# Promises and Challenges in SHM

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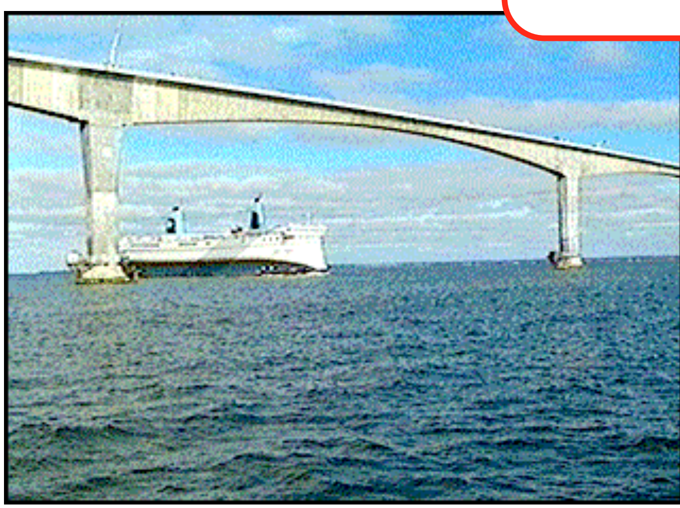
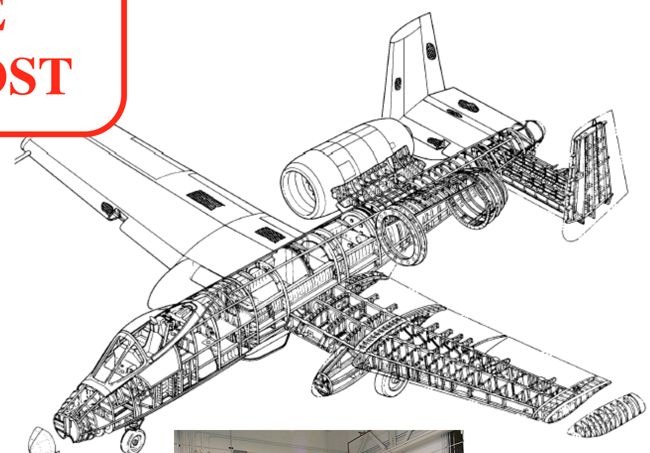
- •RELIABILITY
- •PERFORMANCE
- •LIFE-CYCLE COST





# Benefits from SHM System

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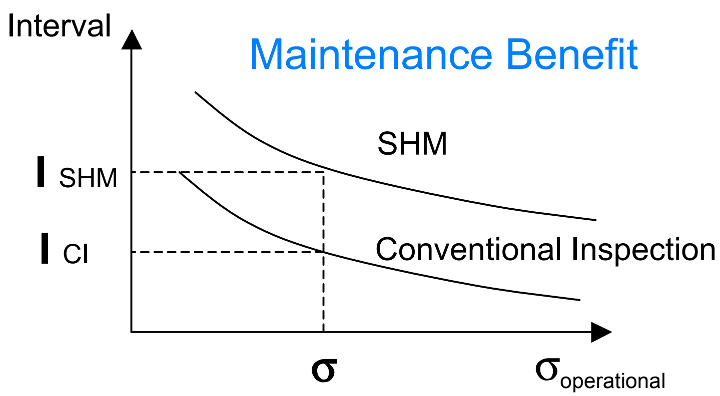
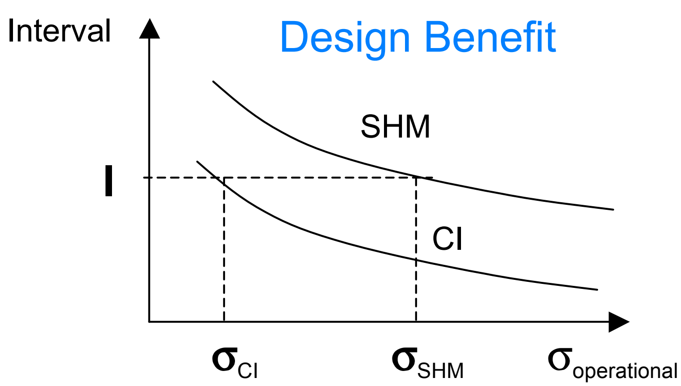
- **Maintenance Cost**

