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Biotechnology · Nanotechnology · Information Technology

NSF / NSE
Nanoscale Conference

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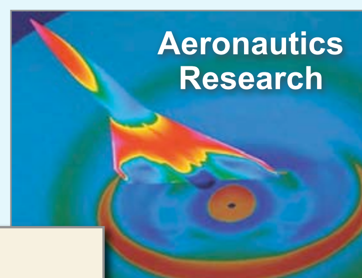
Exploration Systems Mission Directorate
NASA

Mission Statement



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To pioneer in:
- Space Exploration
- Scientific Discovery
- Aeronautics Research

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Future Challenges

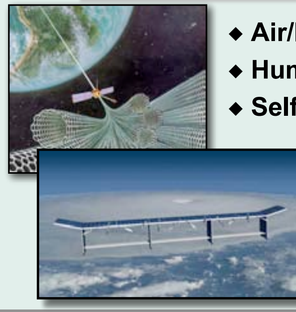
Many of NASA's challenges are not achievable by extensions of current technology

Size per Mass

- Ultra-large apertures
- Solar sails
- Gossamer spacecraft

Diameters > 25-50 m are not achievable by extension of current materials technologies

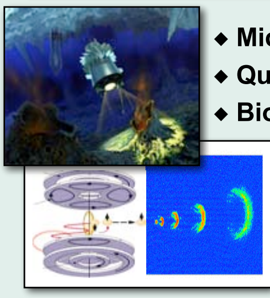
Strength per Mass



- Air/launch/space vehicles
- Human habitats in space
- Self-sensing systems

Factors of 10 - 100 are not achievable by current materials options

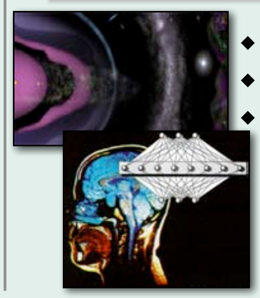
Capability per Mass & Power



- Microspacecraft
- Quantum-limited sensors
- Biochem lab-on-a-chip

Conventional device technologies cannot be pushed much farther

Intelligence per Mass & Power



- Medical autonomy
- AI partners in space
- Evolvable space systems

Current information processing technologies are approaching their limit, and cannot support truly autonomous space systems

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Overarching Constraints

- Performance in Extreme Environments (Radiation, Temperature, Zero Gravity, Vacuum)
- Frugal Power Availability
- High Degree of Autonomy and Reliability
- Human "Agents" and "Amplifiers"

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Key Technology Needs for Lunar Exploration

Structures
- Lightweight cryotanks
- Inflatable space structures

Protection
- Ablative, human-rated TPS
- Lightweight radiation protection
- Dust and contaminant mitigation

Propulsion
- LOX/Methane propulsion system for CEV
- 5 - 20 klbf thrust deep throttleable engine for LSAM
- Non-toxic RCS thrusters
- Expendable SSMEs

Power
- Fuel cells
- Lithium-ion batteries
- Non-toxic Auxiliary Power Unit for CLV

Thermal Control
- Heat rejection for surface systems

Avionics & Software
- Rad hard & low temperature electronics
- Integrated System Health Management
- Spacecraft autonomy
- Automated Rendezvous & Docking
- Autonomous precision landing
- Reliable software

Environmental Control & Life Support
- Atmospheric management
- Environmental monitoring & control
- Advanced air & water recovery systems

Crew Support & Accommodations
- EVA suit
- Crew health care systems
- Habitability systems

Mechanisms
- Low temperature mechanisms

In-Situ Resource Utilization
- Regolith excavation & material handling
- Oxygen production from regolith
- Polar volatile collection & separation

Analysis & Integration
- Tool development for architecture & mission analysis
- Technology investment portfolio assessments

Operations
- Supportability
- Human-system interaction
- Surface handling & operations equipment
- Surface mobility

