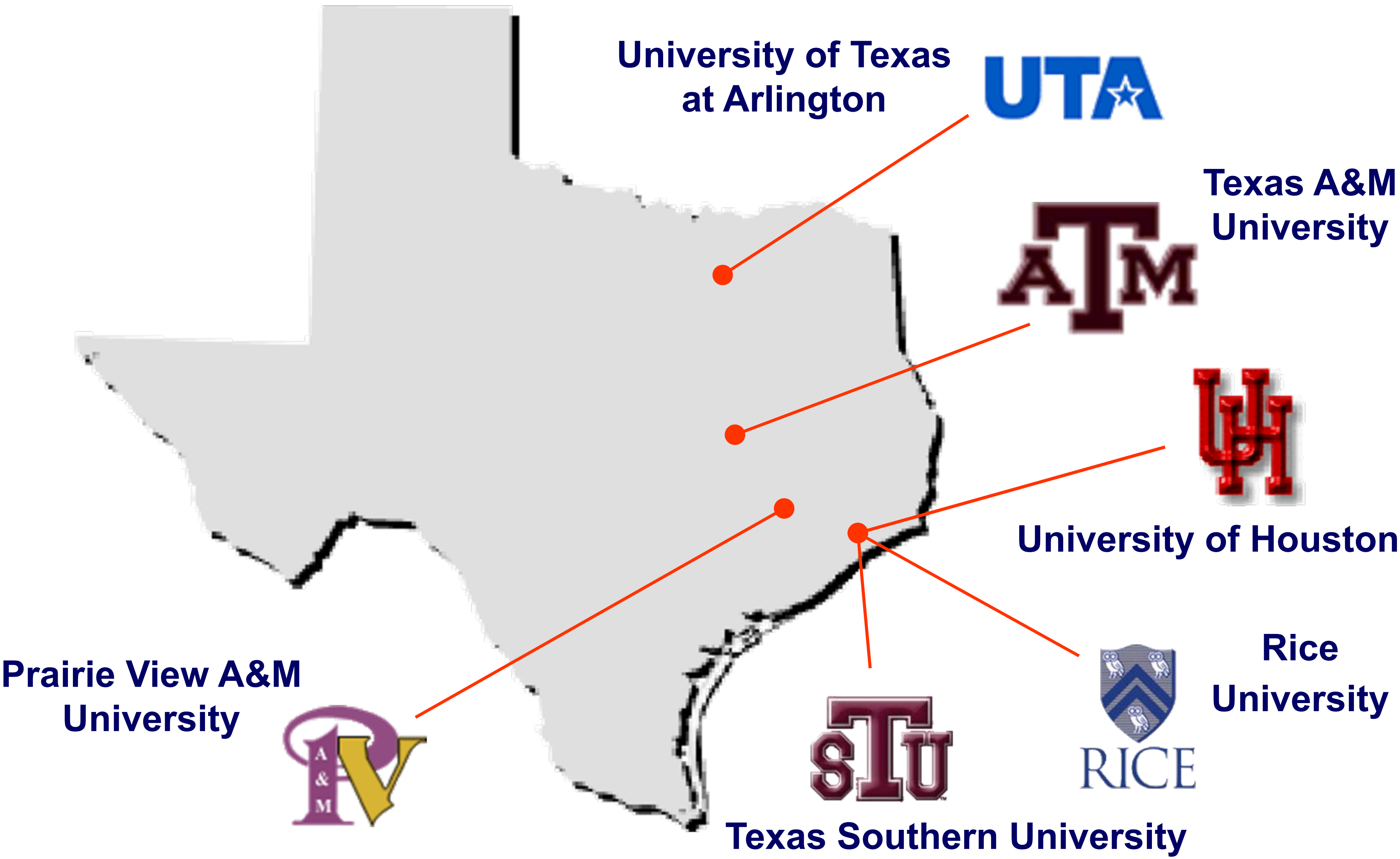
- **Texas A&M**
- Rice
- Texas Southern
- Prairie View A&M
- U of T-A
- U of Houston

Center for Cell Mimetic Space Exploration (CMISE)

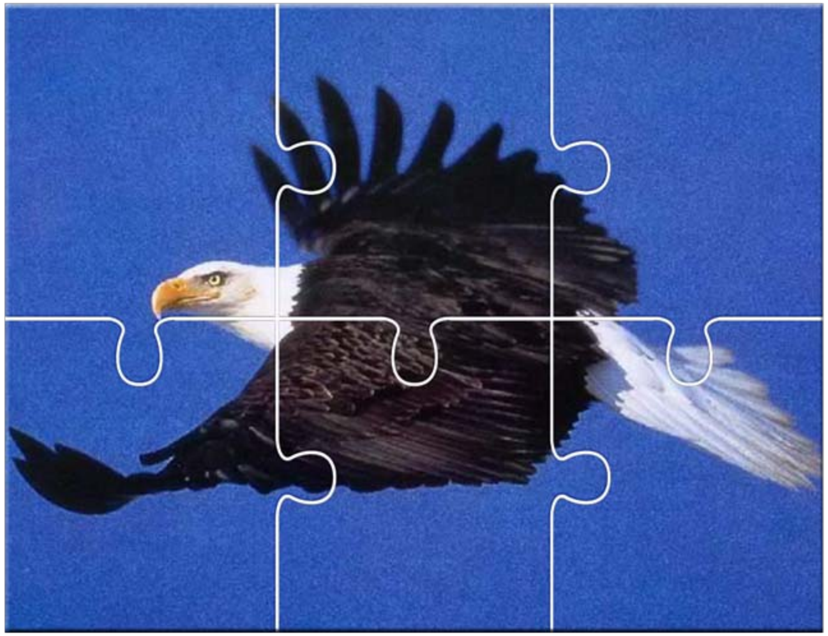
- Bio-informatics for the development of new, scalable nano-technologies in sensors, actuators and energy sources

- **UCLA**
- CIT
- Ariz. St
- UCI

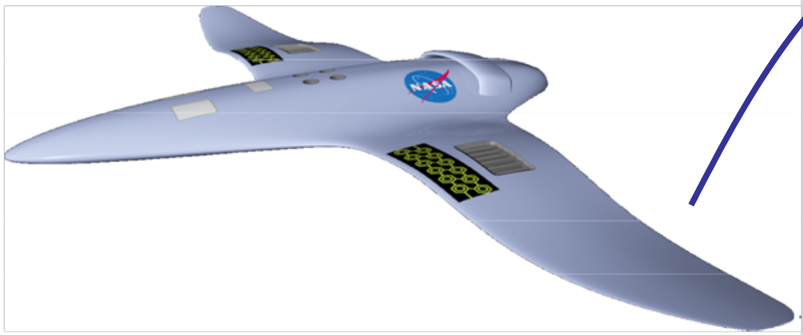
UNIVERSITY PARTICIPANTS



Objectives of TiiMS

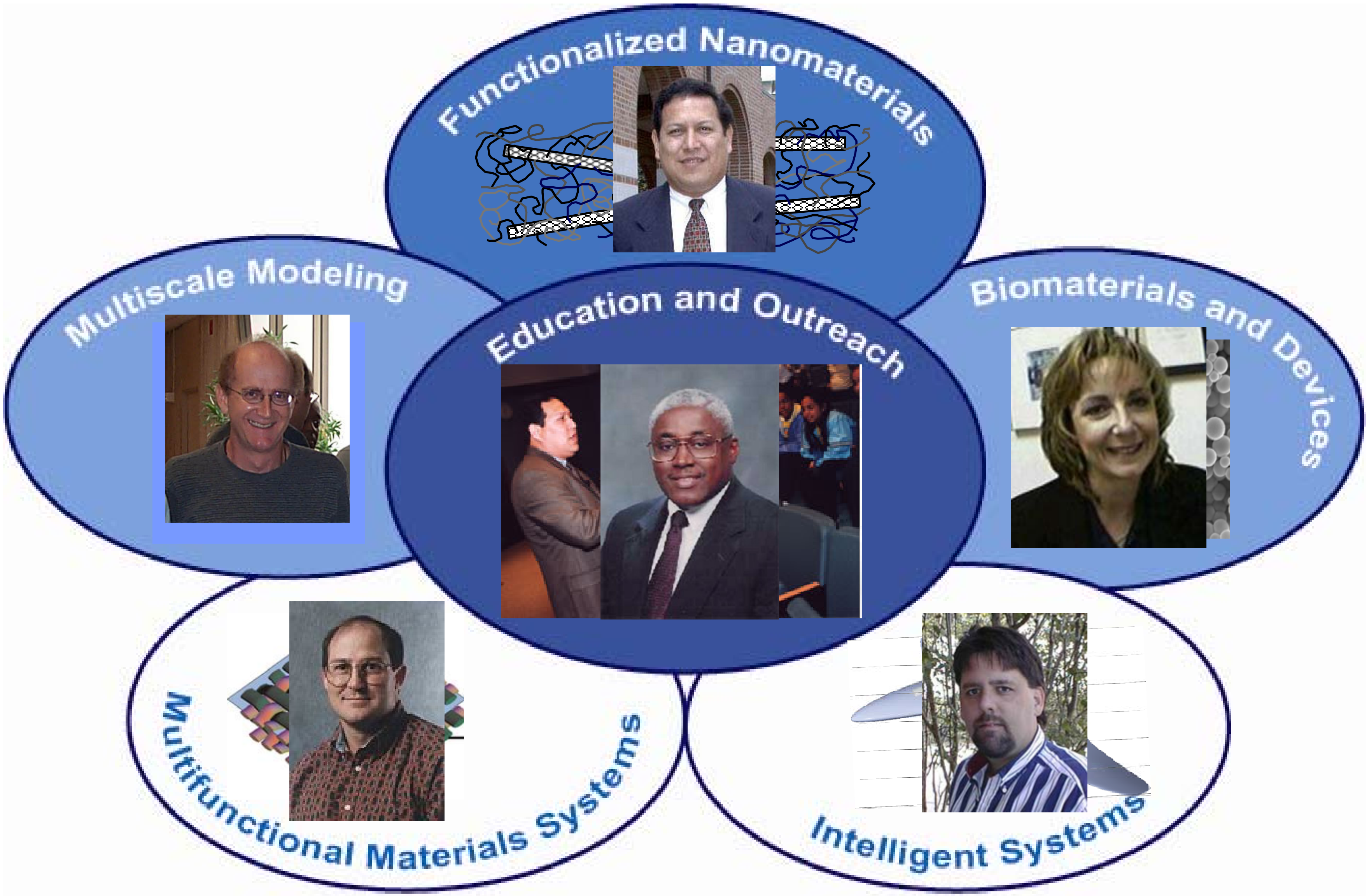


Develop through multiscale approaches and new innovations in nanotechnology, multifunctional materials and devices for the design of future aeronautics and space exploration vehicles and systems.



Through this advanced research and development activity, produce more highly educated and trained science, technology, engineering and mathematics (STEM) professionals for NASA, the Nation's national defense and economic development.

Research and Education Thrust Areas



Technical Structure

NASA Executive
M. Dastoor
NASA Headquarters

Institute Director
D. Lagoudas
Texas A&M Univ.

NASA Technical Liaison
T. Gates
NASA-Langley

Chief Scientist
J. Tour, RU

Chief Engineer
J. Junkins, TAMU

Multiscale Modeling

Thrust Leader
B. Yakobson, RU

Team Members
M. Pettitt, UH
P. Sharma, UH
L. Wheeler, UH
J. Whitcomb, TAMU

Functionalized NanoMaterials

Thrust Leader
E. Barrera, RU

Team Members
R. Krishnamoorti, UH
R. Lee, UH
J. Tour, RU
R. Wilkins, PVAMU

Intelligent Systems

Thrust Leader
D. Zimmerman, UH

Team Members

Adaptive Control
K. Grigoriadis, UH
J. Junkins, TAMU
A. Meade, RU
S. Nagarajaiah, RU

Systems Integration
S. Lin, PVAMU
O. Rediniotis, TAMU
J. Valasek, TAMU

Multifunctional Material Systems

Thrust Leader
J. Boyd, TAMU

Team Members
Y. Chen, UH
D. Davis, TAMU
N. Halas, RU
W. Kirk, UTA
D. Lagoudas, TAMU
Z. Ounaies, TAMU

Biomaterials & Devices

Thrust Leader
A. Rice-Ficht, TAMU

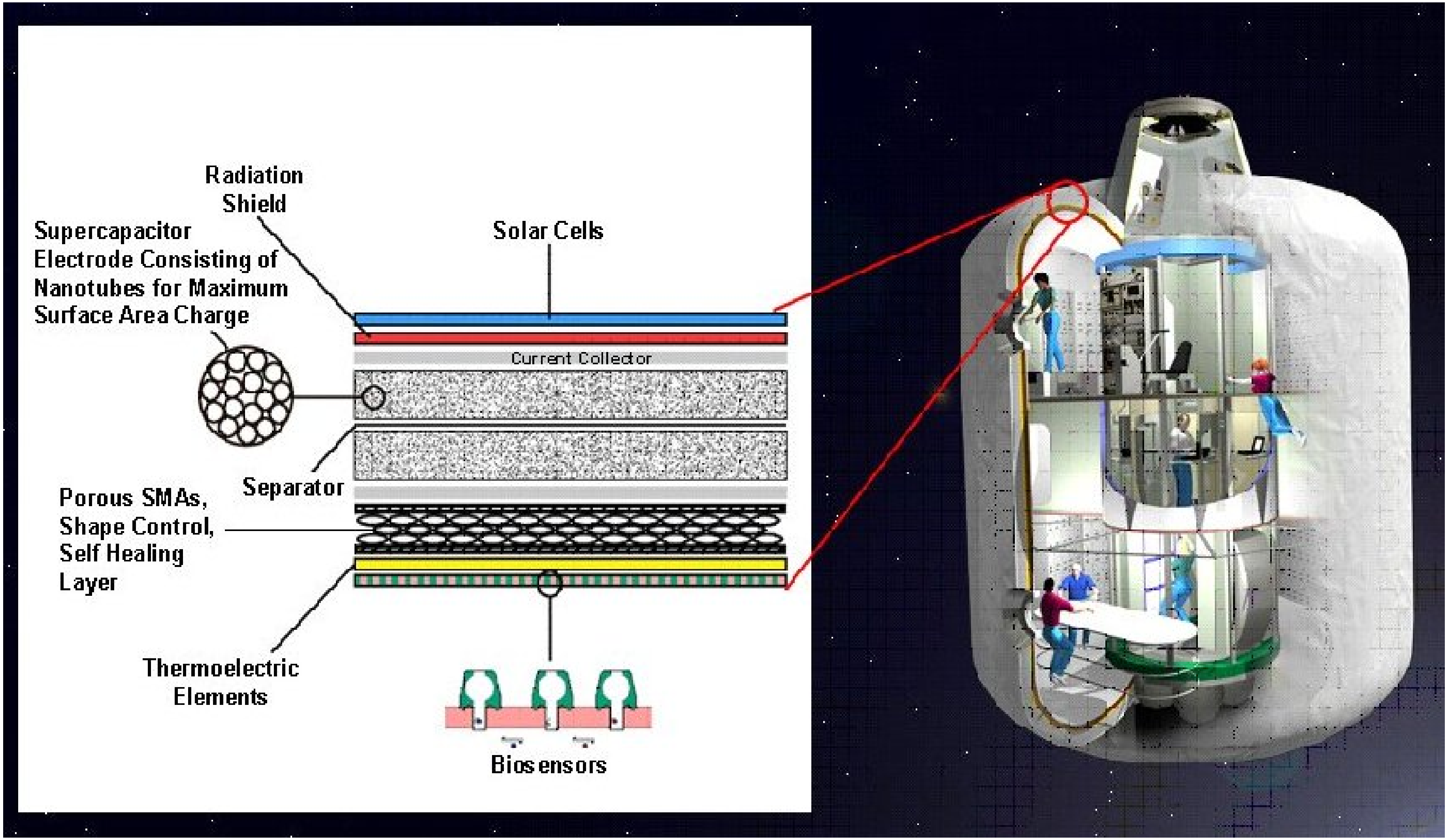
Team Members
M. Andrews, TAMU
H. Bayley, TAMU
J. Clement, TSU
R. Crooks, UT
R. Govindarajan, TSU
O. Jejelowo, TSU

Education & Outreach

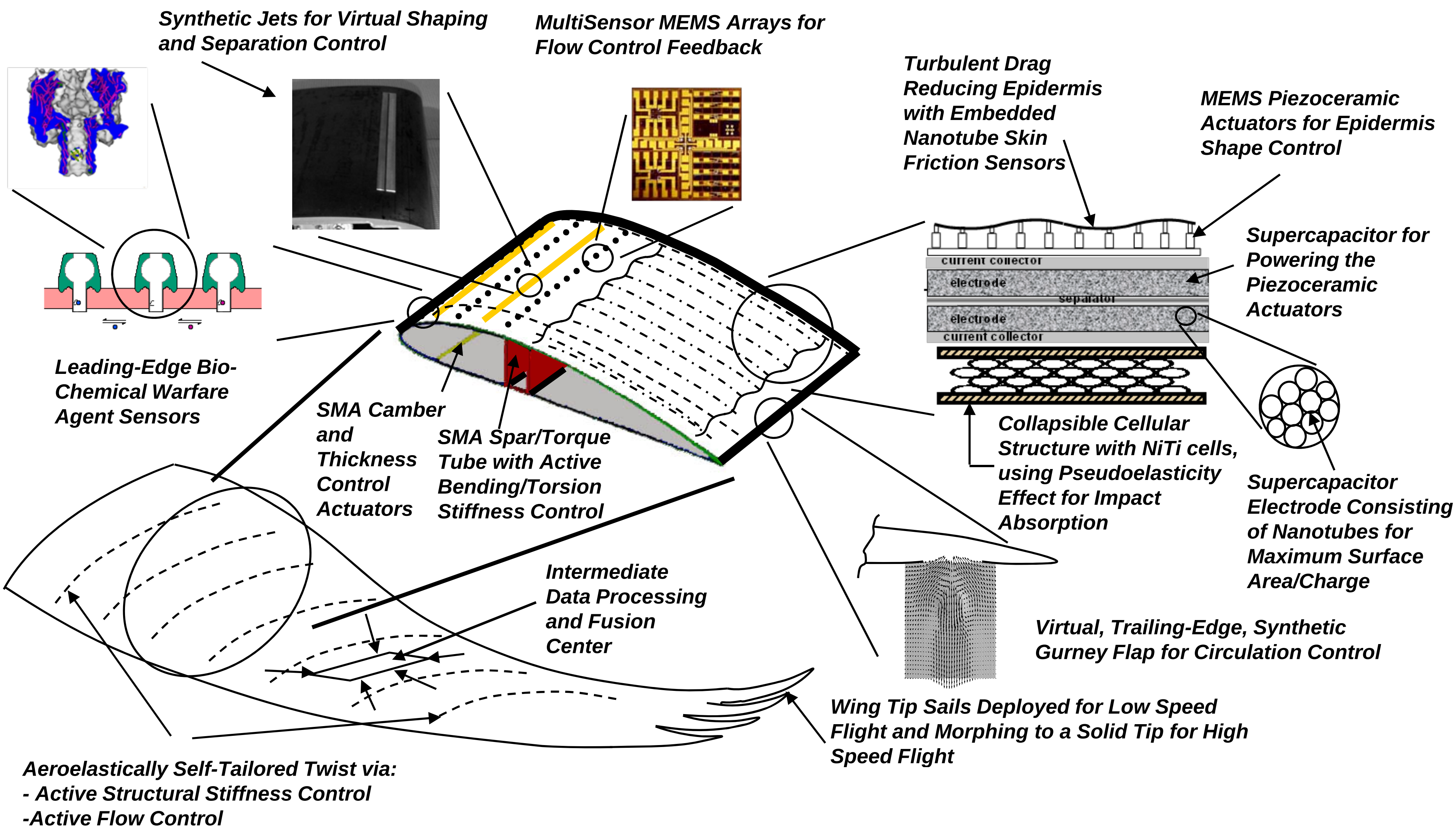
Thrust Leader
D. Davis, TAMU

Team Members
E. Barrera, RU
K. Grigoriadis, UH
O. Jejelowo, TSU
W. Kirk, UTA
D. Lagoudas, TAMU
J. Valasek, TAMU
R. Wilkins, PVAMU

Proof of Concept:
Multifunctional Shell for Space Structure

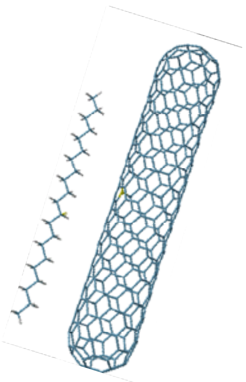
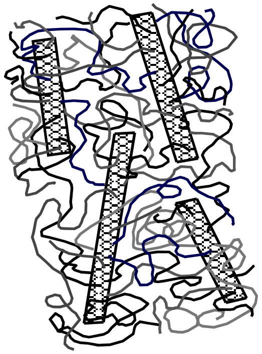
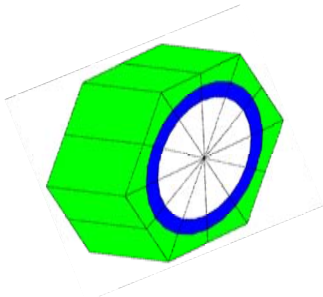
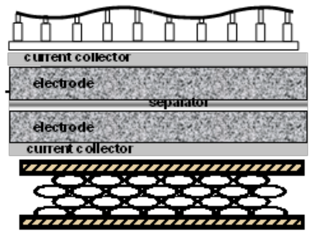
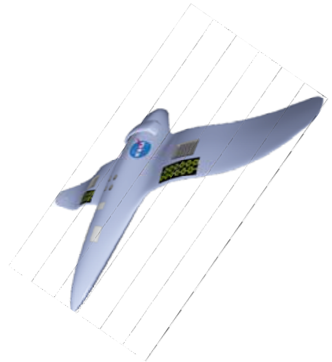


Proof of Concept: Hierarchical Structure of Multifunctional Morphing-Capable Wing



Research Challenge

Bridging the Length Scales – from Nanomaterials to Aerospace Systems

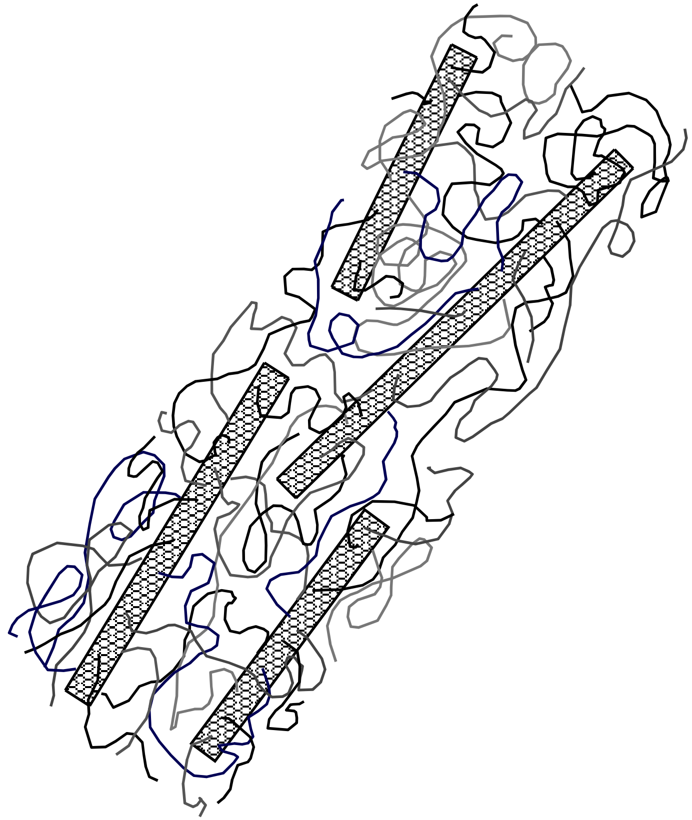
Single Wall Carbon Nanotubes	Functionalized Dispersed Carbon Nanotubes	Multiscale Modeling and Simulations	Multifunctional Material Systems	Intelligent Aerospace Vehicle
				

10^{-10}m ←——————————————————→ 10^{2}m

Research Thrust:
Functionalized Nanomaterials

Research Activities:

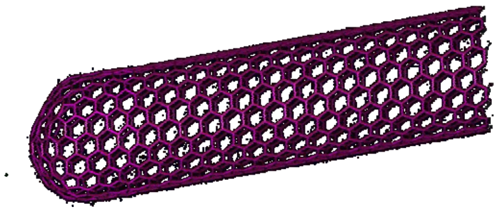
- Nanotube purification, functionalization, separation and dispersion.
- Strength and toughness of organic and inorganic nanocomposites.
- Polymeric nanocomposites for multifunctional use with improved conductivity properties.
- Studying multifunctionality of nanocomposites



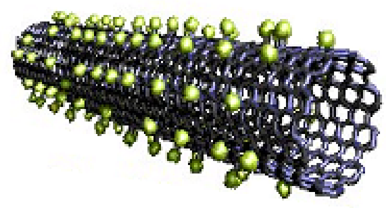
Nanostructures: 100 times stronger than steel at 1/6 the weight.