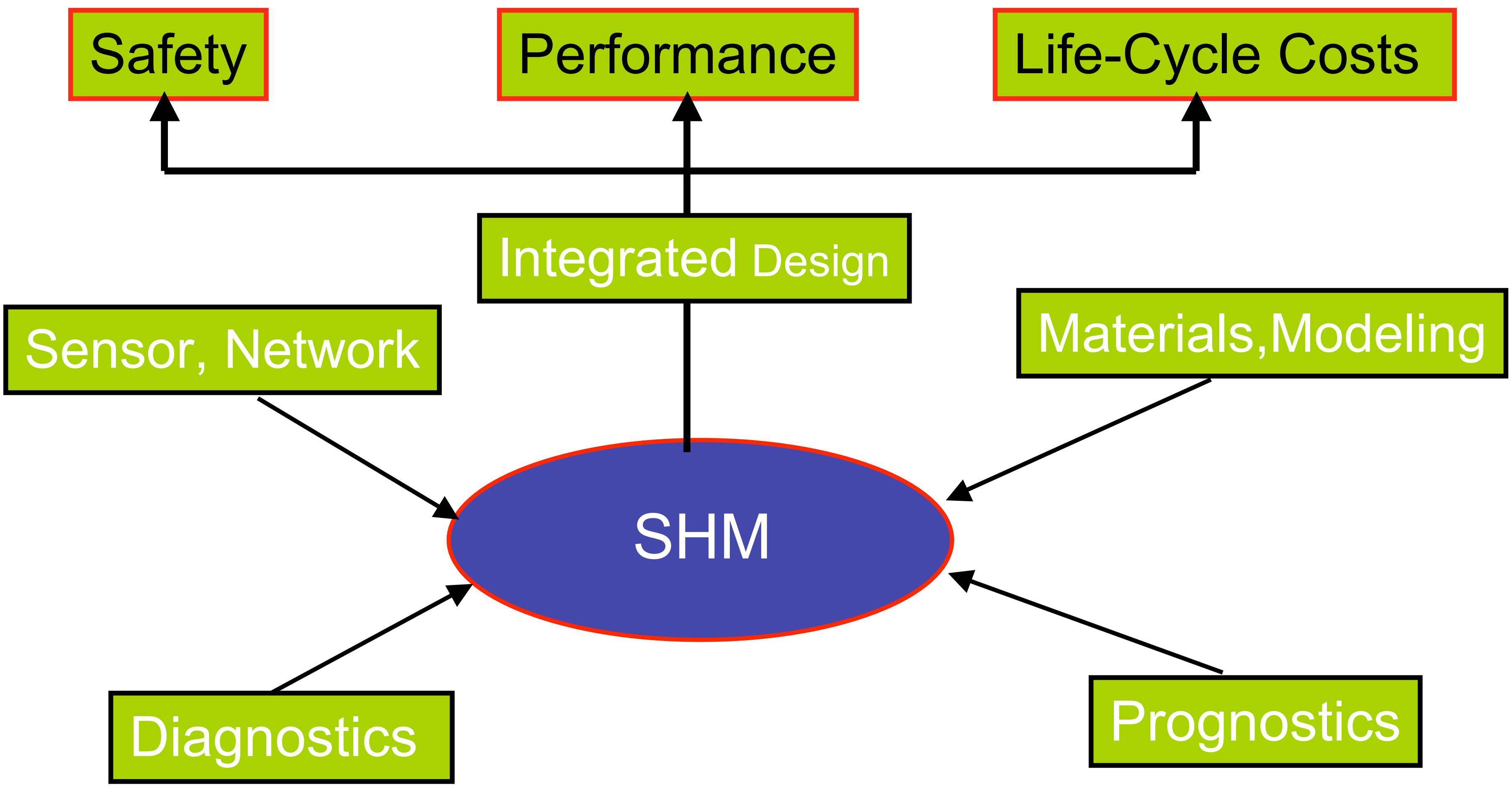



- Minimize ground time
- Reduce inspection time
- Improve operation efficiency