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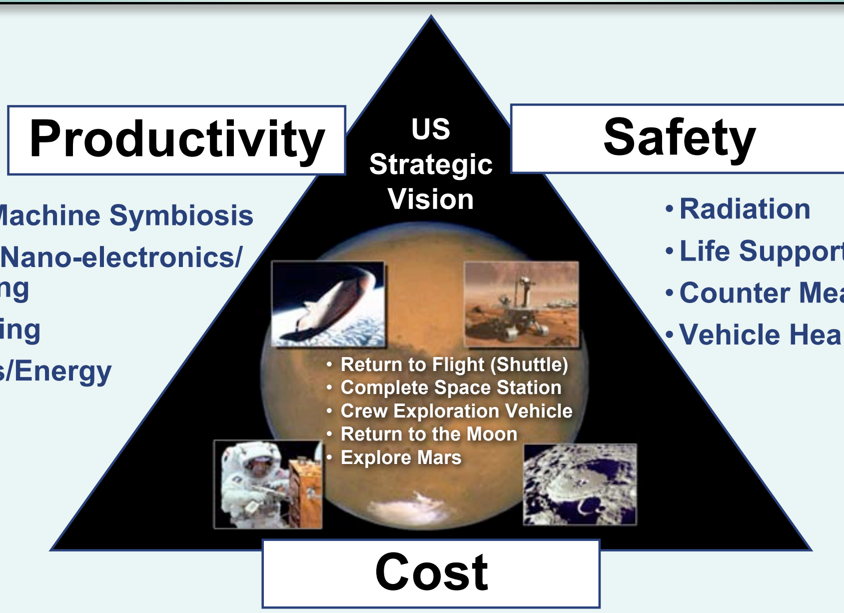
Future Challenges: Exploration Systems



- Human-Machine Symbiosis
- Sensors/Nano-electronics/ Computing
- Data Mining
- Full Cells/Energy Storage

- Radiation
- Life Support
- Counter Measures
- Vehicle Health Mgmt.

- High Strength/Light Weight
- Multifunctionality
- Thermal Management

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Aeronautics Research Mission Directorate

Fundamental Aeronautics:
Subsonic Fixed-Wing and Rotary Wing, Supersonic, Hypersonic

Safety:
Controls, Durability, Integrated Vehicle Health Management (IVHM)

Airspace Management:
Transition and Transit

High Performance, High Efficiency, Low Emissions, Low Noise, Safe Operations Across the Entire Flight Regime

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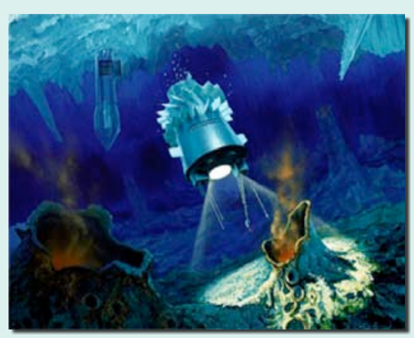
Impact of Nanotechnology on NASA Missions

- **New and Powerful computing technologies**
  - Onboard computing systems for future autonomous intelligent vehicles; powerful, compact, low power consumption, radiation hard
  - High performance computing (Tera- and Peta-flops)
    - processing satellite data
    - integrated space vehicle design tools
    - climate modeling
- **Smart, compact devices and sensors**
  - Ultimate sensitivity to analytes
  - Discrimination against varying and unknown backgrounds
  - Ultrasmall probes for harsh environments
  - Advanced miniaturization of all systems
- **Microspacecraft/Micro-Nanorovers**
  - "Thinking" Spacecraft with nanoelectronics/nanosensors
  - Size reduction through multifunctional, smart nanomaterials



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Ten Most Significant Benefits

- Reduce vehicle structural weight by a factor of 3
- Application Tailored Multi-functional Materials
- Thermal Protection and Management
- Reliable Reconfigurable Radiation/Fault Tolerant Nano-electronics
- On-board Life Support Systems
- On-Board Human Health Management
- 30% lighter EVA Suit
- Micro-craft (< 1 kg) with functionality of current 100 kg spacecraft for science and inspection
- Ultra-Sensitive and Selective Sensing
- Modeling Fabrication Processes for Nano-to-Micro Interfaces

