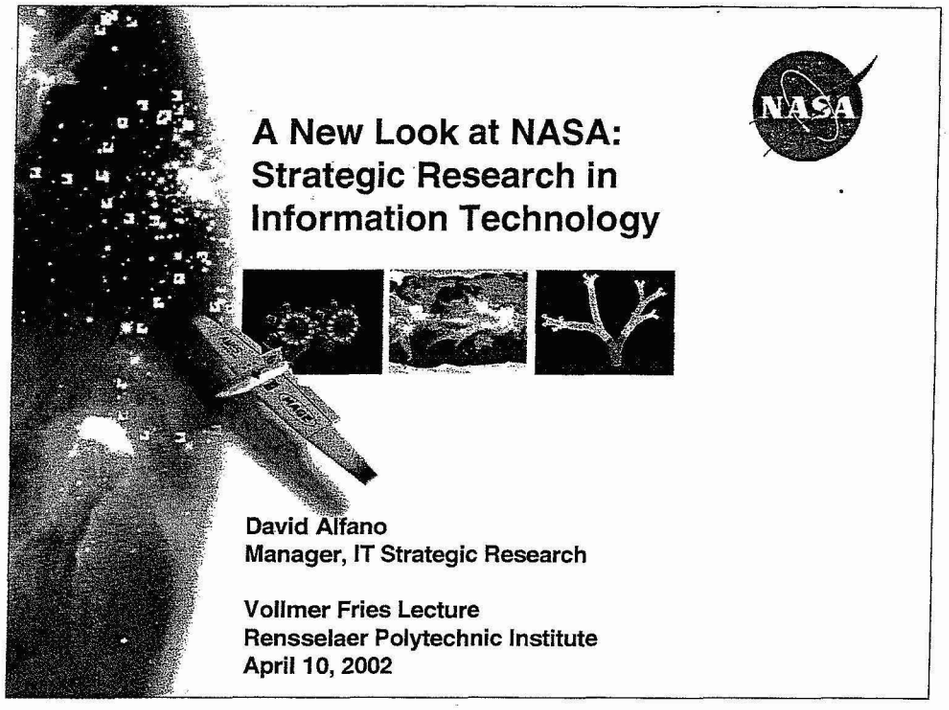


A New Look at NASA: Strategic Research in Information Technology

David Alfano
Manager, IT Strategic Research

Vollmer Fries Lecture
Rensselaer Polytechnic Institute
April 10, 2002

NASA's Strategic Enterprises

Earth Science - Use the unique vantage point of space to provide information about Earth s environment that is not obtainable in any other way.

Space Science - Solve the mysteries of the universe, explore the solar system, discover planets around other stars, search for life beyond Earth, chart the evolution of the universe and understand its galaxies, stars, planets, and life.

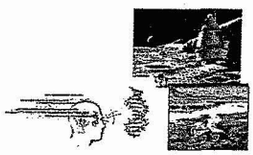
Human Exploration and the Development of Space - Open the space frontier by exploring, using, and enabling the development of space and expand the human experience into the far reaches of space.

Biological and Physical Research - Conduct basic and applied research to support human exploration of space and take advantage of the space environment as a laboratory for scientific, technological, and commercial research.

Aerospace Technology - Pioneer the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics and space transportation technologies.

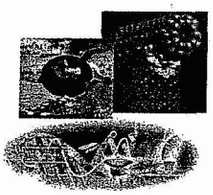
NASA Mission
CICT Technology Requirements

NASA Mid- and Long-Term Mission Plans are reliant on the availability of advanced information technologies:



— **Smarter more intelligent, collaborative systems including:**
- ¥ *Autonomous spacecraft control and scientific discovery*
- ¥ *Intelligent sensor webs and cooperating constellations*
- ¥ *Integrated human/robotic explorers*

— **Advanced computing and communication systems including:**
- ¥ *Breakthrough science and engineering simulation capabilities*
- ¥ *Mobile, distributed analysis, data mining, and collaboration capabilities*
- ¥ *Pervasive Earth-to-deep space NASA web technologies to support robotic and human exploration*



— **Information Technology Strategic Research, including:**
- ¥ *Intelligent controls and diagnostics*
- ¥ *Evolvable systems*
- ¥ *High confidence software*
- ¥ *Biotechnology and nanotechnology*
- ¥ *Revolutionary computing concepts*

ITSR

Ames Research Center

Information Technology Strategic Research

Bio/Nano Technologies
Biomolecular and nanoscale systems and tools for assembly and computing

Evolvable Systems
Autonomous, self-improving, self-repairing hardware and software for survivable space systems in extreme environments

IT Strategic Research:
Research, develop and evaluate a broad portfolio of fundamental information and bio/nano technologies for infusion into NASA missions.

Revolutionary Computing
New computational models to increase capability and robustness to enable future NASA space missions

High Confidence Software Technologies
Formal methods, high-assurance software design, and program synthesis

Intelligent Controls & Diagnostics
Next-generation machine learning, adaptive control, and health management technologies

ITSR

Ames Research Center

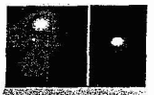
Information Technology Strategic Research

(Technology Research Portfolio Overview)

Bio/Nano Technologies
- ¥*Nanoscale Assembly*
- ¥*Nanoscale Electronics & Computing*
- ¥*Biomolecular Systems*

Evolvable Systems
- ¥*Adaptation and Learning*
- ¥*Optimization and Design*
- ¥*Reconfiguration and Reuse*
- ¥*Biologically inspired technologies*

IT Strategic Research:
Research, develop and evaluate a broad portfolio of fundamental information and bio/nano technologies for infusion into NASA missions.