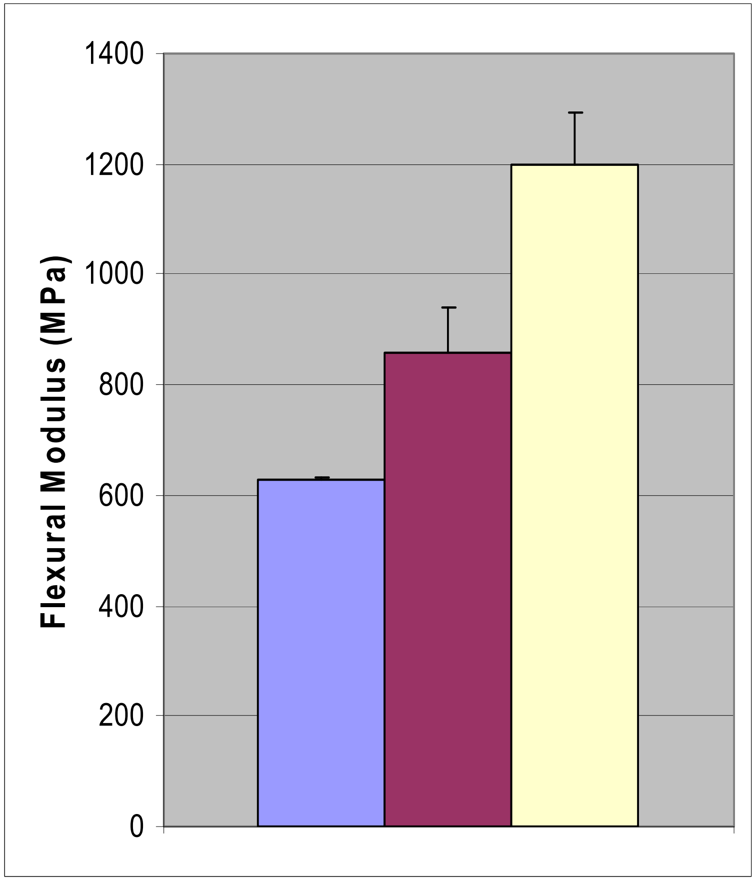
Reinforced PPF polymer with Functionalized SWNTs

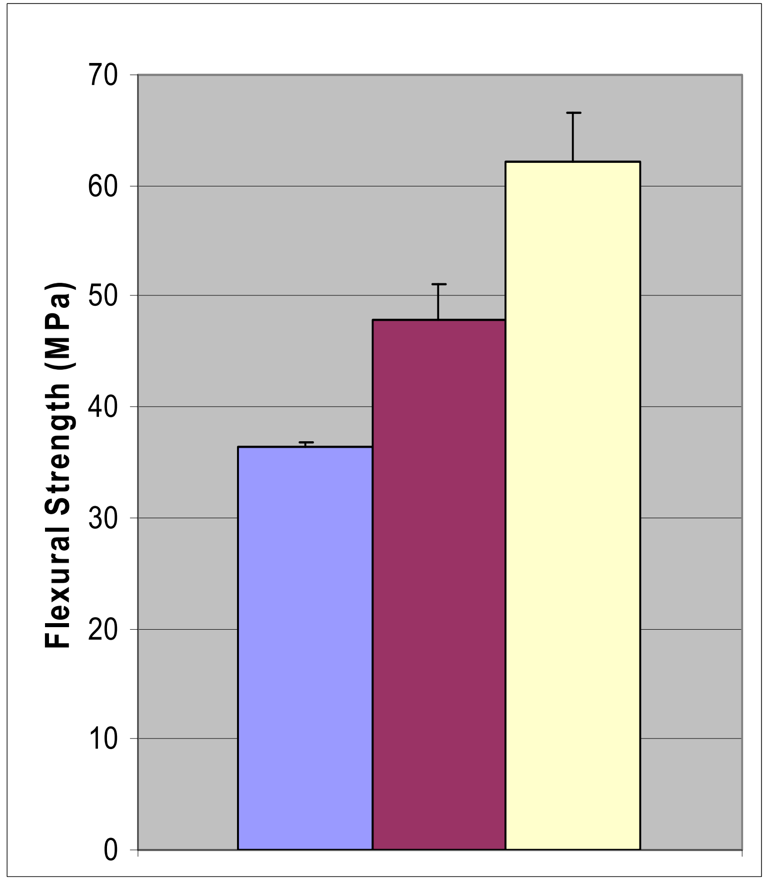
Single-Walled Carbon Nanotubes



Sidewall functionalization



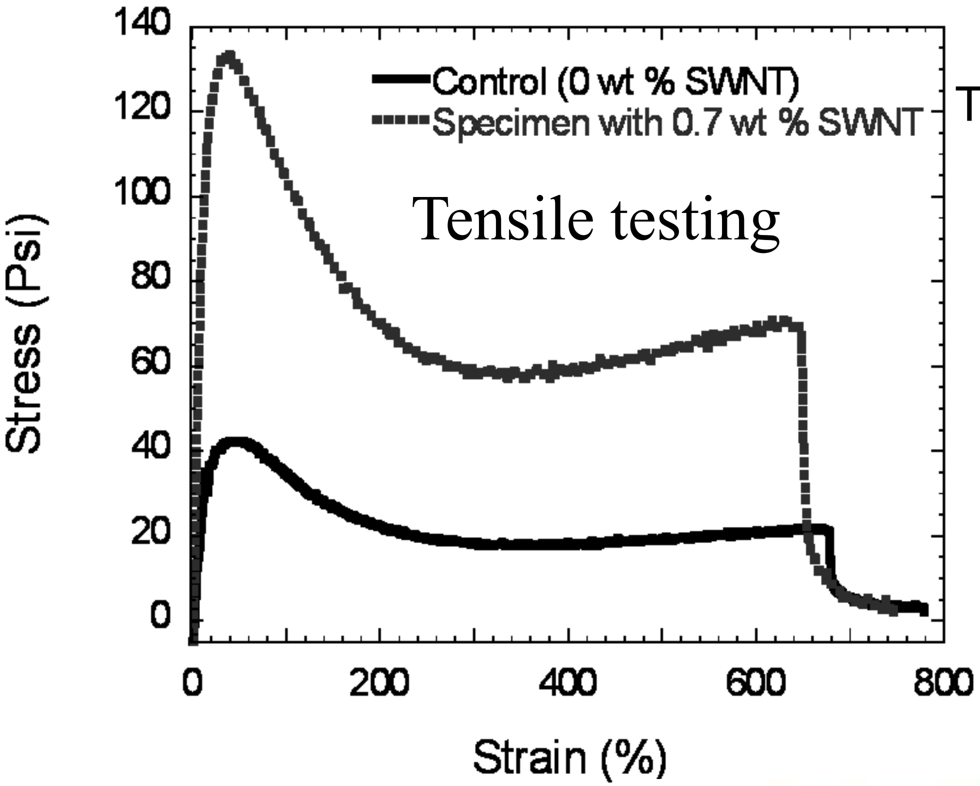




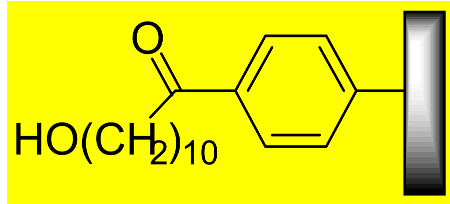
PPF **0.1% Pristine SWNTs / PPF** **0.1% Functionalized SWNTs / PPF**

(J. Tour, E. Barrera, R. Smalley, @Rice)

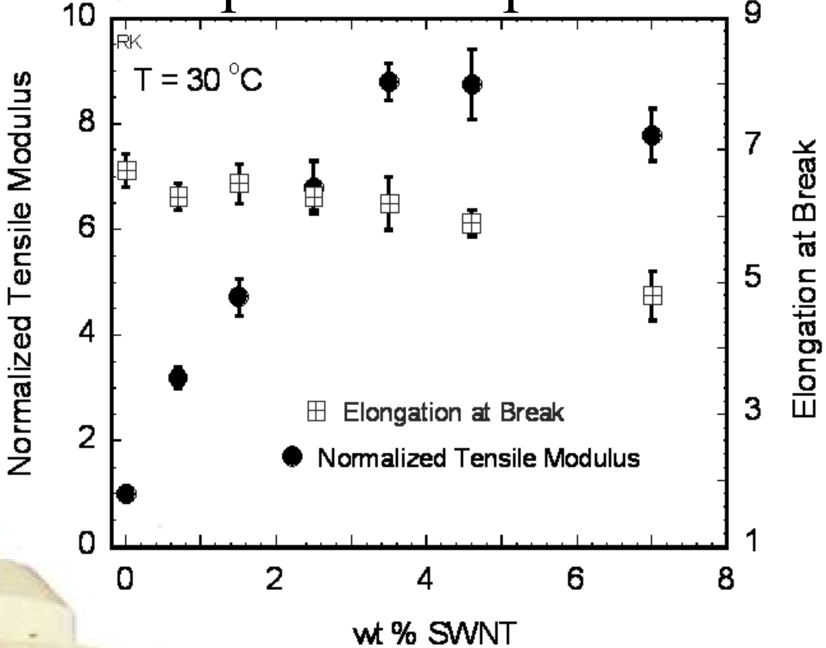
Elastomeric Reinforcement (Siloxane) by Functionalized SWNTs



Tour



Composition dependence



Technology licensed, being commercialized for annular blowout preventers (BOPs), elastomers enduring up to 20,000 psi with 90” ODs

J. Tour, Rice U.; R. Krishnamoorti, U. Houston; C. Dyke, NanoComposites Inc.,

Current TiiMS Projects for FY 2007
Functionalized Nanomaterials

T. Randall Lee, University of Houston, trlee@uh.edu
"Non-covalent polymer-wrapping of single-walled carbon nanotubes SWNTs) for the preparation lightweight, high strength structural composites"

Ramanan Krishnamoorti, University of Houston, ramanan@uh.edu
"Surfactant assisted dispersion of single walled carbon nanotubes in polymers for structural and multifunctional applications"

Enrique Barrera, Rice University, ebarrera@rice.edu
"Nanotechnology to practice: epoxy/carbon fiber/nanotube composites for double cantilever beam testing and proof of concept stress sensing"

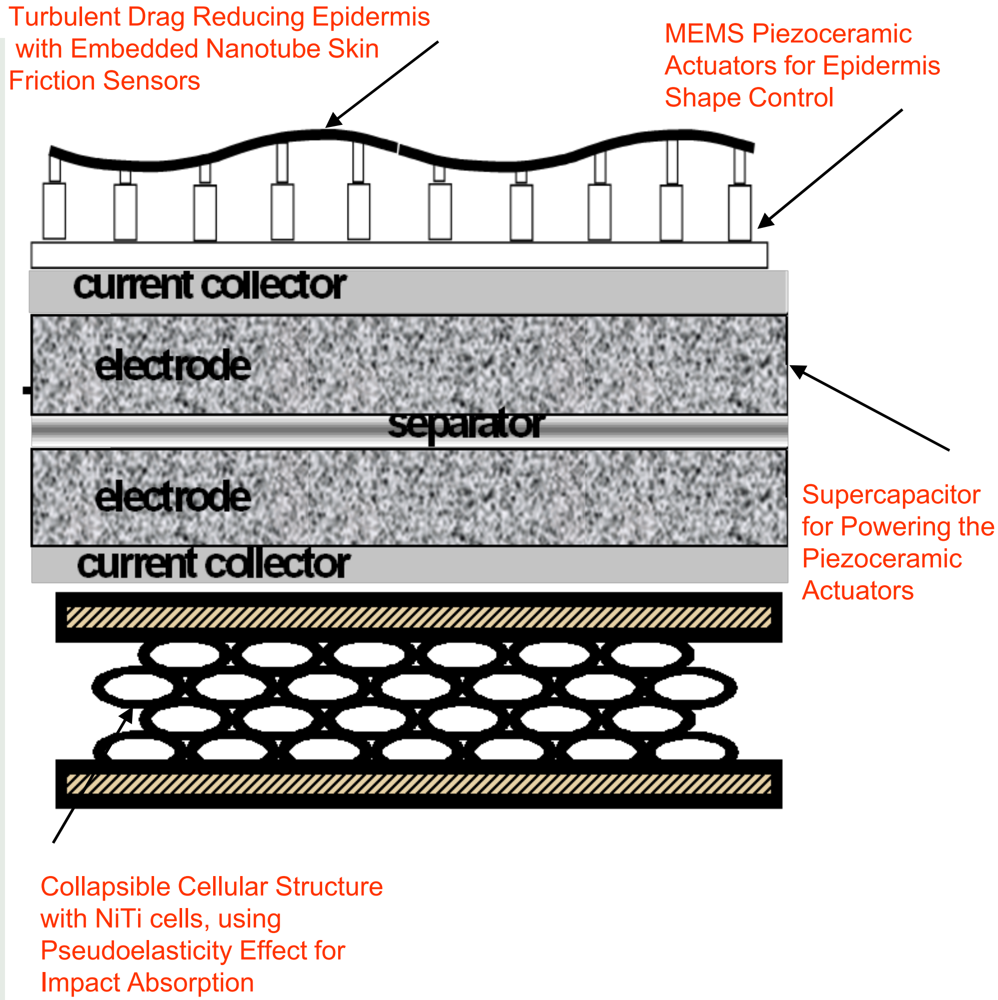
James Tour, Rice University, tour@rice.edu
"Light-weight low-loss magneto-dielectrics using single wall carbon nanotube composites"

Rick Wilkins, Prairie View A&M University, r_wilkins@pvamu.edu
"Radiation studies of bio-nano materials and devices"

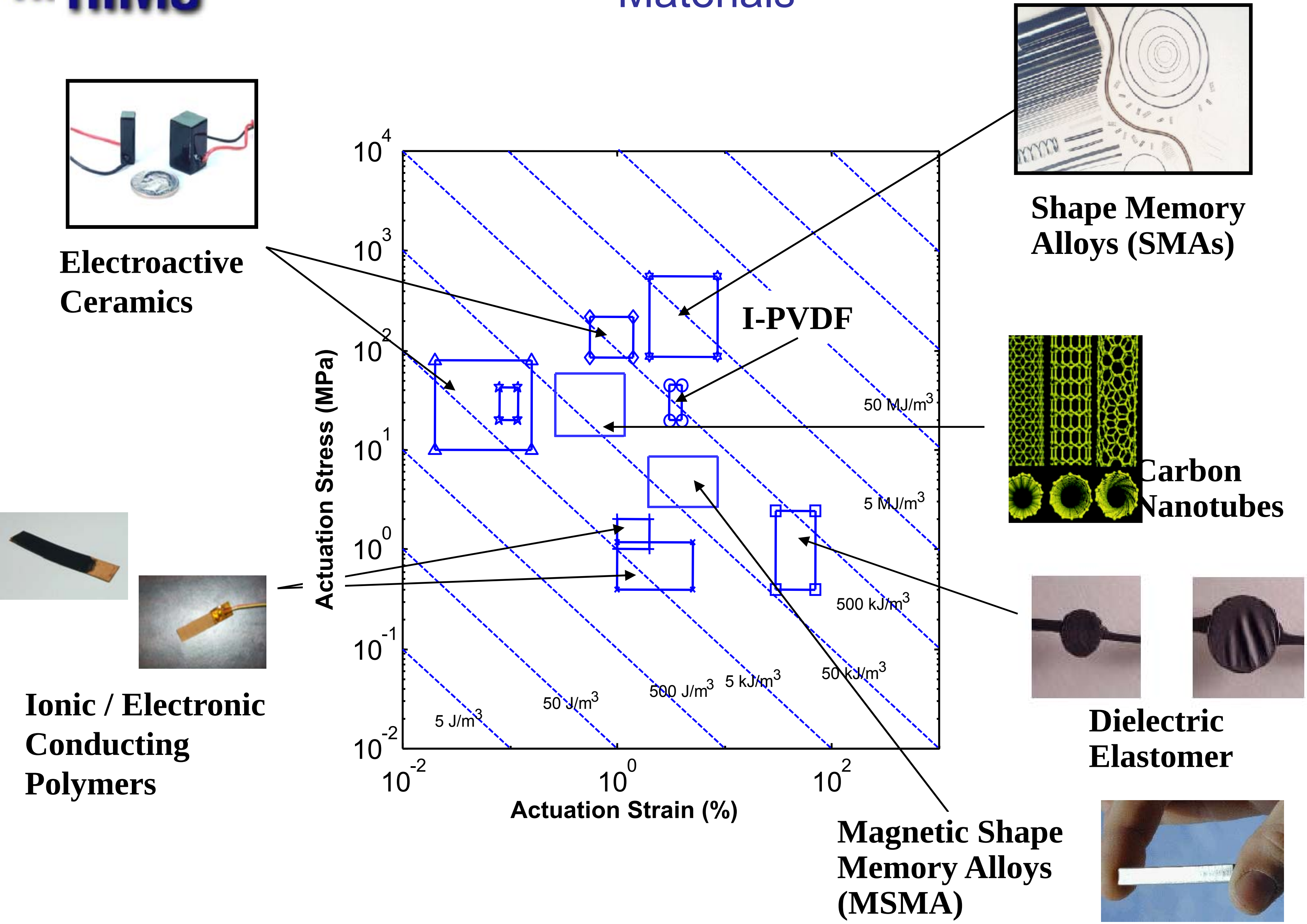
Research Thrust:
Multifunctional Material Systems

Research Activities:

- Multifunctional materials and systems at nano – micro – meso - macro physical length scales.
- Experimental validations of hierarchical material models for structural, electrical, and thermal functionality.
- Integrate porous SMAs into smart structures relevant to multifunctional lightweight space applications and shape control of morphing wings.
- Life assessment of multi-functional nanocomposite materials and structures.



Actuation Characteristics of Multifunctional Materials



Based on Original Graph by Don Leo, VPI

Current TiiMS Projects for FY 2007
Multifunctional Material Systems

Yi-chao Chen, University of Houston, chen@uh.edu
"Constitutive modeling and characterization of shape memory polymers"

Naomi Halas, Rice University, halas@rice.edu
"Nanophotonics-based cancer diagnostics for long duration manned space missions"

Wiley Kirk, University of Texas at Arlington, kirk@nanofab.uta.edu
"Radiation tolerance of multifunctional materials for high-efficiency solar-cell applications"

Dimitris Lagoudas, Texas A&M University, d-lagoudas@tamu.edu
"Novel approach of reinforcing a nanofiber based biosensor via coaxial electrospinning"

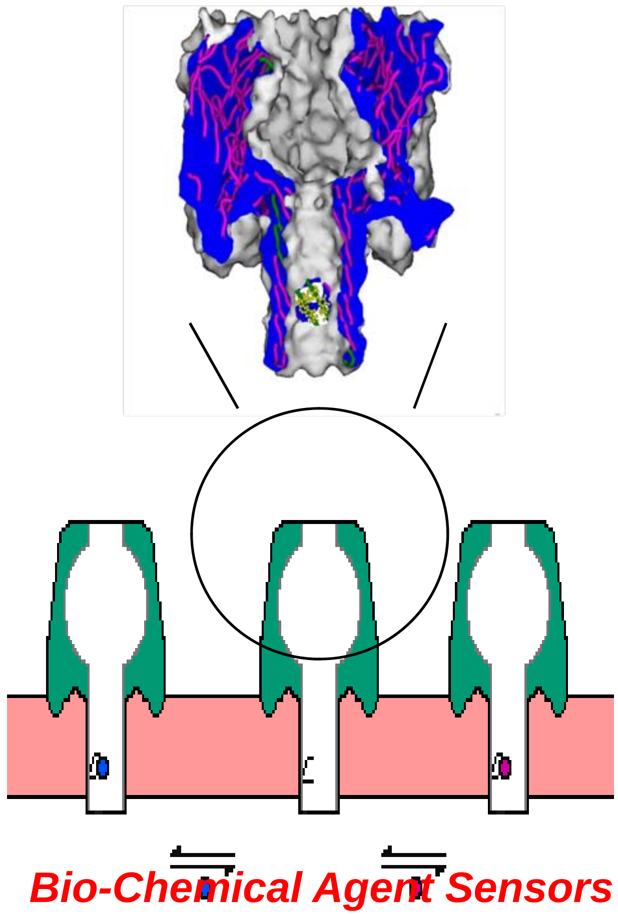
Zoubeida Ounaies, Texas A&M University, zounaies@aero.tamu.edu
"Active nanocomposites for future aerospace applications"

Pradeep Sharma, University of Houston, sharma@uh.edu
"A new paradigm in designing piezoelectric sensors and materials using nanoscale effects"

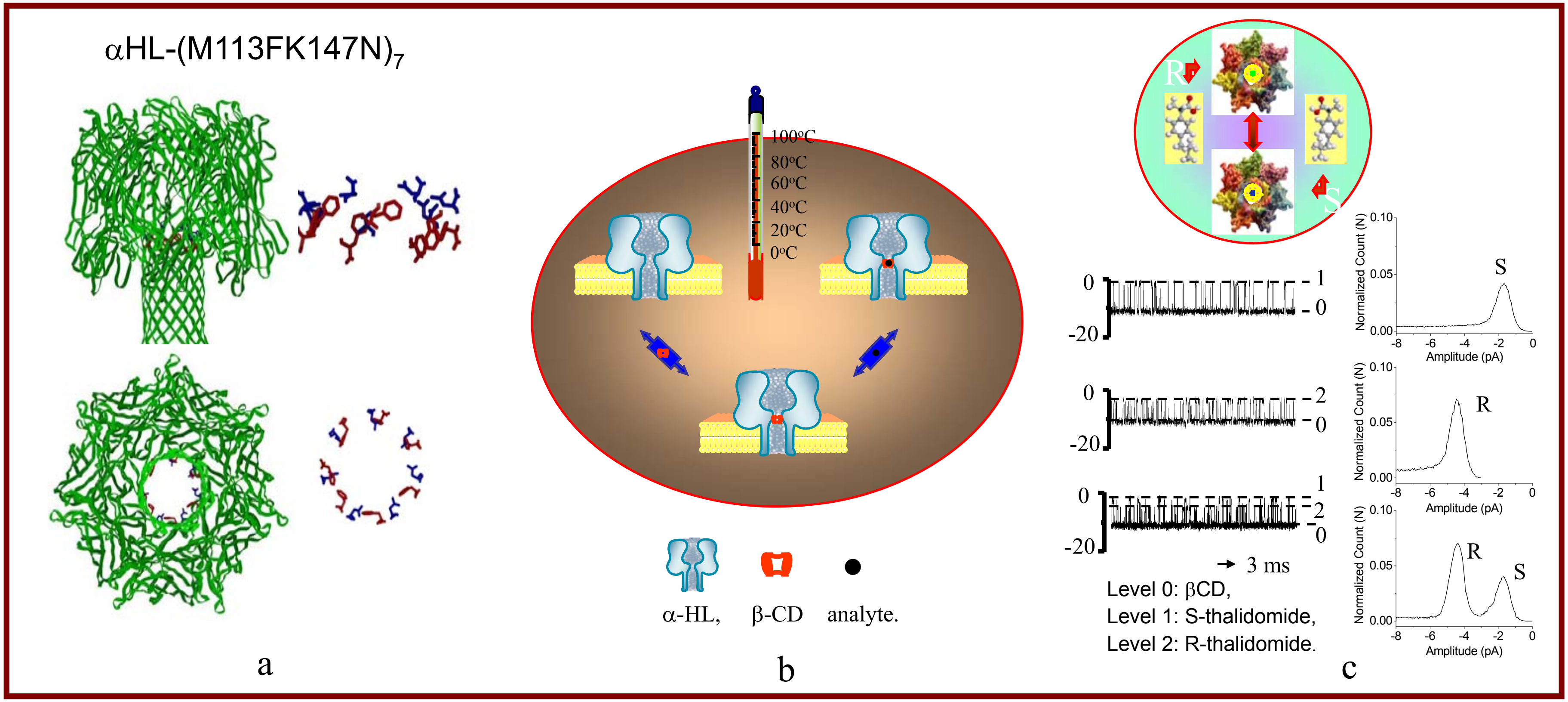
Research Thrust: Biomaterials and Devices

Research Activities:

- Integrate nanomaterials and biomaterials into multifunctional devices.
- Produce novel biomaterials (protein composites) with sealants and adhesives for structural self-healing.
- Develop Continuous Mixer for high shear mixing of SWNT and Bio-fluids.
- Investigate the toxicology of SWNT and nanocomposites.



