Space Transportation - Third Generation

Structures IVHM for 3rd Generation RLVs

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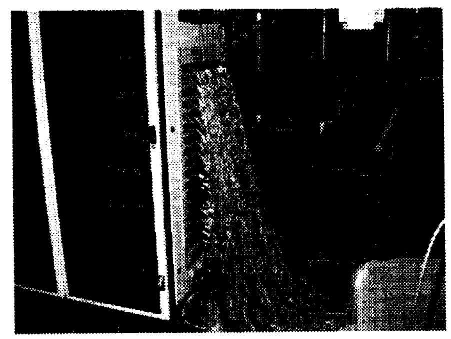
Objective

The primary goal of a Structures IVHM system for 3rd generation RLV's is to provide near 100% structural sensing coverage and thus eliminate both routine, and especially unplanned, inspections which are costly and time consuming. To meet this goal, significant advances in sensing and measurement system technology, data systems architectures, and structures based analysis methodology will be required to enable the needed large numbers of sensors with little weight penalty. This program will leverage X-33, 2nd Gen RLV, Shuttle, and Aviation Safety SIVHM system development experience to address this goal.

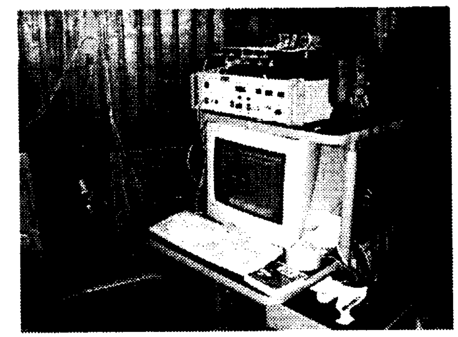
FY01 Activities

- Sensor Development - Investigate fiber-optic (F/O) geometry variations for improved sensors (FY00 follow-on), continue development of structures based model for acoustic emission damage detection (FY 00 follow-on)
- Structural Modeling - Start development of material and structural property databases to guide placement of sensors
- Data Systems Architecture - Investigate enabling micro-instrumentation technologies including COTS micro-sensor and micro computer technologies (FY 00 follow-on)
- Ground/Flight Testing - Evaluate ruggedized COTS tunable laser sources for F/O sensors (FY 00 follow-on) and initiate development of a SIVHM dedicated ground test bed.

