# Structural Health System for Crew Habitats

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**April 21, 2005**

**University of Illinois, Urbana-Champaign**
**Aerospace Engineering and Theoretical and Applied Mechanics Seminar**

# Outline

- JPL background
- Flexible electronics for space applications
- New direction for NASA
- Structural health monitoring for crew habitats

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# History of JPL

1936

1958

1940s

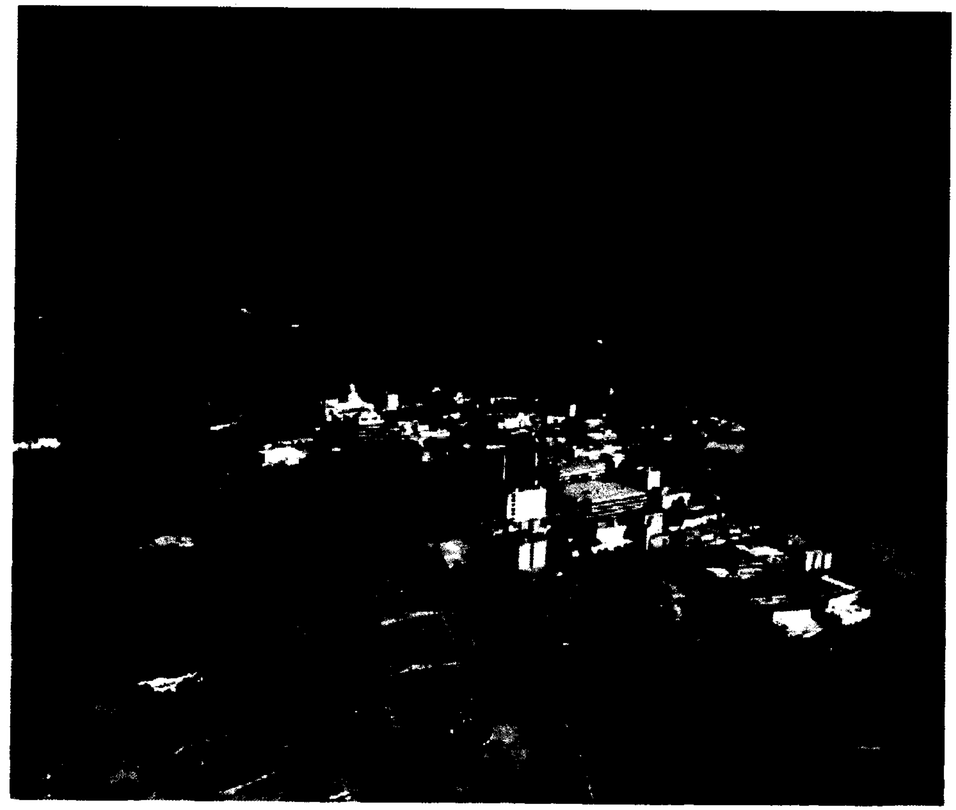
JPL today

1950s

# JPL is part of NASA and Caltech

California Institute of Technology

- Federally (NASA)-owned "Federally-Funded Research and Development Center" (FFRDC)
- University (Caltech)-operated
- $1.7 billion business base
- 5400 employees and contractors
- 177 acres
- 134 buildings and 57 trailers



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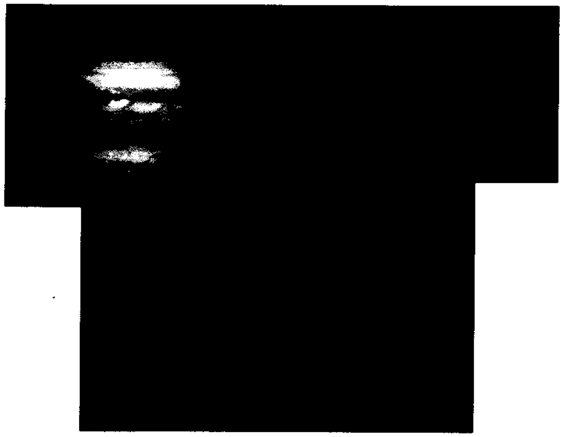
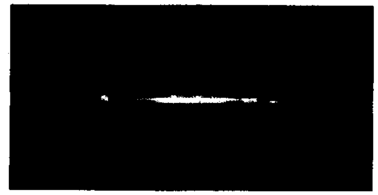
# Forty-six years of exploration



Giant Planets

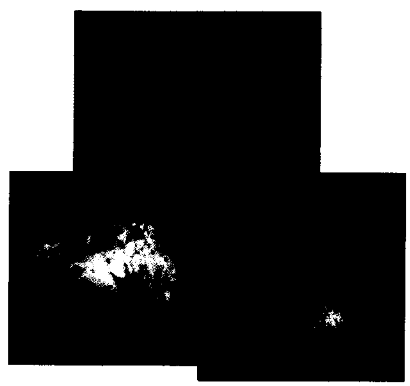
Small bodies

Earth's moon

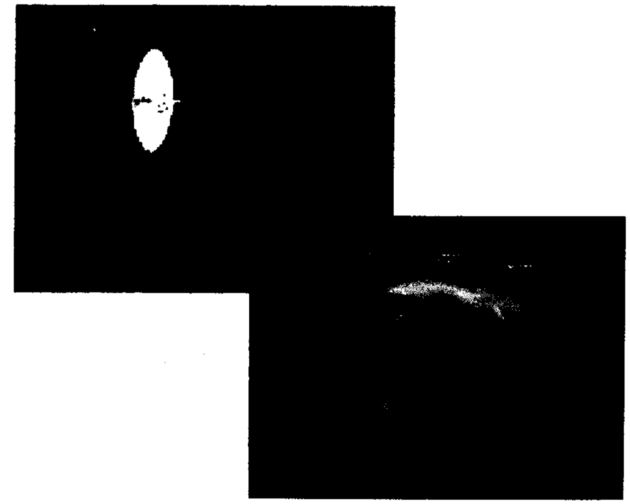


Astrophysics

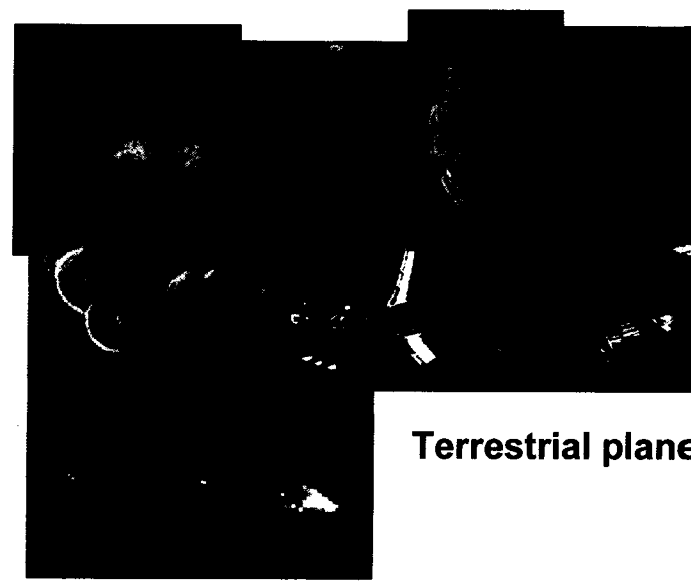
Earth



Planetary satellites



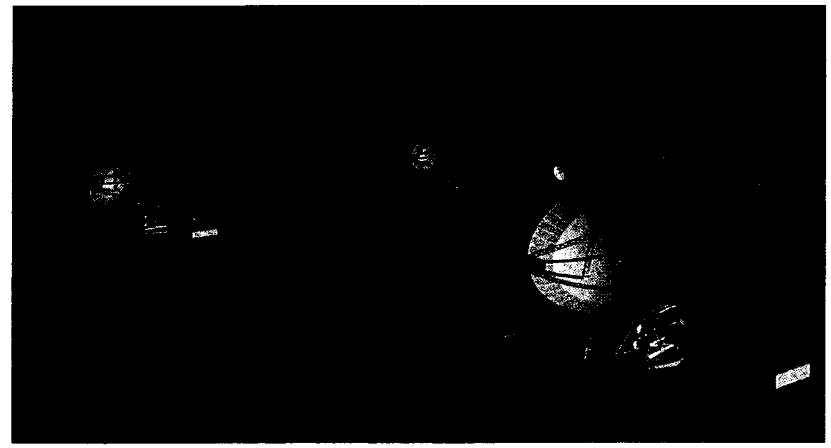
Interstellar space

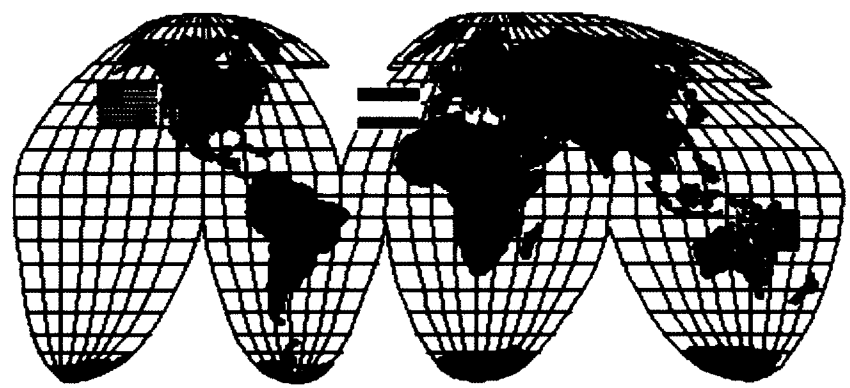


Terrestrial planets

# Deep Space Network

- Telemetry
- Spacecraft command
- Radio Science
- Monitor and Control





# Power and Sensor Systems Section

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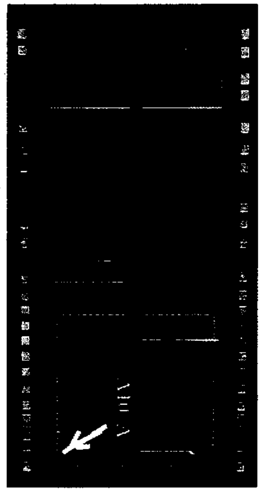
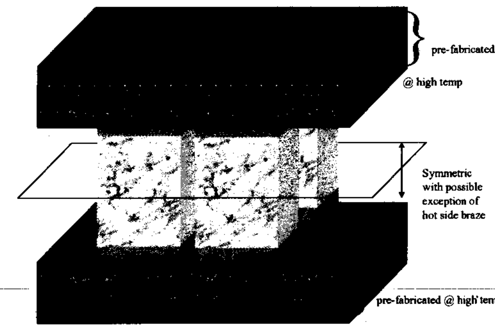


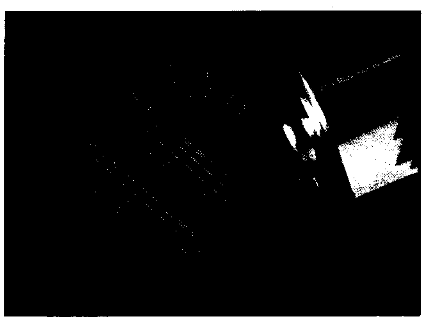
Integrated passive components

Electrochemical sensors

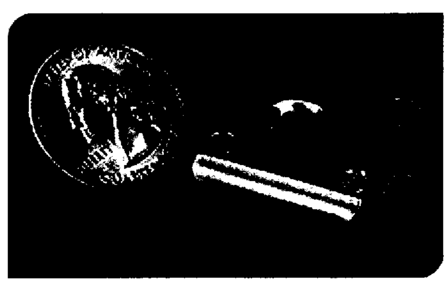



Advanced Thermoelectrics

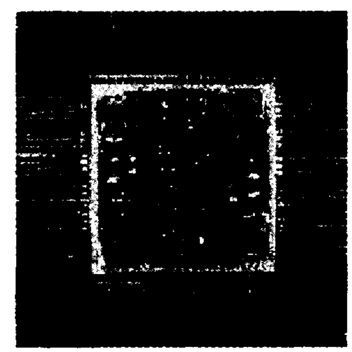
Fuel cells



Microbatteries



Micro sun sensor



Power electronics

# Sensors on deployable structures

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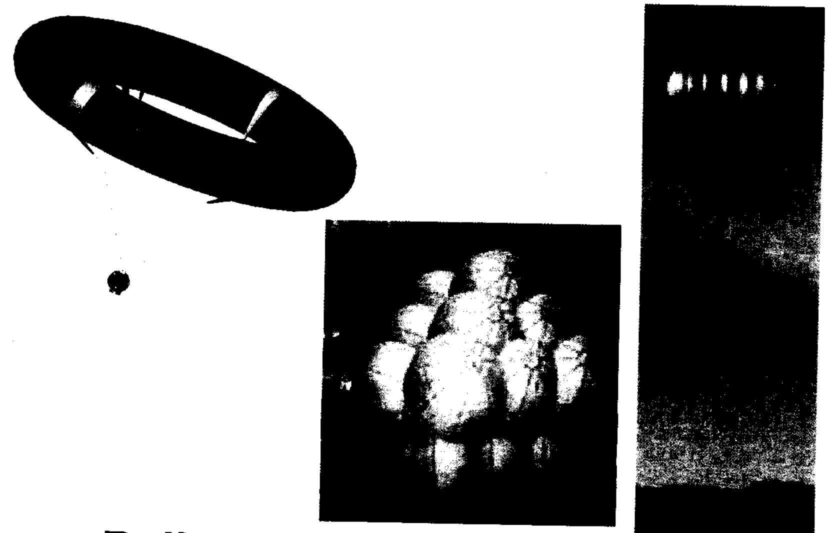
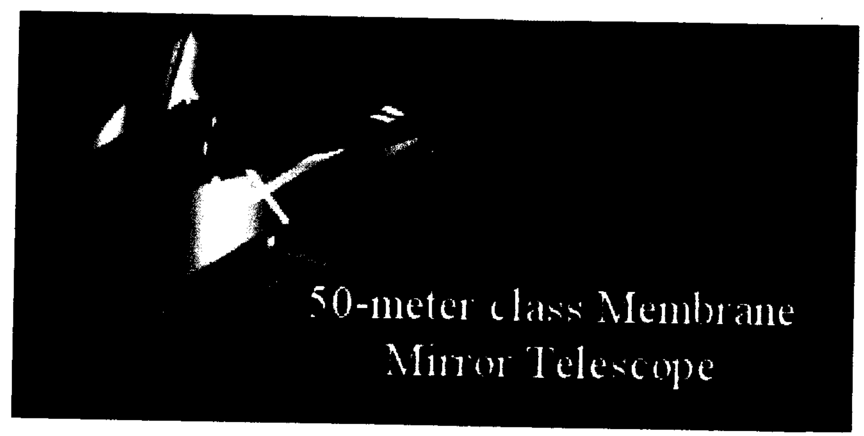
Membrane Radar