High Temperature Protein Nanopore Sensor



- A novel a-hemolysin mutant pore, αHL-(M113FK147N)$_7$ has been designed that is stable and functional at temperatures up to 100°C.
- The single-molecule nanopore chiral sensor at elevated temperatures might have important applications in exobiology and spacecraft.

Xiaofeng Kang, Stephen Cheley and Hagan Bayley @TAMU

Current TiiMS Projects for FY 2007
Multiscale Modeling

Boris Yakobson, Rice University, biy@rice.edu
"Towards predictive multi-timescale modeling of nanotube-matrix interface in Nanocomposites"

John Whitcomb, Texas A&M University, whit@aero.tamu.edu
"Multiscale framework for computational modeling of multifunctional materials"

Biomaterials & Devices

Allison Rice-Ficht, Texas A&M University, a-ficht@tamu.edu
"Fabrication of life sensors: Combining microfluidic technology with protein nanopore sensors"

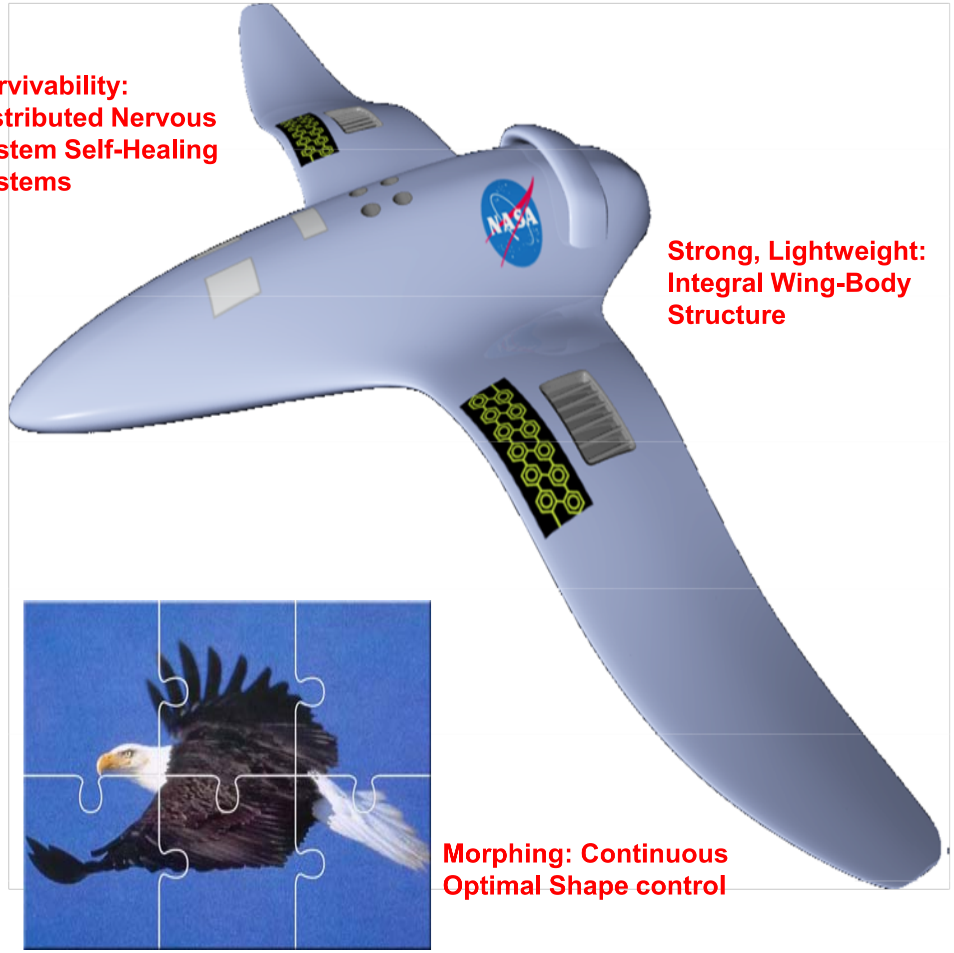
Olufisayo Jejelowo, Texas Southern University, jejelowo_oa@tsu.edu
"Simple Hybridization microbial detection device"

Research Thrust: Intelligent Systems

Research Activities

- Develop sophisticated integrated engineered materials, sensing, and actuation systems with high strength-to-weight ratios.

- Develop autonomous control system designs with the robustness, intelligence and adaptability to accommodate distributed and hierarchical (multiscale) sensing and actuation.

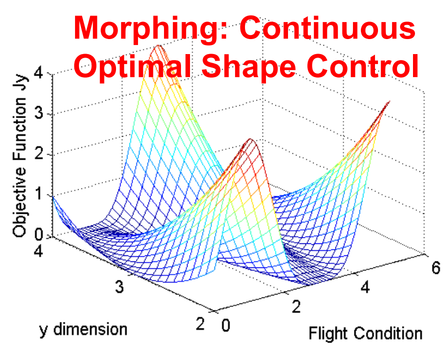


Biologically Inspired Systems: Enabling Aircraft and Spacecraft to Morph

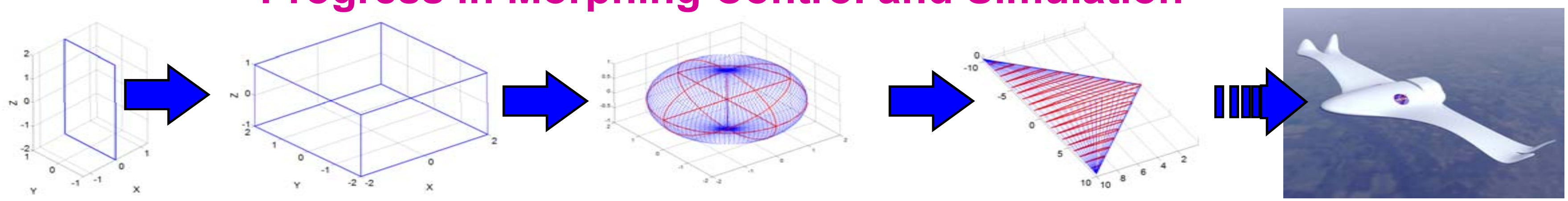
Control Theory for Autonomous, Intelligent, Robust, and Adaptive Systems Comparable to Flying Birds

Original Research that Combines *Traditional Control* and *Intelligent Control*:

- Structured Adaptive Model Inversion Control (SAMI)
  - Flight controller to handle wide variation in dynamic properties due to shape change
- Machine Learning
  - Learns the optimal shape at every flight condition in real-time



Progress in Morphing Control and Simulation



2-D Plate 2003 | Rectangular Block 2004 | Ellipsoid 2005 | Delta Wing 2006 | Final Objective

John Valasek @ TAMU

Current TiiMS Projects for FY 2007
Intelligent Systems

John Junkins, Texas A&M University, junkins@tamu.edu
"Modeling and control of redundantly actuated intelligent and morphable aerospace systems"

Andrew Meade, Rice University, meade@rice.edu
"Development of a knowledge-based numerical tool for the design of functionalized nanocomposites"

Satish Nagarajaiah, Rice University, nagaraja@rice.edu
"Nanocomposites for sensing, actuation, structural health monitoring and damage detection of aero-space systems"

David Zimmerman, University of Houston, dzimmerman@uh.edu
"Structural health monitoring using measured ritz vectors"

TiiMS

REU Site
"Nanotechnology and Materials Systems"

Total Student Participation
FY2005 - FY2006

- Texas A&M University – 24
- Tuskegee University – 1
- Prairie View A&M – 2
- North Carolina A&T University – 3
- Virginia Commonwealth University – 1
- University of Texas – Pan Am – 2
- Indiana University – Bloomington – 1
- University of Puerto Rico – 1
- Louisiana Tech University - 1

Sponsored By:
National Science Foundation NSF Grant No. 0453578
Air Force Office of Scientific Research, U.S. Air Force, Department of Defense ASSURE Program

PIs: Dr. D.C. Davis and Dr. D.C. Lagoudas

Minority Leaders Program
"Sensors and *Nanocomposites Research*"

Participating Universities:

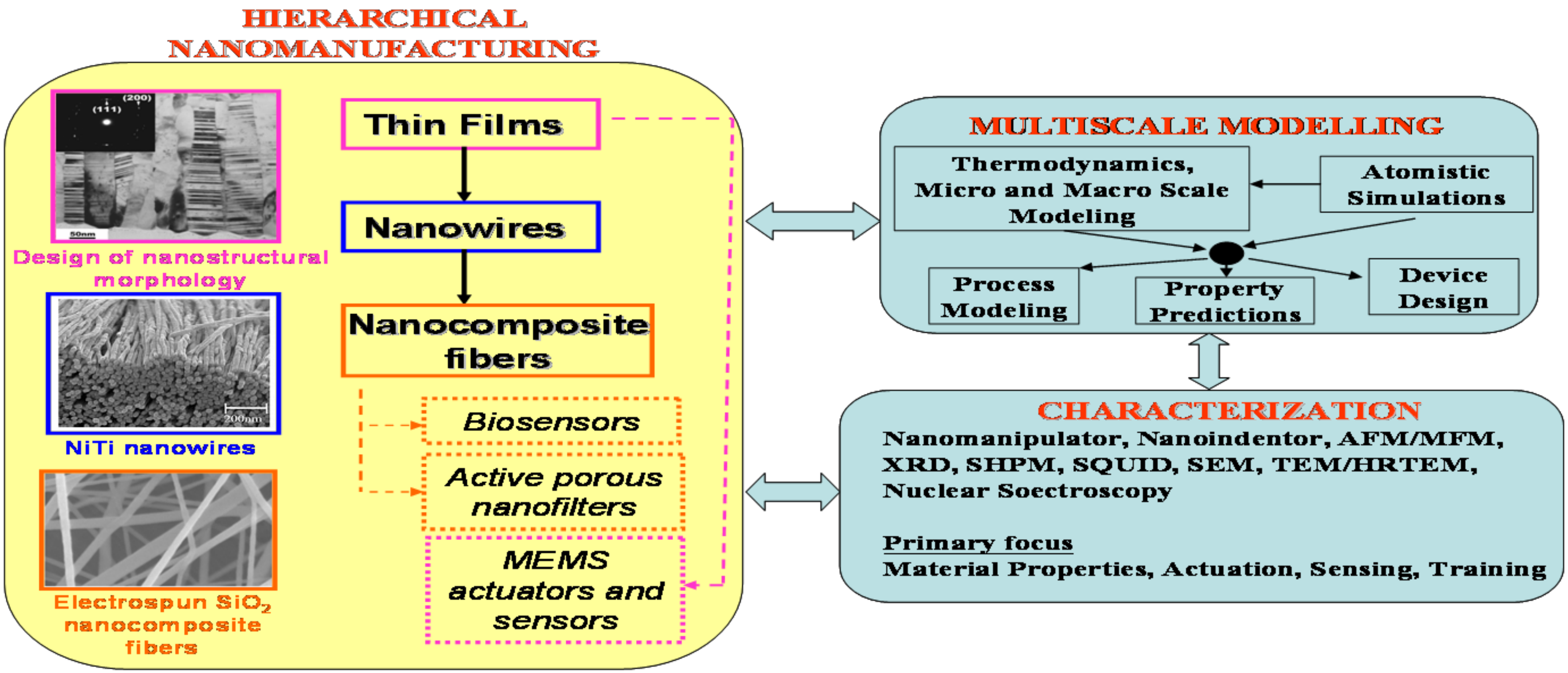
Texas A&M University (Lead University), Prairie View A&M University, Texas Southern University, University of Houston, Rice University, plus 12 other universities.

Dr. Daniel C. Davis, University Lead

A $49.5 million indefinite-delivery/ indefinite-quantity contract (FY 2005 – 2009) focusing on involvement of the Historical Black Colleges and Universities/ Minority Institutes in translation of promising basic research new sensors, materials, and manufacturing process into solutions for broadly defined military needs.

The locations of performance are Universal Technology in Dayton, OH and Clarkson Aerospace in Houston, TX. The Air Force Research Laboratory at Wright-Patterson Air Force Base, OH issued the contract (FA8650-05-D-1912).

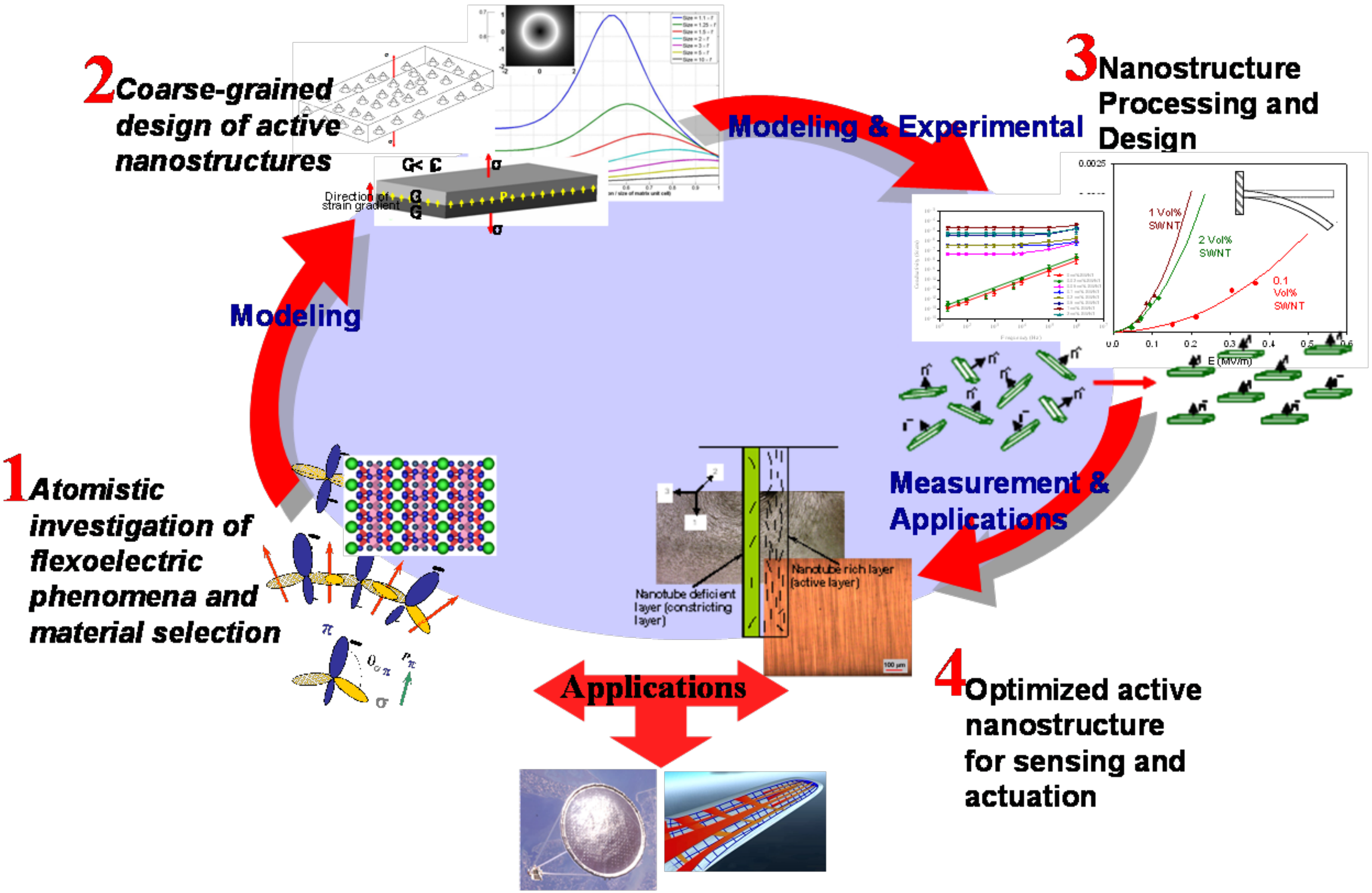
NSF NIRT: “Novel Manufacturing and Modeling Approaches for Multi-Scale Monolithic and Hybrid Phase Transforming Nanostructures”



- Active nanoscale structures and nanosystems capable of actuation and sensing are needed for a wide range of applications in nanomedicine, nanoelectronics, space exploration, homeland security and defense.
- An integrated team of co-PIs from Texas A&M University and Georgia Tech will establish a comprehensive interdisciplinary program in hierarchical manufacturing and modeling for phase transforming magnetic shape memory alloys (MSMA).

PIs: Dimitris Lagoudas, Ibrahim Karaman, Xinghang Zhang, Jun Kameoka, TAMU; Ken Gall, GA Tech

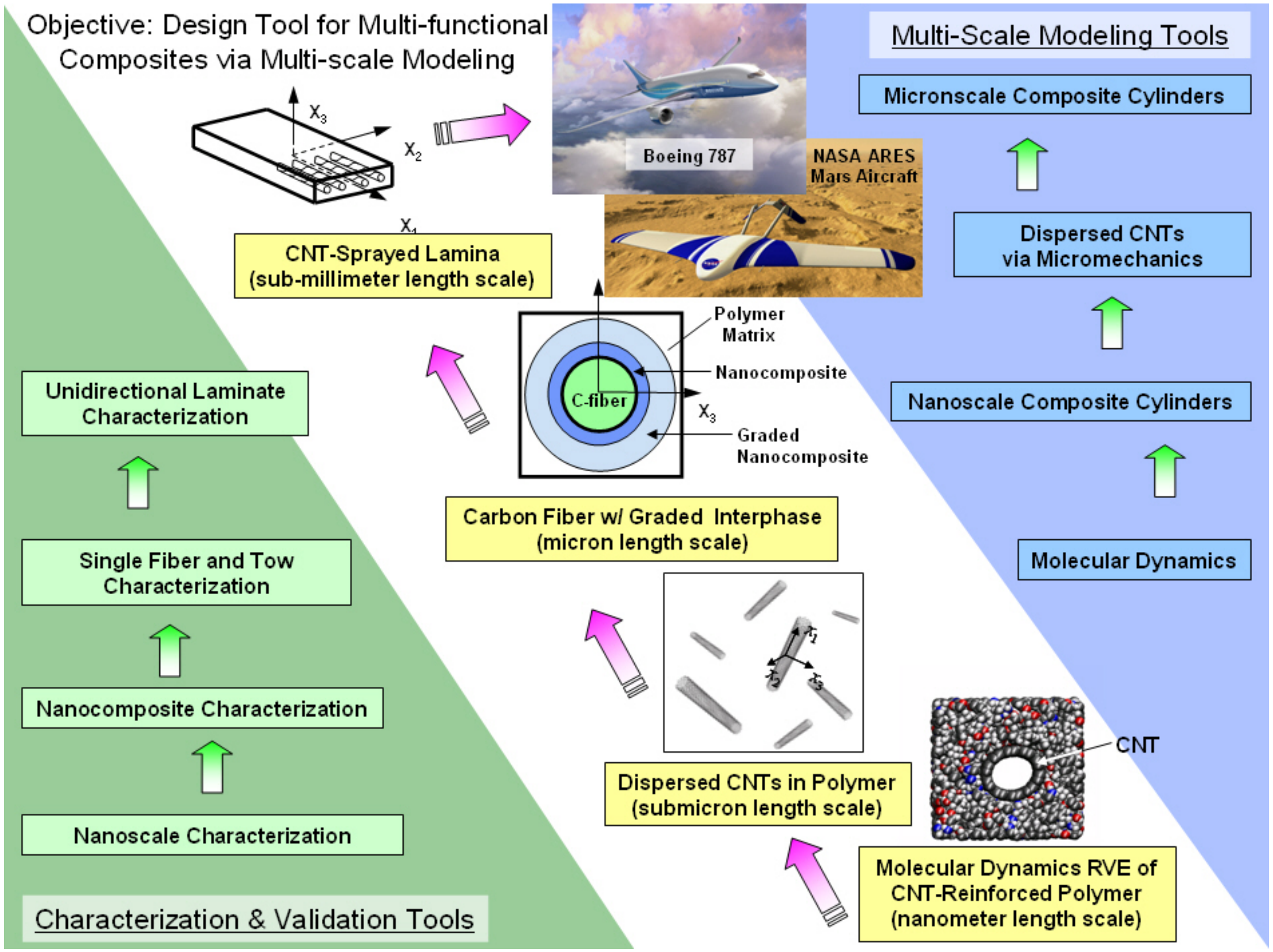
NSF NIRT: "Active Electromechanical Nanostructures without the Use of Piezoelectric Constituents "



- To understand and develop active electromechanical nanostructures that exhibit an apparent piezoelectric behavior even though none of the constituent materials themselves are piezoelectric by exploiting nanoscale effects.

PIs: Pradeep Sharma, UH; Zoubeida Ounaies, TAMU; Ramanan Krishnamoorti, UH; Boris Yakobson, RU

A NASA Cooperative Agreement
Research Opportunities in Aeronautics



Research Focus: Multiscale modeling and characterization of CNT reinforced multifunctional composites as new lightweight durable materials for improved subsonic fixed wing vehicle performance

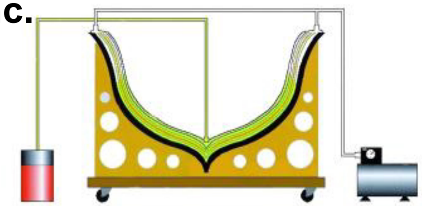
A TAMU collaboration with:
National Institute of Aerospace, NanoRidge and NASA Langley Research Center

PIs: Dimitris Lagoudas, TAMU; Sarah-Jane Frankland, Tom Clancy, NIA

TiiMS Research Leads to New Nanotechnology Companies

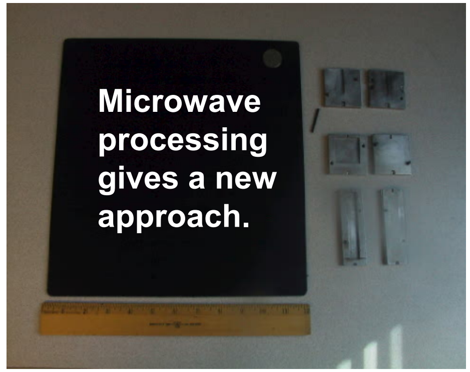
NASA URETI research and Nanotubes from Richard Smalley that lead to commercial work and real revenue for two start-up companies.