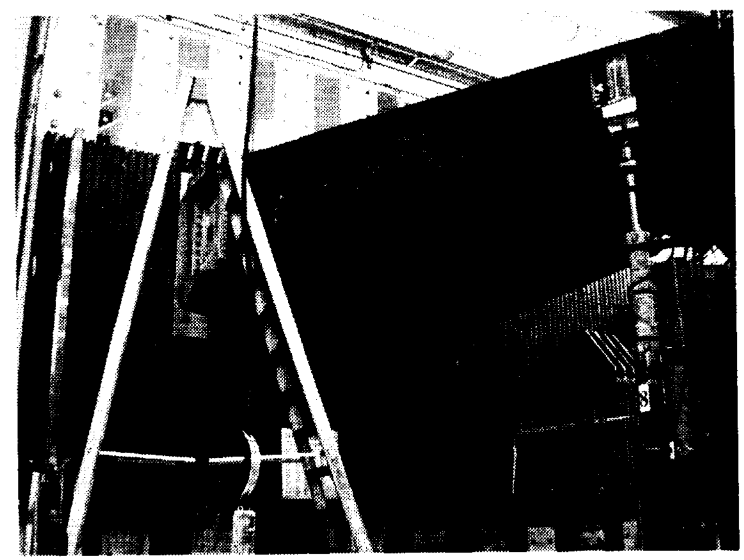
High Density Fiber-Optic Strain Sensing



Wiring for 400 foil gages



Optical Fibers for ~3000 gages

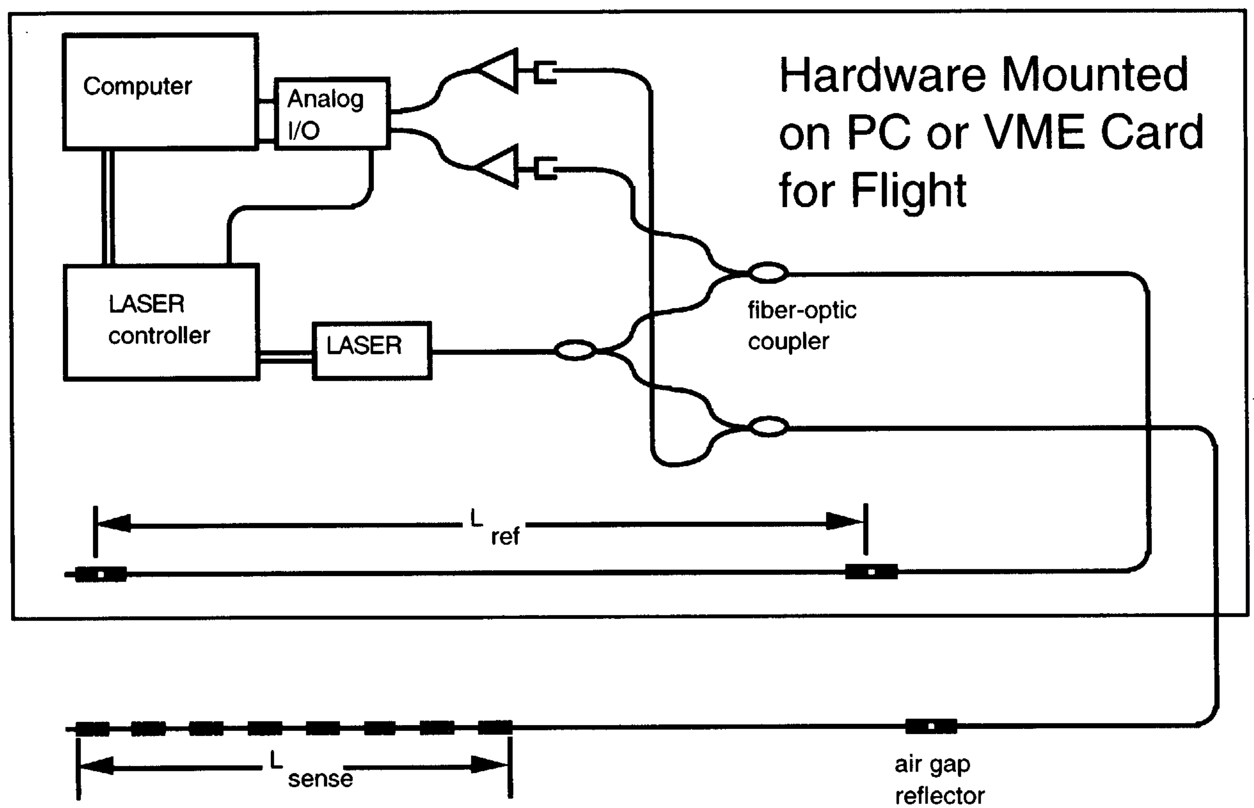


Strain Sensing on Full Scale Composite Wing

SIVHM Impact on 3rd Generation RLV Goals

- Safety
  - Structural failure detection and prediction for improved inherent system safety
  - Early warning for improved abort capability
  - Reduction of critical failures for improved crew survivability
- Cost
  - Increased system development and production costs
  - Offset by decreased operation and maintenance costs
    - ARINC Study - D&P costs could be offset in as little as 2 years for aircraft [4]
    - 50% reduction in inspection time for aircraft [1]
    - "Maintenance for cause" rather than scheduled component replacement
- System Responsiveness and Dependability
  - Improved vehicle processing time for increased system flexibility, capacity, and operability
    - 50% reduction in inspection time for aircraft [1]
  - Improved system reliability and maintainability