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Focus of NASA Investment

- **Nanostructured Materials**
  - High strength/mass, smart materials for aerospace vehicles and large space structures
  - Materials with programmable optical/thermal/mechanical/other properties
  - Materials for high-efficiency energy conversion and for low temperature coolers
  - Materials with embedded sensing/compensating systems for reliability and safety
- **Nano Electronics and Computing**
  - Devices for ultra high-capability, low-power computing & communication systems
  - Space qualified data storage
  - Novel IT architecture for fault and radiation tolerance
  - Bio-inspired adaptable, self-healing systems for extended missions
- **Sensors and Microspacecraft Components**
  - Low-power, integrable nano devices for miniature space systems
  - Quantum devices and systems for ultrasensitive detection, analysis and communication
  - NEMS flight system @ $1\mu W$
  - Bio-geo-chem lab-on-a-chip for in situ science and life detection
- **University Research Engineering and Technology Institutes**
  - Bio-nano-information technology fusion (UCLA)
  - Bio-nanotechnology materials and structures (Princeton)
  - Bio-nanotechnology materials and structures (Texas A&M)
  - Nanoelectronics computing (Purdue)

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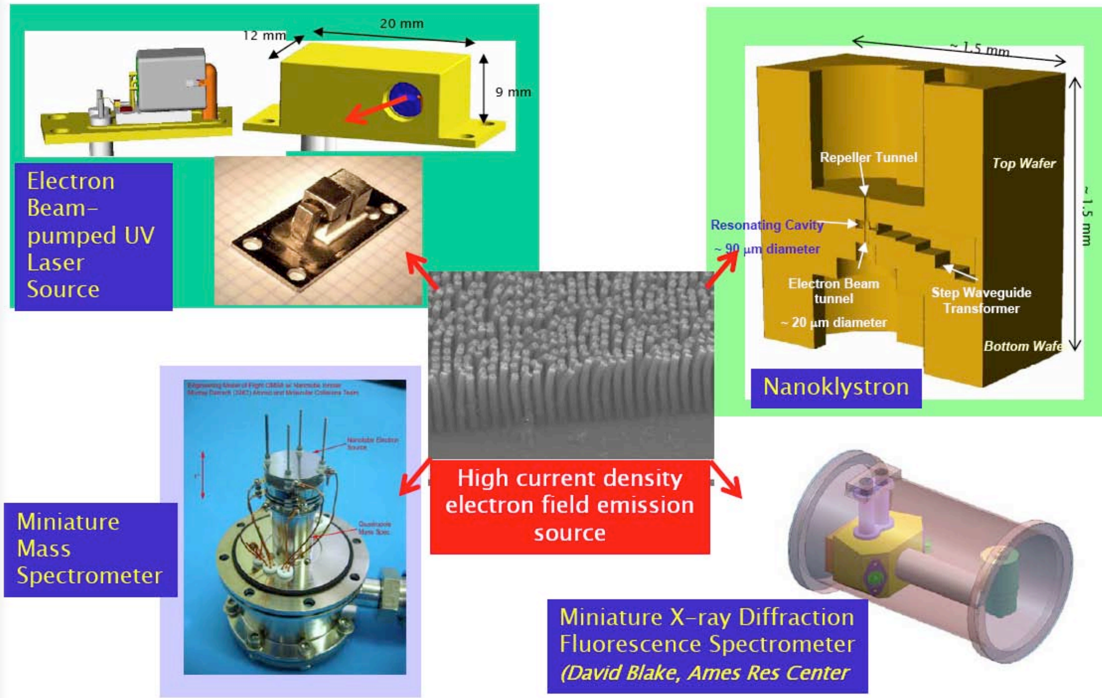
Nanotechnology Accomplishments: Sensors



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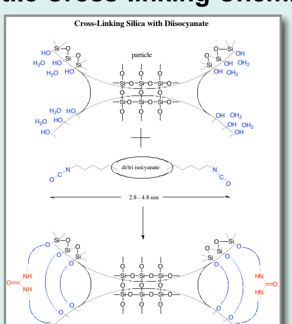
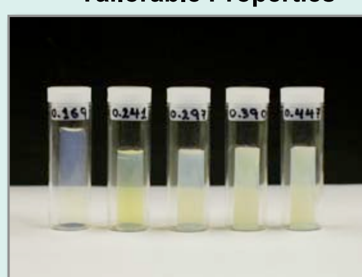
X-Aerogels Have Potential as Structural Materials