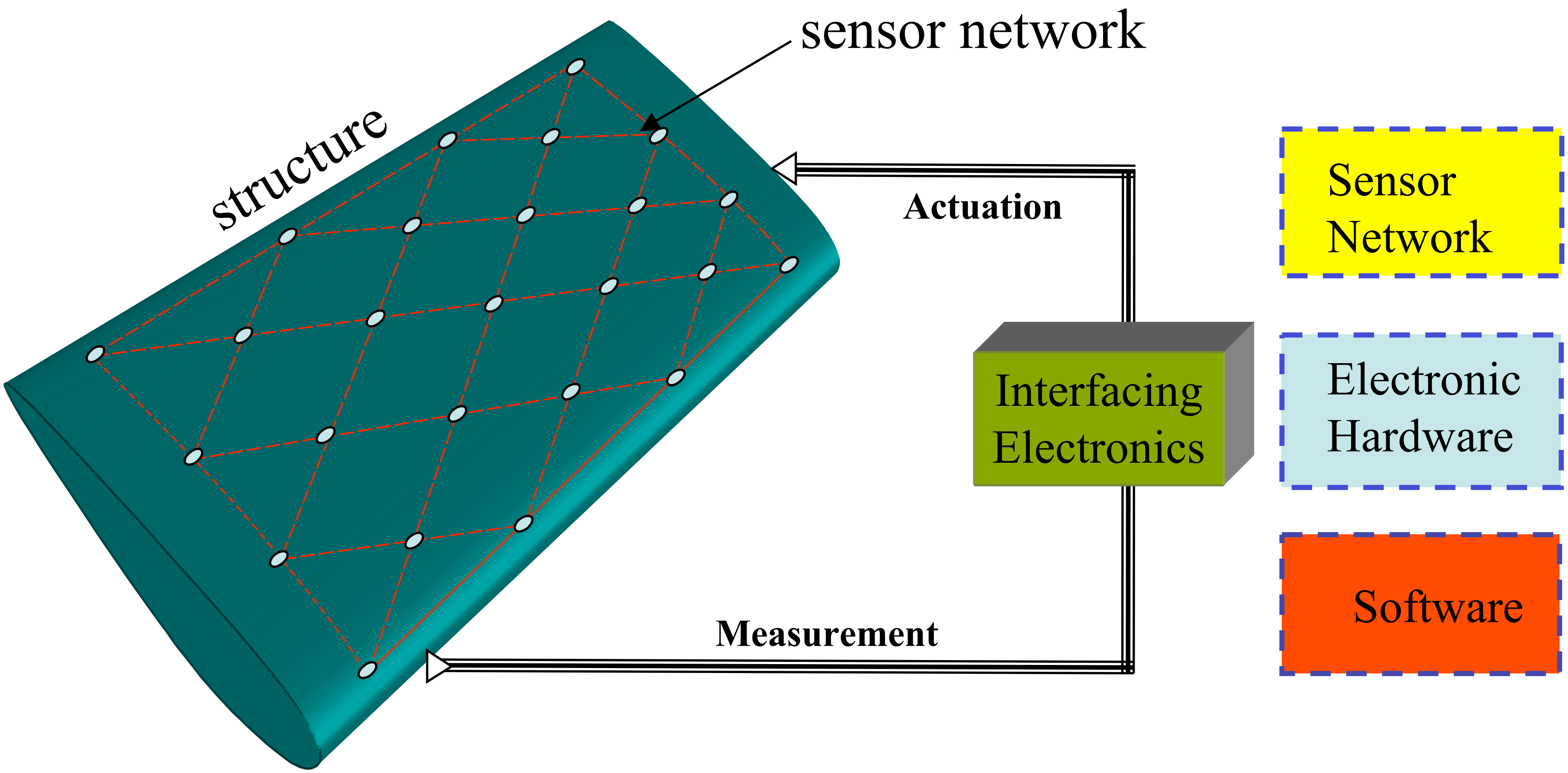
- **Performance Efficiency**




- Reduce weight
- Shorten design cycle
- Optimize component tests
- Improve performance