High Confidence Software Technologies
- ¥*Formal Methods*
- ¥*High Assurance S/W Design*
- ¥*Program Synthesis*

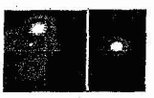
Revolutionary Computing
- *Physics-inspired architectures*
- *Biology-inspired architectures*
- *Space computing*

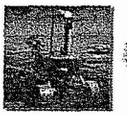
Intelligent Controls & Diagnostics
- *Fundamental neural flight control research*
- *Neuroelectric machine control*
- *Intelligent Automation*
- *Smart sensing & diagnostic technologies*

ITSR

IT Strategic Research

Mission Impact





Capabilities

2001-2005	2005-2010	2010-2015
¥ Scalable aerospace software verification technology	¥ Auto-synthesis of certified software systems	¥ Widespread robotic construction of software
¥ Next-generation evolutionary algorithms	¥ Self-reconfiguring hardware systems	¥ Defect-tolerant, self-improving micro spacecraft
¥ Third-generation neural flight control algorithms	¥ Biomimetic control architectures	¥ Intelligent Maneuvering
¥ Evolutionary algorithms for on-board space algorithms	¥ Quantum algorithms for computationally hard problems	¥ Revolutionary computing platforms
¥ Nanoscale assembly techniques	¥ Biomolecular systems	¥ Self-repairing nanosystems

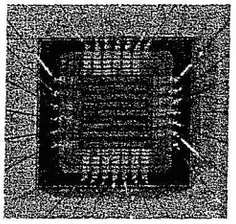
ITSR

Evolvable Systems: Focus Areas

Evolvable Systems can make significant impacts on:

Reconfiguration and Re-use

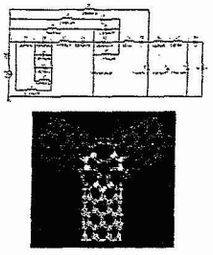
System reconfigures itself or is able to re-use available resources for new or existing functions.



SAFETY

Optimization and Design

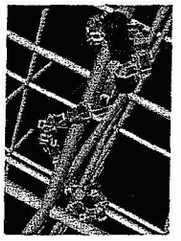
System designed or optimized using evolutionary algorithms.



PERFORMANCE

Adaptation and Learning

System adapts to new environments by sensing, learning, and automated discovery.



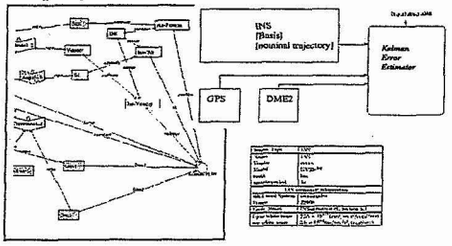
AUTONOMY

ITSR

Ames Research Center

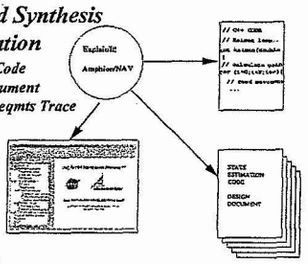
Automated Program Synthesis

Specification



Automated Synthesis & Verification

- *Commented Code*
- *Detailed Document*
- *Web-based Reqmts Trace*



- Verifiably correct program synthesis based on automated reasoning. Demonstrated on critical avionics GN&C domain (2001).
- Spin-off to IS program leading to insertion in JPL's Mission Data Systems project.
- Synthesis enables rapid design-space exploration.
- Verification proof transformed into products that provide basis for manual certification: requirements/design trace and detailed documentation.
- Automated certification technology for synthesized code under development for 2003.
- Longer-term goal: meta-technology for rapid generation of domain-specific program synthesis systems, improving current methods by an order of magnitude.

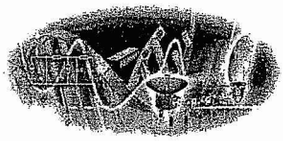
ITSR

Ames Research Center

Revolutionary Computing Architectures: Focus Areas

- Based on current technology and research trends, two approaches have been identified.

Physics-inspired computing
Develop capabilities based on quantum and statistical physics



Quantum computing

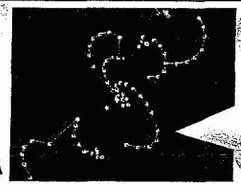
Biology-inspired computing
Develop capabilities based on adaptation, evolution and self-repair

Neural computing
Evolutionary computing
DNA and molecular computing

- Topics pursued here are based on distributed interacting computing elements which offer new models for computation with increased capability and robustness

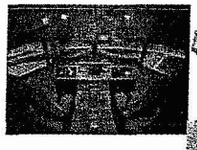
Intelligent Flight Control

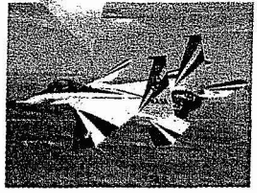
	TRL=7	TRL=5	TRL=3
Gen 1: Indirect Adaptive (F-15)	←	▲	
Gen 2: Direct Adaptive (Transport)	←	----	▲
Gen 2.5: Hybrid Direct/Indirect (C-17)	←	----	▲



High performance neural network algorithms

1st Generation
NASA/Boeing neural flight control system currently being tested on modified F-15 ACTIVE aircraft





2nd Generation
Integrated neural flight and propulsion control system; piloted flight simulation successfully demonstrated

Hybrid
Direct/Indirect adaptive approach being developed for C-17 flight test

Impact: ability to provide improved handling qualities for severe failures in a reduced flight envelope that would otherwise result in a catastrophic event.

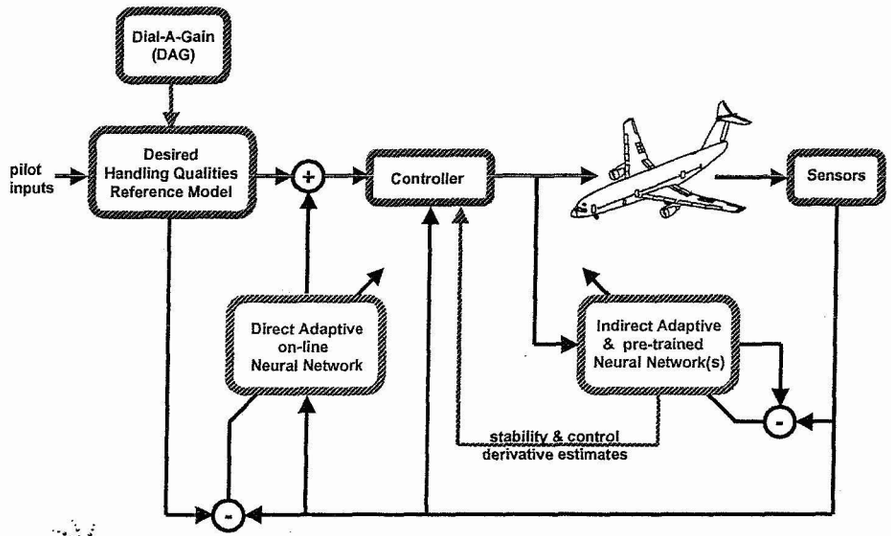
What are Neural Networks?