Versatile Cross-linking Chemistry

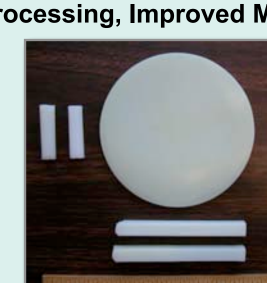


400 Fold Increase in Strength

Tailorable Properties



Simplified (Ambient Pressure) Processing, Improved Machinability



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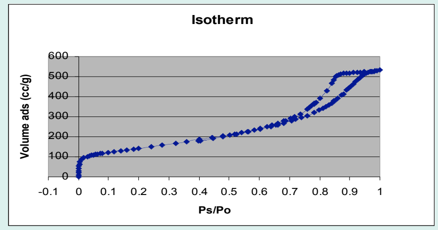
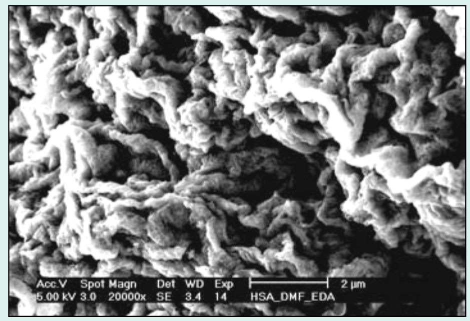
Air Revitalization: Regenerable CO_2 Removal

- Modified Ames process for high/engineered surface area
- Characterization of SWCNT material:
  - BET – Quantitative surface area + pore size
  - SEM – Qualitative surface area characteristics
- **Initial Performance Test:**
  - Solid amine coating: University of Connecticut
  - **Thermogravimetric Equilibrium Experiment**
    - Pressure Swing
    - Temperature Swing

• Reduce system volume
• Increase efficiency
• DoE Smokestack application

BET Surface area 510 m^2/g





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Barriers and Challenges for Nanotechnology

- **Science at the nanoscale**
  - The Physics of the behavior of molecules/atoms at the mesoscale is poorly understood. The full potential of nanotechnology will be realized when such “new” laws are established.
- **Production of nanomaterials**
  - Quantity, quality, control of properties & production in specified forms
- **Characterization at both atomic and bulk scale**
  - Fundamental mechanical, electrical and optical properties
- **Modeling & Simulation**
  - Prediction of physical/chemical properties and behavior from nanoscale to macroscale as well as models for material production

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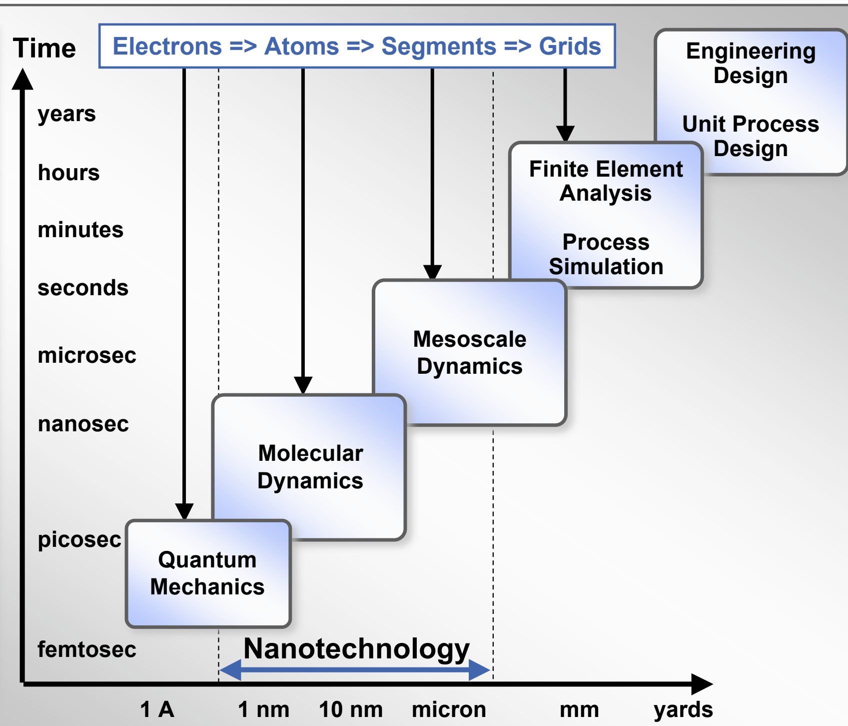
Multi-Scale Simulation Hierarchy

- ***An essential ingredient in the future of nanotechnology is*** the design of new nanoscale devices and test of their performance ***before*** experimental prototyping and manufacturing
- This requires that we base simulations of nanoscale systems on First Principles
- This requires a multiscale strategy in which the information from quantum mechanics is captured in coarser levels to define the essential parameters