Bragg Grating Demodulation System



20' strain sensing length

SIVHM Components, Technologies, and NASA Participants

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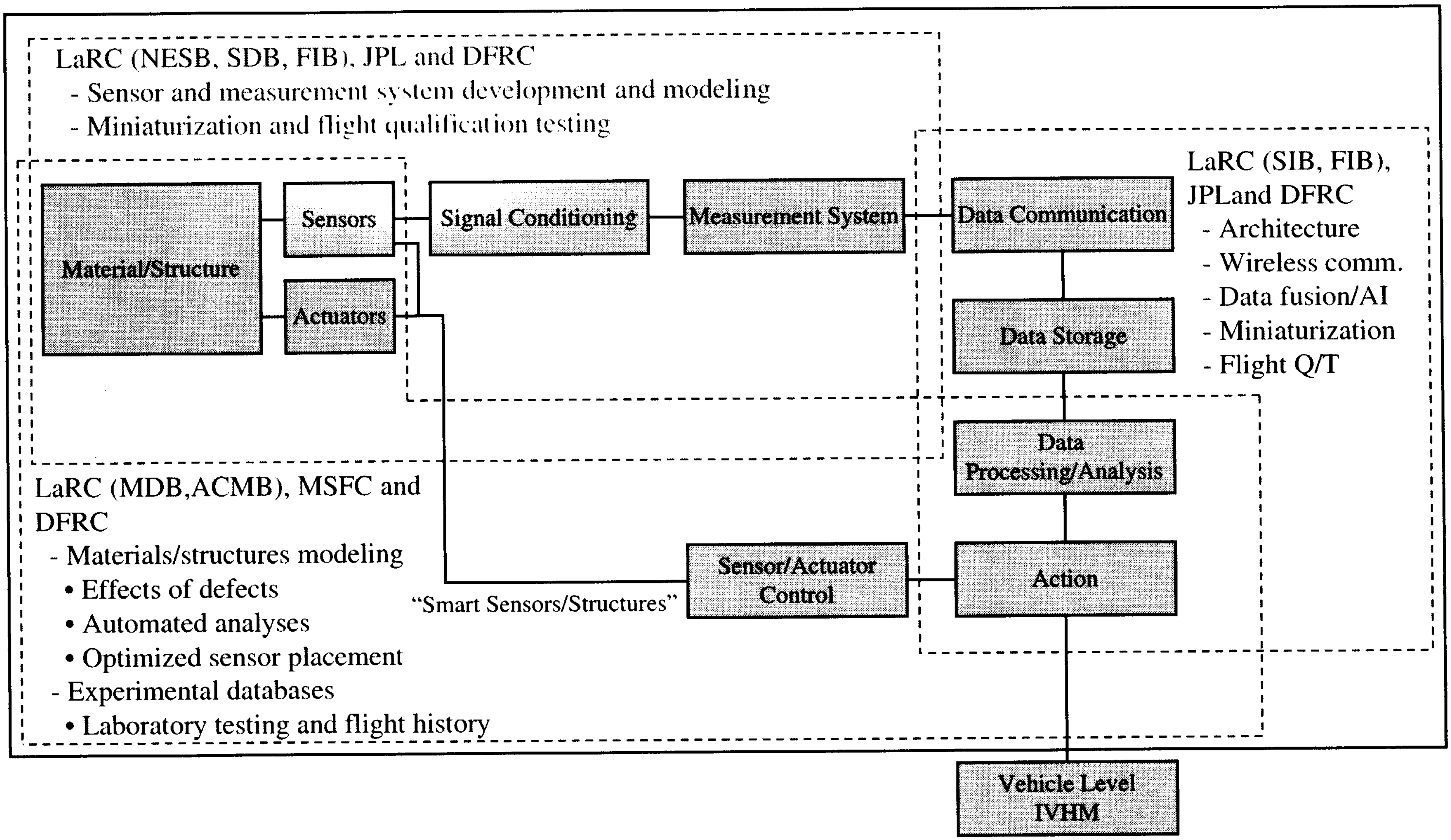

Proposed SIVHM Technologies

- Sensor and measurement systems
- Materials and structures based models for SIVHM optimization and automated data analysis
- Architectures, micro-instrumentation, and data fusion
- SIVHM ground test beds
- SIVHM flight qualification and aero-flight testing