Balloons, ballutes and airbags

Solar Sails

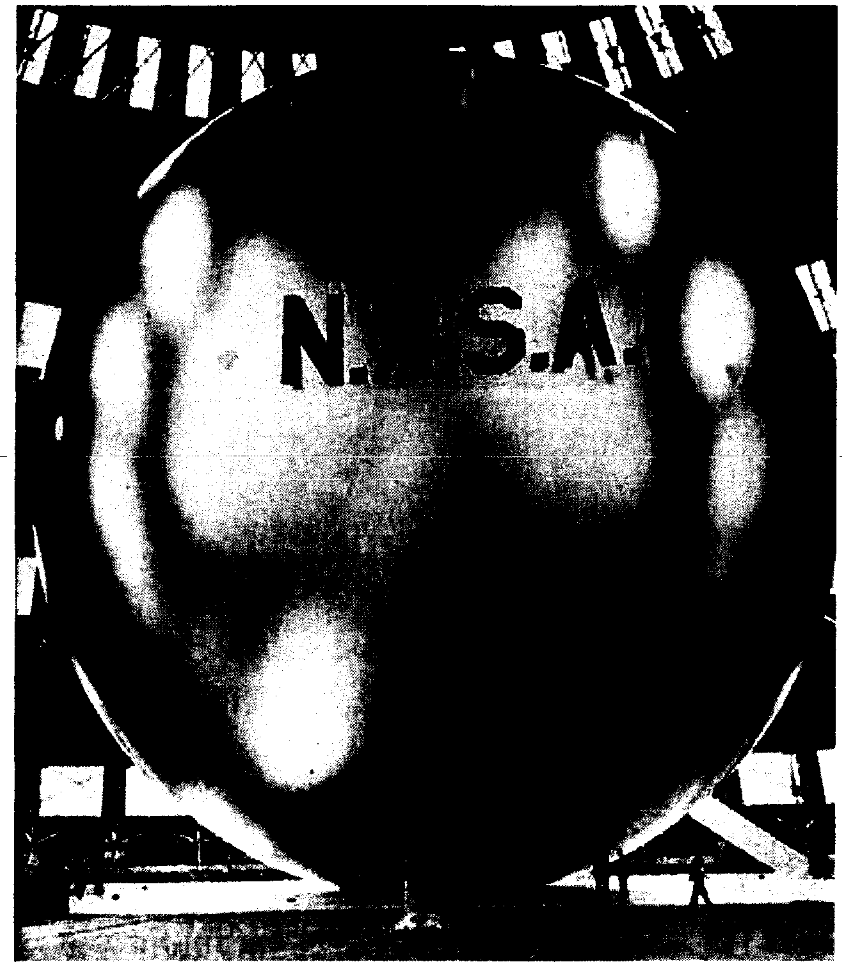



Deployable telescopes

# Inflatable/deployable structures

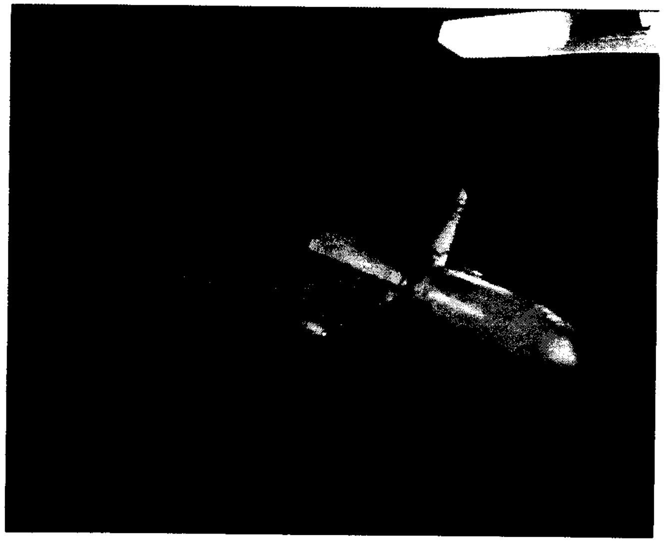


- Date back to the earliest days of NASA
- Lightweight
- Volume efficient
- Low cost
- Flexible launch manifest
- Current research focus on space durable polymers and deployment concepts

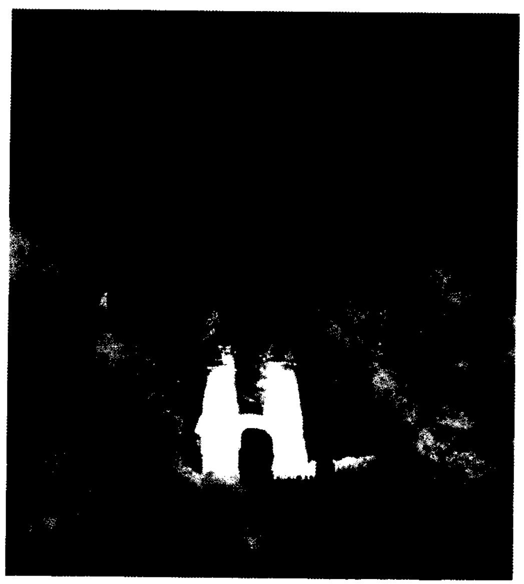


# Structural health





- Focus of structural health on traditional aerospace structures
  - Commercial and military aircraft
  - Launch vehicles



- Emphasis on traditional engineering materials
  - Rigid
  - Metals, alloys, ceramics

# Electronics for deployable structures

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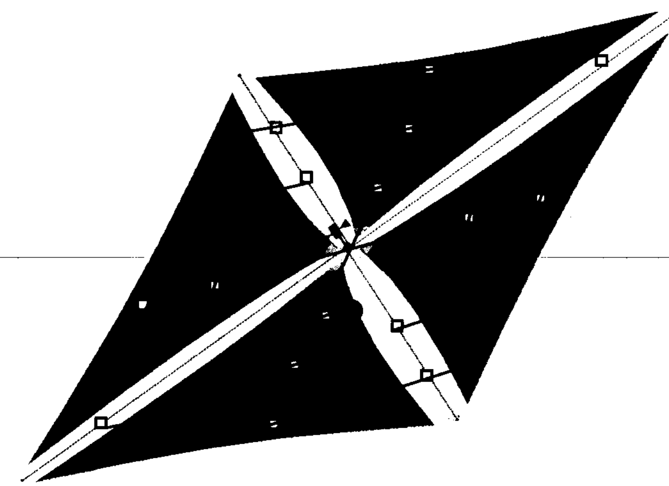
- **How do we integrate robust sensing electronics with thin, large structures?**
  - Thin substrates (<2 mils)
  - Rough substrate (300 nm rms)
  - Maintain low areal density (0.4 $g/m^2$)
  - Large areas (100 m x 100 m)
  - Hundreds to thousands of sensor nodes
  - Minimal perturbation/good CTE match
  - Space durable
  - Low power



**Solar sail with distributed sensing nodes**

JPL

# Flexible electronics for space?

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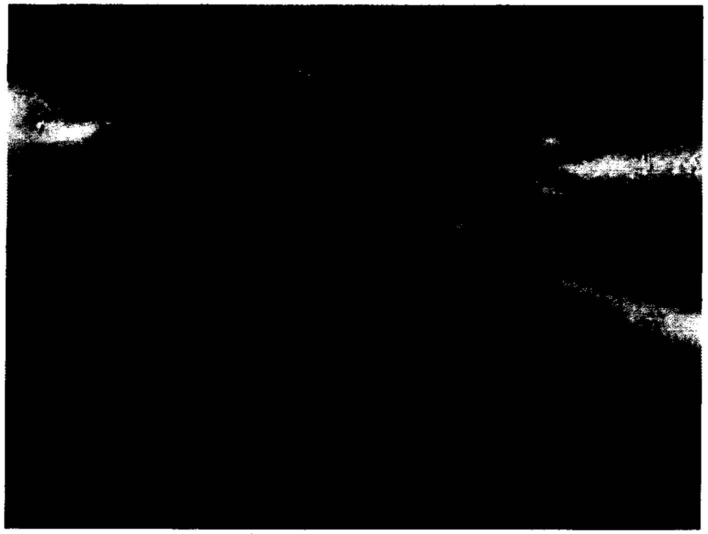
NASA



Flexible displays


Electronic paper

- **Commercial focus:**
  - Low cost
  - High volume
  - Expendable
- **NASA needs:**
  - Long term space durability
  - High reliability
  - Robust operation

# Flexible electronics for space?

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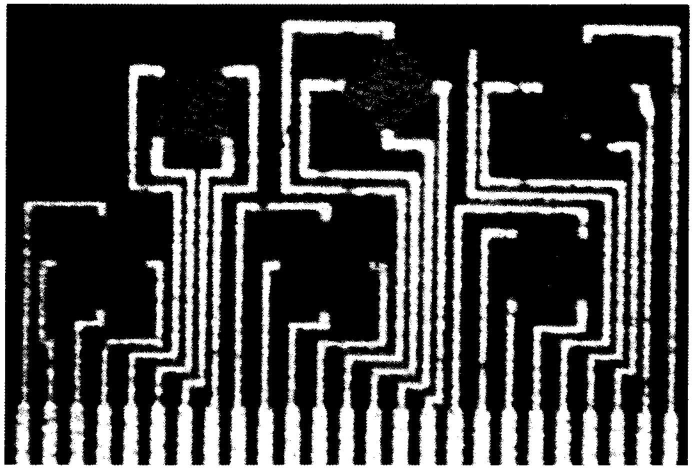

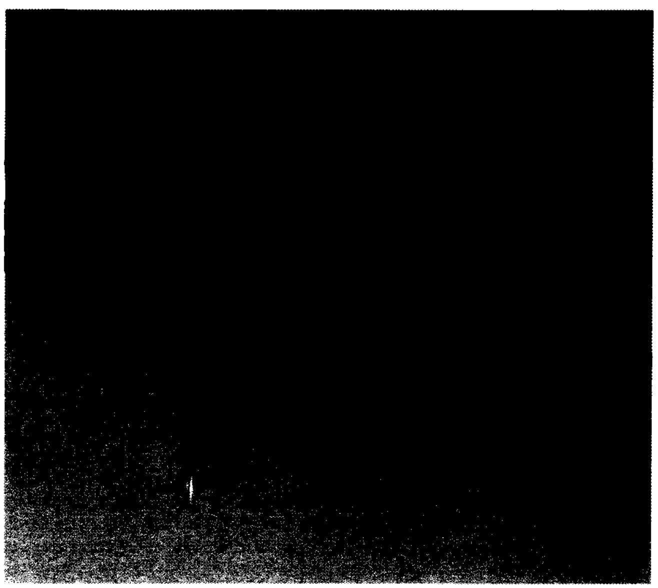

- Use low temperature processing techniques
- Fabricate sensors directly on flexible substrate
- Use matrixing and combine with RFID technology to reduce number of interconnects

# Large area manufacture is here

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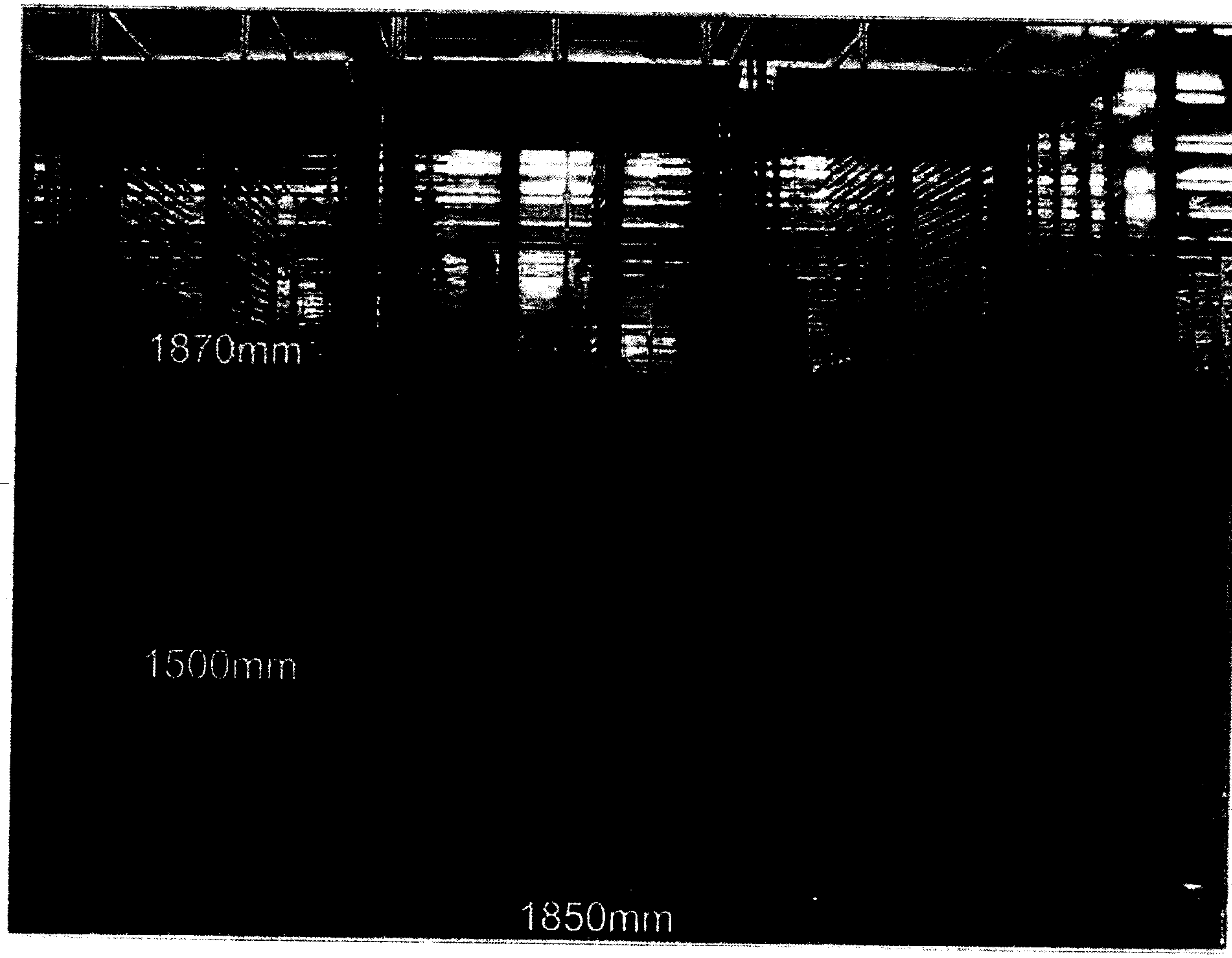
NASA

