Convergence of Nano-, Bio-, & Info- Technologies: A NASA Perspective

Technologies Shaping the Future
UCLA
October 11, 2002
Information Technology

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Office of Aerospace Technology
NASA
Goals for Future NASA Space Systems

**Autonomous**
- Systems that think for themselves and understand uncertainty
- Create information and knowledge from data
- Greater productivity with less people

**Resilient**
- Highly durable and damage tolerant: ability to perform self-diagnosis and repair
- Long life in the harshest conditions

**Ultra-Efficient**
- Optimal use of mass, power and volume
- Travel about the Earth and the universe rapidly, safely and at low cost

**Evolvable**
- Adapt form and function to meet changing demands and overcome unanticipated problems
- Grow and expand capability to exploit new opportunities

**Self-Sufficient**
- Minimal on-board resources
- No lifeline to Earth "Live off the land"

Broad, continuous presence and coverage
Interactive networks to achieve maximum capability and economy
NASA 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
Challenges in Resiliency: Exploring the Solar System

Extreme Environments in Planetary Missions

Temperature K

Radiation Dose in MRads

Planets and Moons: Europa, Io, Triton, Uranus, Jupiter, Mars, Moon, Mercury, Venus, Titan, Comet

Limit of Defense Interest, Limit of Commercial Interest

- Distributed self-assessment and repair
- Adaptive shape control
- Highly efficient propulsion
- Exploits Bio-Nano-Info technology revolution

Bio/Nano/Thinking/Sensing Vehicle

Self-Healing Structure with “Central Nervous System”

Smart Structure with Active Flow Control

Modern Advanced Metal Aircraft

- Ultra Safe
- Whisper Quiet
- “Zero” Emissions
- Extreme Maneuverability
- High Survivability
- Ultra Low Fuel Burn

Time
Chemistry/Physics of Biological Nanostructure

Earlier Detection and Treatment of Disease
Contrast Agents for Imaging
Sensors
Susceptibility Testing (DNA/RNA)

Improved Implants

Therapeutic Delivery
Enhanced Solubility
Targeted, Local Delivery

Nanosphere enhanced drug solubility (Nanosphere)
Revolutionary Technology Vision:
The “Zone of Convergence”

Biotechnology → Intelligent, Evolvable, Adaptive Systems → Nanotechnology

Information Technology
Critical Nanotechnology Investment Areas

- **Nanostructured Materials ($10 M)**
  - 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 ($9 M)**
  - 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 ($8 M)**
  - Low-power, integrable nano devices for miniature space systems
  - Quantum devices and systems for ultrasensitive detection, analysis and communication
  - NEMS flight system @ 1µW
  - Bio-geo-chem lab-on-a-chip for in situ science and life detection

- **University Research Engineering and Technology Institutes ($12 M)**
  - Bio-nano-information technology fusion (UCLA)
  - Bio-nanotechnology materials and structures (Princeton)
  - Bio-nanotechnology materials and structures (Texas A&M)
  - Nanoelectronics computing (Purdue)

- **Basic Nanoscience ($15 M)**
  - Biomolecular self-assembly and processing in space
  - Non-invasive diagnostic tools
  - Molecular signature for early detection
  - Tools for study of space-induced health effects
An essential ingredient in the dream of nanotechnology is to design new nanoscale devices and test 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.

Electrons $\Rightarrow$ Atoms $\Rightarrow$ Segments $\Rightarrow$ Grids

- Time
  - Years
  - Hours
  - Minutes
  - Seconds
  - Microsec
  - Nanosec
  - Picosec
  - Femtosec

- Distance
  - 1 Å
  - 1 nm
  - 10 nm
  - Micron
  - mm
  - yards

Multi-Scale Simulation Hierarchy

Engineering Design
  - Unit Process Design
  - Finite Element Analysis
  - Process Simulation
  - Mesoscale Dynamics
  - Molecular Dynamics
  - Quantum Mechanics
ASSEMBLY

ATOMIC/MOLECULAR MANIPULATION

SELF ASSEMBLY
DEFECT MINIMIZATION
DIRECTED HEIRARCHICAL

MATRIX EMBEDDED (COMPOSITE)

COMPACTION

COATING

Quantum Corral
(D. Eigler, IBM)

Self Assembled Au
(Whitesides, Harvard)

Net Shape Forming via Consolidated Titania and Alumina Nanoparticles
(R. Siegel and Nanophase Technology Corp.)
NASA Research in Nanotechnology

Aerospace Vehicle Materials and Structures

Program Elements
- Nanotube Fiber Development
- Composite Matrix Development
- Multifunctional Structures

11 Participating Universities

Nano-Electronics and Computing

Program Elements
- Computational Modeling
- Computing Architectures
- Bio-Nano Synergy

11 Participating Universities

High Temperature Materials

Program Elements
- CNT / Polymer & Ceramic Matrix Comp
- High Temperature Nanotubes (e.g. BN)
- Nanostructured Alloys & Coating

7 Participating Universities

Sensors and Components for Microspacecraft

Program Elements
- Advanced Sensing and Actuation
- Micro-Electro-Mechanical Systems
- Nano-Electronics

12 Participating Universities
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<tr>
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<td><strong>Total</strong></td>
<td>~$1400M</td>
<td>&gt;$2000M</td>
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*Fiscal year start/stop varies from country to country*
Barriers and Challenges for Nanotechnology

- 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

- Applications Development
  - Tools and techniques for applications of nanotechnology
  - Verification of predicted behavior/performance in actual environments
  - Systems Analysis to guide technology development
Summary

- NASA’s nanotechnology initiative is part of a national effort to stay in the race for the 21st century technological leadership.

- NASA faces unique challenges in the coming decades that cannot be achieved with existing technologies.

- Emerging nanotechnology-based capabilities in nano engineered materials, nano electronics and biomolecular nanotechnology offer possible solutions for these challenges.
Summary

The most direct path from the Earth to the depths of Europa's ocean....

Will be the path enabled by advances in info-, nano, and bio-based technologies.