SIVHM Sensor Systems

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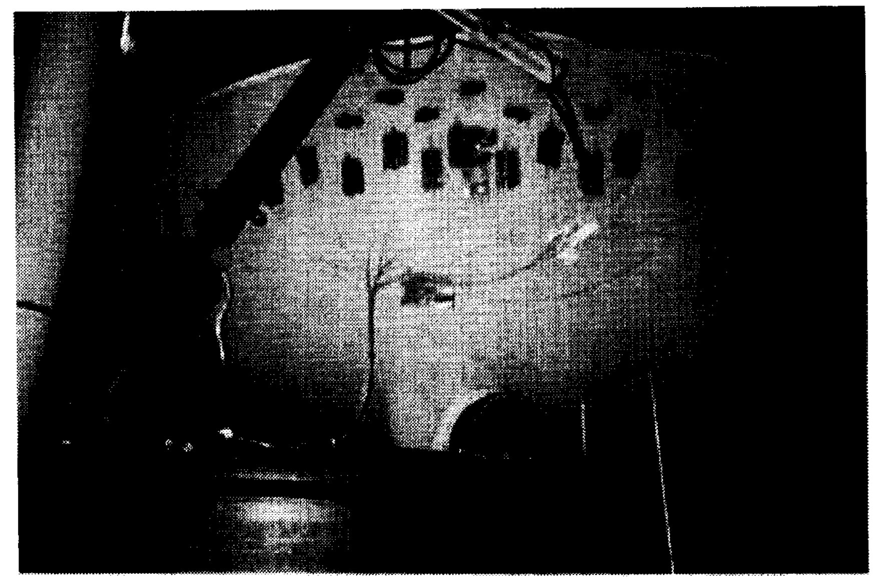
Goals

- Development of advanced, high density, light weight sensor technologies to enable 100% structural sensing coverage
- Development of miniaturized, rugged, flight capable measurement systems
- Development of physics based sensor response models for enhanced sensor performance, optimization of sensor placement, and improved, automated data analysis methodologies

Products

- Investigate fiber-optic (F/O) sensor measurement alternatives such as in-fiber spectroscopic methods to provide multi-variable chemical sensing capabilities.
- Investigate specialty optical materials (e.g., saphire) along with fiber geometry variations to achieve improved F/O sensor performance capable of extreme environments while providing multi-variable (e.g. strain, temperature, vibration, etc.) measurements.
- Investigate capabilities of wireless micro-transmitters in conjunction with piezoelectric and MEM's sensors to provide impact and vibration sensing.
- Develop physics based sensing models to integrate with structural models for SIVHM system optimization and automation of analyses. Initial effort to model acoustic emission damage and impact sensors.



X-33 LH2 Tank IVHM Sensor Instrumentation

Materials and Structures Knowledge Based Models for SIVHM

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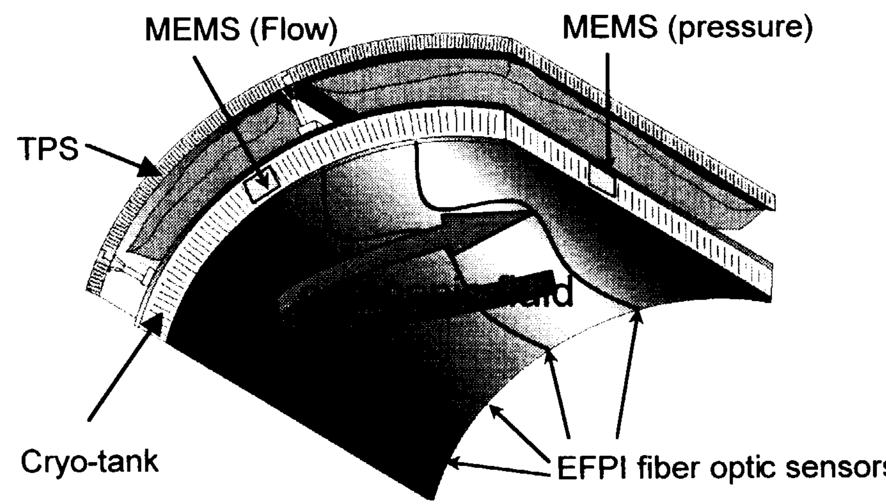
Goals