## 7th generation active matrix LCD substrate




**2200mm**

*P7 fab 1950 x 2250 mm, operational in 2006 (Philips)*

# Large area *flexible* electronics?

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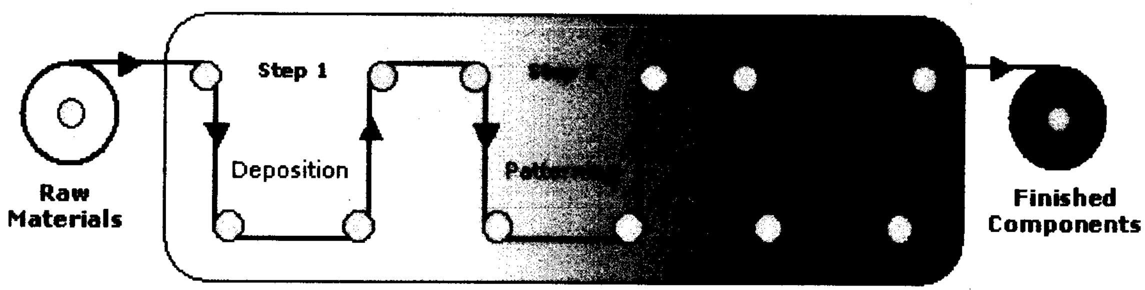
NASA

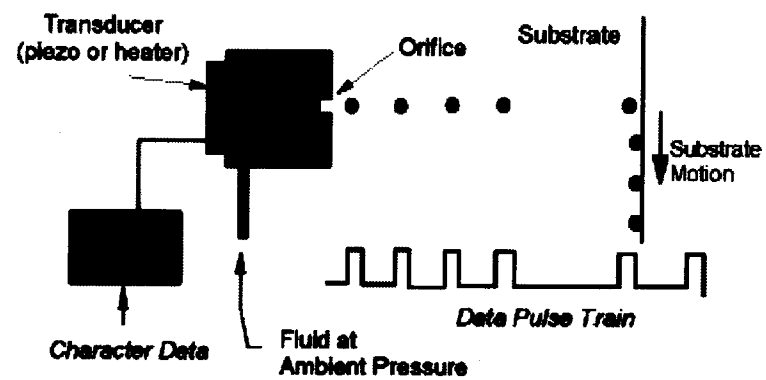
Roll-to-roll processes

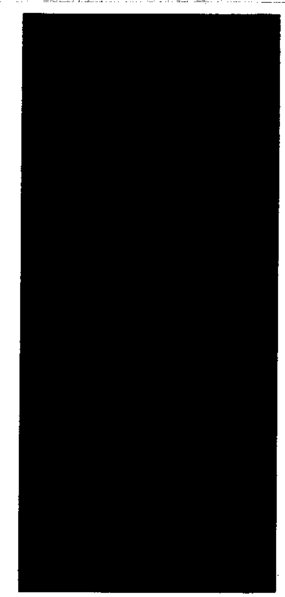



**MicroFab Technologies, Inc.**

## Demand Ink-Jet Technology

Ink Jet printing



# Challenges of flexible electronics for aerospace

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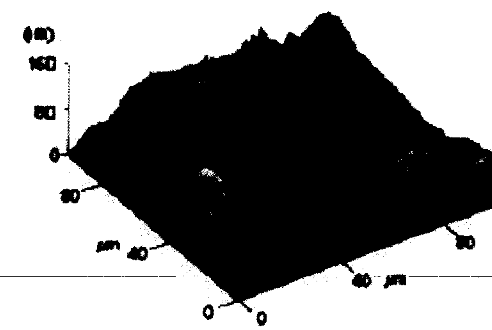
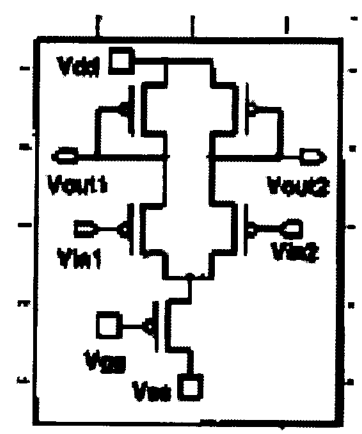
- **Fabrication of devices on flexible, polymer substrates**
  - Polyimide surface micro-roughness (not pristine substrates)
  - Quality of semiconductor (which impact mobility)
  - Quality of gate dielectric



AFM of Pristine polyimide surface

- **Reliability of TFT devices**
  - Evaluate relevant materials (organics, a-Si-H)
  - Radiation tolerance
  - Mechanical properties

- **TFT Circuits**
  - Design of op amps for signal processing
  - Low TFT transconductance
  - High input offset bias, low amplifier gain
  - Development of TFT based multiplexing circuits




TFT amplifier

# Organic TFTs - X-ray irradiation

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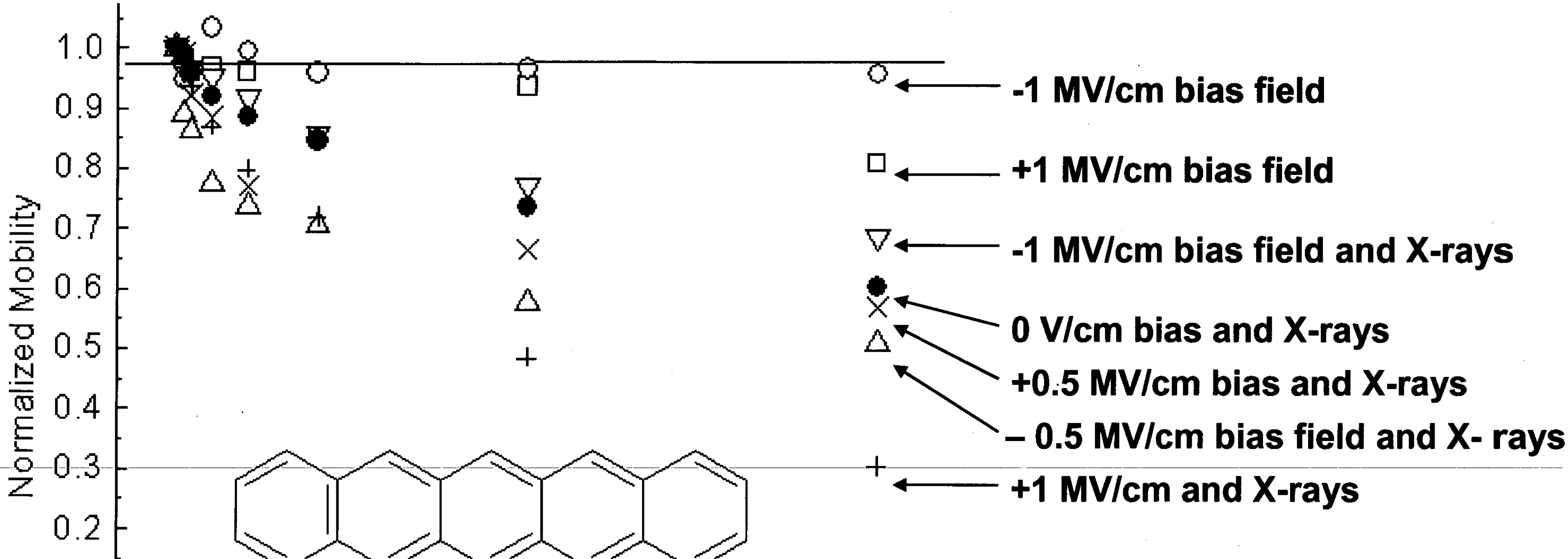
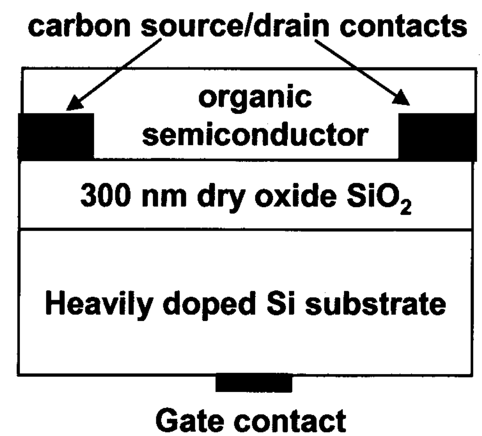


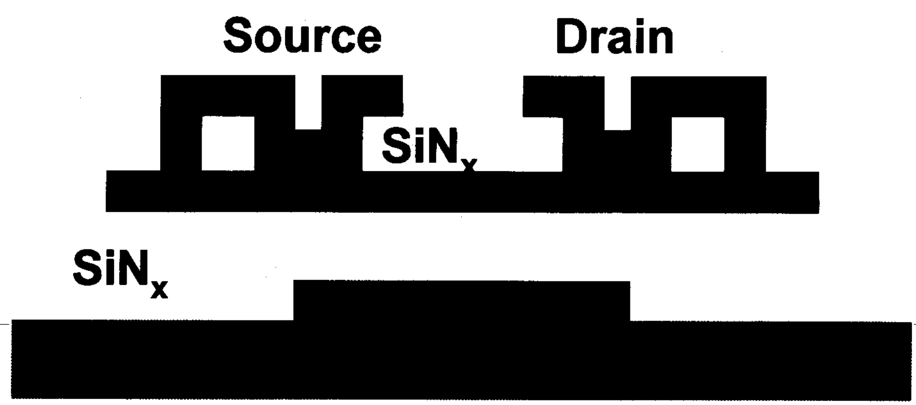

**X-ray irradiation**
**dose rate ~280 rad ($SiO_2$) per second**

**Collaboration with Kirtland Air Force Base**

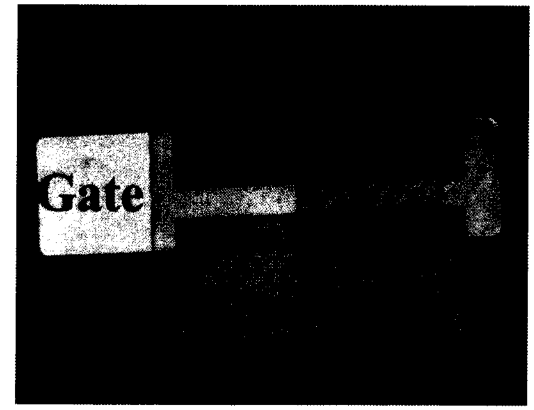
# a-Si:H thin film transistors



PENNSTATE

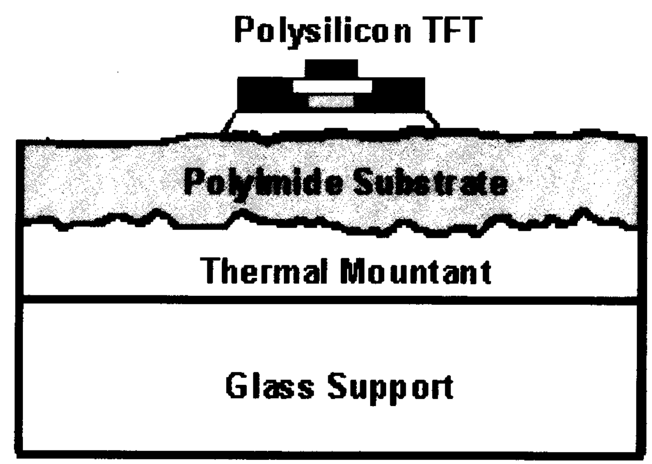



TFT cross-section




TFT top view

| substrate | mobility, $cm^2/V\text{-}s$ | threshold voltage, V |
|---|---|---|
| glass | 1 | 0.1 |
| polyimide | 0.7 to 1 | 2 |




PSA to glass used to improve flatness

# $n^+$ μC-Si Ungated Strain Sensor

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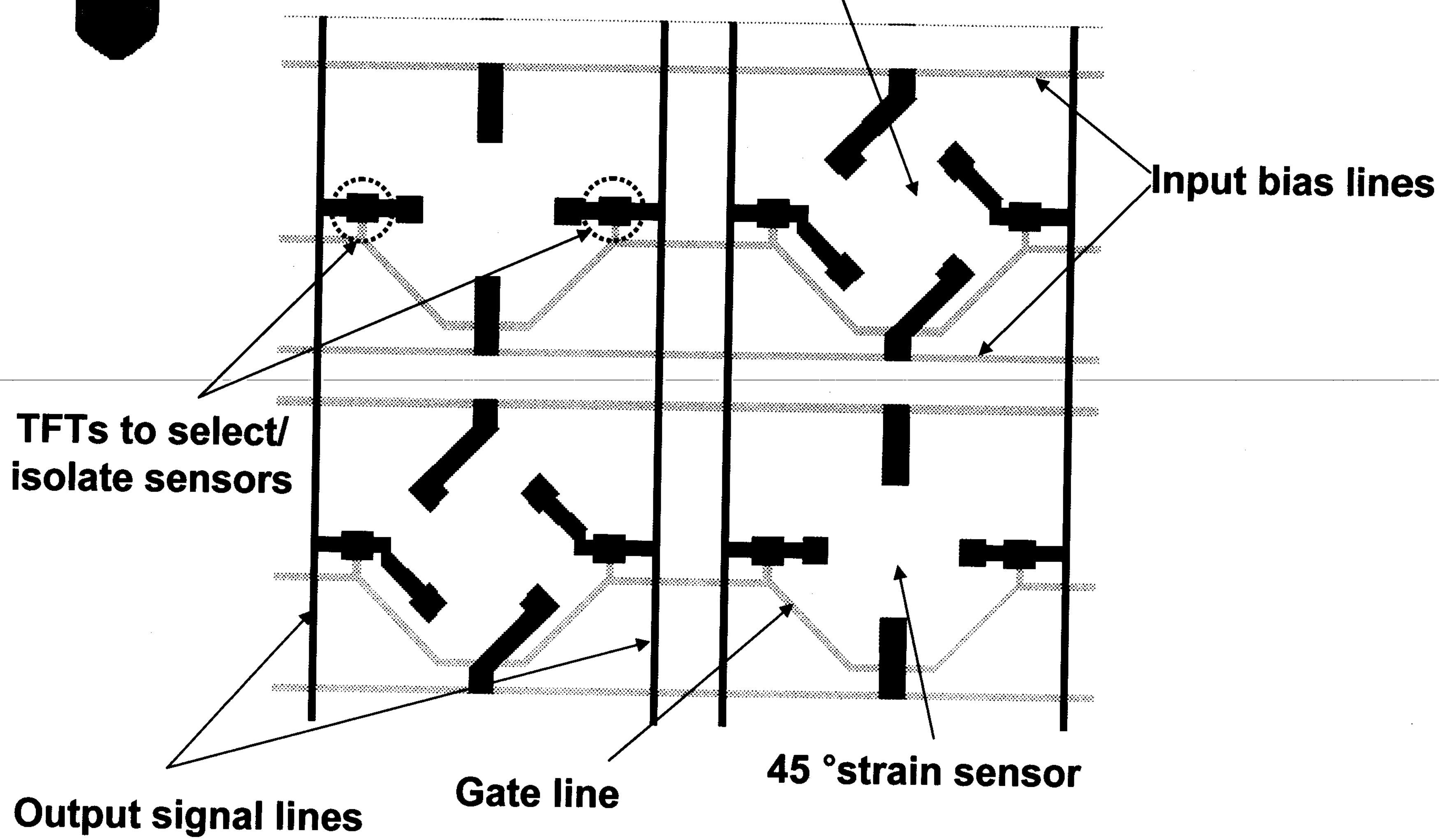
NASA