Safety
Performance
Life-Cycle Costs
Integrated Design
Sensor, Network
Materials,Modeling
SHM
Diagnostics
Prognostics

# Structural Health Monitoring



# SHM Inputs & Outputs

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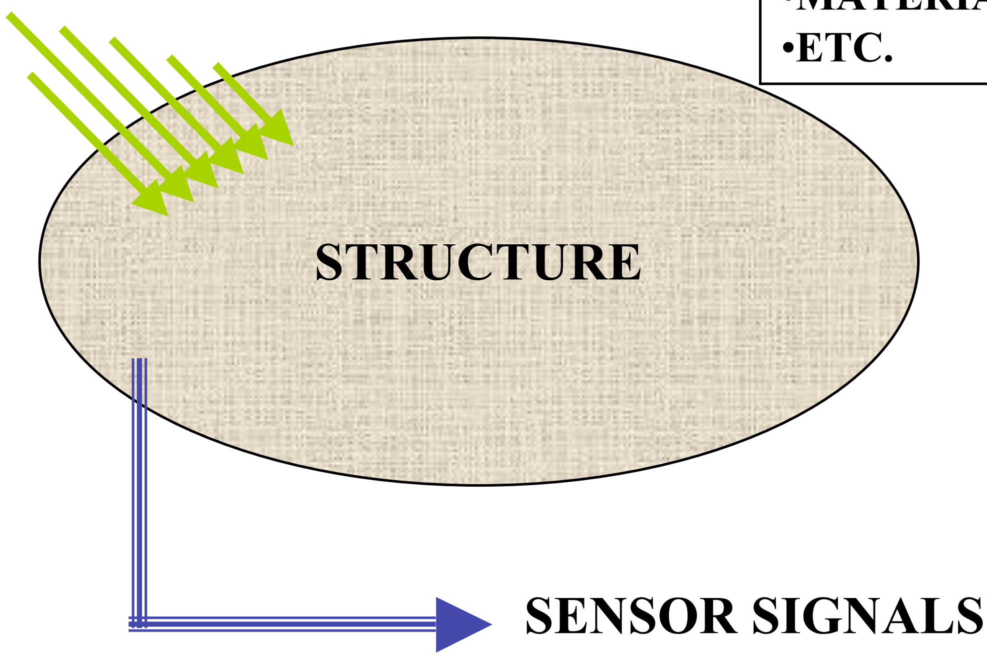
**GIVEN SENSOR MEASUREMENTS, DETERMINE EXTERNAL AND/OR INTERNAL PARAMETERS.**