Development of tools for analysis of SIVHM sensor data to assess structural health of advanced aerospace vehicles using:

- mechanics based analysis methods
- sensor-structure integrity
- data analysis methods
- property databases
- material behavior
- structural response
- knowledge base and knowledge management

Products

- Provide descriptions of critical failure locations to guide acquisition of data and placement of sensors.
- Integration of sensor data and materials/structure response to establish relationships between sensor resolution and damage size, location, mode.
- Establish sensor-structure integration schemes to account for synergistic effects.
- Data analysis methods that utilize the knowledge base to assess residual life, strength, stiffness.
- Updated prediction of remaining life taking into account rate of change of properties and loads.



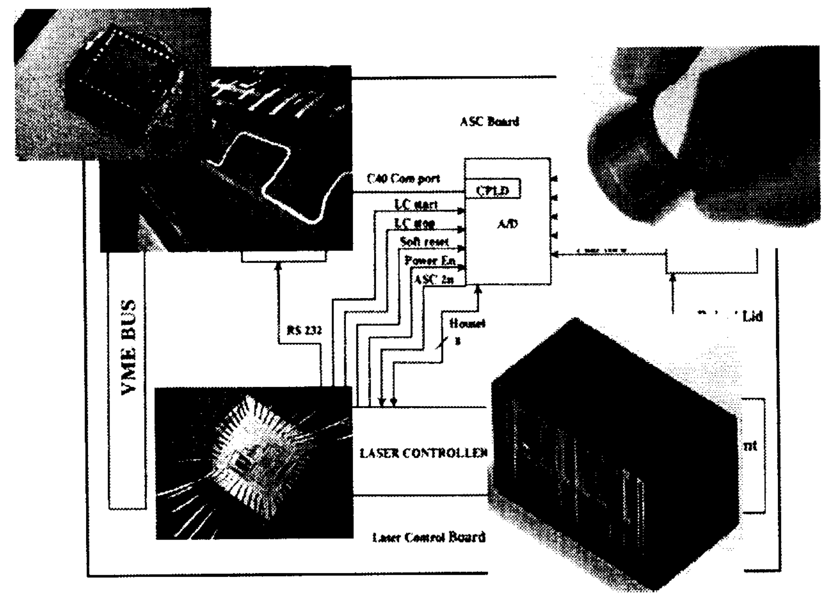
Structural/material integrity integrated with IVHM

SIVHM Data Fusion and Architectures

POC: Eric Cooper, NASA Langley Research Center, 757-864-6674, e.g.cooper@larc.nasa.gov

Goals

Develop miniaturization technologies along with data fusion and architectures that enable densely distributed sensor suites for managing the health of aerospace vehicle structures. Technology considerations will focus on reducing the weight, power, and volume requirements for sensor data acquisition, storage and processing. The effectiveness of micro-instrumentation sensor suites comprised of advanced sensing technologies such as fiber optic, MEMS, and acoustic emission, as well as computing miniaturization technologies such as multi-chip modules, chips-on-board, die-on-flex, and three-dimensional silicon die stacking, will be investigated.



Products

- Suitability assessment of current and emerging miniaturized sensing and computing technologies for use in aerospace structures health management

- Acceleration of lab-emergent miniaturization technologies

- Distributed “smart sensor” concept that forwards pertinent structural health information to higher-level IVHM reasoning processes

- Demonstrated distributed remote sensing modules and communications architecture