- There are many variations of neural networks, but fundamentally they can be characterized as:
  - Composed of a very large number of simple processing elements based upon our understanding of the brain s neurons;
  - Processing elements acquire data via sensory inputs;
  - Processing elements store data locally, and pass information to other processing elements via interconnections;
  - Processing elements have a fundamental ability to be trained until a desired output is achieved, and are able to adapt to change.
- Advanced neural control designs are crossing engineering barriers of high numerical accuracy and provable system stability
- Neural Flight Control Systems merge nonlinear optimization and control techniques with neural learning and adaptivity
  - Stochastic Optimal Control
  - Feedback Linearization
  - Generalized Predictive Control
  - Numerical optimization

Dynamic Cell Structure Neural Network Learning Nonlinear Problem

ITSR

Neural Flight Control System



ITSR

Information Technology Program
Technical Accomplishment

Intelligent Neural Flight and Propulsion Control System (INFPCS)
POC: Dr. Karen Gundy-Burlet, Ames Research Center (704-30/31-12)

Relevant Milestone: Description:Combine Propulsion Controlled Aircraft (PCA) control laws with the Intelligent Flight Control System (IFCS) to demonstrate a new capability for adapting to absence or loss of any and all control surfaces resulting from failures or malfunctions up to and including propulsion only flight. Output: Flight control system capable of maintaining adequate flying qualities throughout a broad range of failures, including the complete loss of all control surfaces in reduced flight envelope. Outcome: Integrated controls/propulsion system for enhanced safety of commercial aircraft

Shown: Depicted is the INFPCS daisy-chain control allocation scheme, based on a second generation neural flight control architecture applied to generic transport aircraft simulation. The daisy-chain scheme utilizes remaining operational surfaces and the propulsion system in an unconventional manner (e.g. symmetric ailerons or symmetric throttles for pitch control and rudder or differential throttles for yaw-based roll control) in order to compensate for more severe failures.

Accomplishment / Relation to Milestone: Accomplishments include reduced or eliminated need for a-priori knowledge of the nominal plant dynamics, explicit parameter identification, and the type/extent of failure or damage, incorporation of a Rate-Command-Attitude-Hold (RCAH) capability, fine-tuned handling qualities, redundant control power in the event of the loss of actuator control, additional control authority in the event of actuator control saturation, and demonstrated ability to provide improved handling qualities for severe failures in a reduced flight envelope that would otherwise result in a catastrophic event.

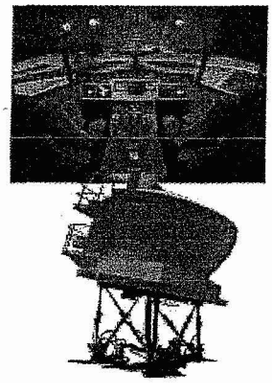
Future Plans: Flight Research R&T Base Program, Intelligent Systems Program, and the Design for Safety Initiative are directly involved in funding/planning flight tests on the F-15 837 (formerly ACTIVE) and C-17, with defined milestones designed to systematically develop and mature existing and new neural flight control systems that exhibit increasing levels of intelligence. A short-term study has also been initiated to examine a low cost retrofit solution for commercial transports, and is scheduled to be complete in 3QFY01.

ITSR

ETG: 1) Reduce aircraft accident rate resulting from loss of control in-flight
2) Provide next generation design tools to reduce control law development cost and time

Intelligent Neural Flight Control System

- ¥ Handling Qualities Evaluation
  - — Performance Under Nominal Conditions
  - — Performance Under Failure Conditions
  - — Neural Network Adaptive Performance
- ¥ Failure Analysis & Ratings
  - — Stabilizer (Nose-Down Trim) Failure
  - — Engine-Out Failure
  - — Rudder (Hard-Over) Failure
  - — Overall Pilot Ratings
- ¥ Evaluation Criteria
  - — *Improve flying qualities* over the standard and conventional controllers under failure conditions.
  - — Achieve *consistent handling qualities* in the presence of failures while sufficient control authority remains.



NASA DFRC Test Pilots
- Gordon Fullerton
- Jim Smolka

ITSR

Flight Control Accidents & Incidents

(over 1100 lives lost)

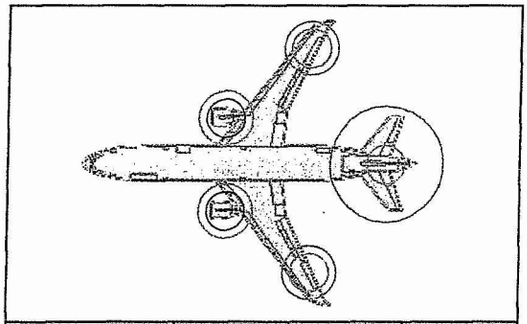
Approach is to consider trends in the area of "Loss of Control In-Flight": In a survey of 10 flight control accidents and incidents, systems remaining operational after damage/failure usually include all engines and flaps, and often ailerons. Tail controls are usually lost.