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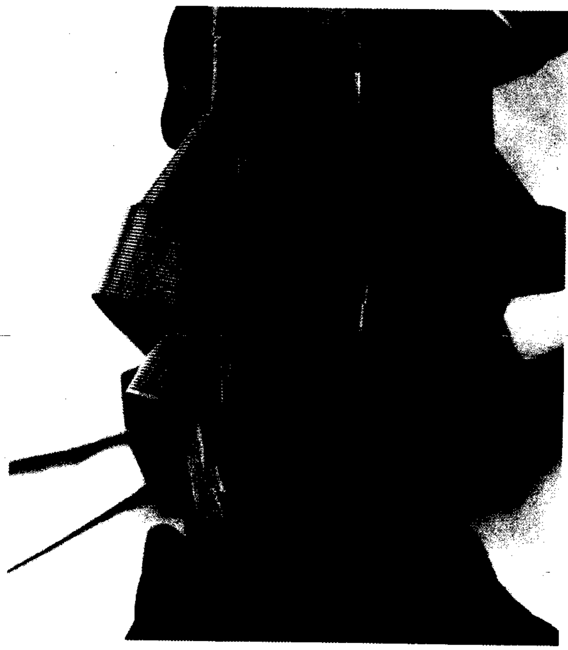
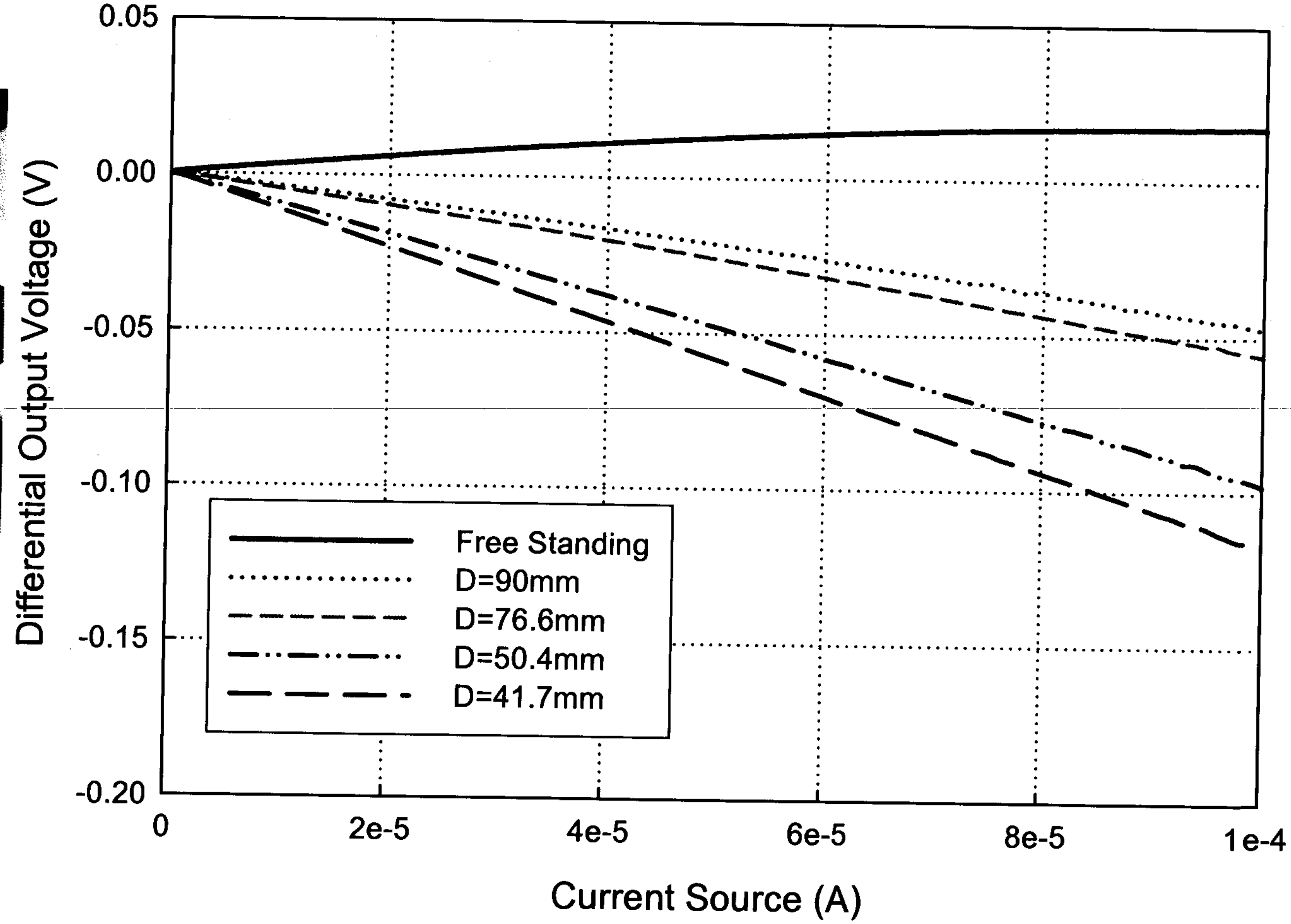
# a-Si:H Strain Sensors



Ungated n+ μC-Si strain sensors

300um n+ uC-Si on Kapton
Current is 45 degree to bending direction



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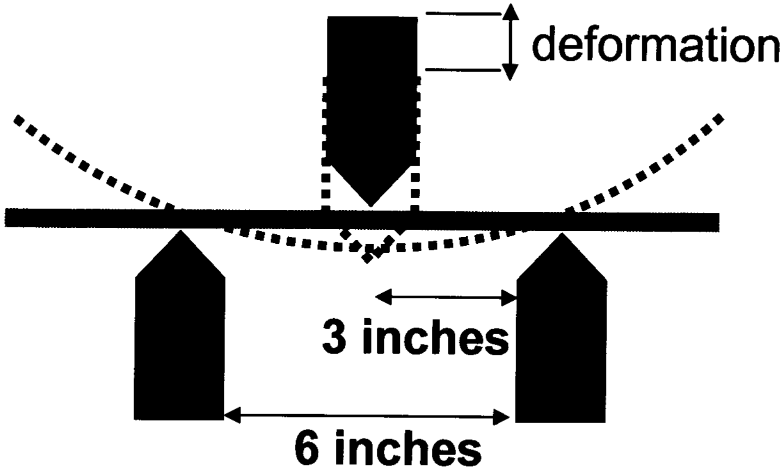
# Simulated deployment

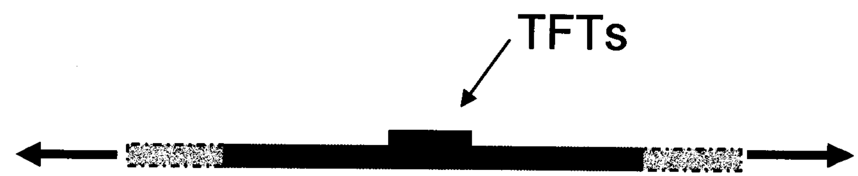
## Bending Stress Test




Three point bending test, 100 cycles
Haversine waveform, 0.25 Hz
1.18 inch deformation

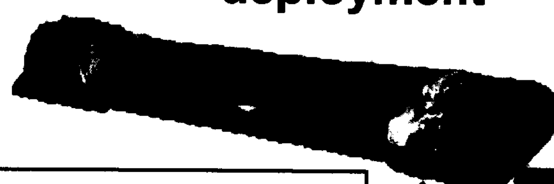
Used to represent unrolling during deployment

## Tensile Stress Test




Uniaxial stress test
2000 psi
Hold 1 hour

Represents tensioning during deployment



Attempting to replicate service conditions

# Initial results of mechanical testing

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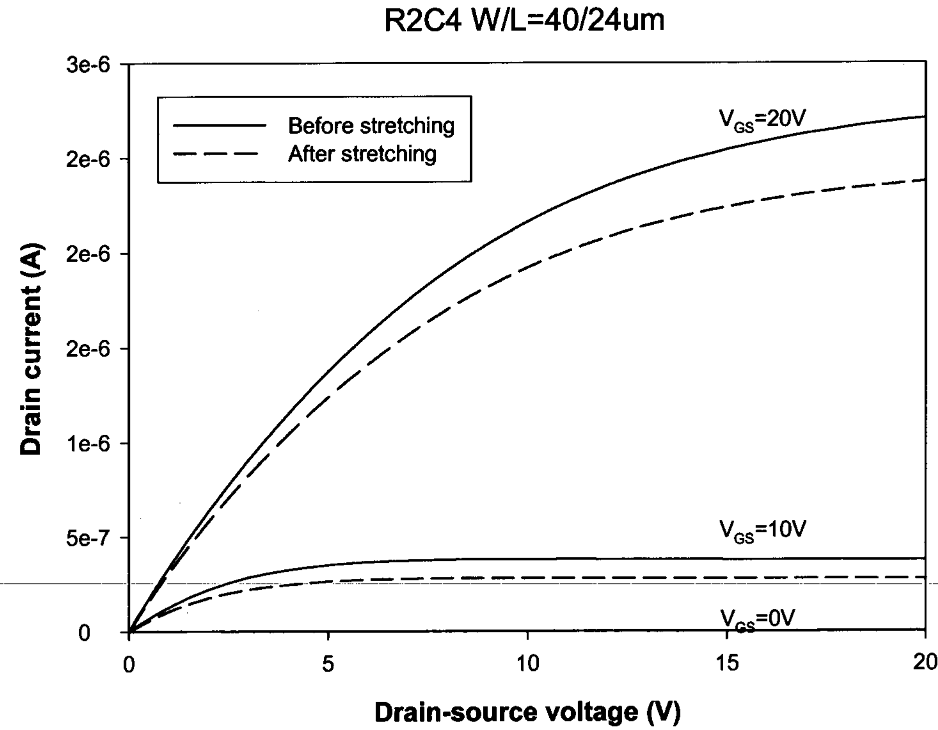
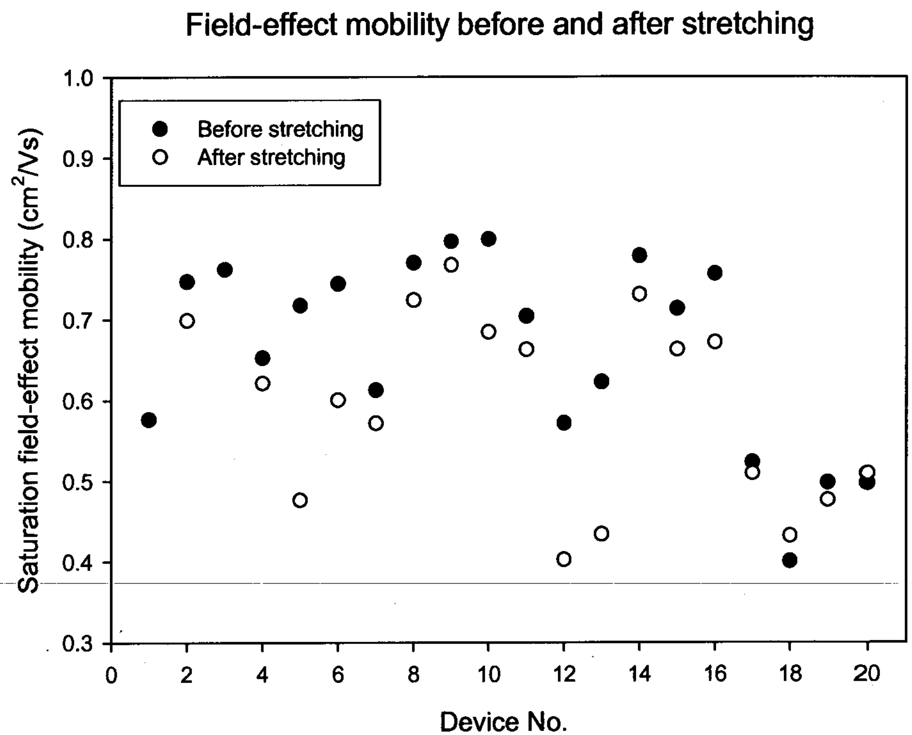



**TFT output characteristics before and after tensile stress**




**Field effect before and after tensile stress**

## Recent test results:

- 2,500 psi uniaxial tension for 60 minutes
- 20 a-Si:H TFTs on polyimide characterized
- 90% of TFTs survived
- 70% TFTs exhibited minor changes in mobility and $V_t$