NanoRidge Materials, Inc.
Houston, TX
CEO: Chris Lundberg
CTO: Enrique Barrera
Initial funding raised
Four initial projects for NASA, DOD, and a a polymer Co.
Licensed key IP

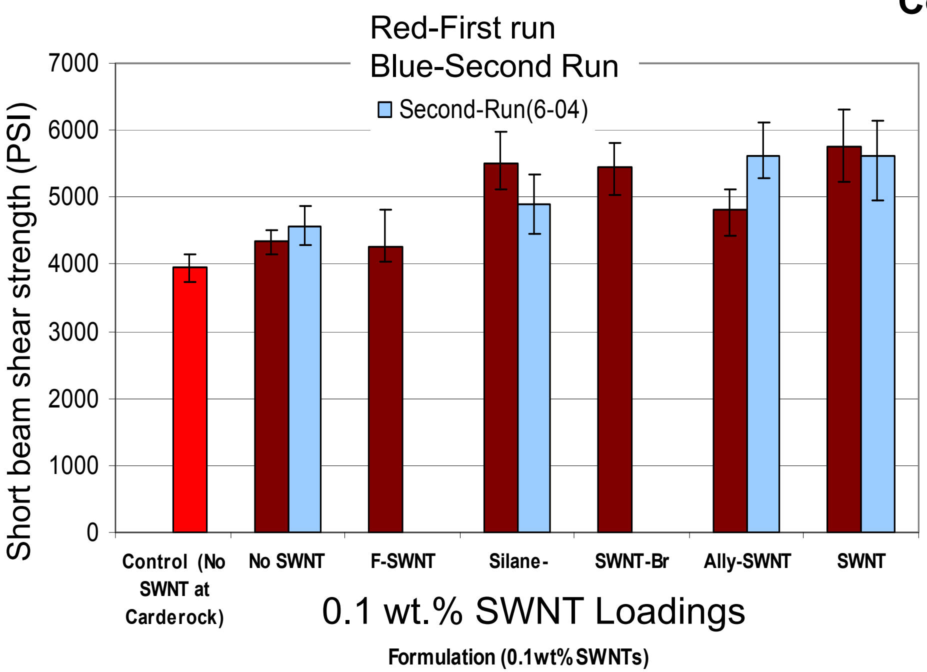


VARTM used to make large components.

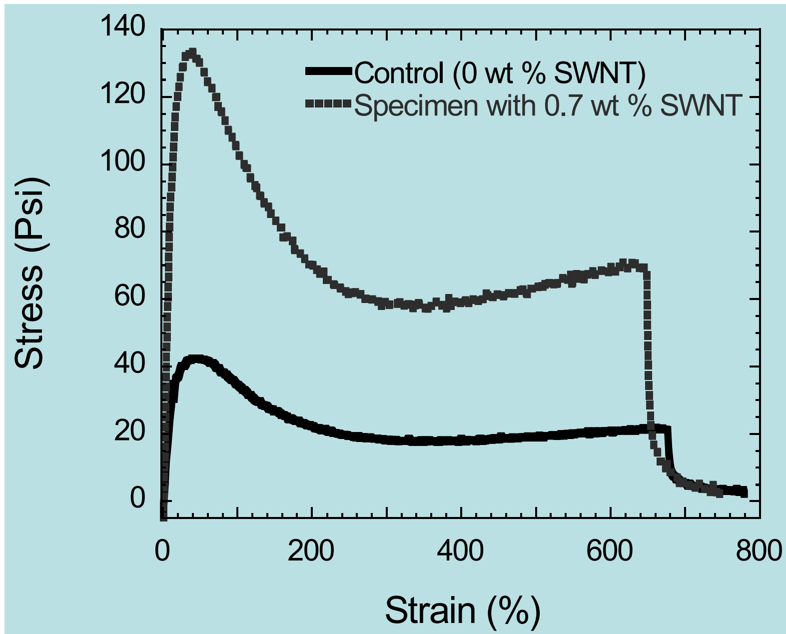
NanoComposites, LLC
Houston, TX
CEO: Barry Drayson
CTO: Chris Dyke
CTAdvisor: James Tour
Initial funding raised
Key project with Hydril
Licensed key IP



~50% Improvement in Z-axis properties for composites currently being sold.



Three times the strength increase in rubber. An Oil Field o-ring that was shown at the Offshore Technology Conference in Houston, TX.

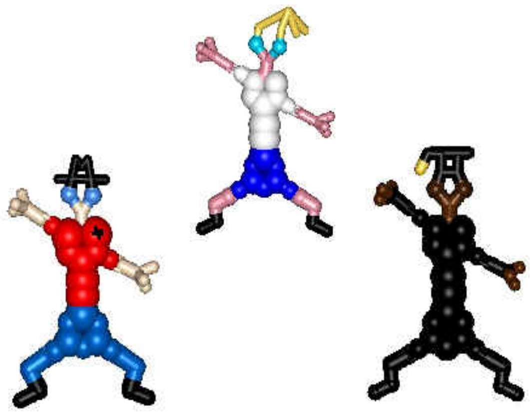


Education and Outreach

Major Objectives:

- Train the next generation of aerospace engineers and scientists.
- Increase the number of engineers and scientists from under-represented groups.
- Introduce nano-science and engineering to K-12 schools through established and emerging education programs.
- Provide professional development opportunities for K-12 educators focusing on nanoscience and engineering initiatives.
- Provide training to students and educators in interdisciplinary education in science, mathematics, and engineering.

Undergraduate Student Design



"The majority of the Institute's budget will be spent on education."

Field Trips

- **NASA Johnson Space Center (JSC)** in Houston, Texas
- **The Zyvex Corporation** in Richardson, Texas
- **The University of Texas at Dallas** in Richardson, Texas
- **The Lockheed-Martin Corporation** in Fort Worth, Texas

REU students in front of an F-16 at Lockheed Martin

Nanotechnology Presentation

In front of mock shuttle

TiiMS 3rd Annual Review - Poster Session - 2005

Poster presentations can be seen at: tiims.tamu.edu/2005summerREU/presentations.html

SUMMARY

Extended funding is being sought to sustain the operations of the Texas Institute for Intelligent Bio-Nano Materials and Structures (TiiMS).

TiiMS will continue to focus on supporting precollege, undergraduate and graduate students, and post-doctorate researchers to produce a new generation of highly trained, educated and diverse cadre of science, technology, engineer, and mathematics (STEM) professionals for the Nation and the State of Texas.

TiiMS will provide a base for the growth of new research and education programs in multifunctional materials development for applications in aerospace, energy and power generation, sensors and communications and bio-sciences to serve NASA, the national defense and economic growth of the Nation and the State of Texas.

Thank You
For further information contact:

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College Station, TX 77843-3409
Phone: 979/ 845-9409
Fax: 979/ 862-7087
e-mail: pam@aero.tamu.edu
http://tiims.tamu.edu

☺

TiiMS

TEXAS INSTITUTE FOR INTELLIGENT BIO-NANO MATERIALS AND STRUCTURES FOR AEROSPACE VEHICLES

A NASA University Research, Engineering and Technology Institute (URETI)

Multifunctional Materials for Aerospace Applications

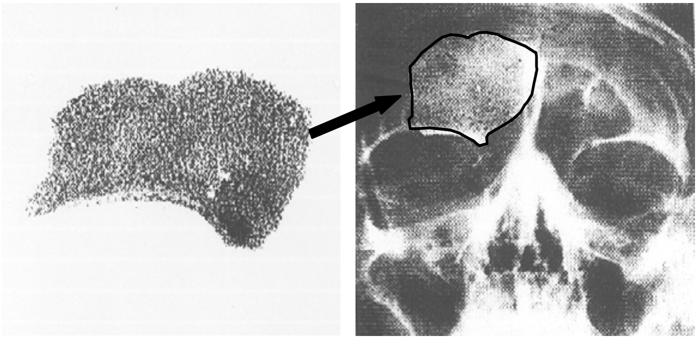
Dimitris C. Lagoudas

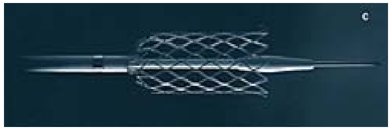
Department of Aerospace Engineering

Texas A&M University

- Funded by the National Aeronautics and Space Administration
- Administered by the Texas Engineering Experiement Station
- A collaborative effort among: Prairie View A&M University | Rice University | Texas A&M University | | Texas Southern University | University of Houston | University of Texas - Arlington

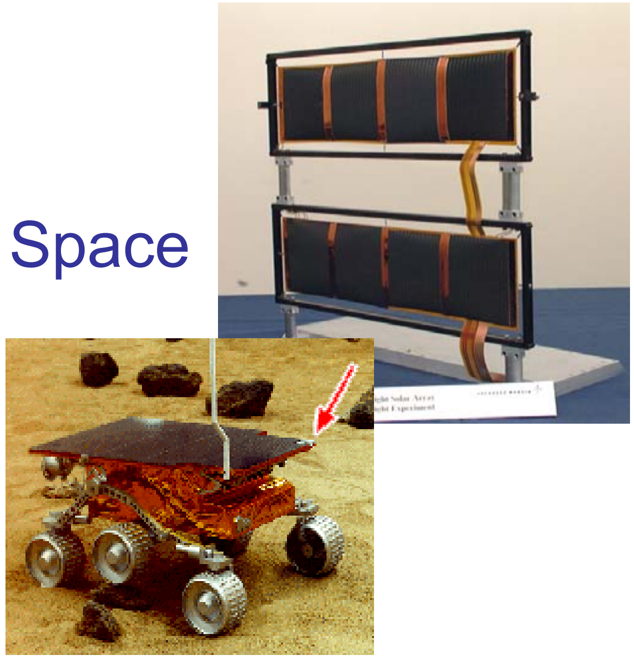
Current Applications of SMAs



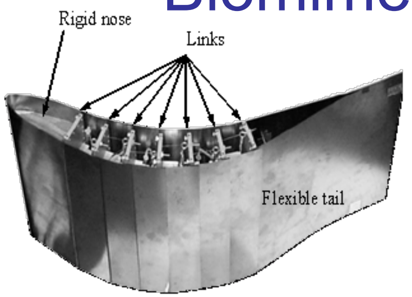


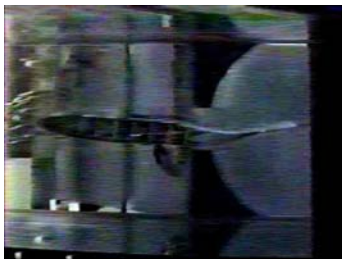
Biomedical

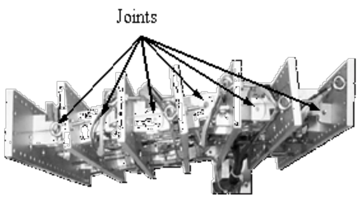
Space



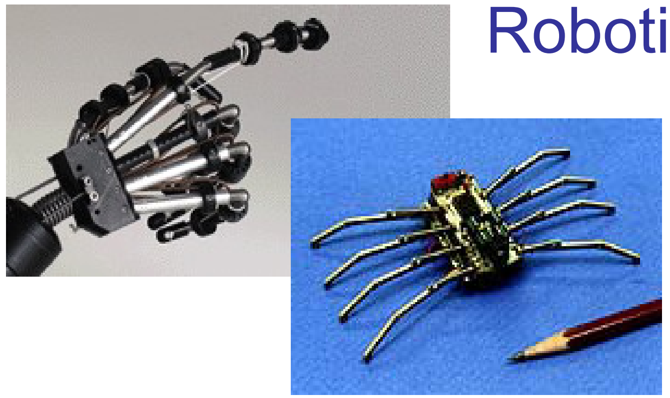
Biomimetics



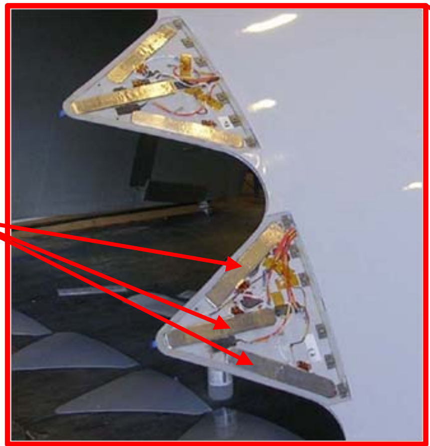




Robotics



SMA-Actuated Variable Geometry Chevrons



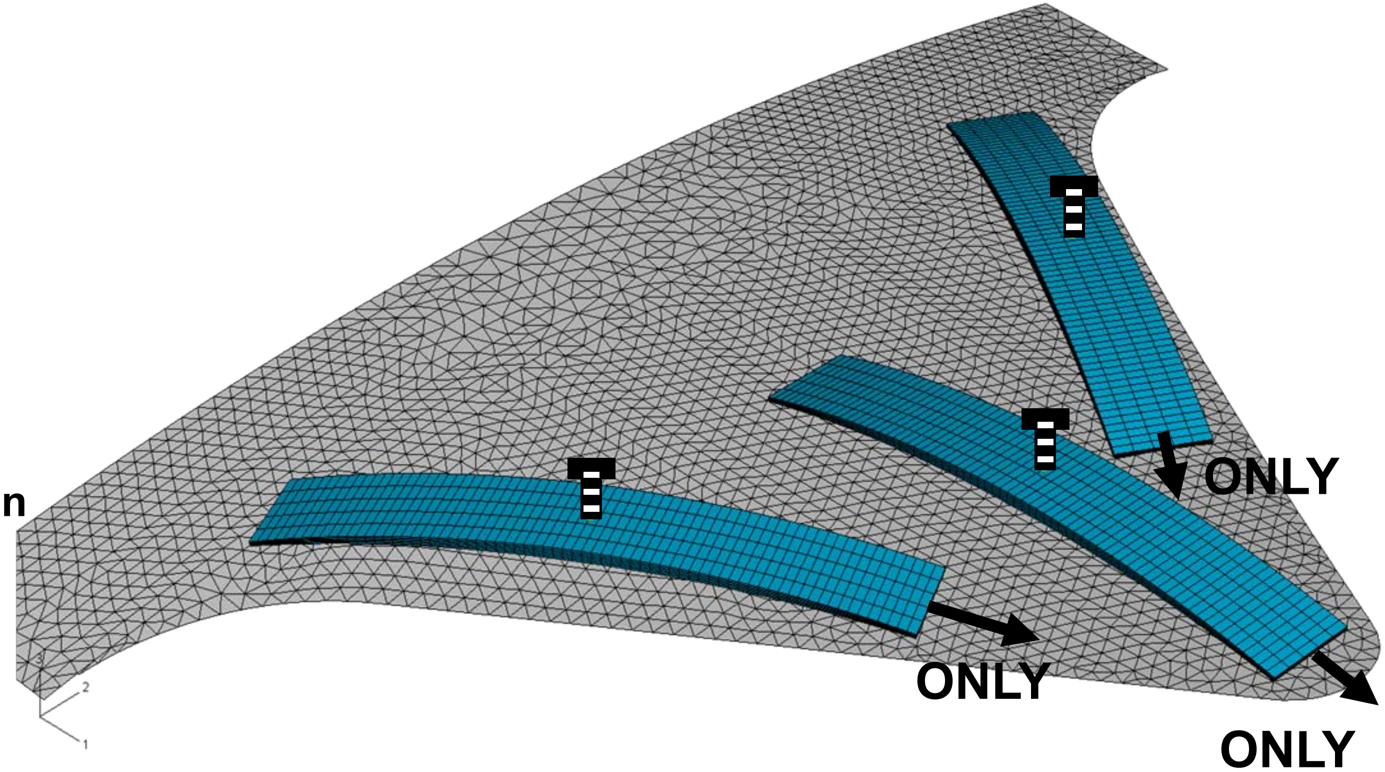
- Noise reduction at take-off due to SMA-actuated chevrons
- Autonomous retraction during low temperature cruise increases efficiency

(Courtesy of The Boeing Company)

Model Implementation: FEA

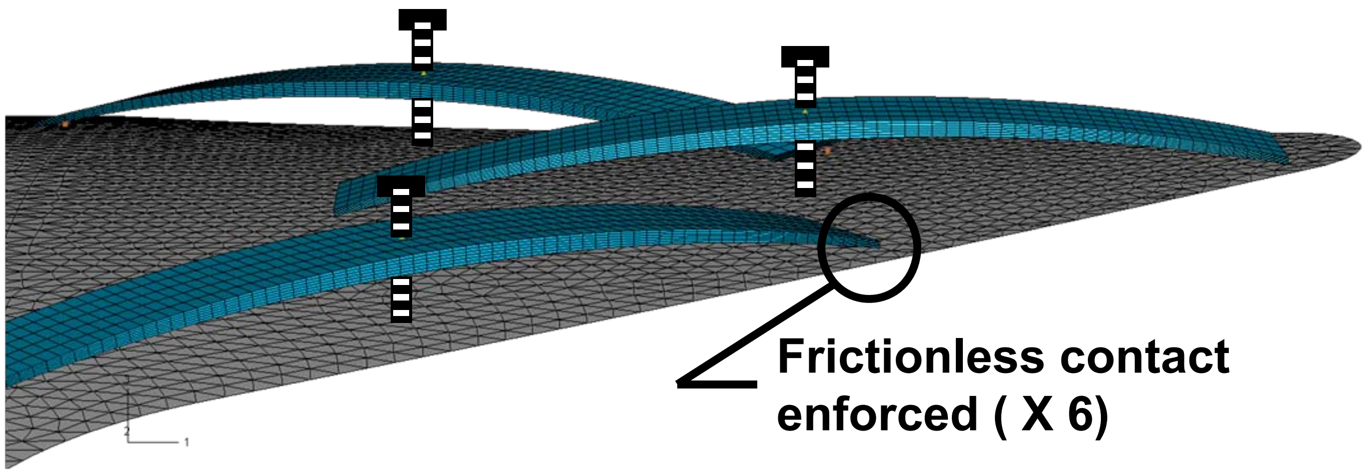
Assembly

- SLOT connectors used to “bolt” down SMA beams
- SLIDE-PLANE connectors used to prevent beam rotation
- Contact enforced between SMA beam edge nodes and chevron elements (no friction)