Aircraft	Aileron	Flaps	Rudder	Elevator	Stabilizer	Engines	Cause
UA DC-10	no	no	no	no	no	center out	fan disk/hyd
JAL B-747	no	yes	no	no	no	all OK	aft bulk/hyd
USAF C-5A	yes	yes	no	no	no	all OK	cargo ramp/hyd
USAF B-52H	yes	yes	no	no	no	all OK	hyd leak/tail
Turkish DC-10	yes	yes	no	no	no	all OK	door/cables/hyd
USN F/A-18	no	yes	no	yes	yes	all OK	stab LVDT/mec
USAF A-10	yes	yes	no	no	no	all OK	AAA/cables
USAF B-52G	yes	yes	no	no	no	all OK	hyd leak/tail
Delta L-1011	yes	yes	no	yes	one side	all OK	jammed stab
AA DC-10	yes	yes	no	part	yes	center idle	cargo dr/cables

ITSR

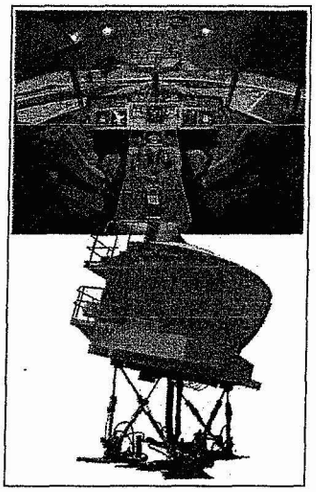
Information Technology Program

Daisy-Chain Control Allocation Scheme



Daisy-Chained Control Allocation	Lateral	Directional	Longitudinal
Primary Flight Controls	Differential Ailerons	Rudder	Symmetric Elevators
Backup Flight Controls	Yaw-Based Roll Control	Differential Thrust	Symmetric Ailerons
---	---	---	Symmetric Thrust

Advanced Concepts Flight Simulator



ITSR

Intelligent Neural Flight Control System

Handling Qualities Evaluation

Neuro-Electric Machine Control

Current research areas:

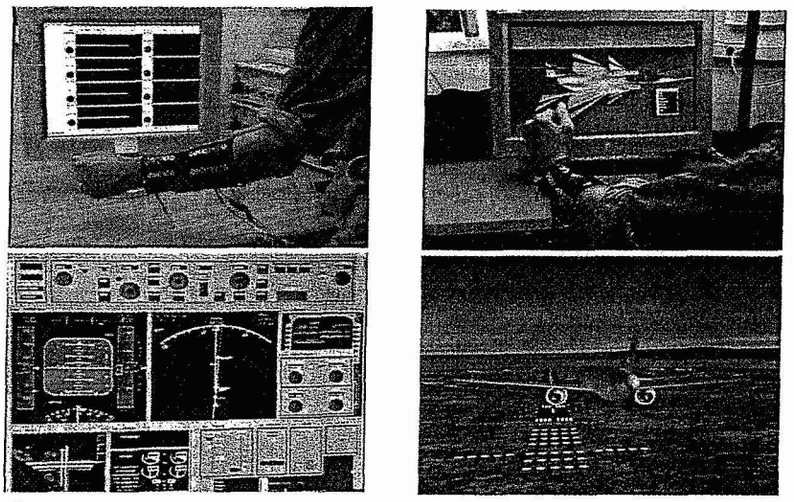
Silent sub-vocal Speech (EMG):

- ¥Using throat EMG to detect silent sub-vocalized speech.
- ¥ Provides speech recognition in a noisy environment.
- ¥ Allows communication without external movement.

Cursor Control (EEG):

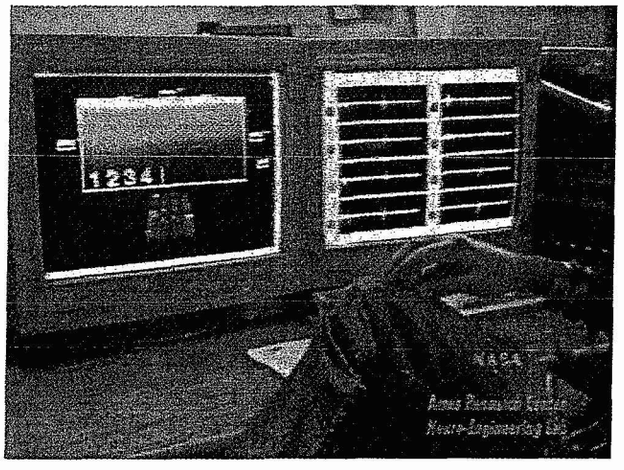
- ¥ Using EEG scalp electrodes for cursor control.
- ¥ mu-rhythm sensed from motor cortex for imagined. movement translated to motion control commands.
- ¥ Evoked response potentials used for selection tasks.