# Fast electron irradiation of TFTs

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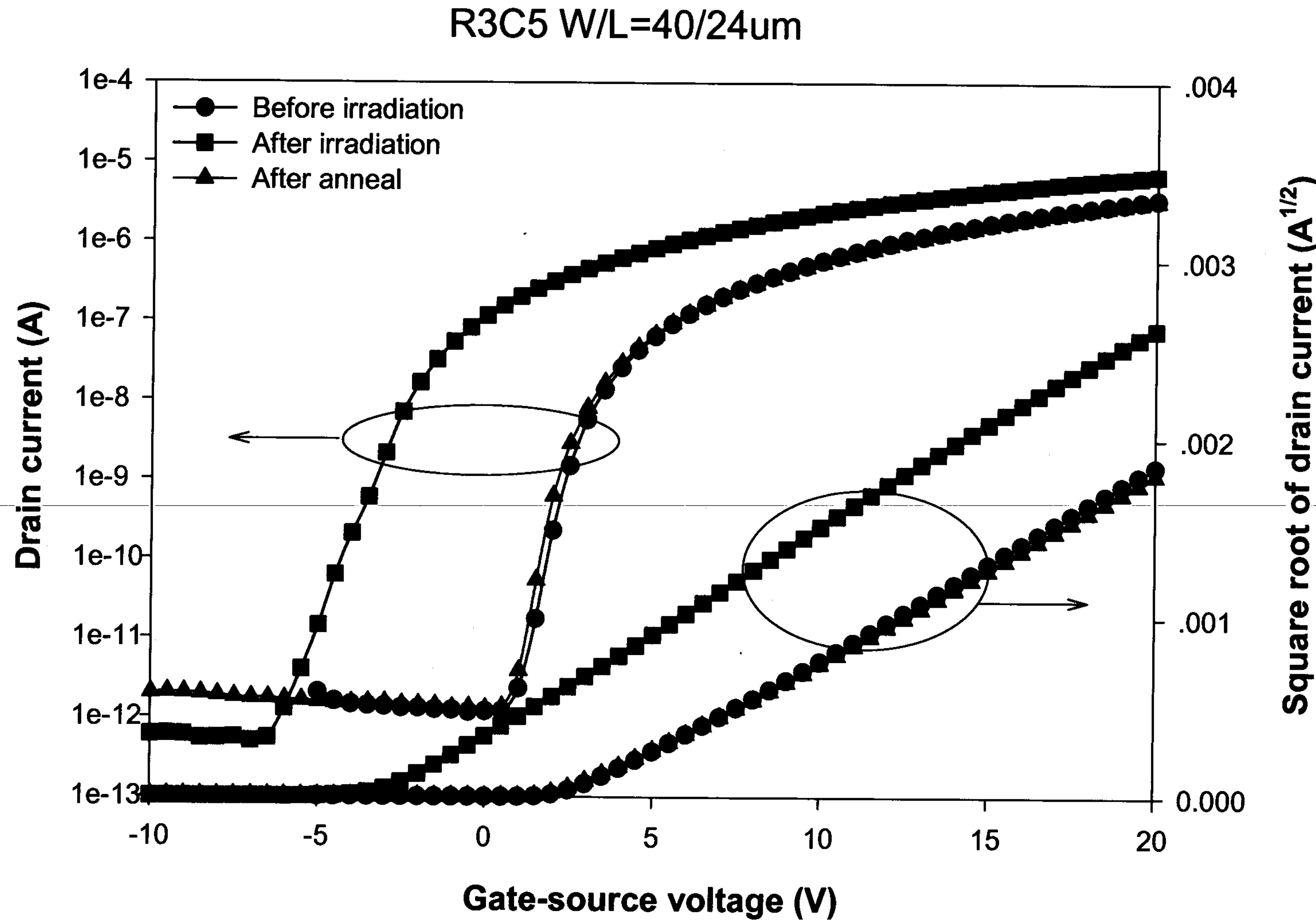


**1 MeV electron beam, 1 Mrad (Si) total dose, Current = 8.5 μA**

# Synthetic aperture radar application

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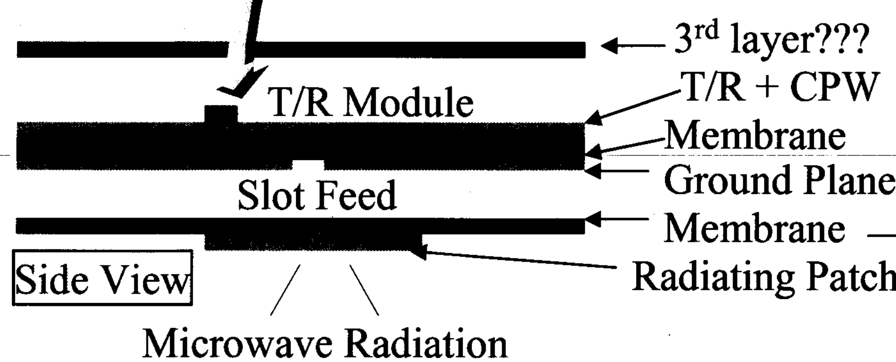
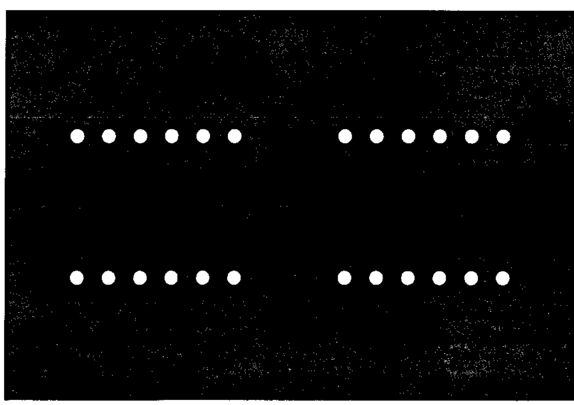
T/R layout developed by ACT/code Y funding

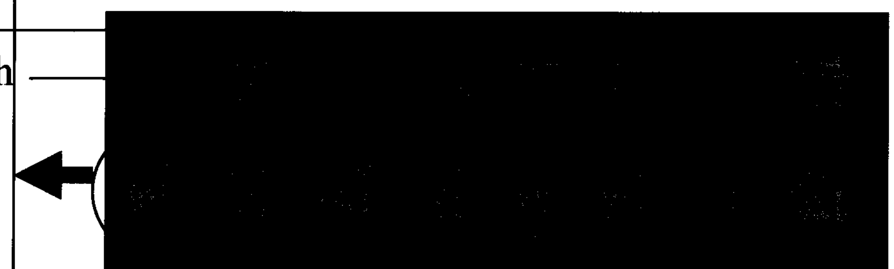



Goals:

- Demo a 2x8 active membrane antenna
- Flip-chip on flex
- Feed design
- RF interconnects

2x8 active membrane antenna



**Kapton thickness:** 2mils
**Copper thickness:** 5 - 12um
**Layer spacing:** 1.25cm

# Fabrication of TFTs on patch antenna array

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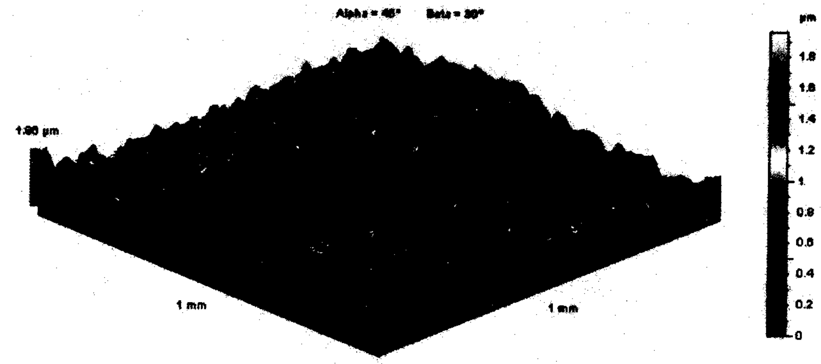
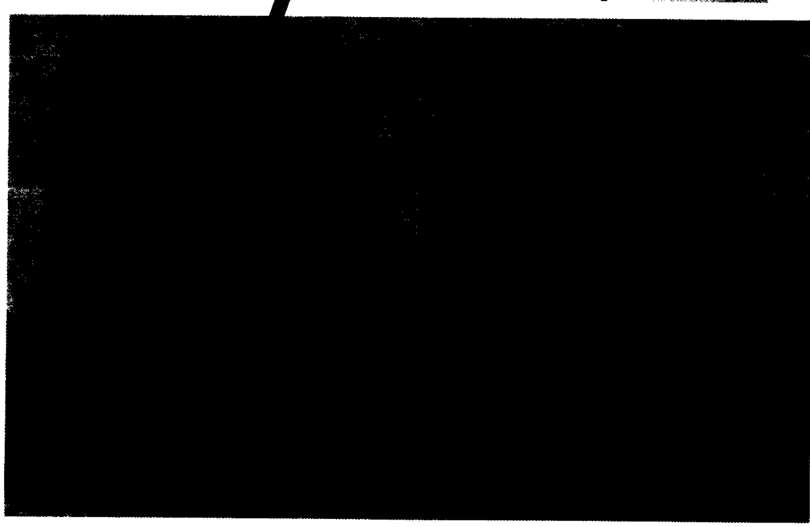
**Synthetic Aperture Radar Transmit/Receive structure:**

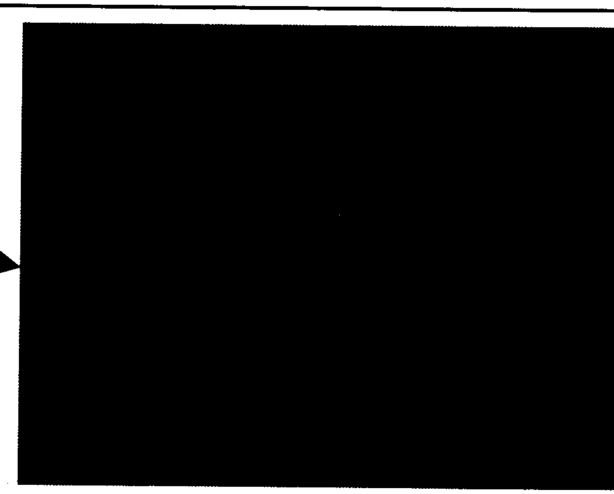




**profilometry of etched Kapton AP**

| **Typical substrate roughness values:** |
|---|
| Glass-0.5 nm rms |
| Pristine polyimide-30 nm rms |
| Processed polyimide-300 nm rms |



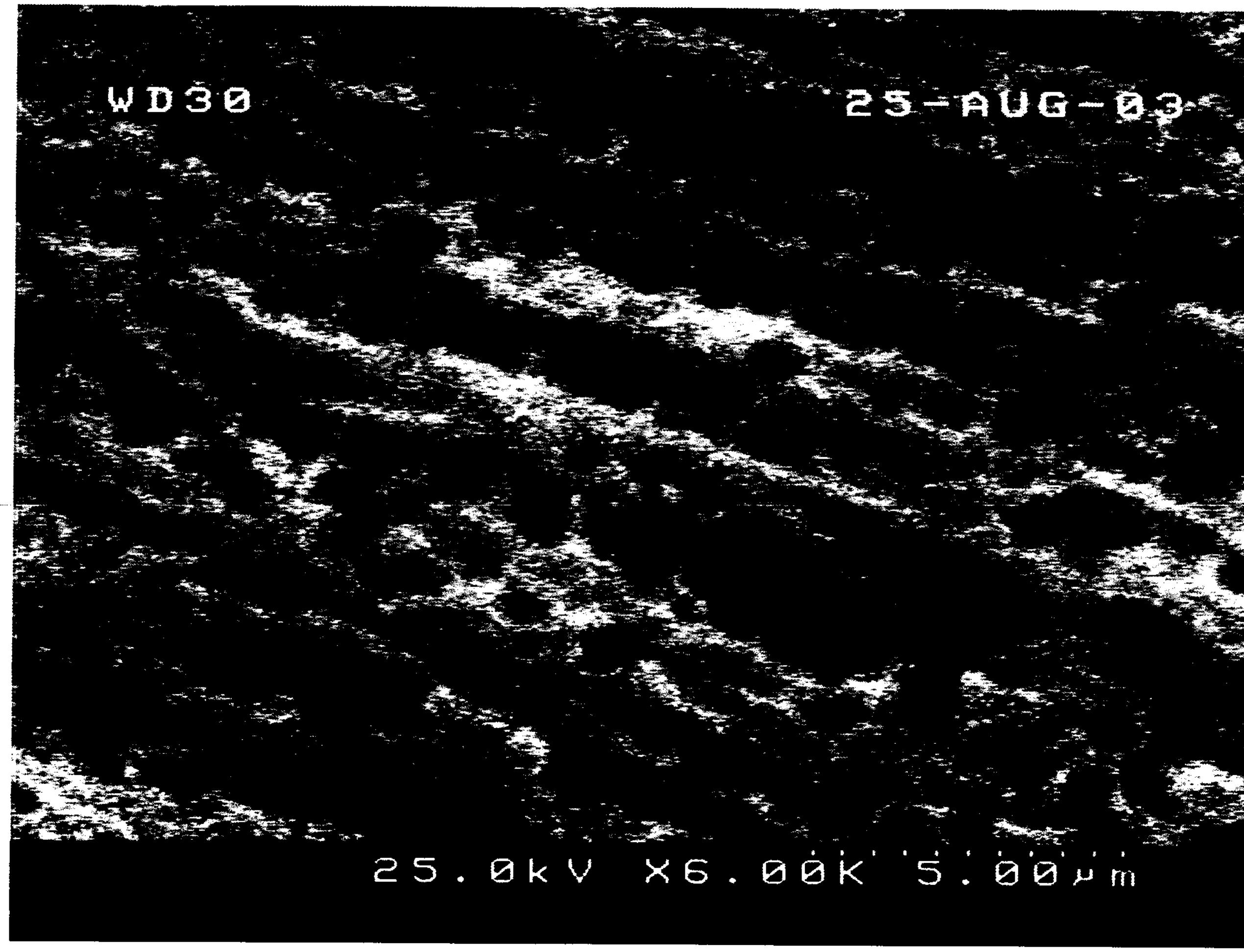
**Fabrication of a-Si:H TFTs on back of patch**



**TFTs on Kapton patch**

# SEM of etched polyimide surface





# VP Cheney visits JPL for announcement of new NASA vision

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NASA

# A new focus for NASA

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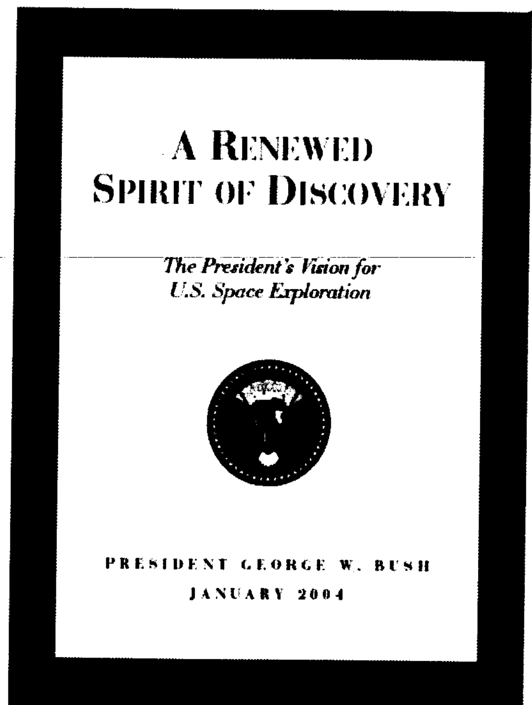
NASA

## THE FUNDAMENTAL GOAL OF THIS VISION IS TO ADVANCE U.S. SCIENTIFIC, SECURITY, AND ECONOMIC INTEREST THROUGH A ROBUST SPACE EXPLORATION PROGRAM




Implement a sustained and affordable human and robotic program to explore the solar system and beyond

Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;

Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and

Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

# NASA Exploration Objectives



- **Spiral 1 (2008-2014)**
  - Provide precursor robotic exploration of the lunar environment
  - Deliver a lunar capable human transportation system for test and checkout in low Earth orbit
- **Spiral 2 (2015-2020)**
  - Execute extended duration human lunar exploration missions
  - Extend precursor robotic technology demonstrations at Mars
- **Spiral 3 (2020-TBD)**
  - Execute a long-duration human lunar exploration campaign using the moon as a testbed to demonstrate systems (e.g., Lander, habitation, surface power) for future deployment at Mars
- **Spiral 4 (~2025-TBD)**
  - Execute human exploration missions to the vicinity of Mars
- **Spiral 5 (~2030-TBD)**
  - Execute initial human Mars surface exploration missions

# Inflatable Lunar Habitats

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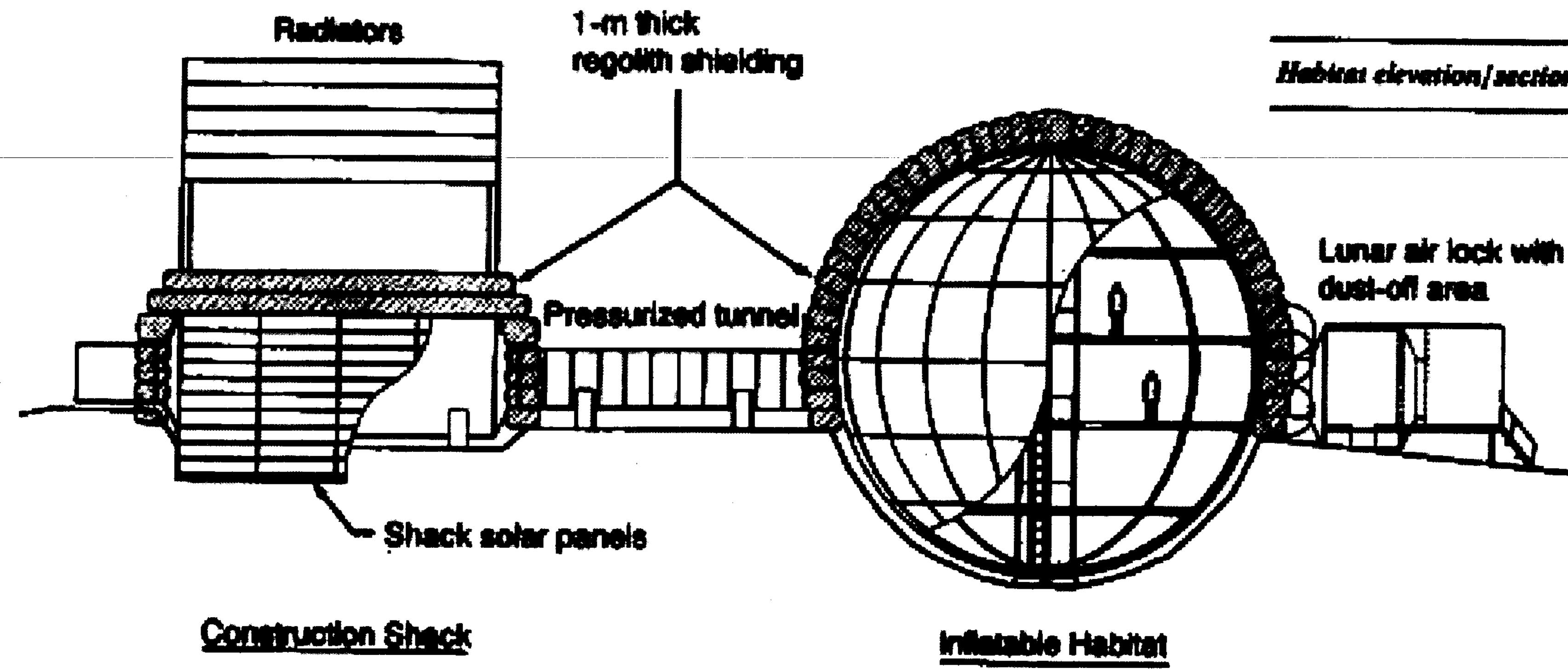
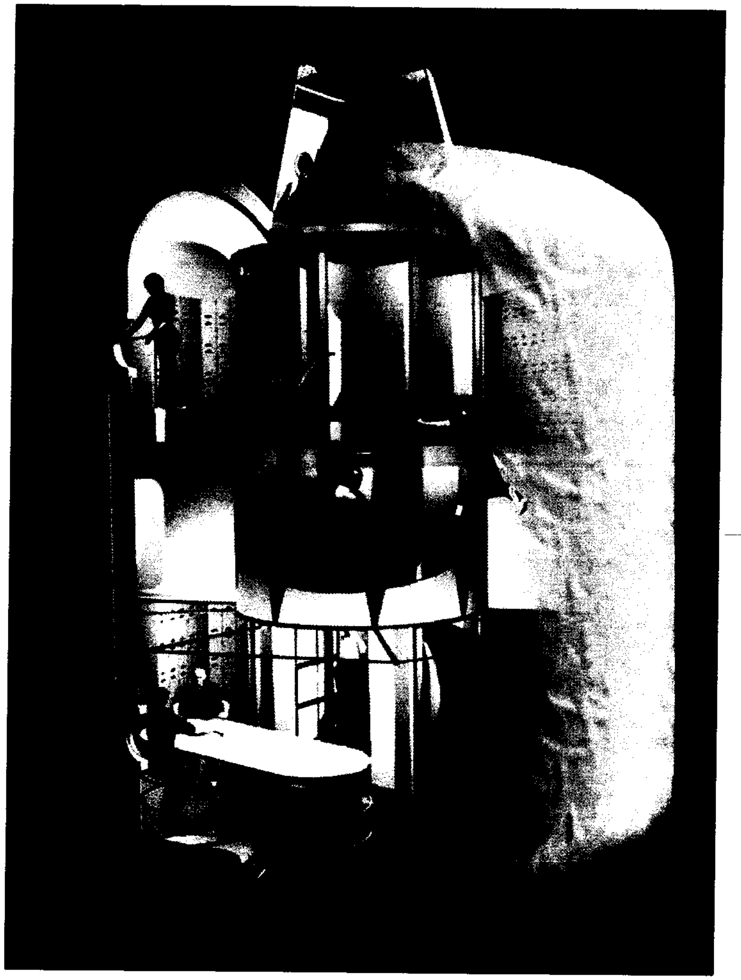
- Inflatable surface habitats can provide large habitable volumes
- Deployable lunar surface habitats have been studied since the 1960s




From K. Kennedy, NASA JSC, 1990

# Habitat issues





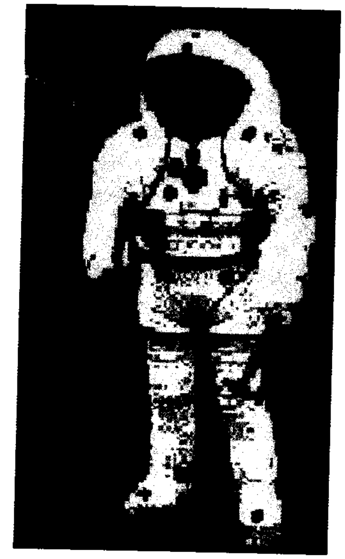
NASA TransHab

- **Advanced structural materials in place of traditional engineering materials**
  - Multi-layer polymers
  - Foams
  - Fabrics
- **Unique requirements**
  - Highly compact stowed configuration
  - Deployment mechanism
- **Complex, multilayer structure**
  - Bladder
  - Restraint layer
  - MMOD shielding

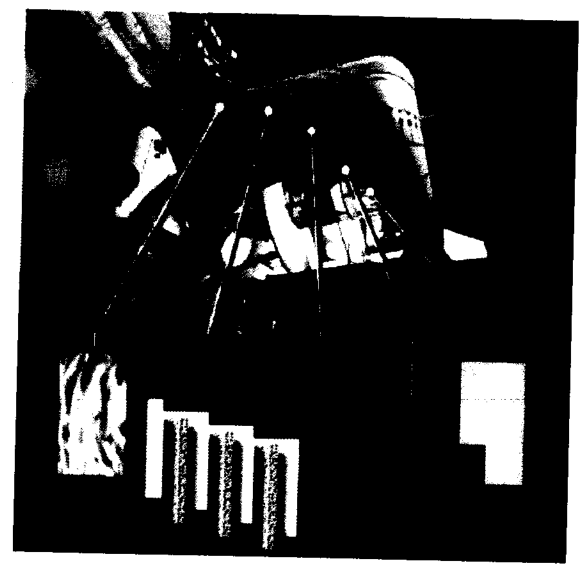
# Space suits



- Space suit is the ultimate inflatable habitat
- Engineers use this analogy in describing habitats



- Employs a single bladder system
- Size difference influences MMOD protection issues



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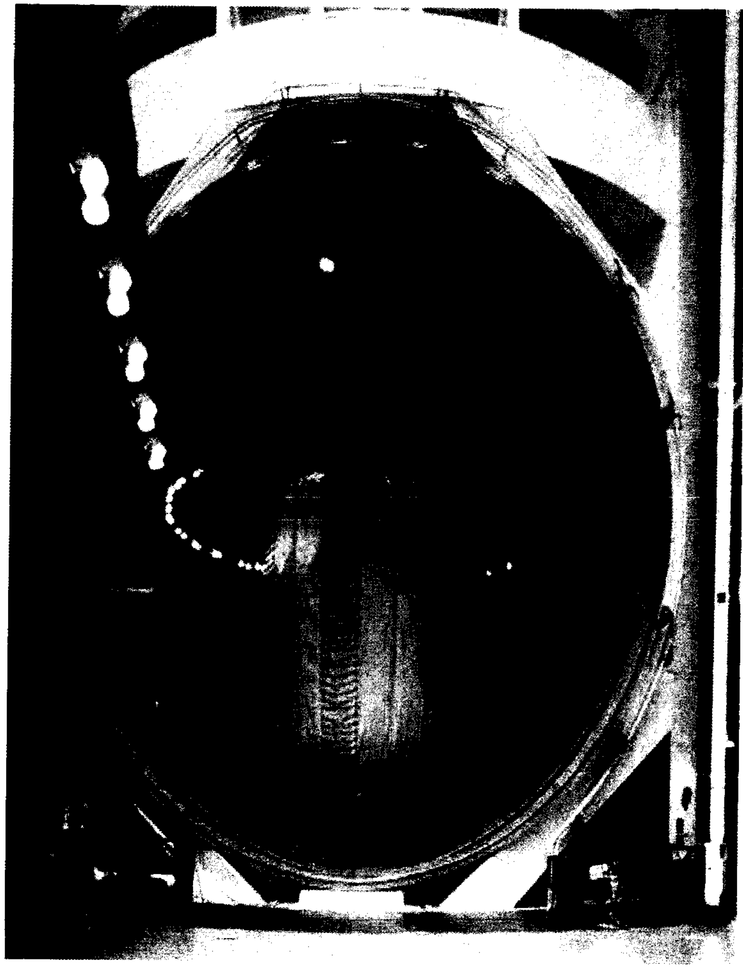
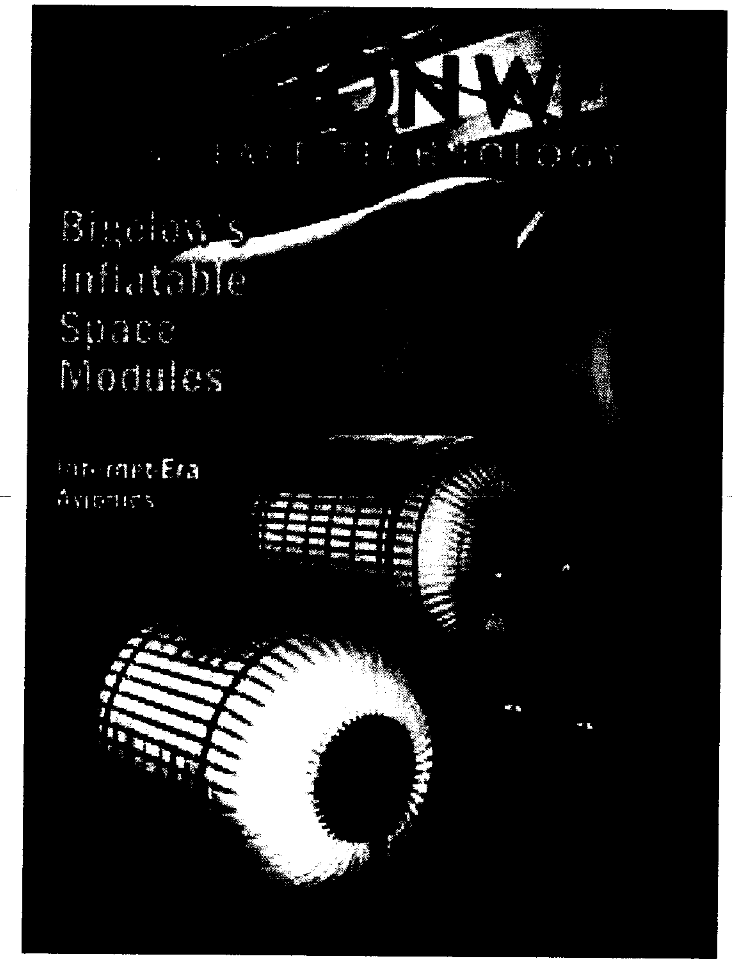
# Transit Habitat (TransHab) at NASA Johnson Space Center