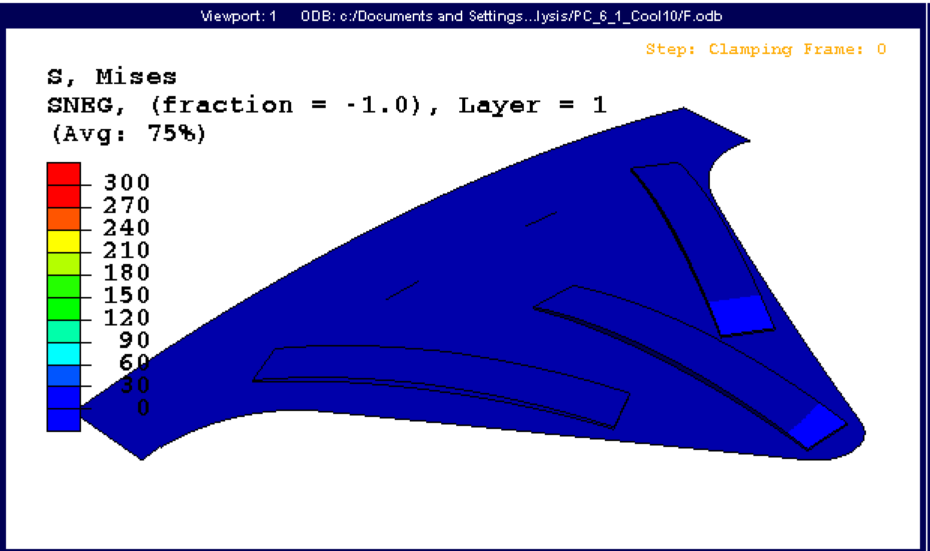
Loading Steps

1. Clamp beams ($T<A_s$)
2. Heat beams ($T>A_f$)
3. Cool ($M_f<T<M_s$)
4. Heat beams ($T>A_f$)

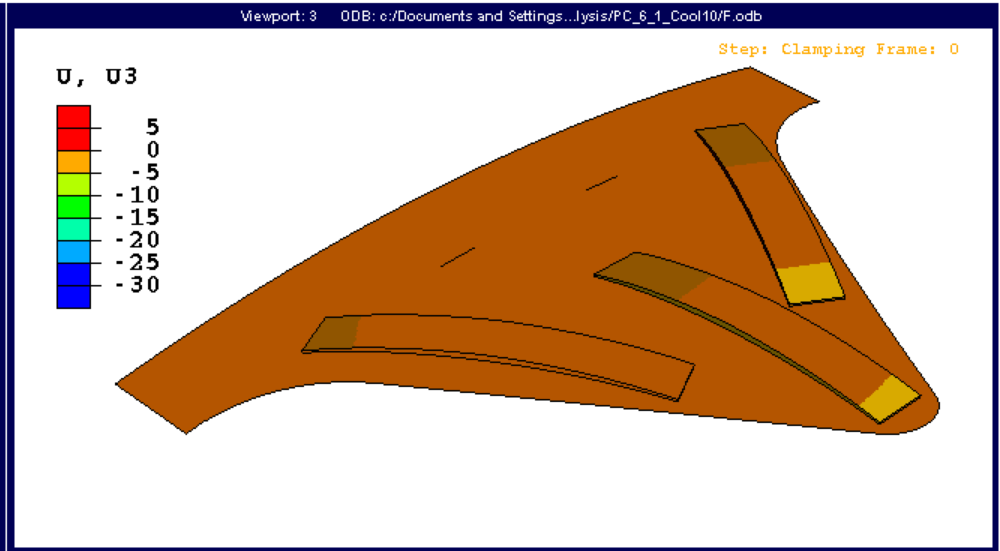


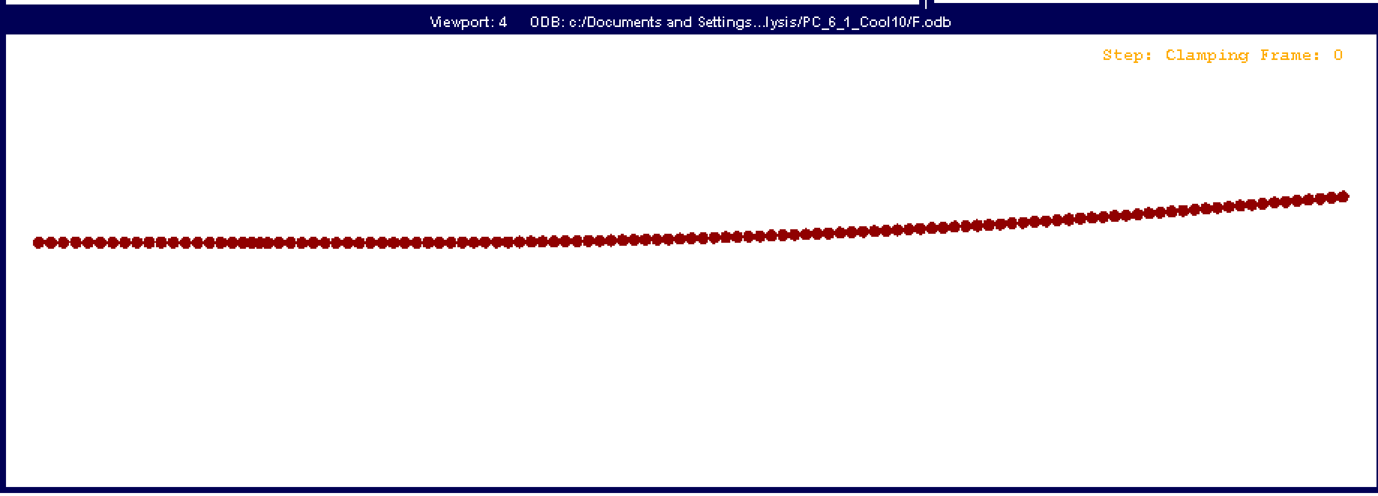
Results of FEA Analysis: Overview

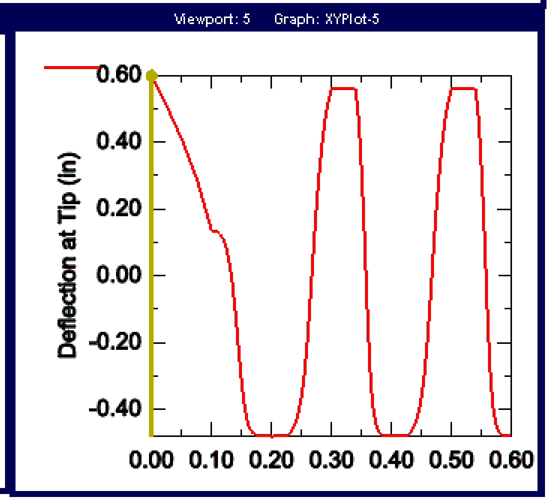
Stress (VM) Contours



Deflection Contours



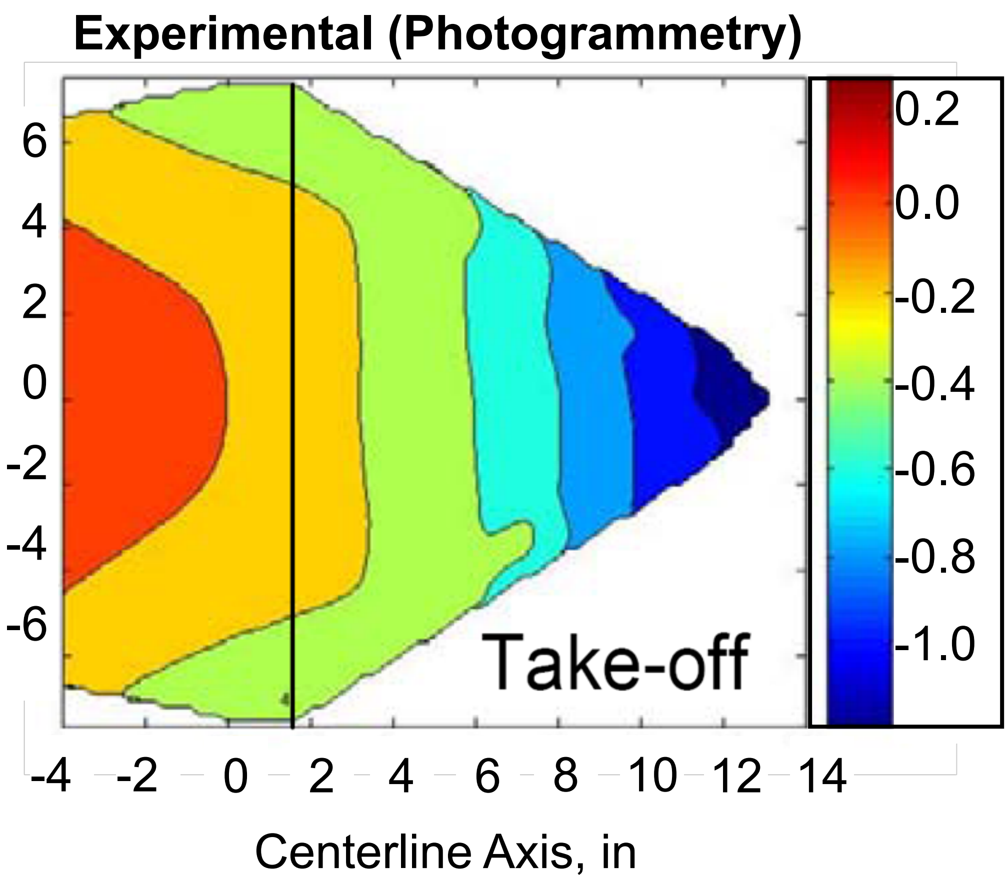


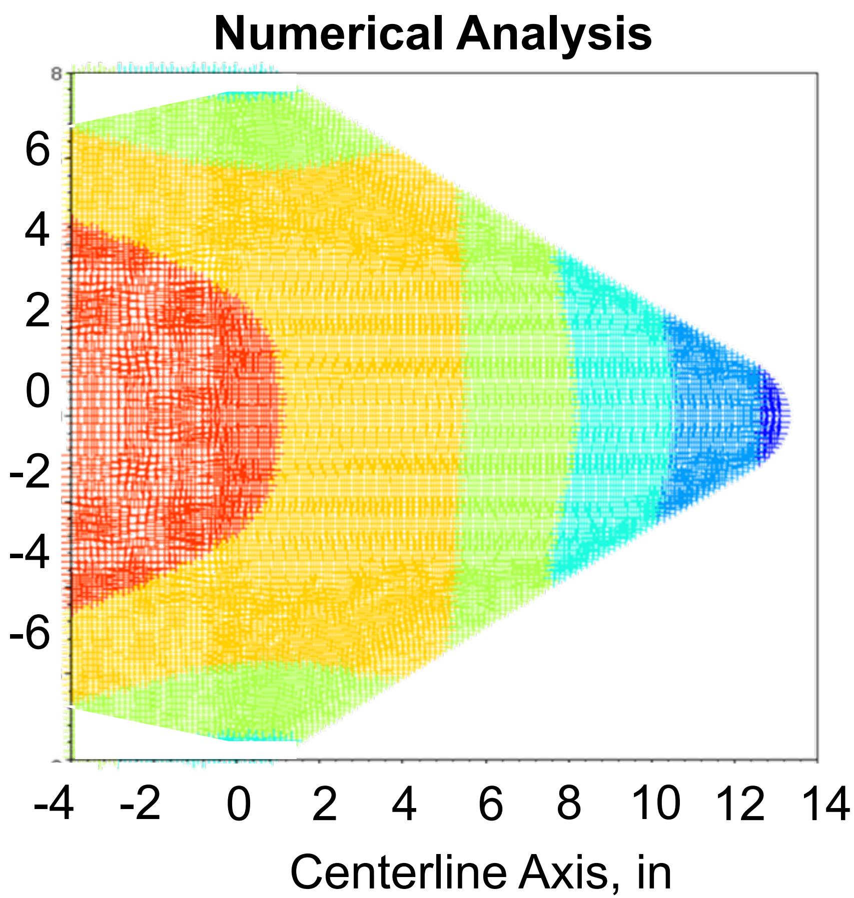


Centerline Profile

Tip Deflection History

Experimental Validation: Flight Testing

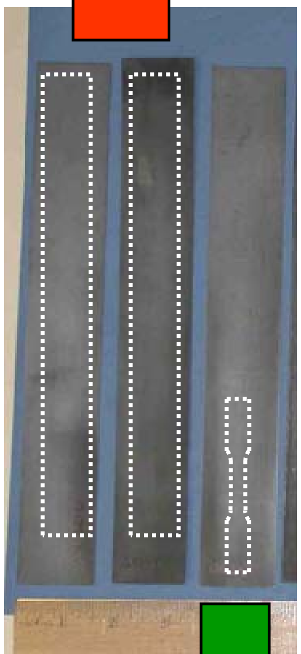




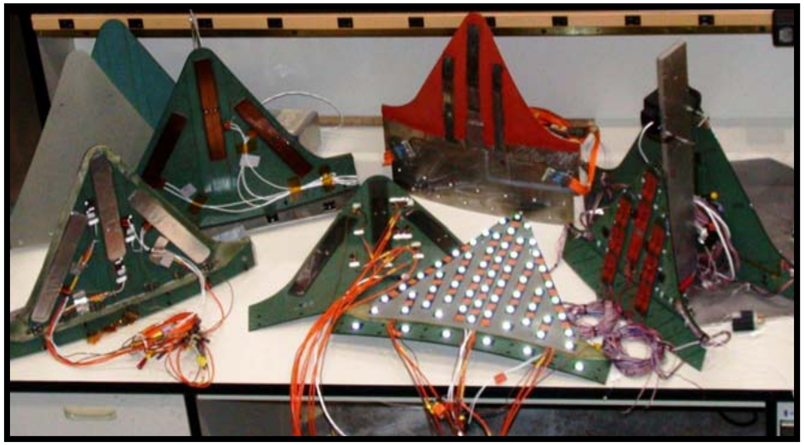
Comparison of flight test data with analysis; Take-off condition

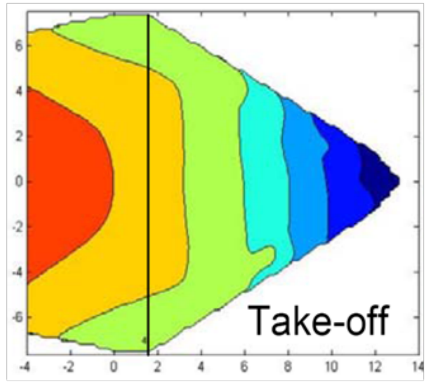
(Calkins, Butler, Mabe: AIAA 2006-2546)

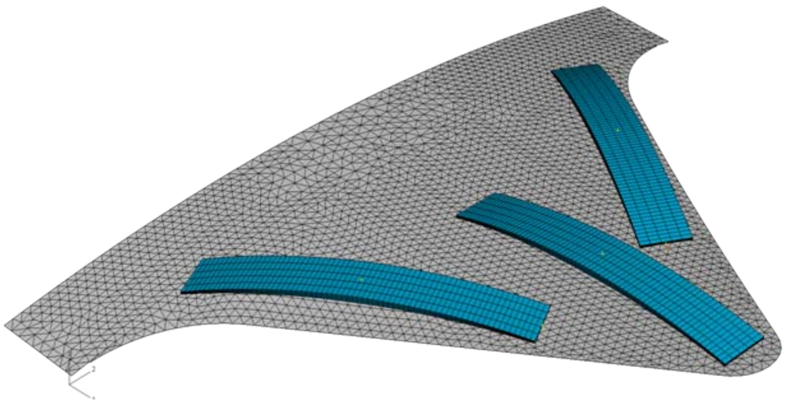
Use of Analysis Tools for Modeling of VGC Actuation Cycles

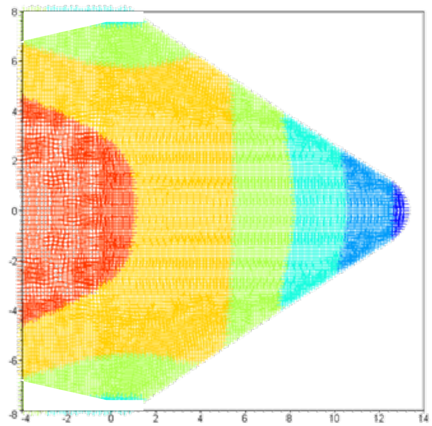


Legacy Method: Design, Build, Test, Iterate→ Optimize



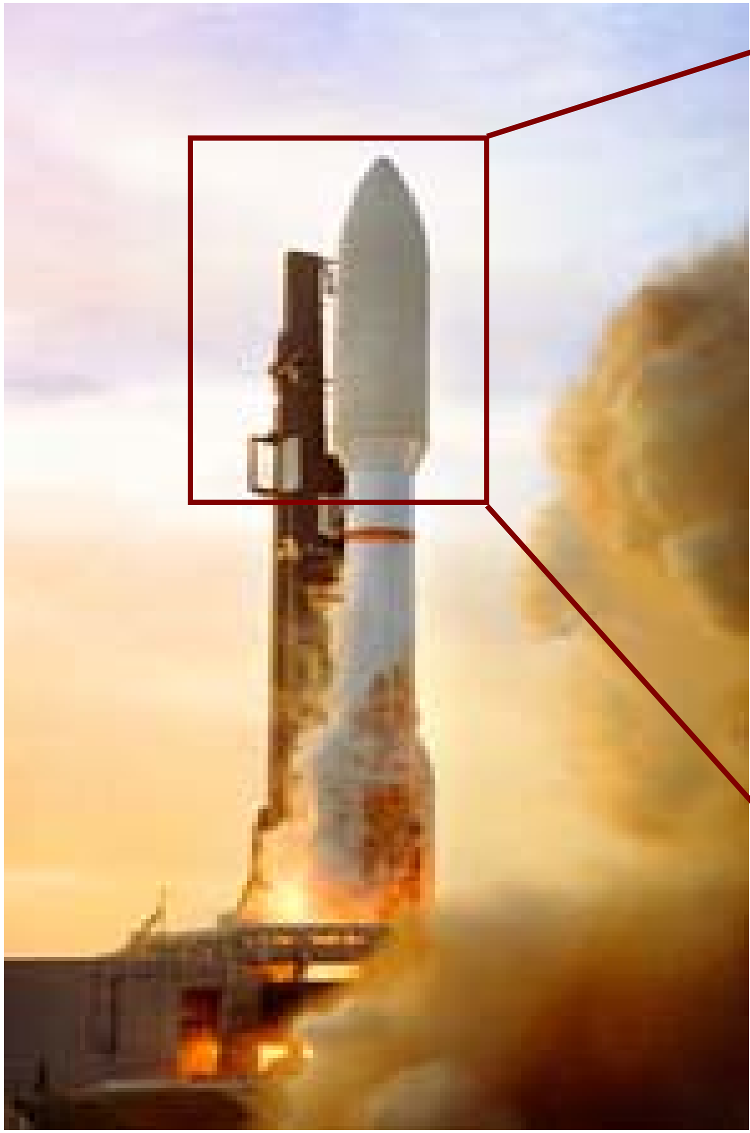


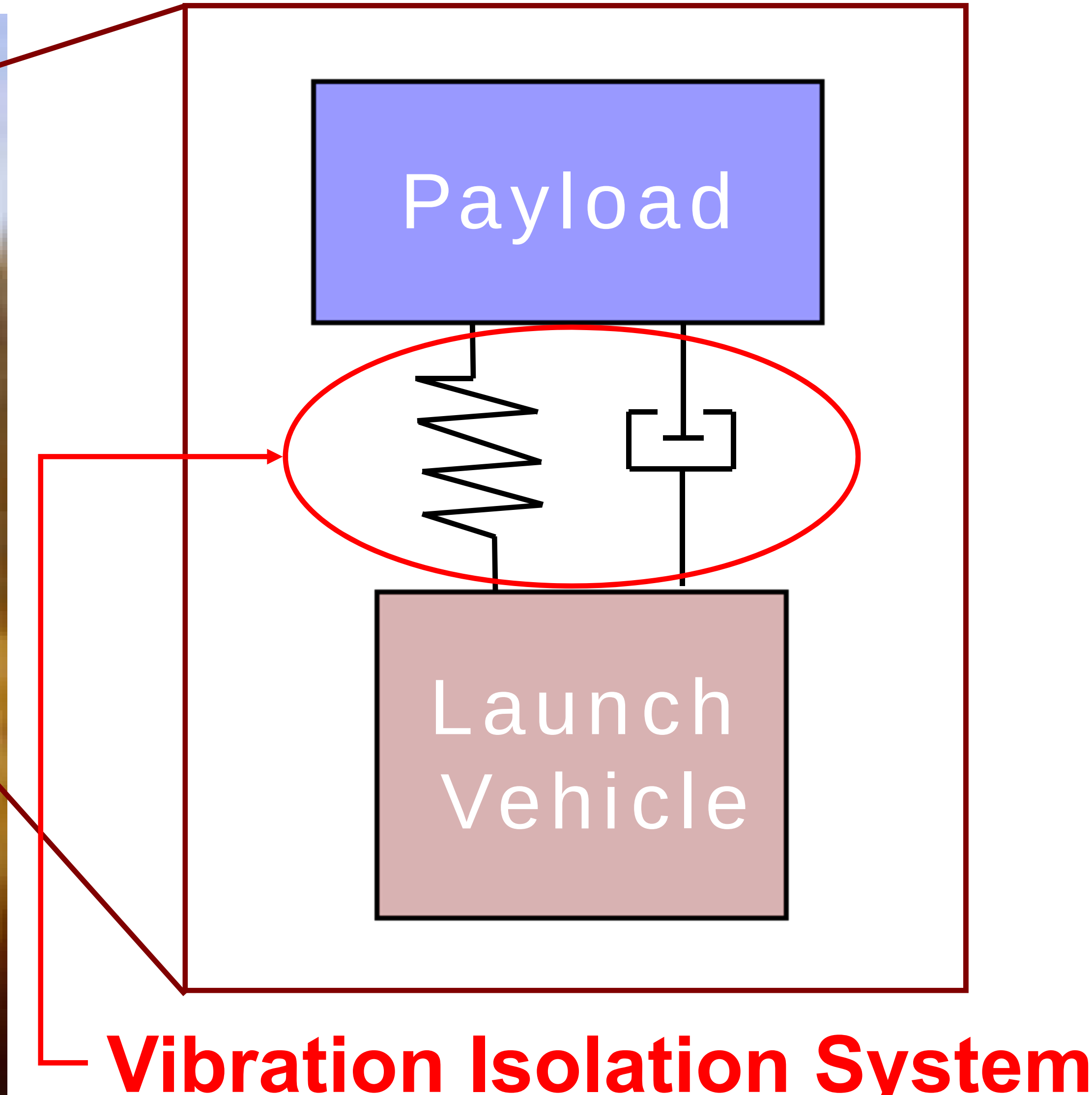




Preferred Method: Characterize, Analyze → Optimize

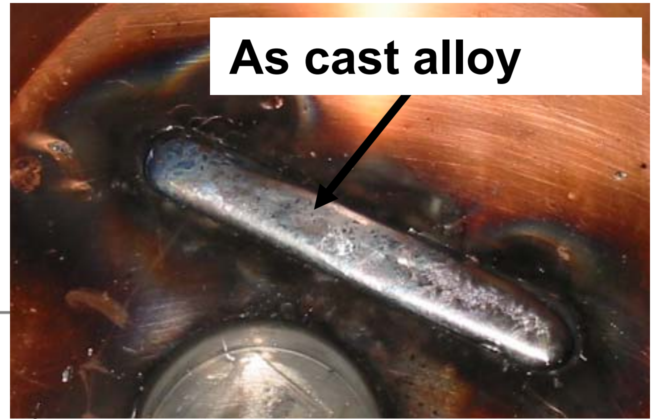
Potential Use of SMAs for Passive Vibration Isolation in Aerospace Vehicles

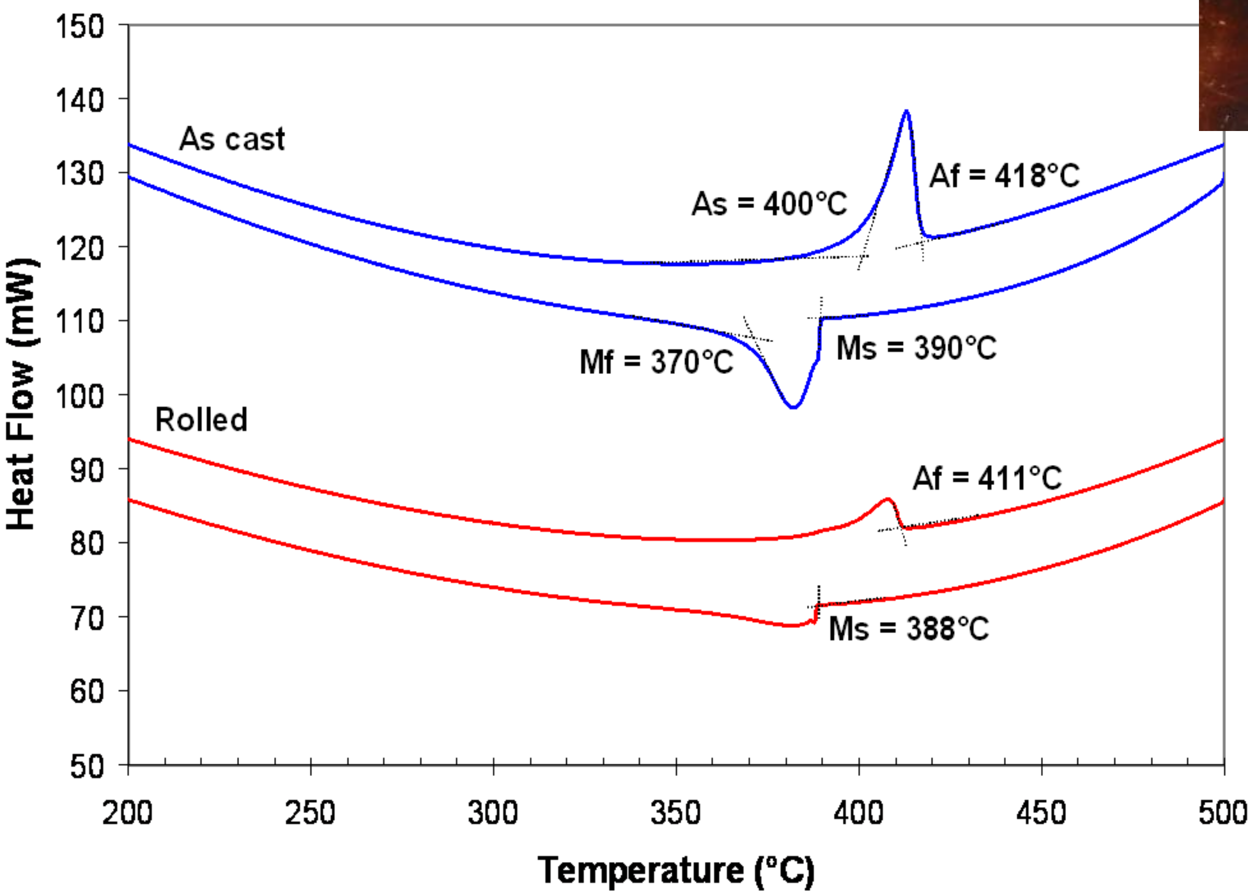




Transformation temperatures of $Ti_{50}Pd_{40}Ni_{10}$ alloy

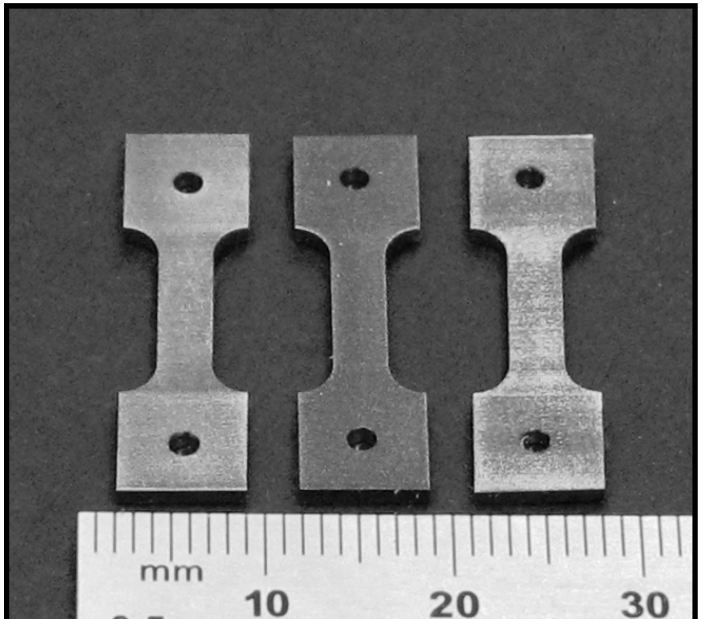
Nominal composition of $Ti_{50}Pd_{40}Ni_{10}$ alloy fabricated by Vacuum arc melt technique.