Output Sensory Mapping: Virtual Joystick



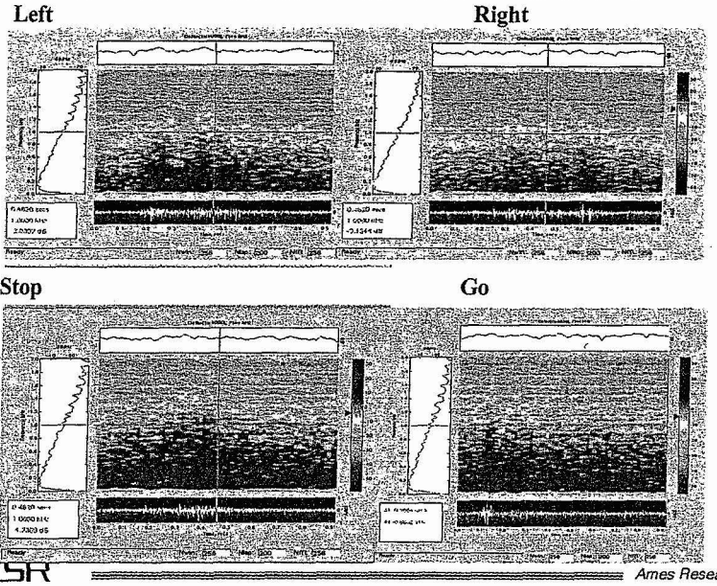
ITSR

Output Sensory Mapping: Virtual Typing

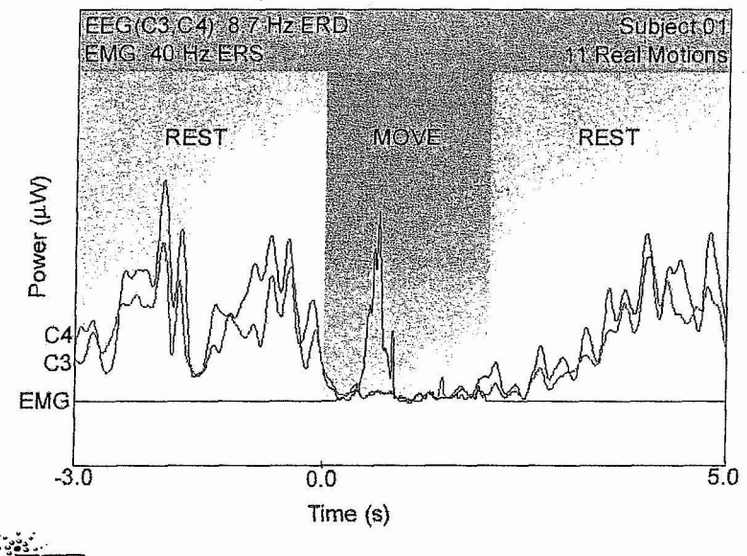


ITSR

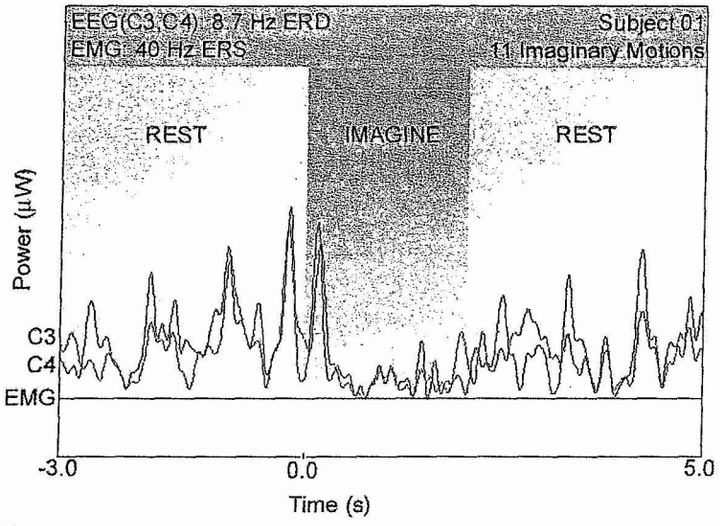
Spectrogram on EMG Data: silent "left", "right", "stop", and "go"