Thermal-vac testing of TransHab at JSC




Commercial version of TransHab

# TransHab multi-layer structure

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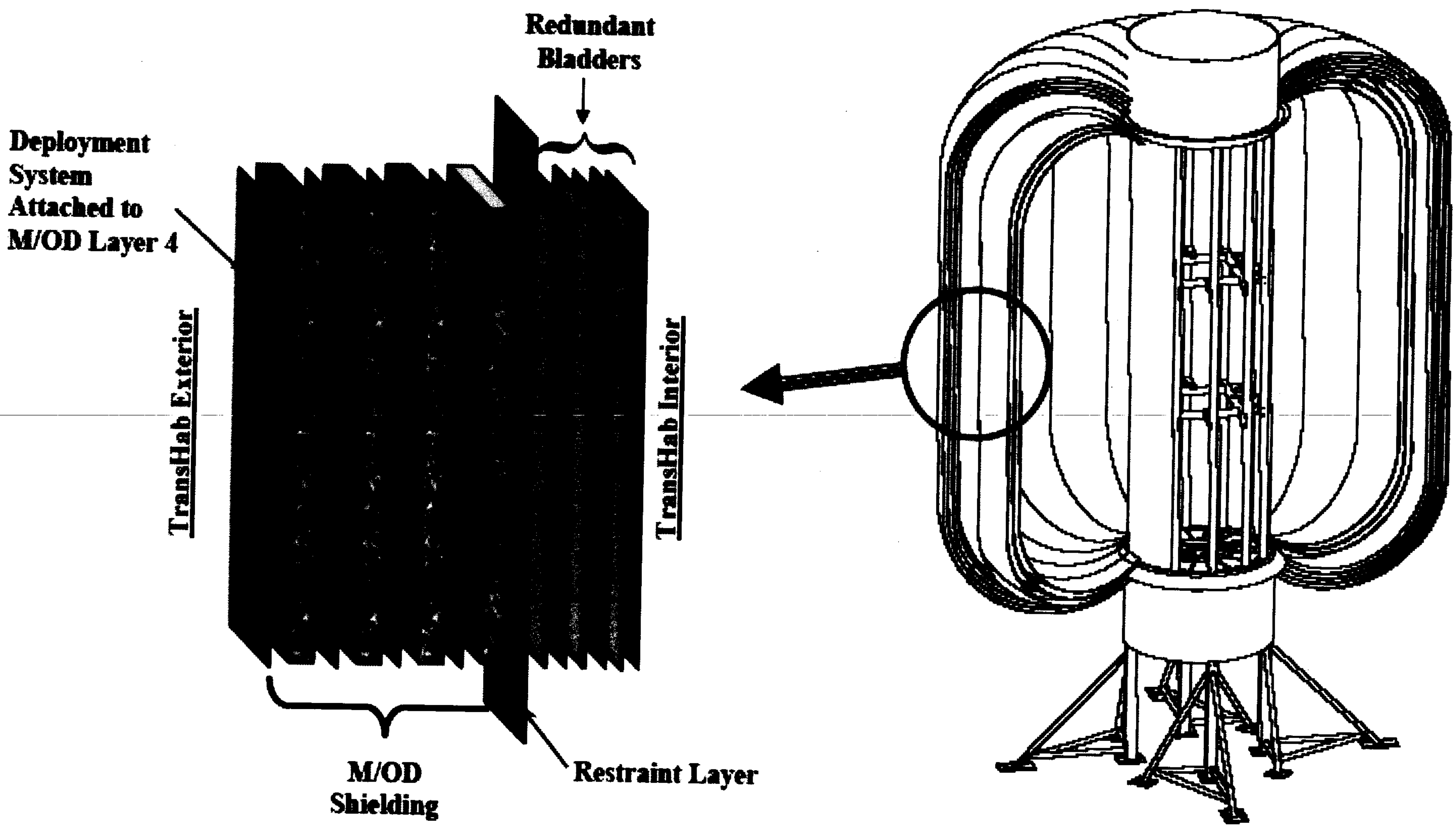

# Structural health for deployable crew habitats



- New generation of experimental crew vehicles and surface habitats under development
- Detection of unforeseen damage is critical
- Use a combination of:
  - Embedded health monitoring sensors
  - Embedded adaptive mechanisms
- Alert the crew in real time to adverse structural conditions
- Mitigate these conditions, when possible

# Technology approach

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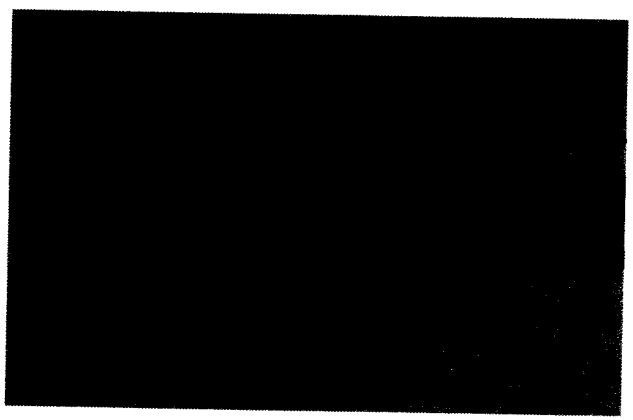
**Multifunctional Structures + Smart Materials**

- *Sensing technologies*
  - Thin film sensors
  - Acoustic imagers
  - Wireless technology
- *Adaptive capabilities*
  - Self-repair
  - Variable emissivity surface
  - Actuators



Fully integrated strain gages

Embedded piezoelectric actuators

# Possible technology advantages



- Mechanical flexibility
- Minimally invasive
- Reduction in wiring and interconnects
- Autonomous or semi-autonomous
- Embedded/integrated in hidden or difficult-to-access areas
- Manufacturability
- Enhanced reliability
- Reduced touch labor

# Team



- Jet Propulsion Laboratory
- NASA Johnson Space Center
- NASA Langley Research Center
- University of Illinois
- Boeing Phantom Works
- Penn State University

# Flexible Electronics – Penn State

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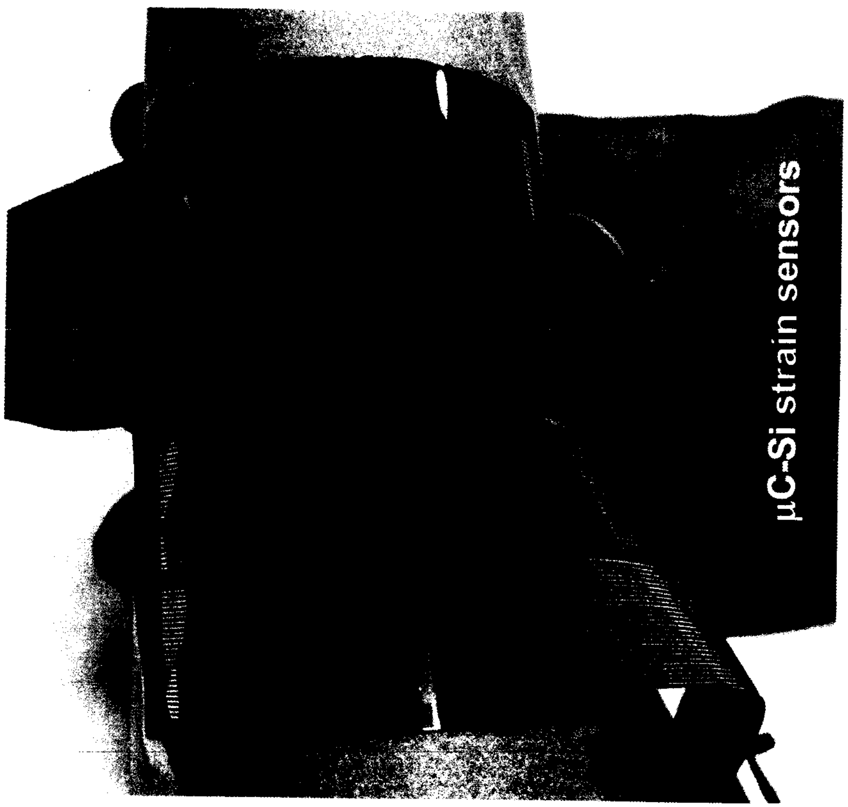
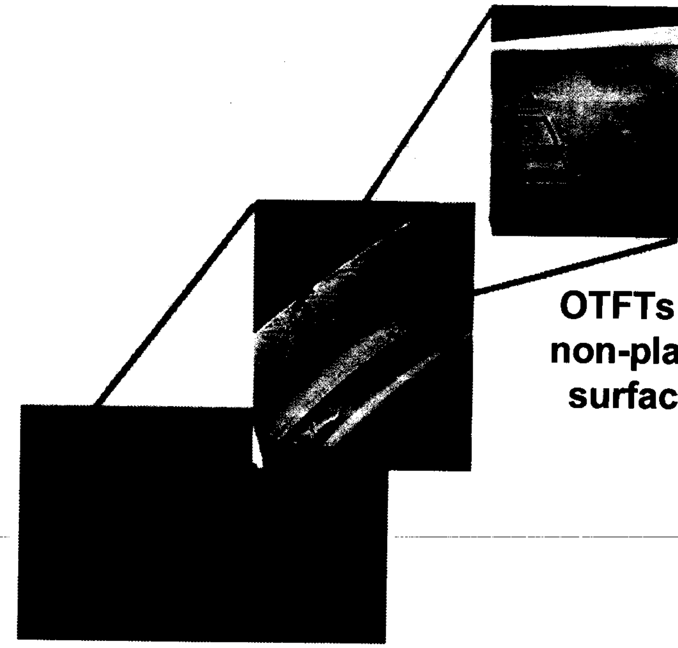
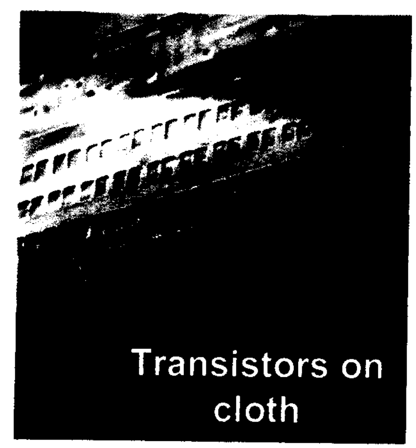
PENNSTATE



OTFTs on non-planar surfaces




Contact: Tom Jackson, Penn State

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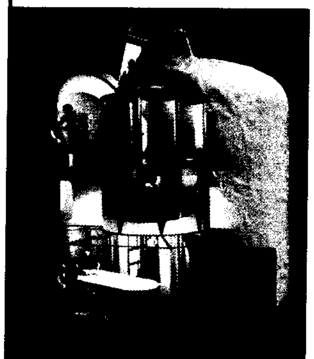
# Boeing Approach For Crew Habitat

BOEING

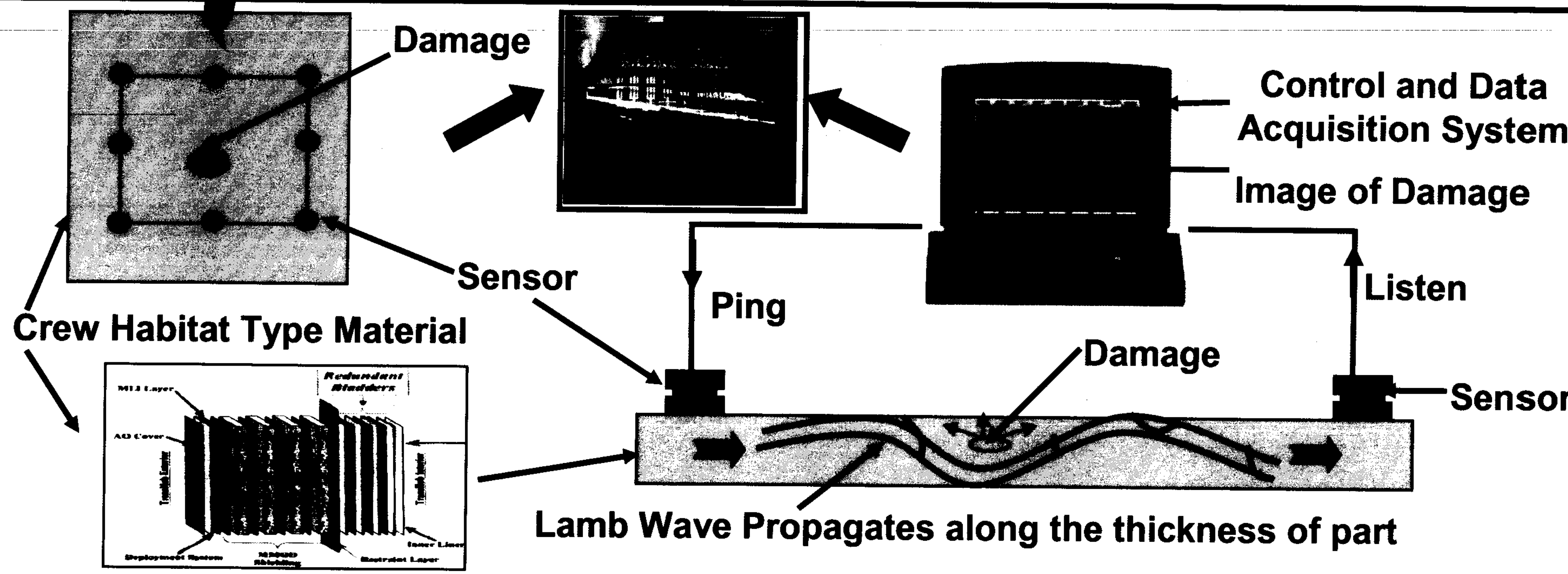


**Approach:**

- Mount Sensors on Habitat Type Test Material
- Impact Test Material
- Propagate Applicable Sound Wave into the Material
- Collect data and Form Image of Damage .

**Concern:**

- Understanding Sound Wave Propagation through these Materials.



JPL
# Cabling and wiring harnesses

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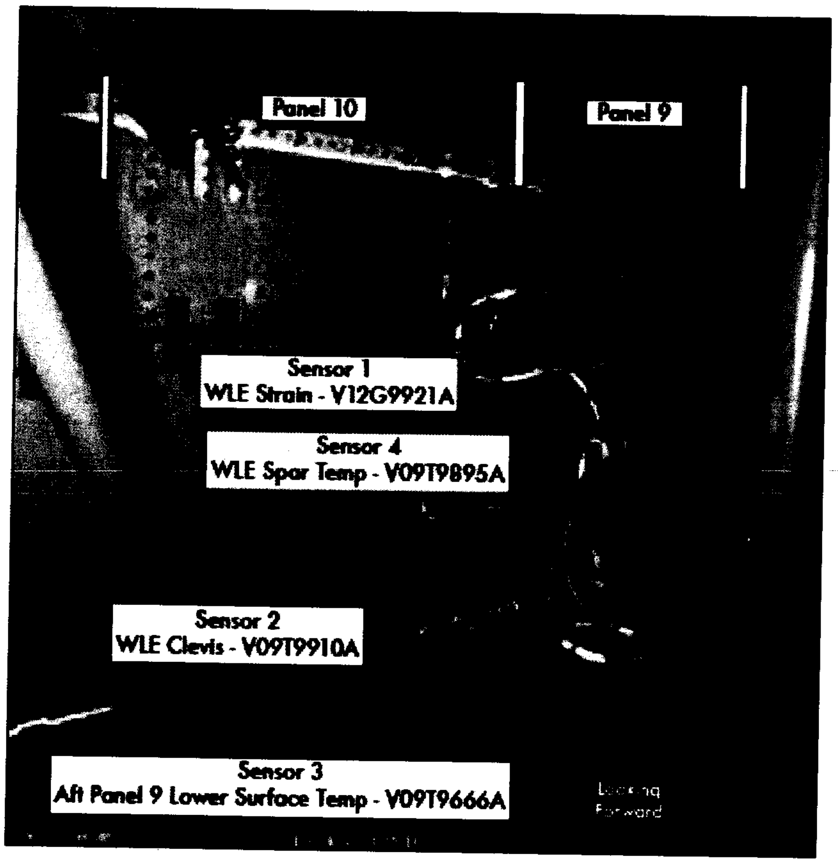
NASA