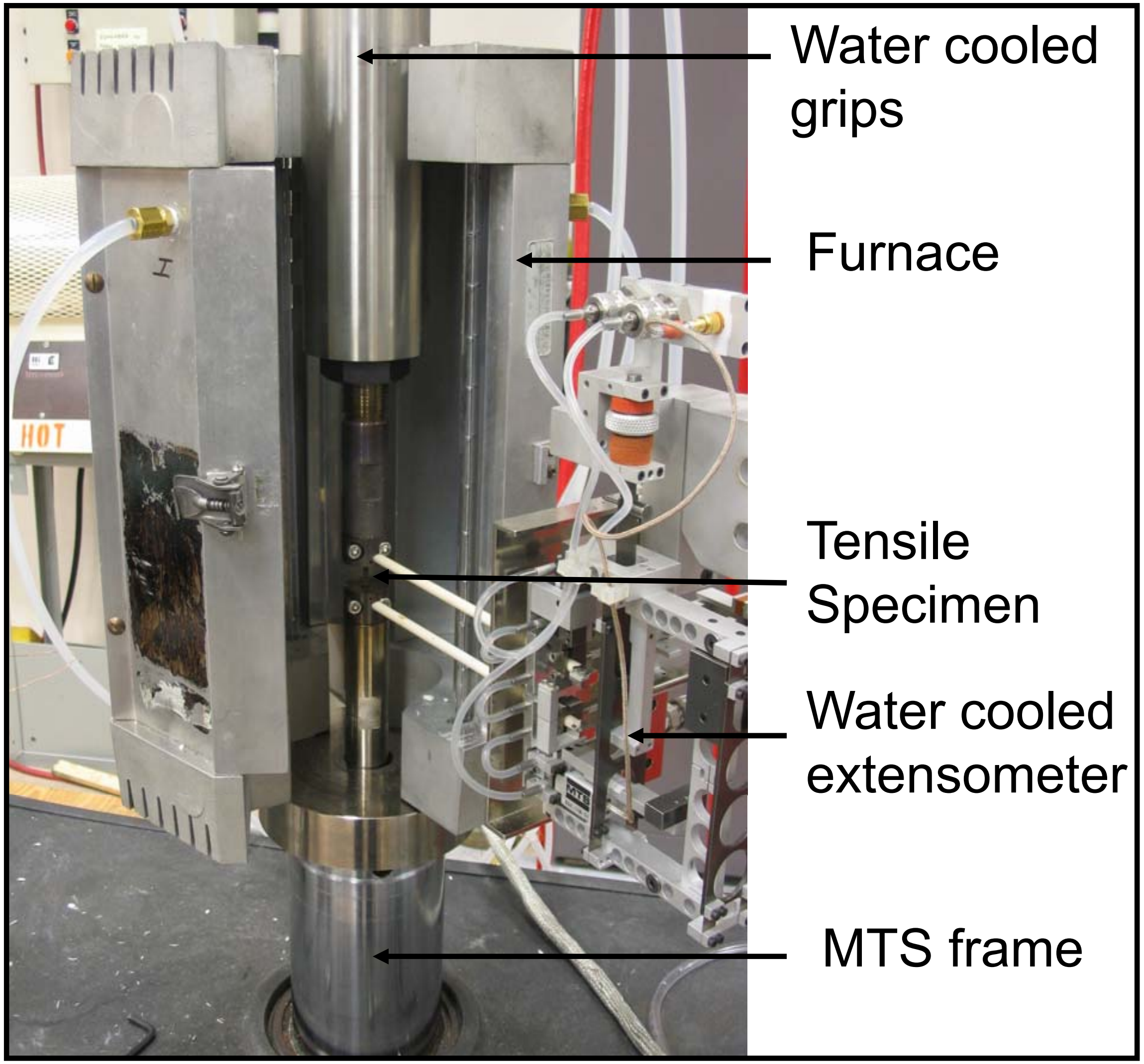


Hot rolled at 900°C (30% reduction in thickness)

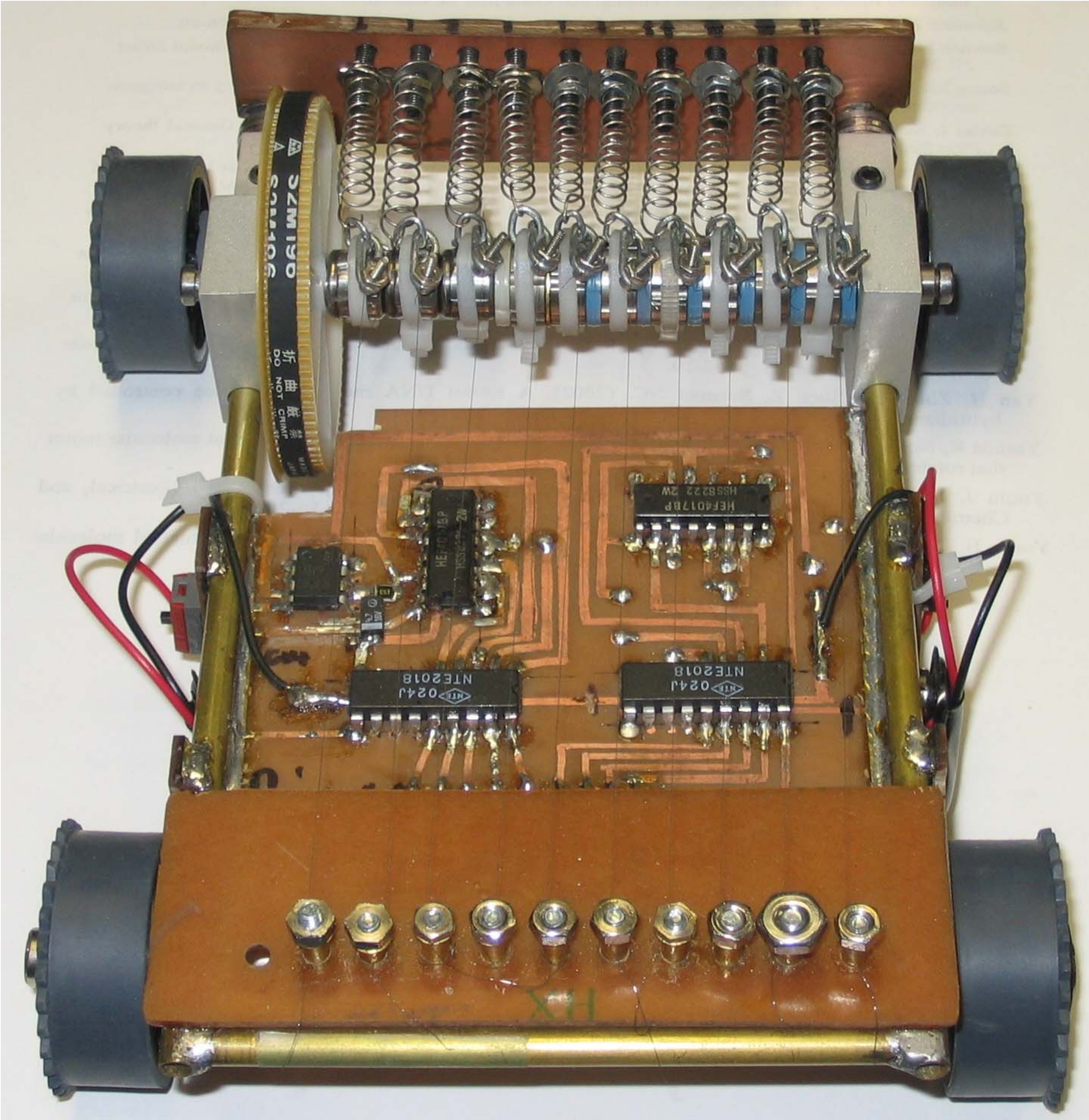
Specimens and Experimental Setup for Characterization of HTSMAs



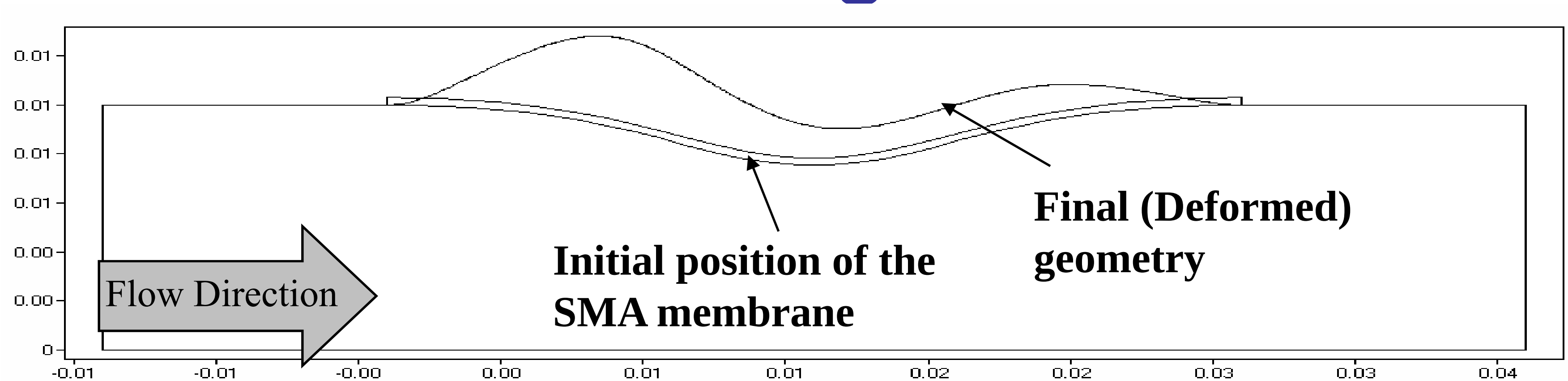
EDM cut tensile specimens

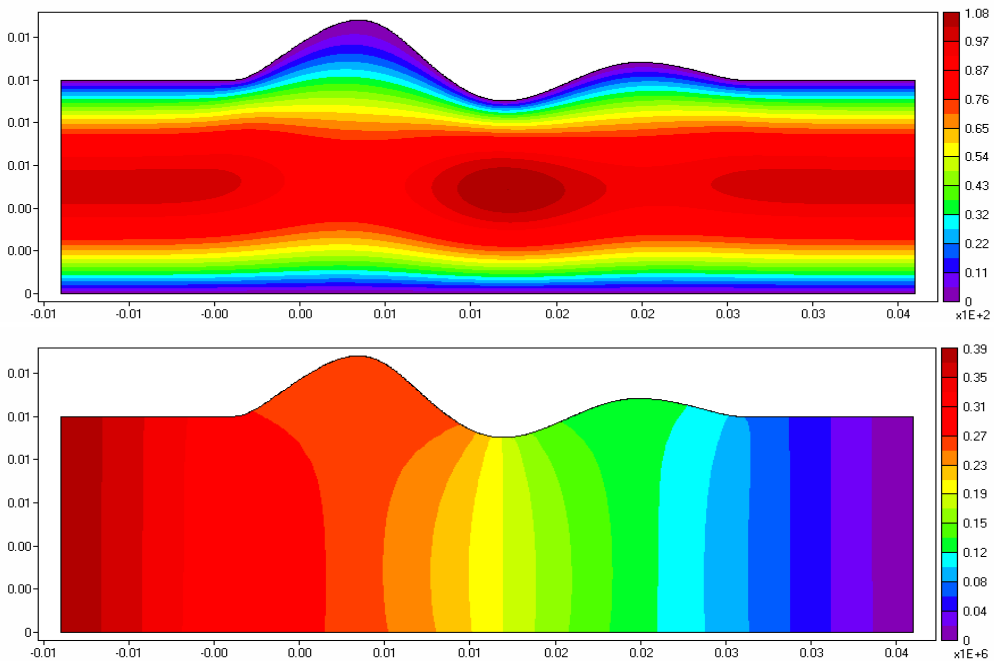


SMA Actuated Automobile

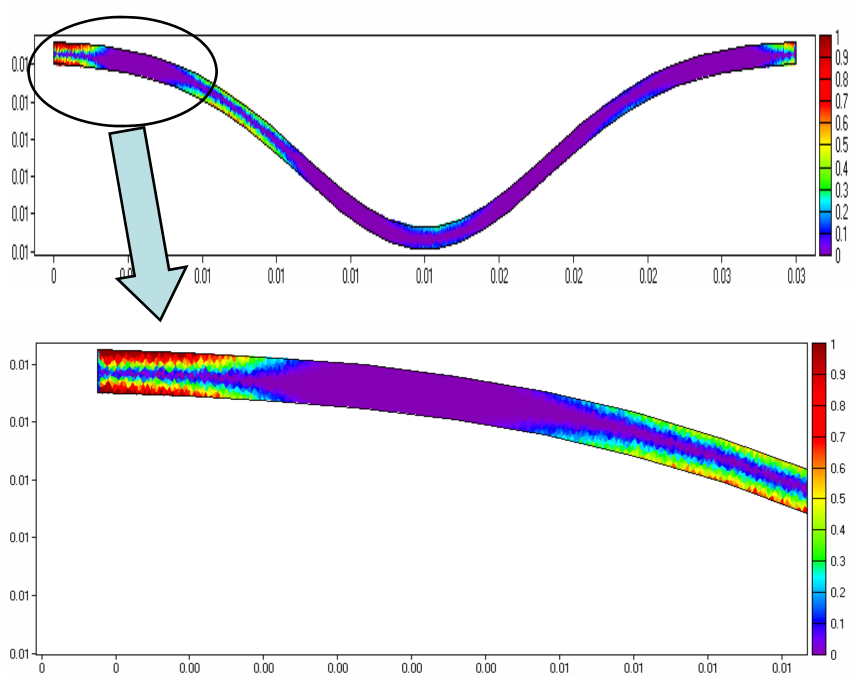


Temperature Actuated SMA Flow Regulator



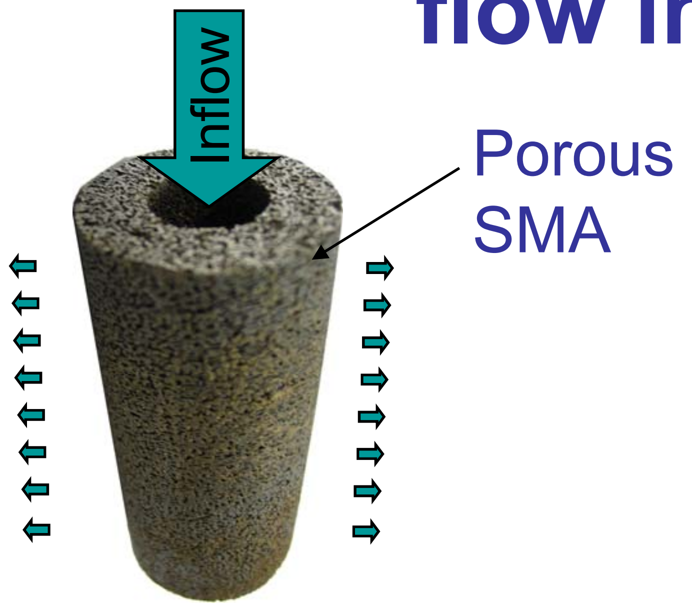


Horizontal velocity and pressure profiles

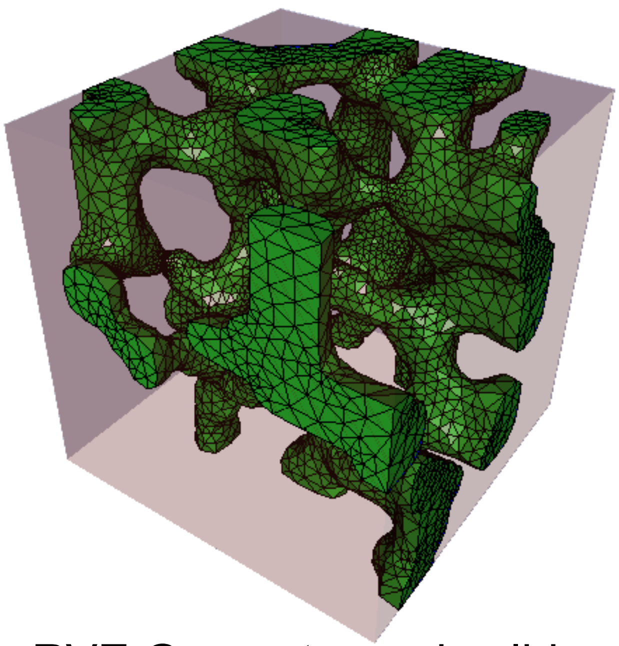


Detwinned martensite

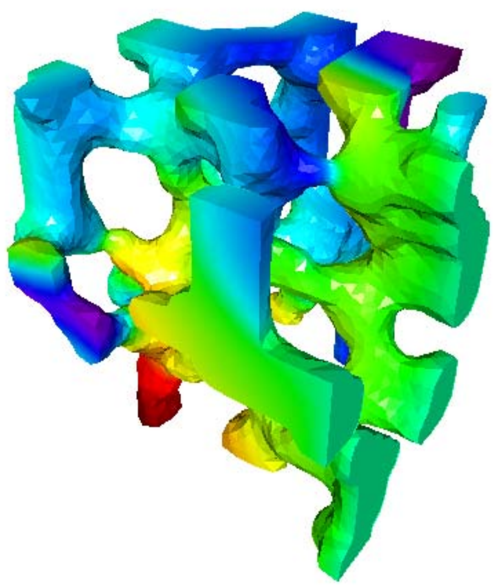
Multiscale modeling of fluid flow in porous SMAs



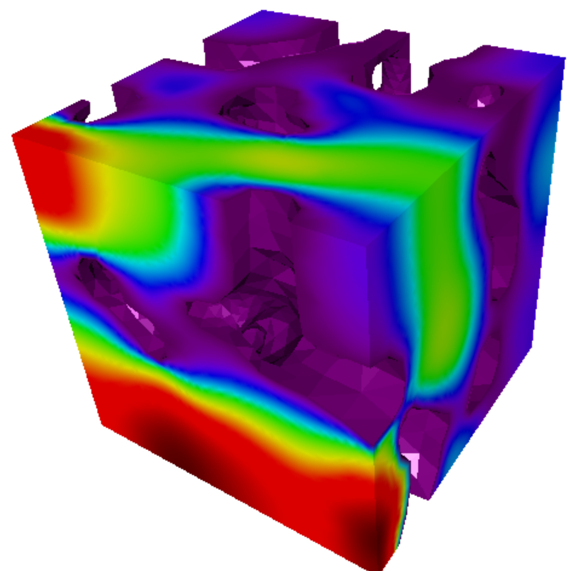
Development of numerical homogenization FEM methods for complex flow problems in shape changing materials



RVE Geometry and solid domain (green)



Typical fluid-structure coupling Cell problem

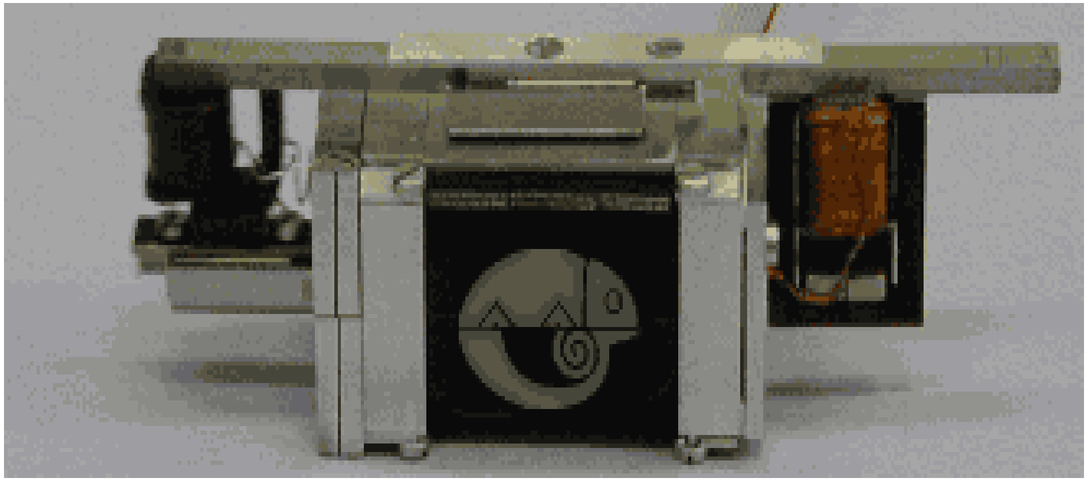


Typical cell problem for diffusion coefficient

Magnetic Shape Memory Alloy Applications

High Frequency MSMA Actuators:

source:
http://www.adaptamat.com

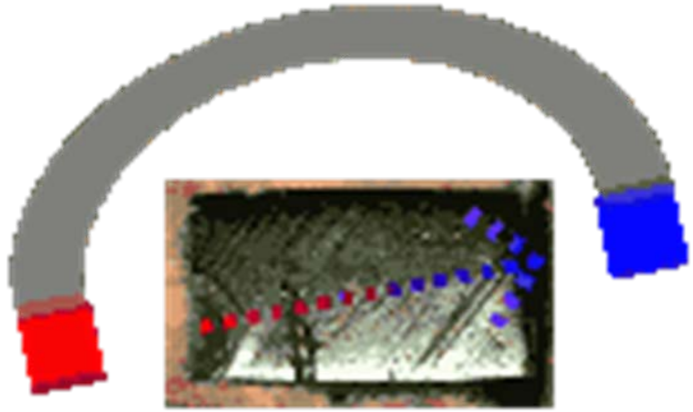


Force: 1 kN (max)
Stroke: 1 mm (max)
Frequency: 0-100 Hz

Force: 3 N (max)
Stroke: 0.6 mm (max)
Frequency: 0-1000 Hz

Large Recoverable Magnetic Field-Induced Strains

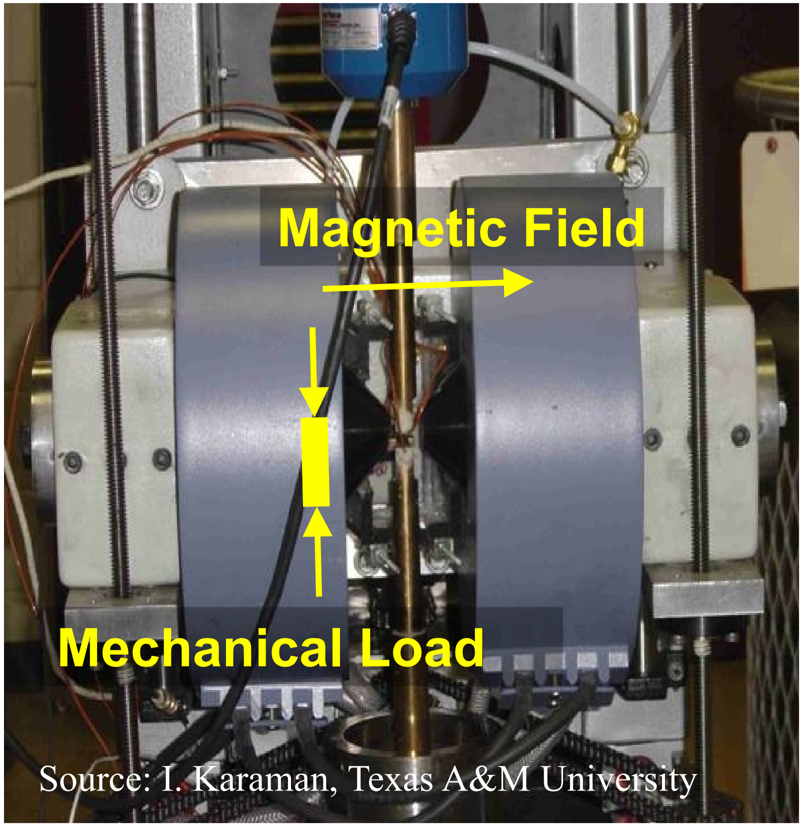
NiMnGa Single Crystal Specimen



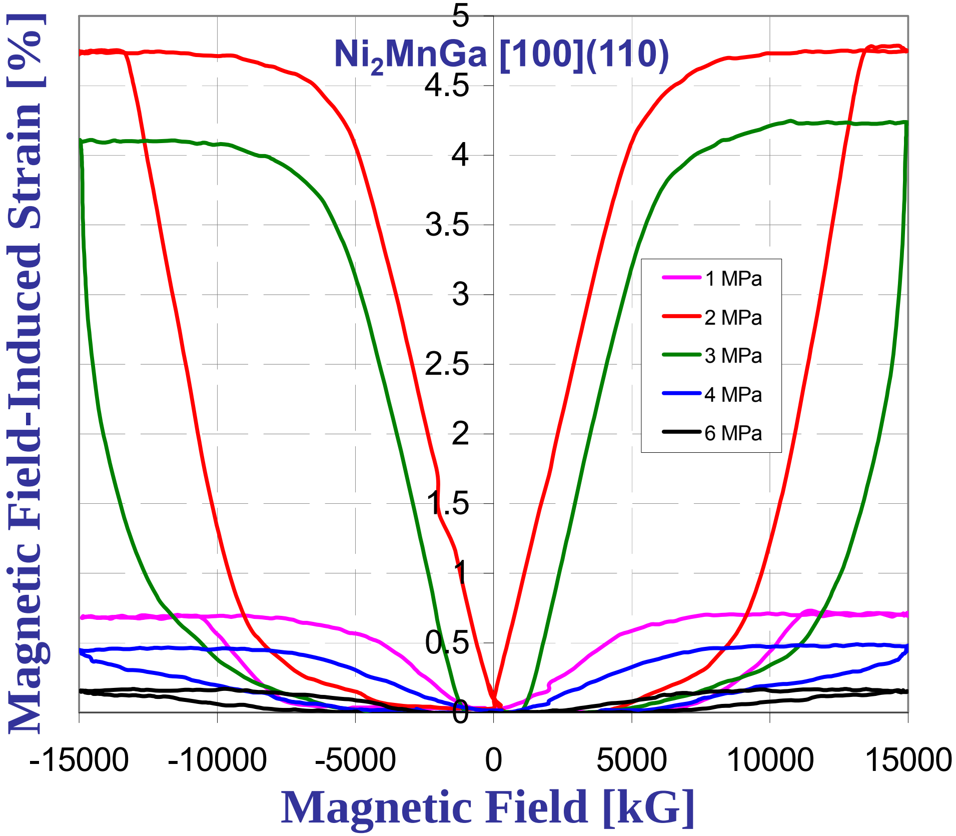
Reference: www.adaptamat.com

Magneto-Thermo-Mechanical Testing of MSMA

Experimental Setup



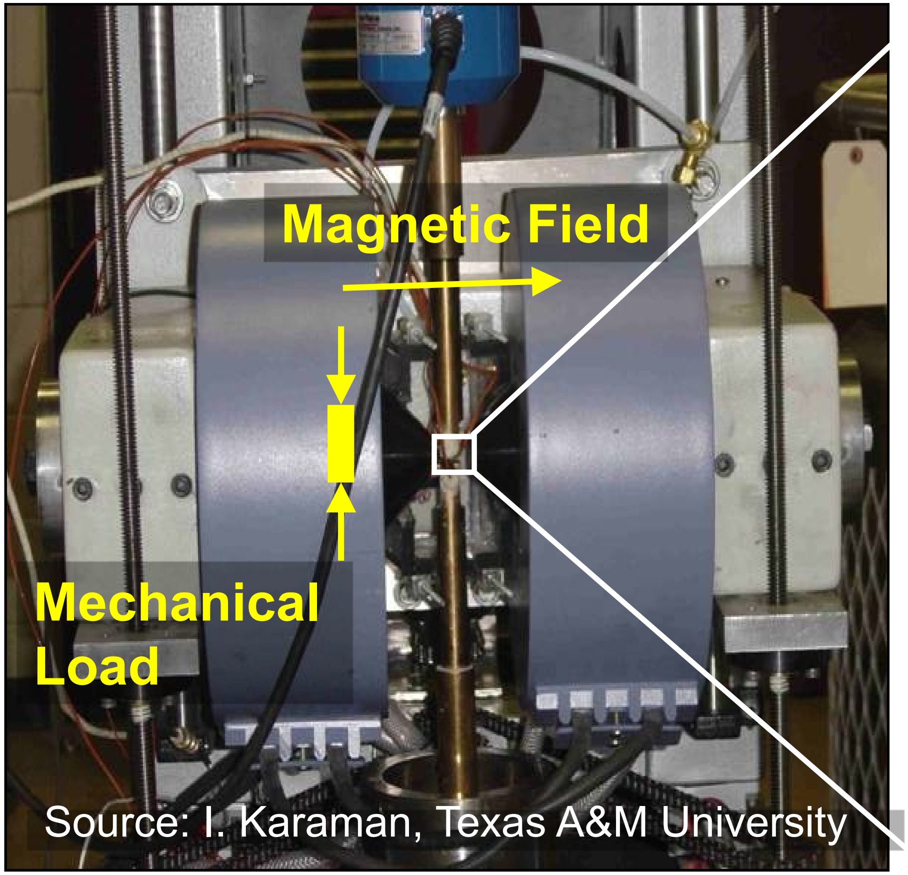
Magnetic Field-Induced Strains

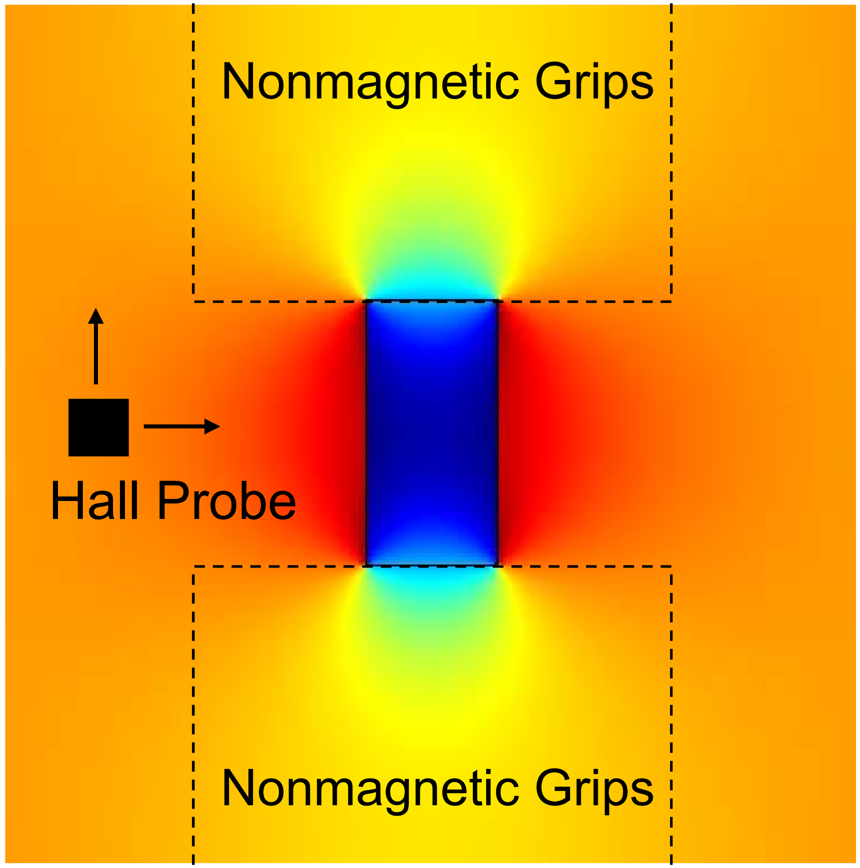


- Tension/compression mechanical loading on MTS frame
- Variable magnetic field (<2T)
- Controllable temperature (-110 °C to room temp.)
- Cyclic Loading
- Tested material systems: NiMnGa, CoNiAl, CoNiGa

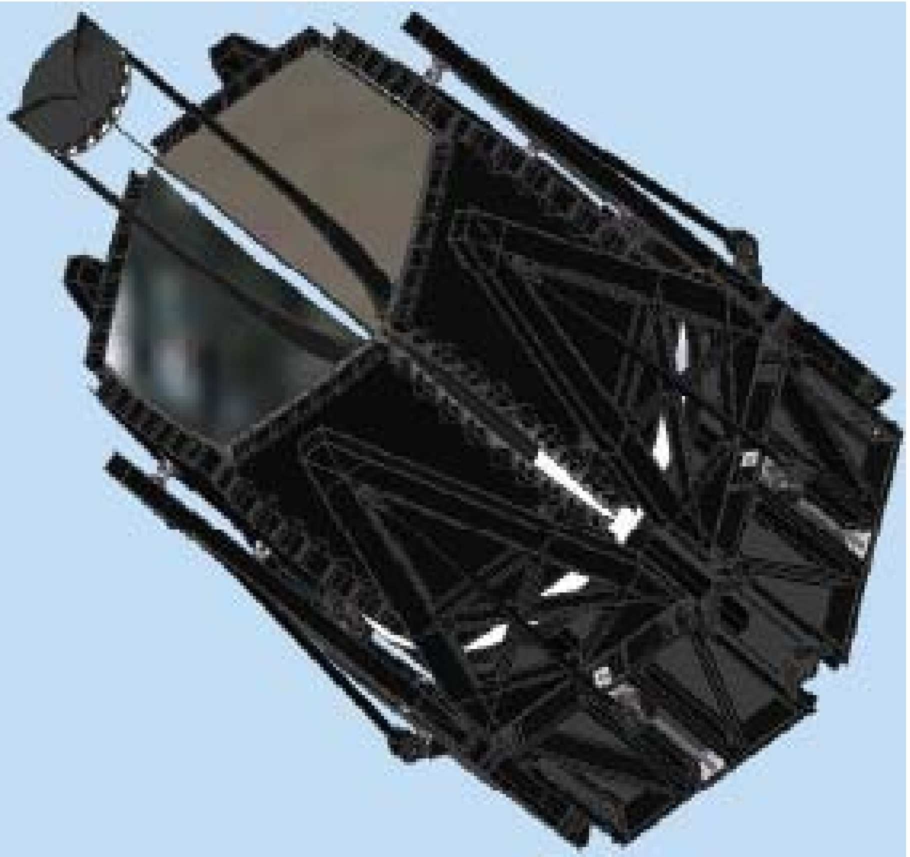
Application of FEM Analysis with MSMAs

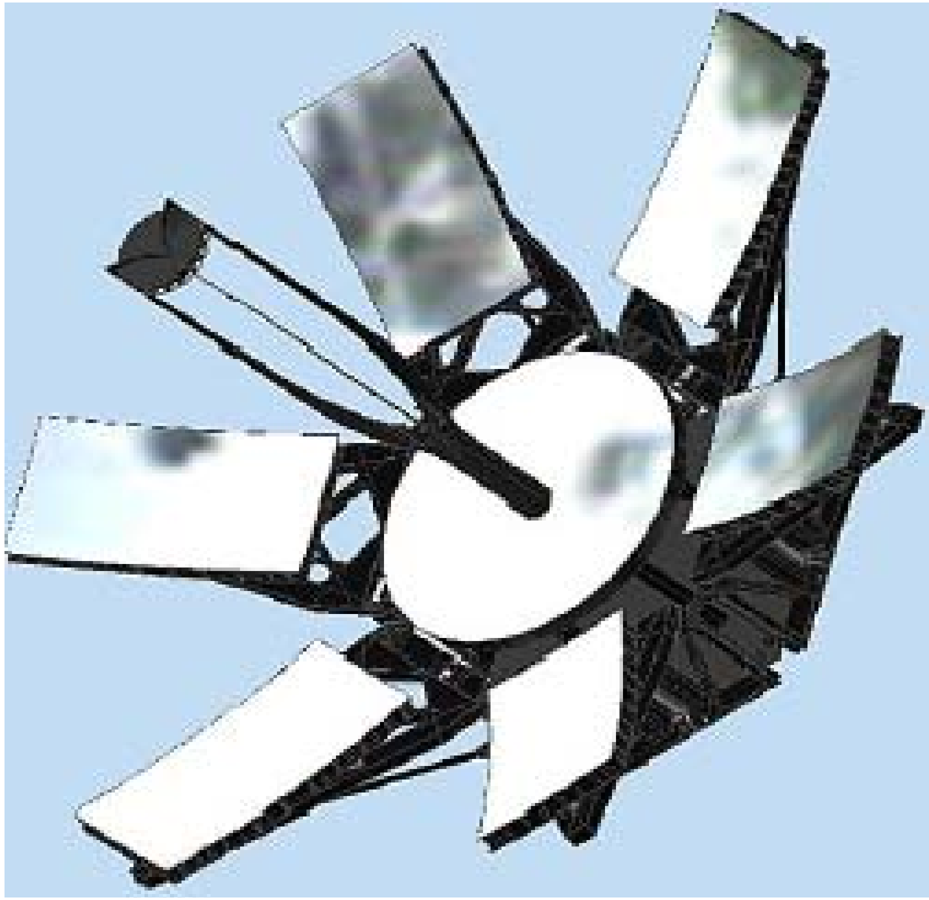
Improved Design of Experiments





Space Applications of Shape Memory Polymers (SMPs)





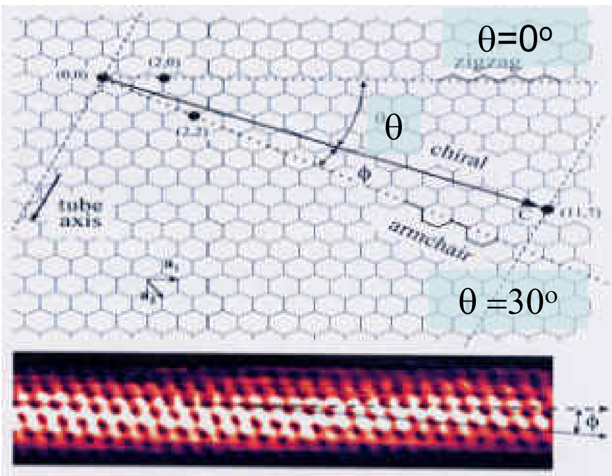
Develop an integrated computational environment for design and analysis of SMP structures and devices

Future Challenges in Shape Memory Materials

- Integration of models into commercial software with **standardized material characterization protocols**
- **H**igh **T**emperature **SMA**s - Modeling efforts must address true material **rate dependency**
- Magnetic **field induced phase transformation** in **MSMA**s with higher blocking stress
- Integration of **thermo-magneto-mechanical** coupling

Motivation For Carbon Nanotube Reinforced Composites: Applications

- High modulus and strength to weight ratios of carbon nanotubes and their large aspect ratio make carbon nanotubes attractive as reinforcing material
- Electrical and thermal properties of carbon nanotubes as well as storage ability make carbon nanotube composites multifunctional
- Applications in terms of engineering design require large scale production and reliable **estimates material properties** from measurement and **modeling**



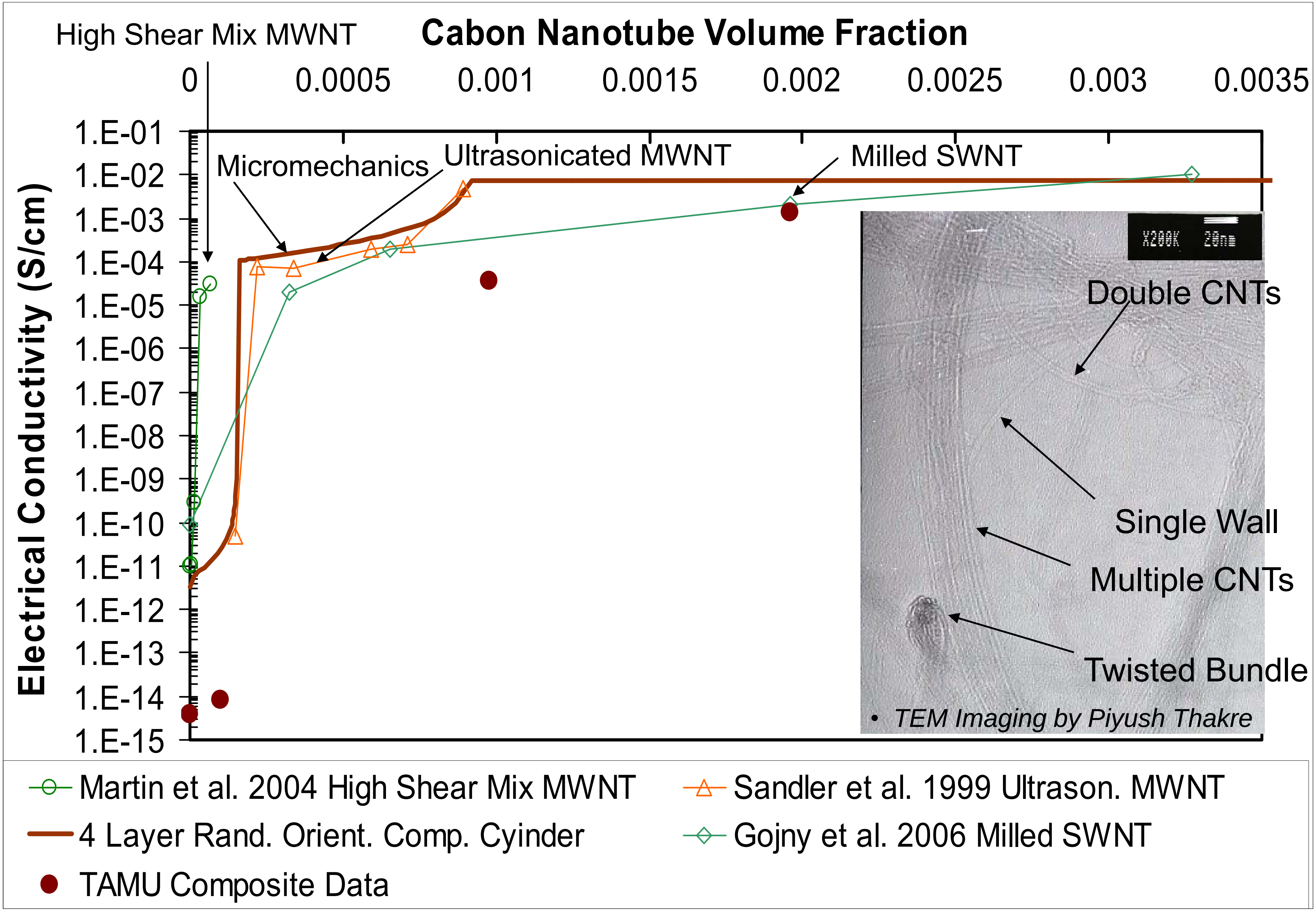
Grams	SWNT 90wt%	SWNT 50wt%	MWNT <8nm	MWNT >50nm
10	$1,350	$300	$275	$75
100	$8,500	$2,250	$1,500	$400
1KG	$75,000	$30,000	$3,500	$900

http://www.cheaptubesinc.com

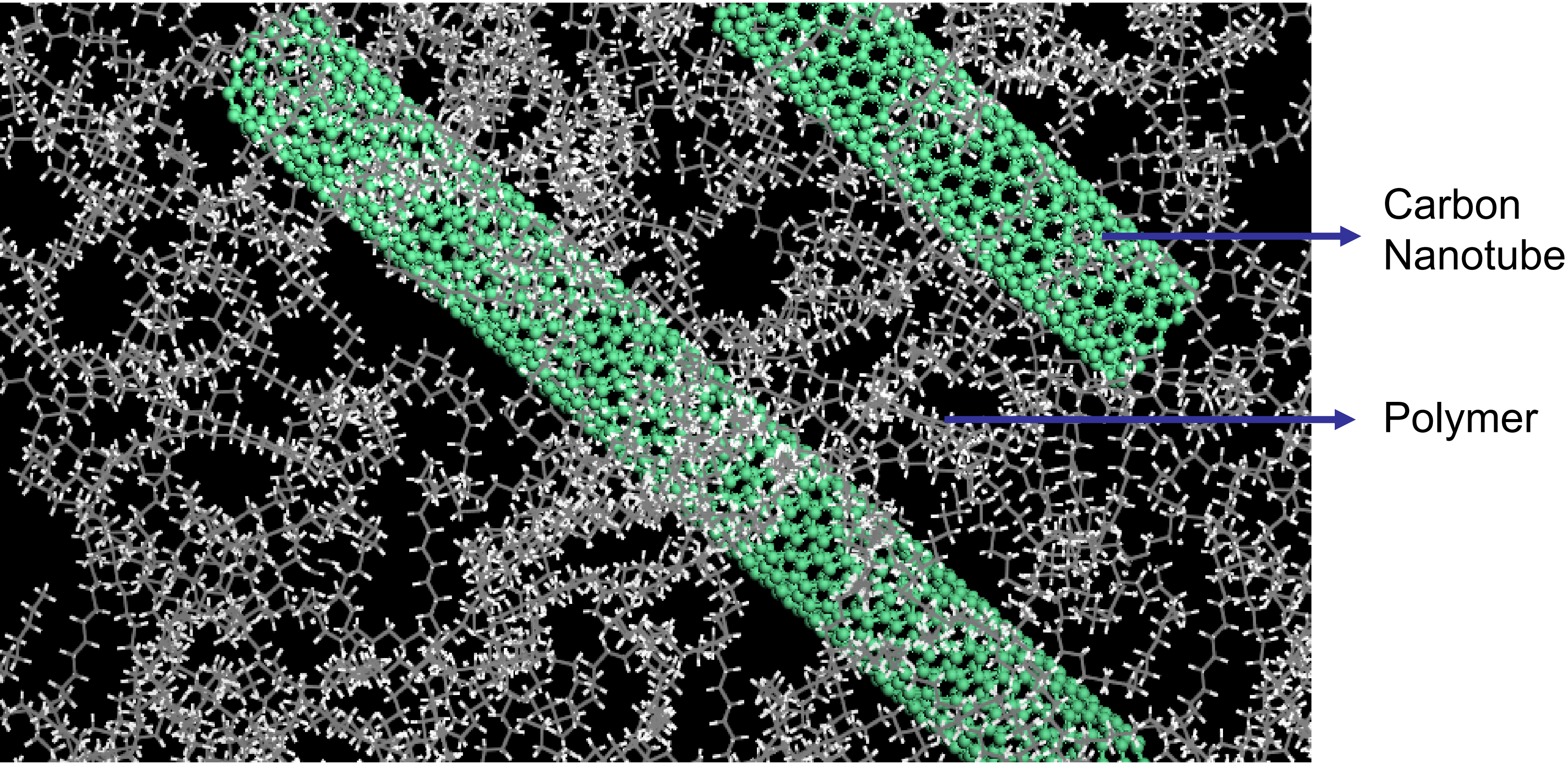
Motivation for Carbon Nanotube-Polymer Multifunctional Nanocomposites