EEG Desynchronization with Movement



EEG Desynchronization with Imagination



ITSR

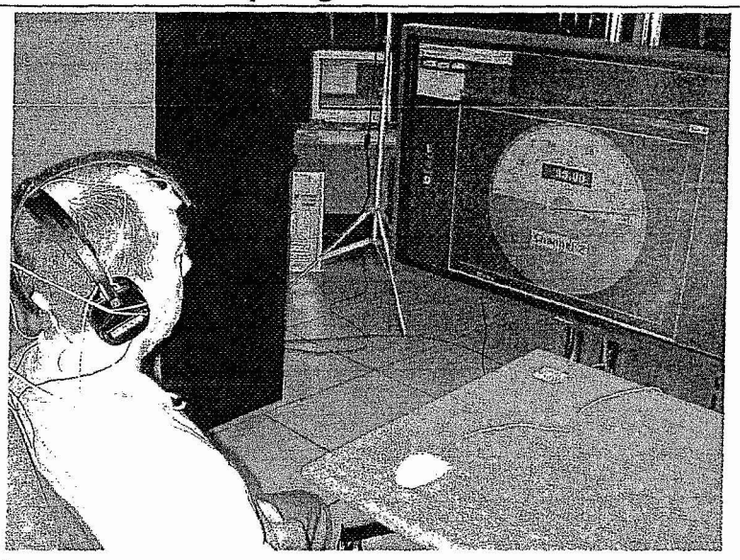
Ames Research Center

Closed Loop EEG Training: 64 electrodes

ITSR

Ames Research Center

Closed Loop EEG Training: sponge electrodes



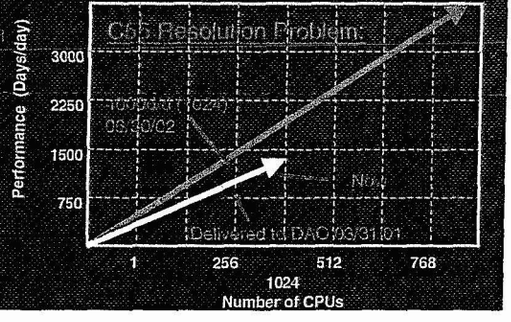
ITSR

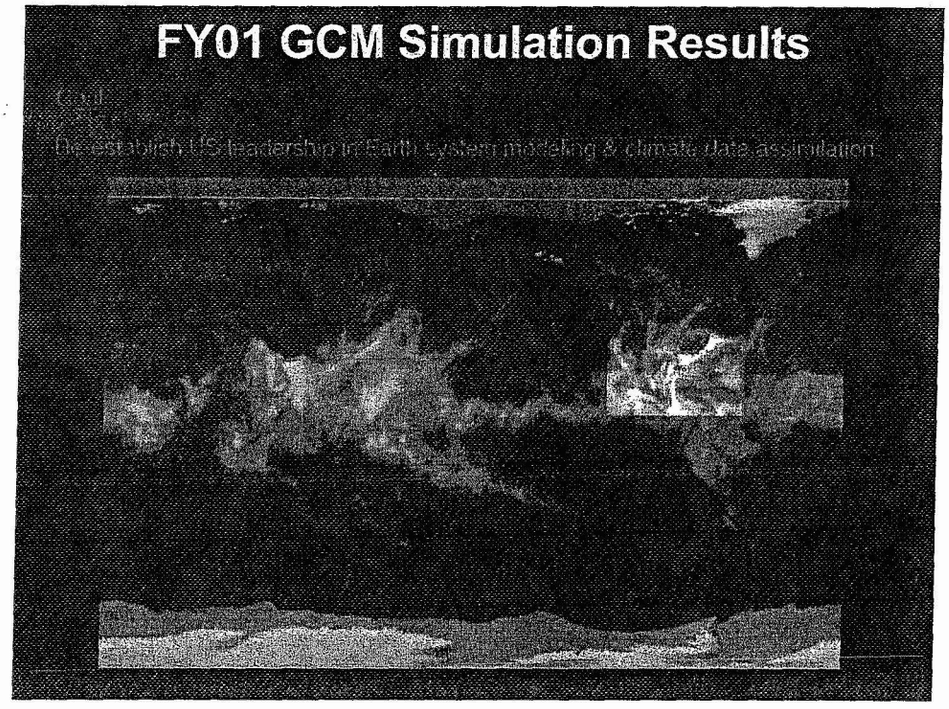
Ames Research Center

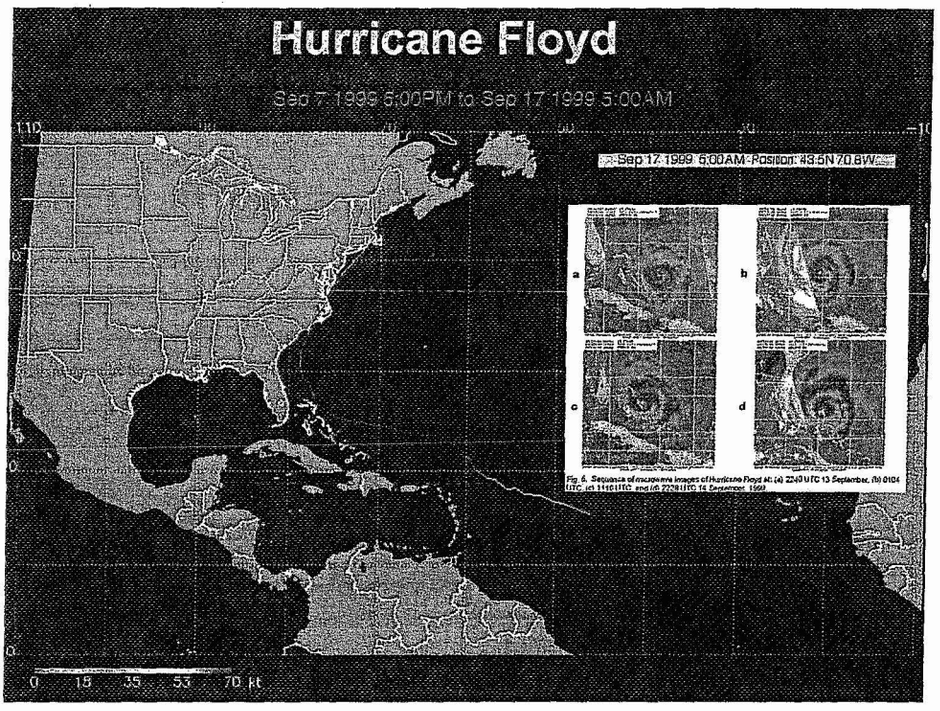
Earth System Modeling

Working with Earth Science Enterprise & Goddard Space Flight Center

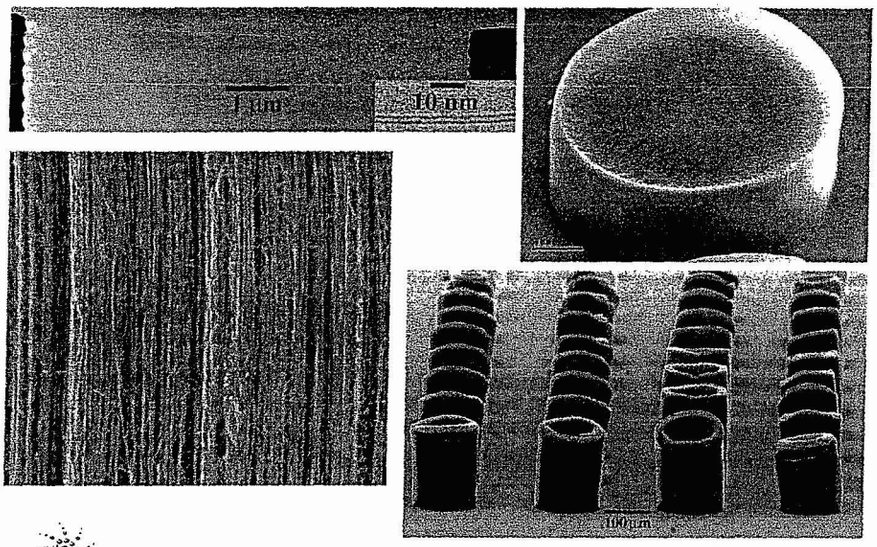
- ARC to provide a path-finding role in computing testbed, [illegible] and platform stabilization to support [illegible] production computing needs




FY01 GCM Simulation Results
Re-establish US leadership in Earth system modeling & climate data assimilation


Hurricane Floyd
Sep 7 1999 5:00PM to Sep 17 1999 5:00AM
Sep 17 1999 5:00 AM Position: 33.5N 70.8W
a
b
c
d
0 15 35 53 70 kt

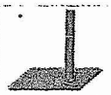
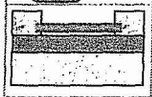
Carbon Nanotubes at Ames Research Center



Why Nanotechnology at NASA?