W. A. Goddard: Caltech

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Future Research Directions

NOVEL PHENOMENA

Present Phase

- Production of Nanomaterials
- Characterization at Atomic/Bulk Scale
- Nanoscale Modeling and Simulation

Next Phase

- Integration of “Nanoworld” with the “ Macroworld”
- Integration of Wet World with Dry World
- Emergence of Intelligence from Complexity
- Multi-scale Modeling and Simulation Hierarchy

NOVEL PHYSICS (NANOSCALE)

Appendix

Information Sheet on NASA URETIs

University Research, Engineering & Technology Institutes (URETIs)

Princeton University URETI

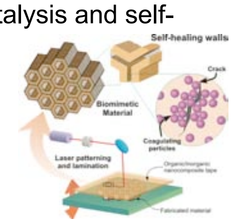
Bio-Inspired Design and Processing of Multi-Functional Nano-Composites (BIMat)

http://bimat.princeton.edu

University of California-Santa Barbara, Northwestern University, University of North Carolina, Nat'l Institute for Aerospace

Technical Emphasis:

To develop innovative processing technologies for the design and modeling of hierarchically structured materials capable of bio-sensing catalysis and self-healing



Education Features:

New coursework at all participating universities and available through the URETI virtual classroom, undergraduate and graduate research projects, ICASE to facilitate NASA/University collaboration, workshops, and seminars

Value to NASA:

The cutting-edge, interdisciplinary R&D complements LaRC work in material and structures and provides new bio perspective and expansion into broad nano-technology areas not otherwise attainable

University Research, Engineering & Technology Institutes (URETIs)

Purdue Institute URETI

Institute for Nanoelectronics and Computing (INAC)

http://inac.purdue.edu

Yale, Northwestern, University of Florida, Cornell, University of California-San Diego, Texas A&M

Technical Emphasis:

Develop fundamental knowledge and enabling technologies in materials/devices, fabrication/assembly, circuit systems and modeling for integrated nanoelectronic systems; major themes of ultradense memory, ultraperformance devices, integrated sensors, and adaptive systems

Education Features:

Emphasis on growing need for interdisciplinary training and professional development, including; curriculum development at all levels; summer institutes for pre-college, college and practicing professional learners; web-based initiatives and training modules

Value to NASA:

Research and development aimed to provide the future generation of high performance computing and advanced miniaturized devices-both critical enabling technologies for NASA missions

University Research, Engineering & Technology Institutes (URETIs)

Texas A&M University URETI

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

http://tiims.tamu.edu/

Rice University, Texas Southern, Prairie View A&M, University of Texas-Arlington, University of Houston

Technical Emphasis:

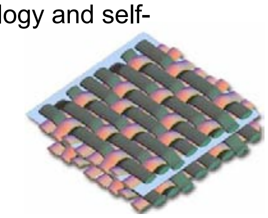
Basic and applied research in the integration of sensing, computing, actuation and communication in smart materials and bio-materials; to enable health monitoring and fault-tolerant, adaptive control; focus on carbon nano-tube technology

Education Features:

A full spectrum of educational opportunities including, curricular renovation and research opportunities at all post-secondary levels; special degree tracks for aerospace professionals; personnel exchange between NASA and universities; and distance learning components via the Trans-Texas Video Network

Value to NASA:

Continuation and expansion of carbon nano-tube research and scale-up of critical interests to NASA, introduction of bio-mimetics into the development of sensor/actuator technology and self-assembly



University Research, Engineering & Technology Institutes (URETIs)

University of California-Los Angeles URETI

Center for Cell Mimetic Space Exploration (CMISE)

http://www.cmise.ucla.edu/

California Institute of Technology, Arizona State, University of California-Irvine

Technical Emphasis:

To mimic the complexity of the multi-scale information management (bio-informatics) of living systems, coupled with the development of new, scalable nano-technologies in sensors, actuators and energy sources

Education Features:

To provide opportunities across the entire spectrum of learner; learning tools for K-12, research experiences and internships for undergraduates, support for graduate training, cross-disciplinary coursework, and seminars and workshops

Value to NASA:

Addresses the fusion of bio, nano, and information technology in areas of direct relevance to NASA, such as, energetics, systematics and metabolics, and rich in the the development of bio-mimetic devices of critical interest

Biomotors systems powered by ATP production