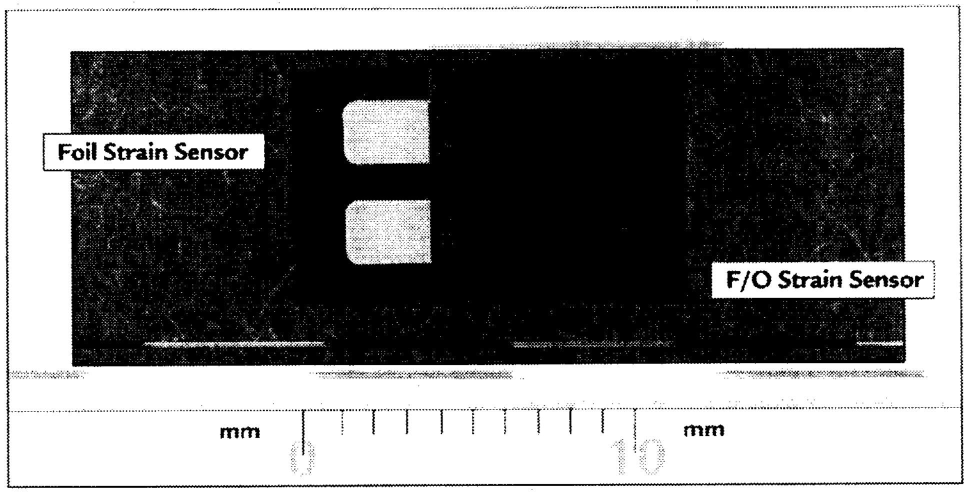
Synergies and Dependencies

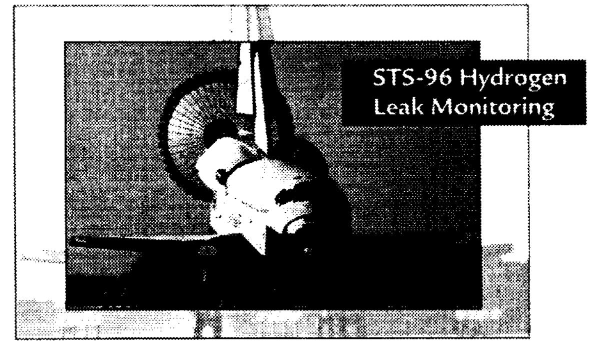
- Success dependent on sizable 2nd Gen. SIVHM effort
  - Address more near term technologies
    - Miniaturize and flight harden high speed, tunable fiber laser
    - Multiplexing architectures for high bandwidth sensors
    - Etc.
- Must coordinate with TPS, propulsion, etc. IVHM elements
- Leverage previous and ongoing SIVHM programs
  - X-33, X-34, X-37, Shuttle
  - Bantam
  - Aviation Safety
  - Etc.
- Need to identify and fund future space flight opportunities
  - X-33B, Shuttle, Pathfinder, etc.
  - Not funded within current limited scope of Spaceliner

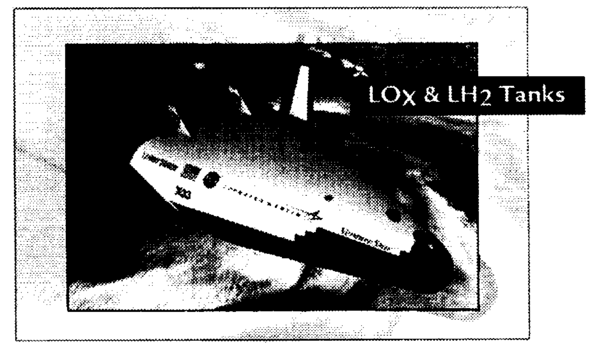
Other Potential High Payoff Long Term SIVHM Technologies

- Self-healing materials and structures
- Smart (adaptive) materials and structures
- Large area, remote NDE for SIVHM follow-up inspections
- Autonomous NDE/IVHM micro-robots for monitoring/inspections
- Nanomaterials and sensors
- Etc.

Distributed Fiber-Optic (F/O) Sensing for Structures IVHM







High Density Structural Sensors

- 10,000 Sensors < 1 pound
- Strain, Temperature, & Hydrogen (Propellant Leaks)
- Future Research - Vibration, Shape, Acoustic Emission, Chemistry (Corrosion)
- < $10/Sensor