- ¥ Advanced miniaturization, a key thrust area to enable new science and exploration missions
  - Ultrasmall sensors, power sources, communication, navigation, and propulsion systems with very low mass, volume and power consumption are needed
- ¥ Revolutions in electronics and computing will allow reconfigurable, autonomous, thinking spacecraft
- ¥ Nanotechnology presents a whole new spectrum of opportunities to build device components and systems for entirely new space architectures
  - Networks of ultrasmall probes on planetary surfaces
  - Micro-rovers that drive, hop, fly, and burrow
  - Collection of microspacecraft making a variety of measurements
- ¥ In vivo and noninvasive astronaut health diagnosis and prognosis, in vivo therapy

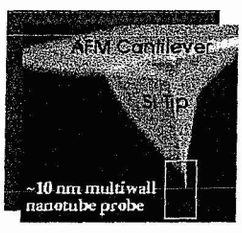
Applications of Nanotubes

Device	Description	Application
	Nanotube grown on silicon substrate	Extraordinary mechanical and electrical properties enable (1) **scanning probes**, (2) nanoelectrodes, and (3) **field emitters**
	Molecular probe bonded on nanotube ends	Nanoelectrodes enable a variety of biosensors when attached with molecular probes such as DNA and proteins. **DNA sensors** enable in-vitro and in-vivo detection of diseases.
	Membrane coated on nanotube side wall	Nanoelectrodes enable a variety of biosensors when coated with molecular membranes such as enzyme and polymers
	Nanotube between two electrodes in MOSFET configuration	Ultra sensitive electric response to electric and chemical signal enable nanotube transistors for nanoscale logic devices and **chemical sensors**
	Buckled or junction nanotube between two electrodes for intra-molecular electronic devices	Ultra sensitive electric response to structural / mechanical deformation enables intra-molecular devices for single Electron transistors and quantum dots. (Cees Dekker, http://www.mb.tn.tudelft.nl/nanotubes.html)

Carbon Nanotubes in Microscopy

Atomic Force Microscopy is a powerful technique for imaging, nanomanipulation, as platform for sensor work, nanolithography...

Conventional silicon or tungsten tips wear out quickly. CNT tip is robust, offers amazing resolution.



Simulated Mars dust

H. Dai

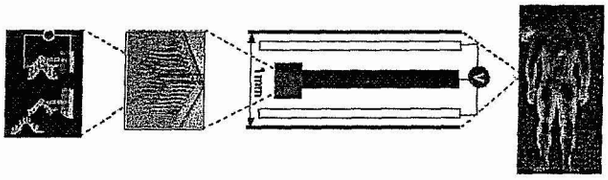
NASA Ames Research Center
Ramsey Stevens, Lance Delzeit, Cattien Nguyen

Carbon Nanotube Based Biosensors

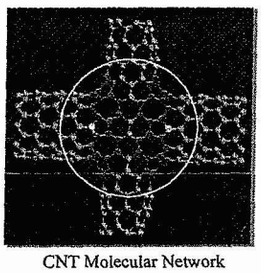
¥ Our interest is to develop sensors for astrobiology to study origins of life. CNT, though inert, can be functionalized at the tip with a probe molecule. Current study uses AFM as an experimental platform.

¥ The technology is also being used in collaboration with NCI to develop sensors for cancer diagnostics
- Identified probe molecule that will serve as signature of leukemia cells, to be attached to CNT
- Current flow due to hybridization will be through CNT electrode to an IC chip.
- Prototype biosensors catheter development

- High specificity
- Direct, fast response
- High sensitivity
- Single molecule and cell signal capture and detection

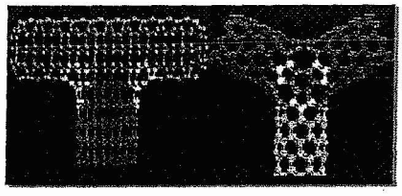


Computational Nanotechnology

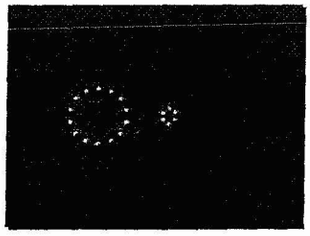


CNT Molecular Network

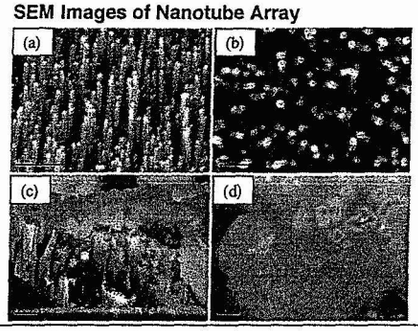
- Large scale computer simulations based on ab initio methods enable understanding nanotube characteristics and serve as design tool
  - Evaluation of mechanical properties
  - Evaluation of electronic properties
  - Electron transport in CNT devices
  - Functionalization of the nanotubes
  - Design of electrical and mechanical devices
  - Evaluation of storage potential (H_2, Li)



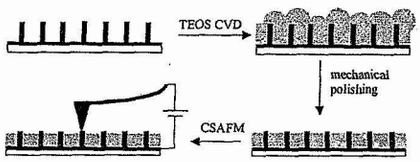
CNT "T" and "Y" Junctions



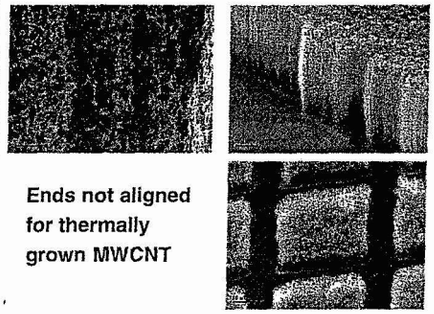
SEM Images of Nanotube Array



Schematic of CNT Vertical Array Fabrication Procedure

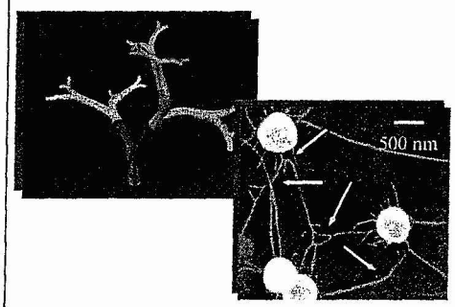


Multi-Walled Carbon Nanotubes



Ends not aligned for thermally grown MWCNT

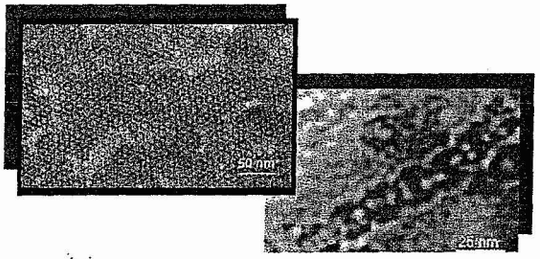
Four Level CNT Dendritic Neural Tree

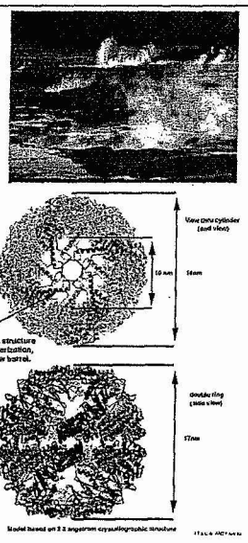


Protein Nanotubes

- Heat shock protein (HSP 60) in organisms living at high temperatures ("extremophiles") is of interest in astrobiology