- Extensive cabling and harnesses for strain gages and temperature sensors
- Serious issue for instrumenting deployable structures
  - Stowage concerns
  - Deployment concerns
  - Reliability issues

# Wireless technologies – NASA JSC

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NASA

## NASA JSC, Invocon and Sandia National Labs

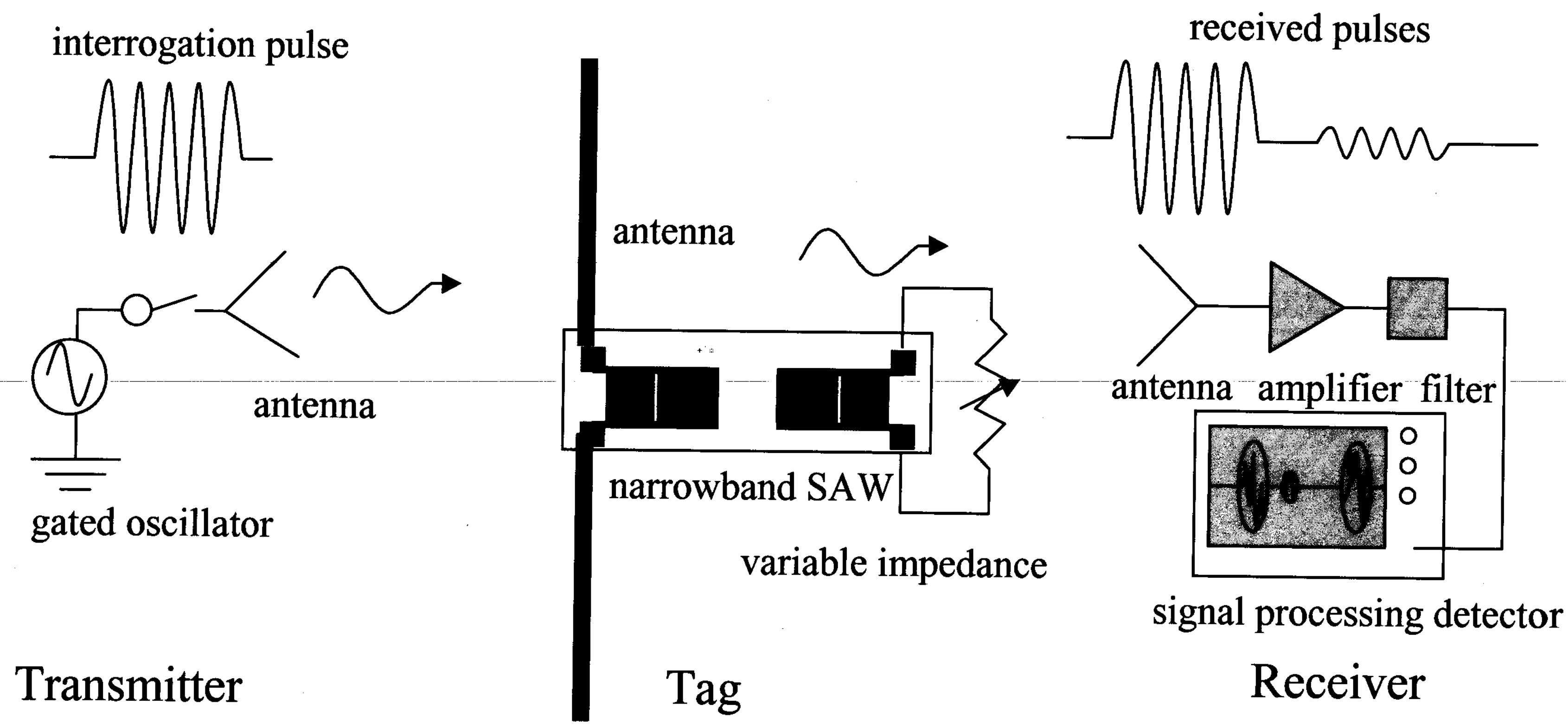


Figure 1: SAW sensor transmitter-tag-receiver configuration

**Contact: George Studor, NASA Johnson Space Center**

# Macro-Fiber Composite Actuator – NASA Langley

**Contact: Keats Wilkie, NASA Langley**

# Self healing of habitats – U. Illinois

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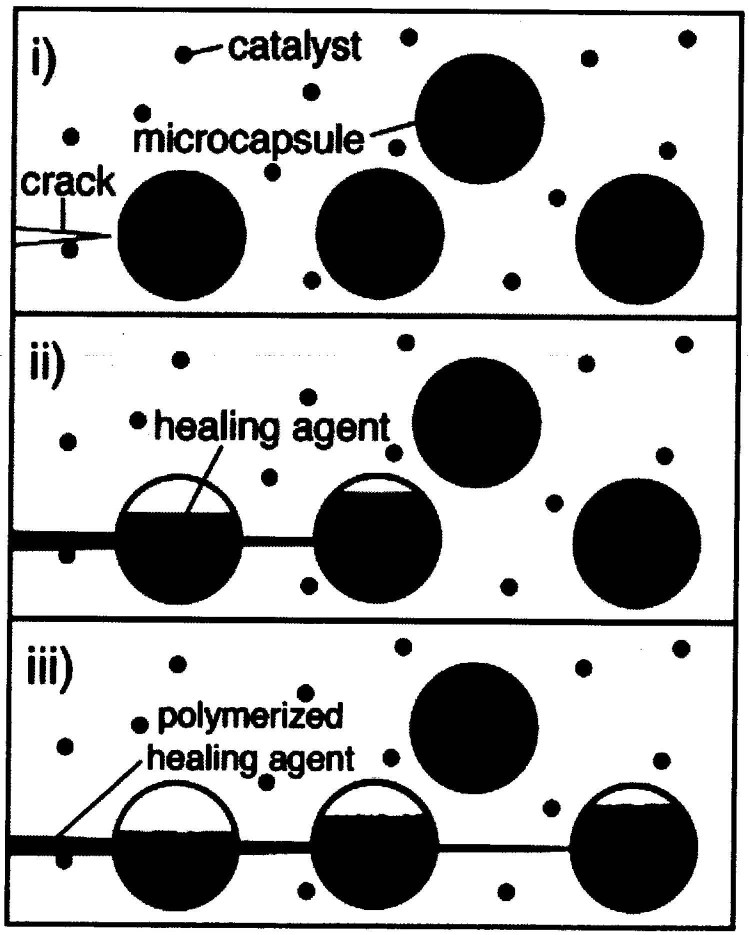
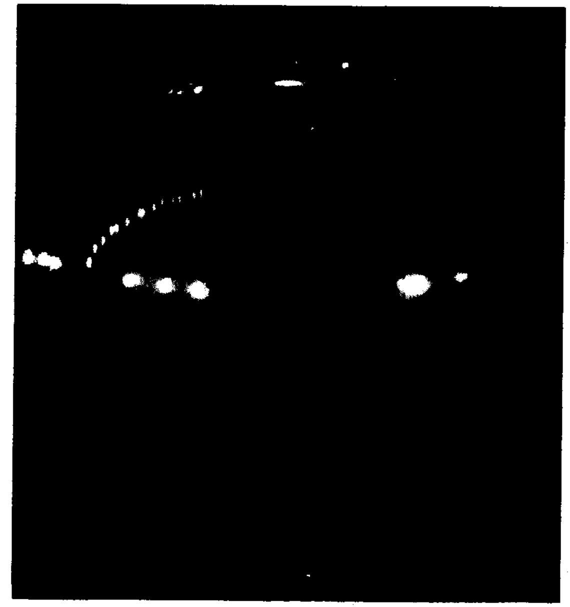
NASA

## Contacts: Nancy Sottos and Scott White



TransHab bladder

SEM photo of the damage in Layer 3

SEM photo of the damage in Layer 2

# Unique repair issues in space



- On-orbit repair an increasingly important issue
- Current methods geared toward ceramic tiles and RCC
- Deployable structures utilize a range of polymers, composites and fabrics

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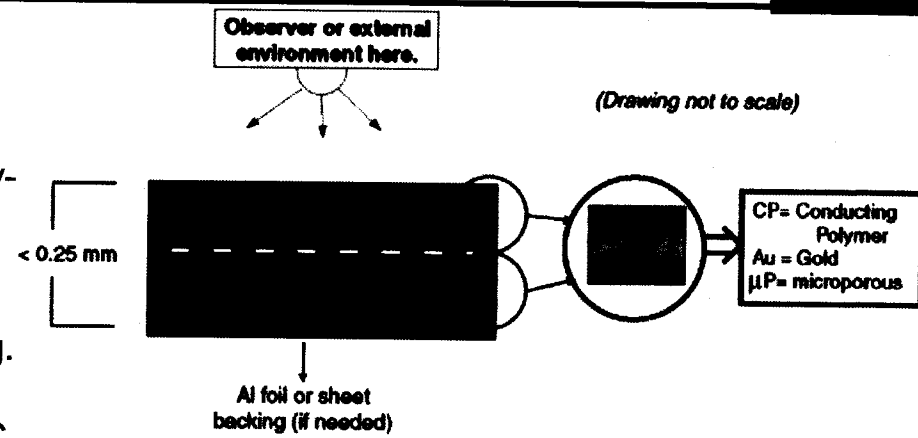
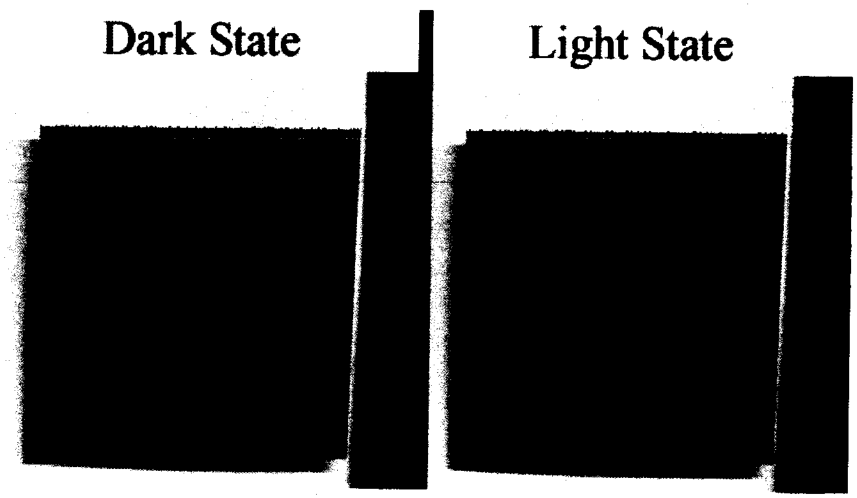
# Conducting Polymer-based Electrochromics

NASA

- **Ashwin-Ushas Corp., Lakewood, NJ (Dr. Prasanna Chandrasekhar) / NASA-JPL SBIR**
- **Operational principle:**
  - Active CP layer undergoes electrochemically-induced oxidation and reduction with an applied voltage.
  - Completely reduced state is IR-transparent. Partially oxidized state is highly IR-absorbing.
  - Uses an Ionic Electrolyte, also called “room temperature molten salt”. Liquid from –100°C to + 280°C
- **Performance:**
  - Delta-e ~0.55,
  - Tailorable emissivity from 0.15 to 0.85
  - Switching times: < 5 s at room temp , < 1 min at -35°C
  - Solar Absorptance < 0.29
- **Thin (< 0.5 mm), flexible panel construction**
  - Can be affixed to any surface. Conform to any shape/size.
  - May be cut with scissors.
- **Light weight: ~ 0.8 kg/m^2**
- **Low power consumption:**
  - Peak Transient ~4 mW/cm2 for < 30 sec
  - Steady-state: < 40 $\mu$W/cm2

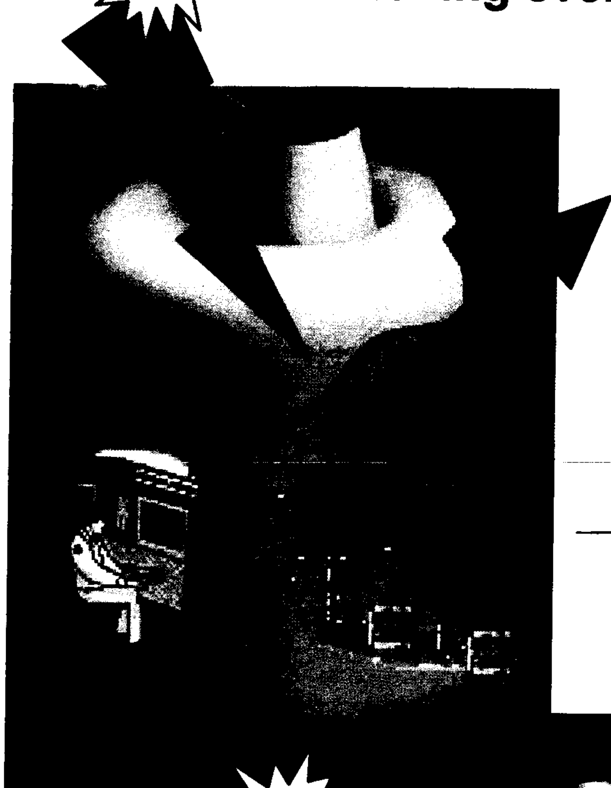


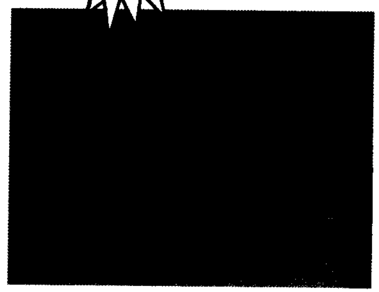

**Contact: Tony Paris, JPL**

# Structural Health System Concept

1 **Threatening event**

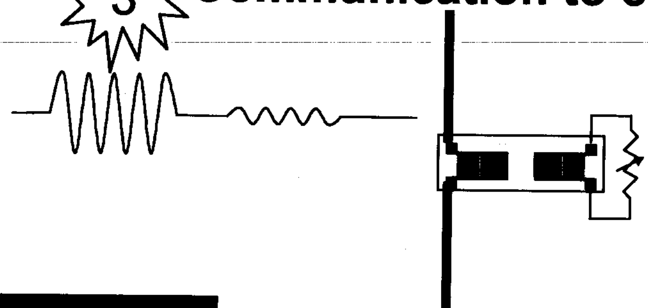


2 **Detection by embedded sensors**



- Flexible strain gages
- Acoustic imagers

3 **Communication to crew via RFID nodes**



4 **Corrective measures**

- Self-repairing material (passive)
- Embedded actuators (based on strain gages)
- Electrochromic material (based on T sensors)

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# Acknowledgements


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- **Penn State University**
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