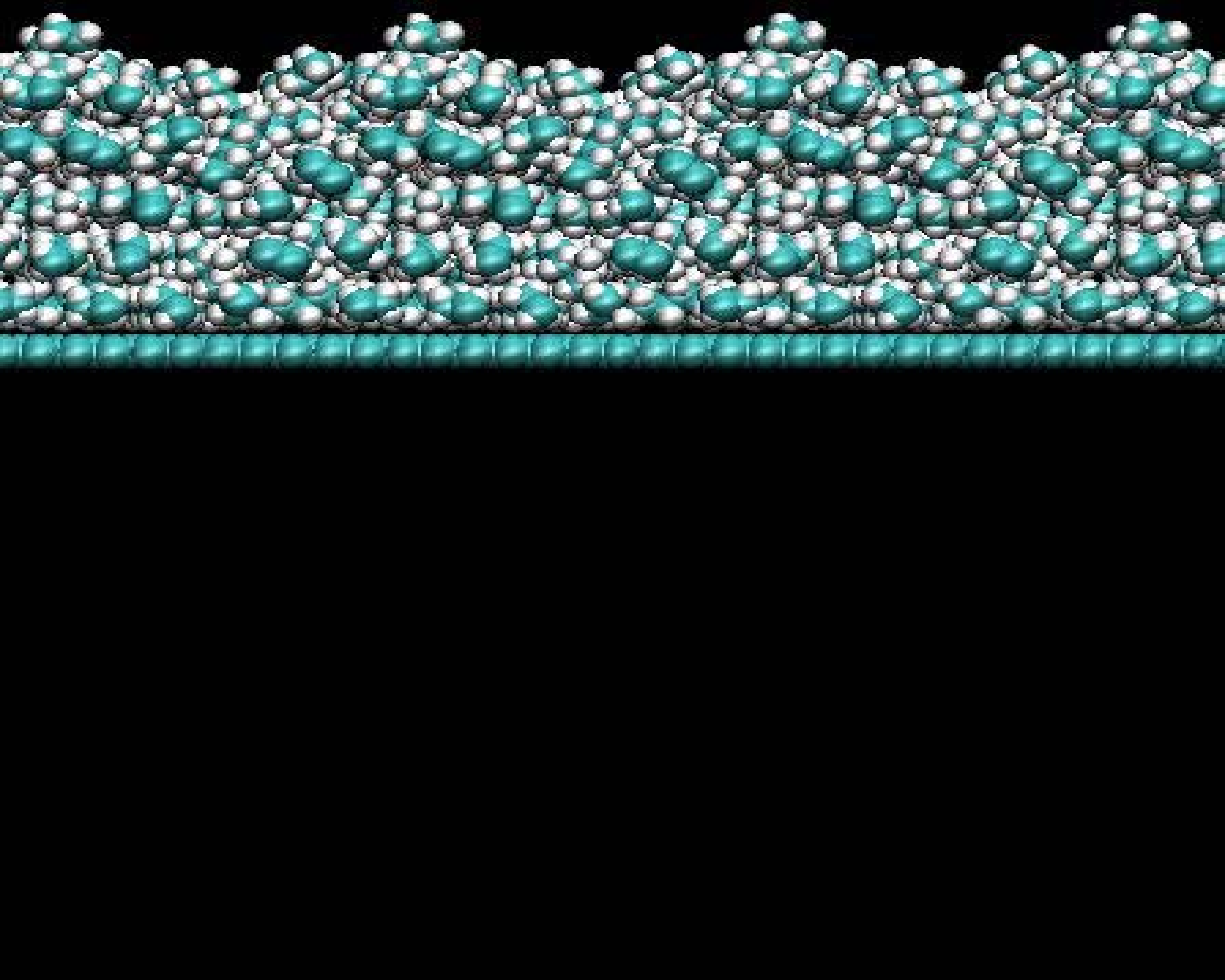
- **Large disparity between CNT, Polymer Properties:**
  - Young's Modulus: CNT 2-3 Orders Larger than Epoxy
  - Thermal Conductivity: CNT 4 Orders Larger than Epoxy
  - Electrical Conductivity: CNT 14-18 Orders Larger than Epoxy
- **Measured nanocomposite properties less than some anticipated**
  - Young's Modulus: 20% increase at 1% weight
  - Thermal Conductivity: 30% increase to at 1% weight
  - Electrical Conductivity: 9 order increase at 1% weight
- **Nanoscale effects identified as having strong influence on nanocomposite properties:**
  - Load transfer governed by van der Waals forces and functionalization
  - Thermal Conductivity governed by interface thermal resistance
  - Electrical Conductivity governed by electron hopping

Comparison of Micromechanics Model to Measured Nanocomposite Electrical Conductivity



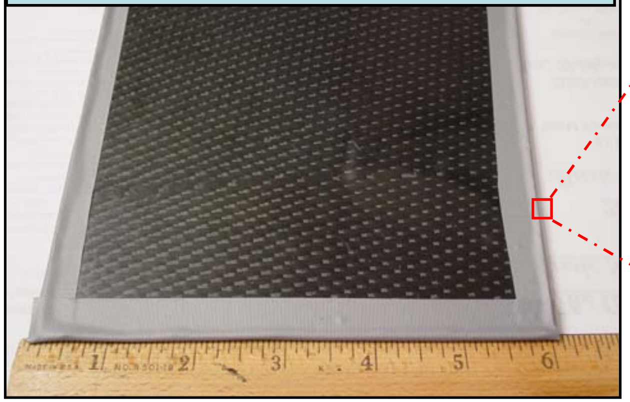
Atomistic Description of Carbon Nanotube Polymer Composite

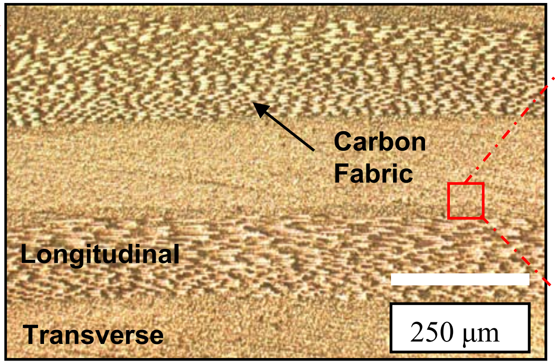


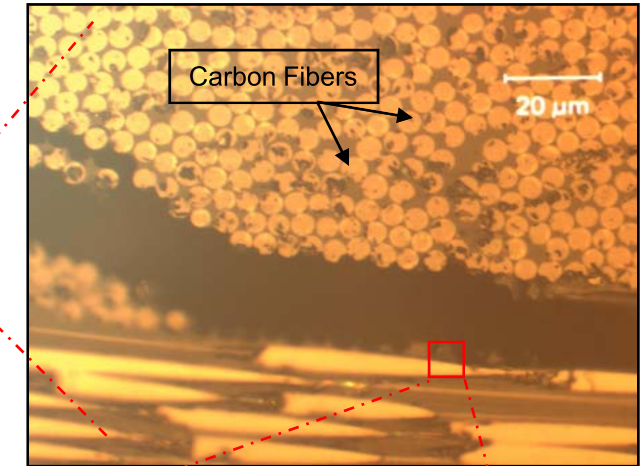


Characterization of Composites at Multiple Scales

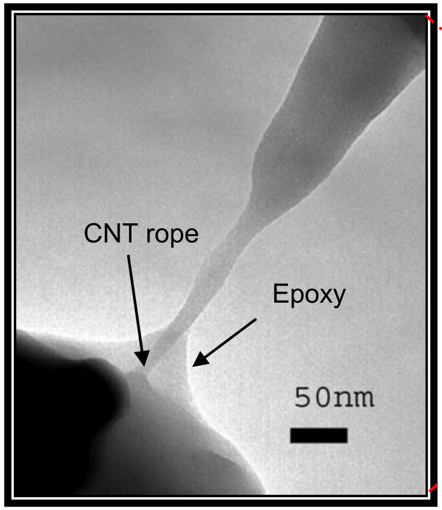
Macroscale Composite



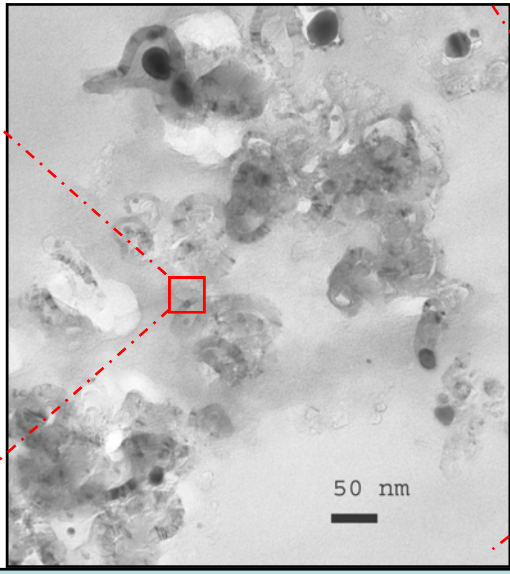




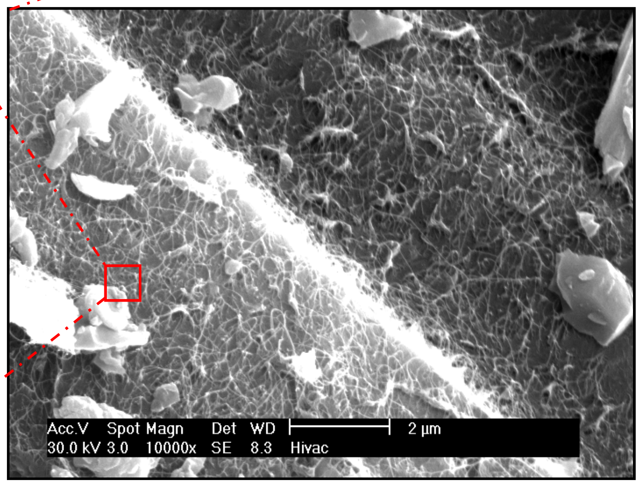
Lamina Microscale



TEM micrograph showing good wetting between **SWCNT rope and Epoxy**

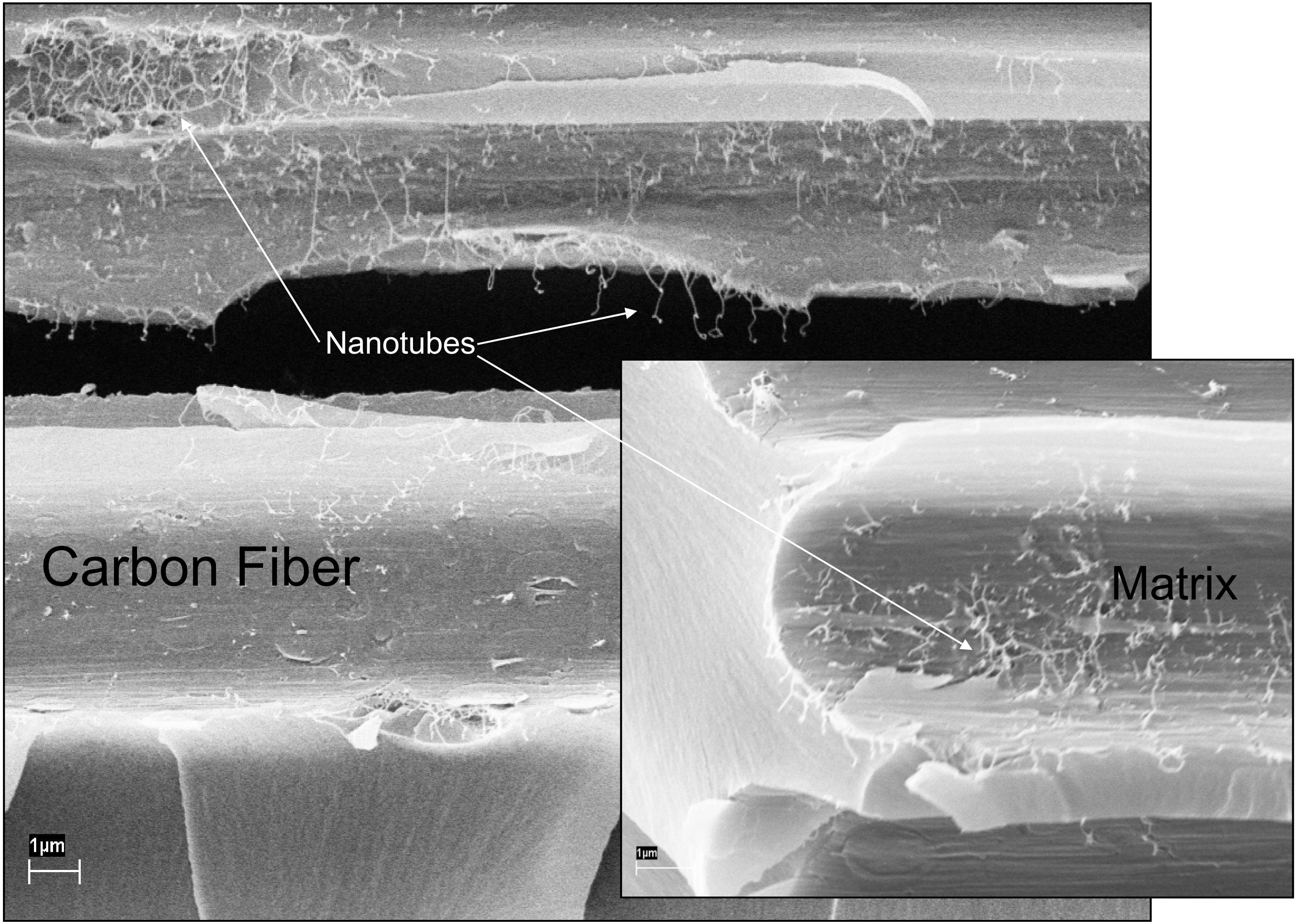


Nanocomposite: Nanoscale and microscale



Fiber-Graded Interphase Scale

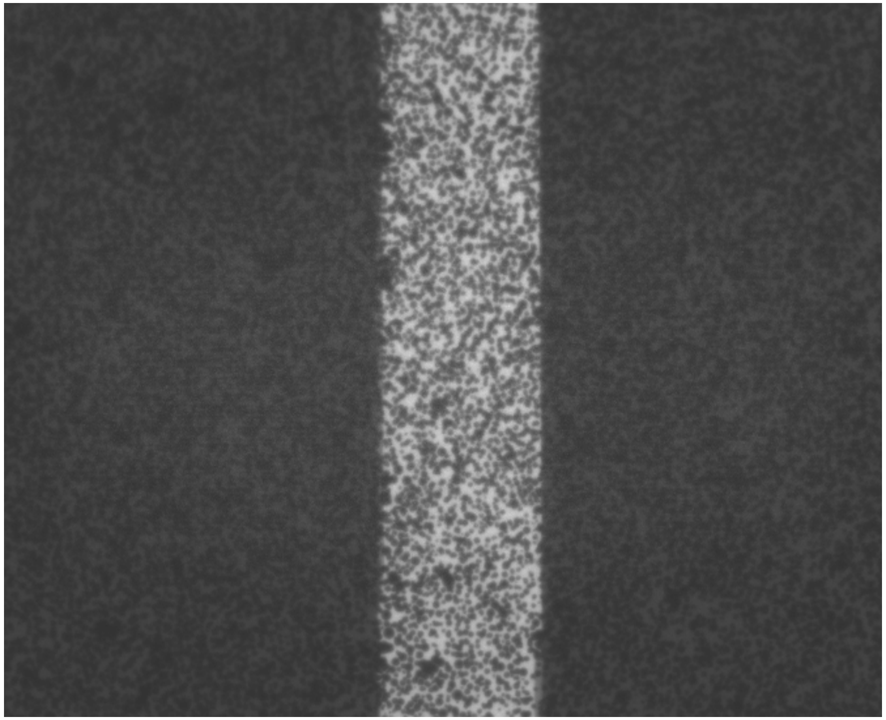
Fracture surface of laminate with Pristine SWCNTs



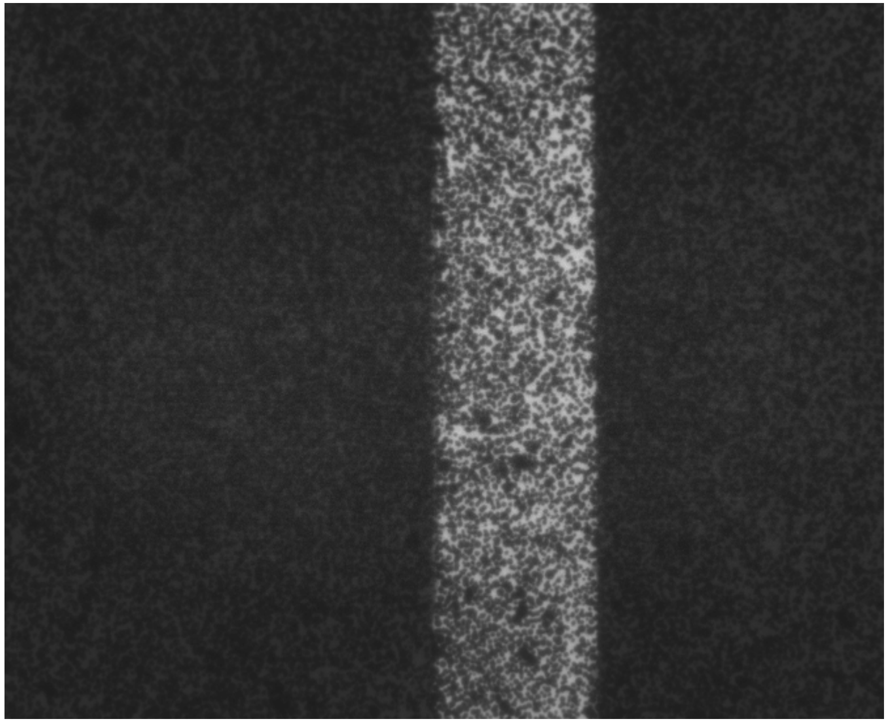
SEM image showing CNT bridging cracks but weak fiber-matrix bonding

Multifunctional Colloidal Suspensions: Reversibility and Switch Between “Resistor” & “Capacitor” from Reconfigurable Antennas

2.5 V, 1 MHz



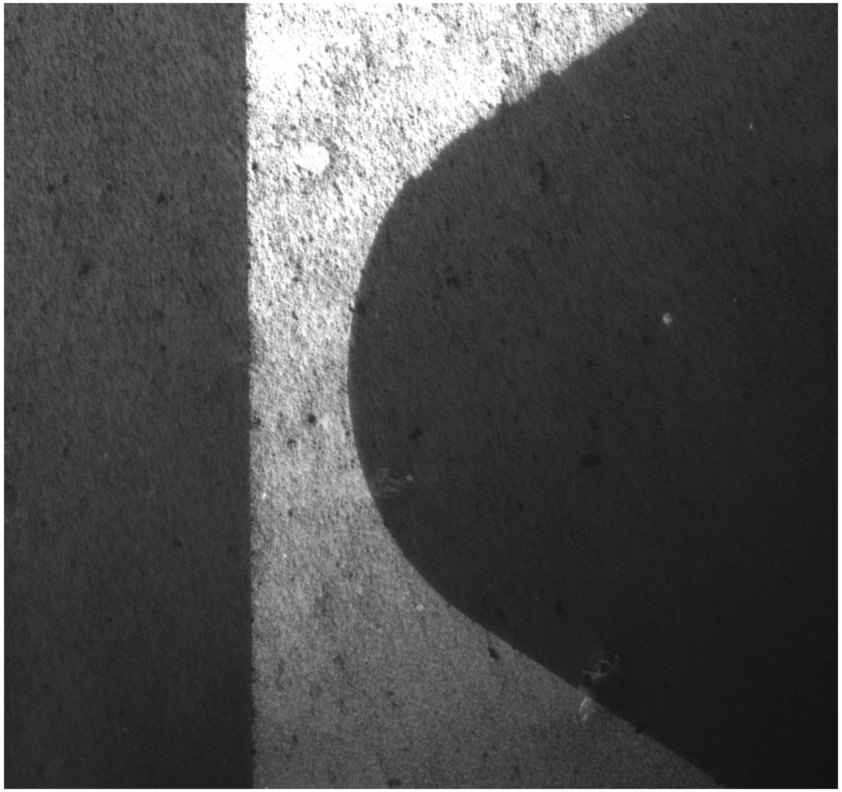
2.5 V, 100 Hz-1 MHz-10 Hz



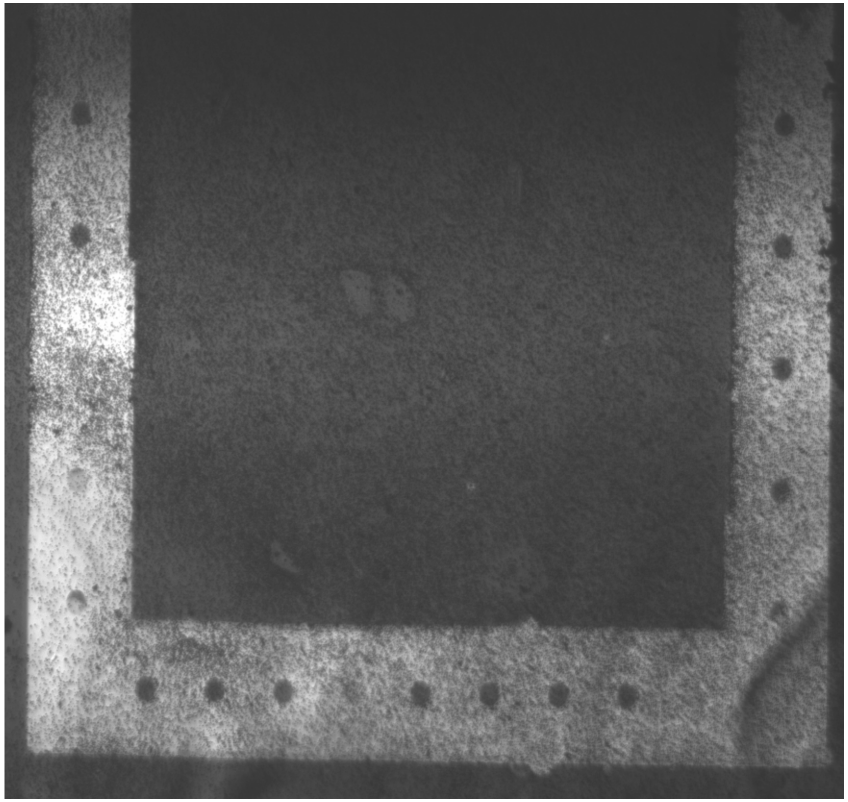
- 800 nm gold nanoparticles, 0.1 mM $NaHCO_3$

- **Effect of Inhomogeneous Electric Fields on Colloidal Transport**

pointed electrode near a flat electrode



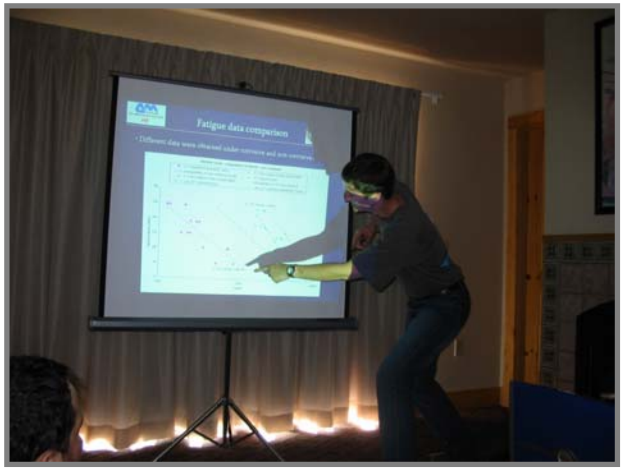
conducting islands between planar electrodes



Acknowledgement to Sponsors

- Army Research Office (ARO)
- Air Force Office of Scientific Research (AFOSR)
- Air Force Laboratory (AFRL)
- Defense Advanced Research Projects Agency (DARPA)
- National Science Foundation (NSF)
- Sandia National Laboratories
- NASA – TiiMS URETI
- NASA – LaRC
- NASA - Glenn
- Boeing Co.
- Schlumberger
- CRDF, NDSEG

Graduate and Undergraduate Students "Research Activities"



Graduate and Undergraduate Students "Research Activities"

Σας ευχαριστώ

Thank you!

Celestial Mechanics with Atoms