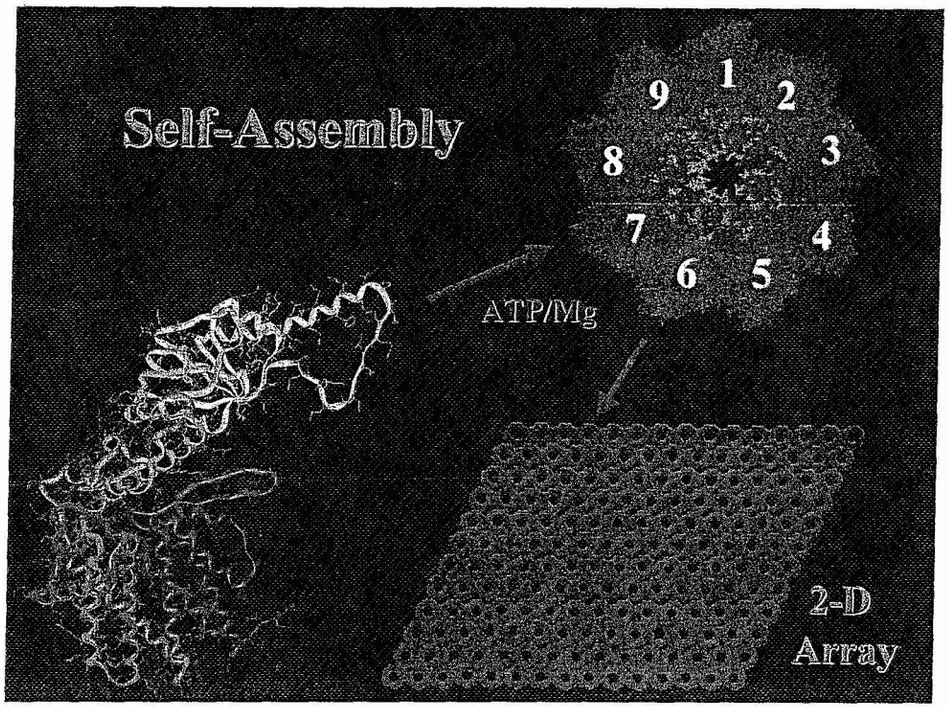
- HSP 60 can be purified from cells as a double-ring structure consisting of 16-18 subunits. The double rings can be induced to self-assemble into nanotubes.





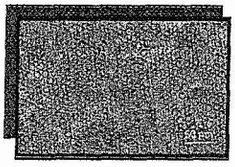
ITSR

Ames Research Center

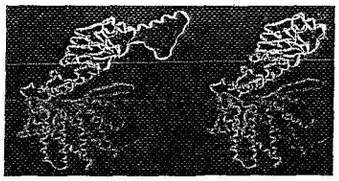


Extremophile Proteins

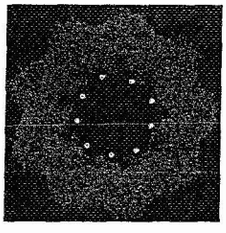
Easily purified



Self-assemble



Genetically alterable



New Tools for Nanotech.

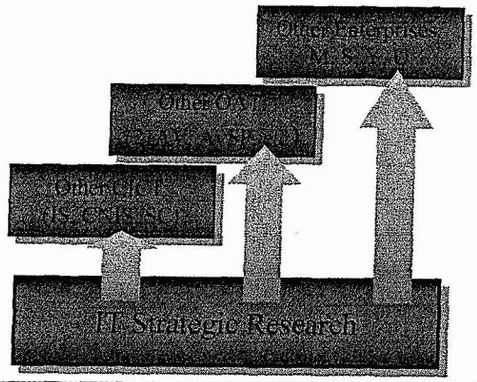
ITSR

Ames Research Center

ITSR as Technology Incubator

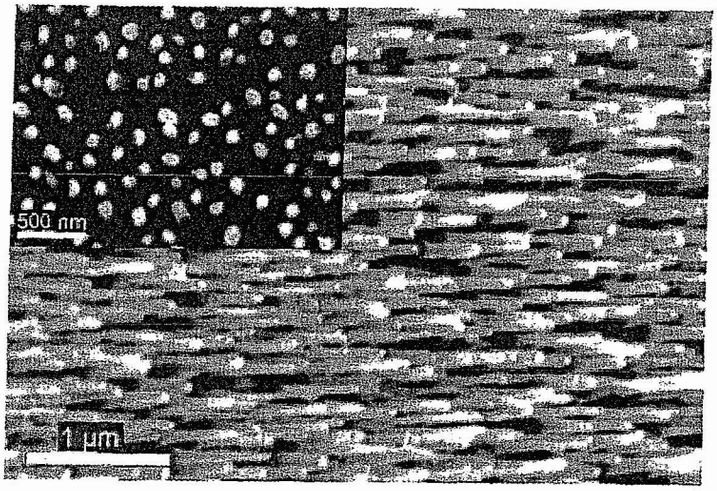
¥IT Strategic Research explores new and revolutionary concepts in information technology, and provides proof-of-concept demonstrations as well as low- Technology Readiness Level technology maturation.

¥ITSR technologies are handed off to other projects within CICT, and other Programs and Missions throughout NASA.



ITSR

Thanks for your attention!



(vertically aligned carbon nanotubes)

ITSR