**<u>EXTERNAL:</u>**

- **LOAD**
- **TEMPERATURE**
- **MOISTURE**
- **ETC.**

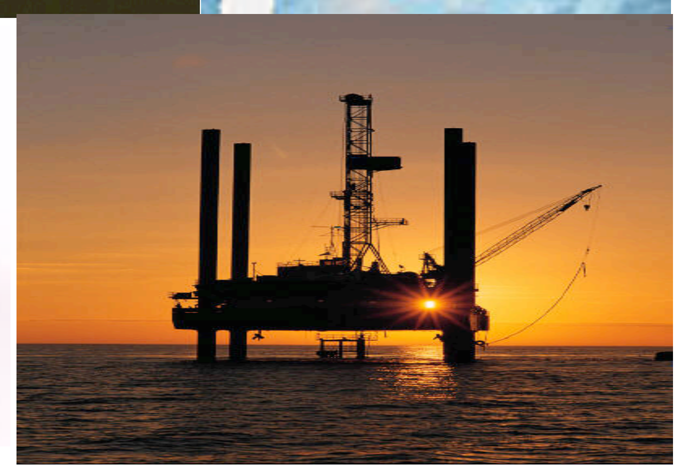
**<u>INTERNAL:</u>**

- **DAMAGE LOCATION**
- **DAMAGE SIZE/TYPE**
- **MATERIAL PROPERTIES**
- **ETC.**

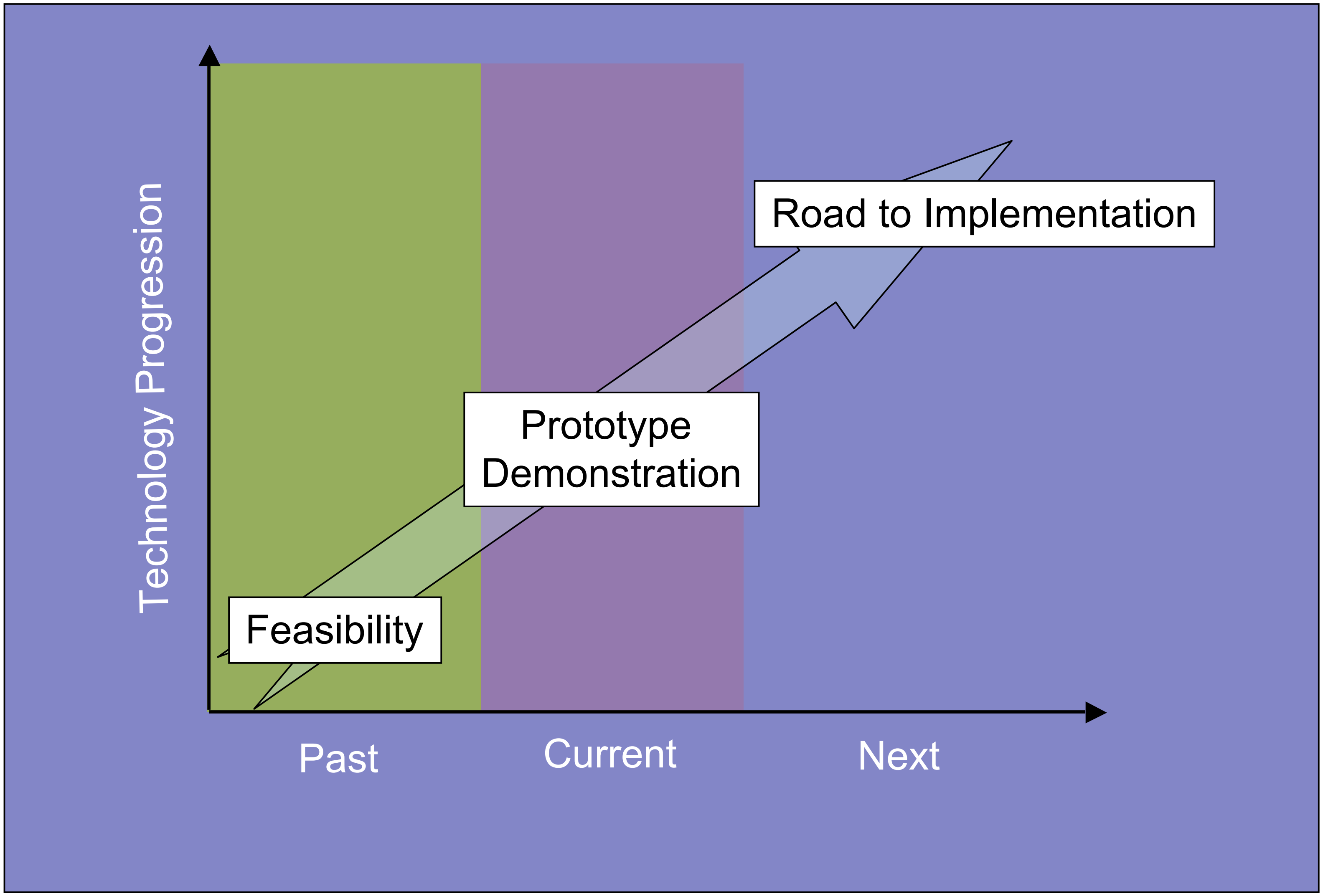


# Applications

- *Aircraft*
- *Space Systems*
- *Automotive*
- *Off-shore*

# SHM Technology Progression

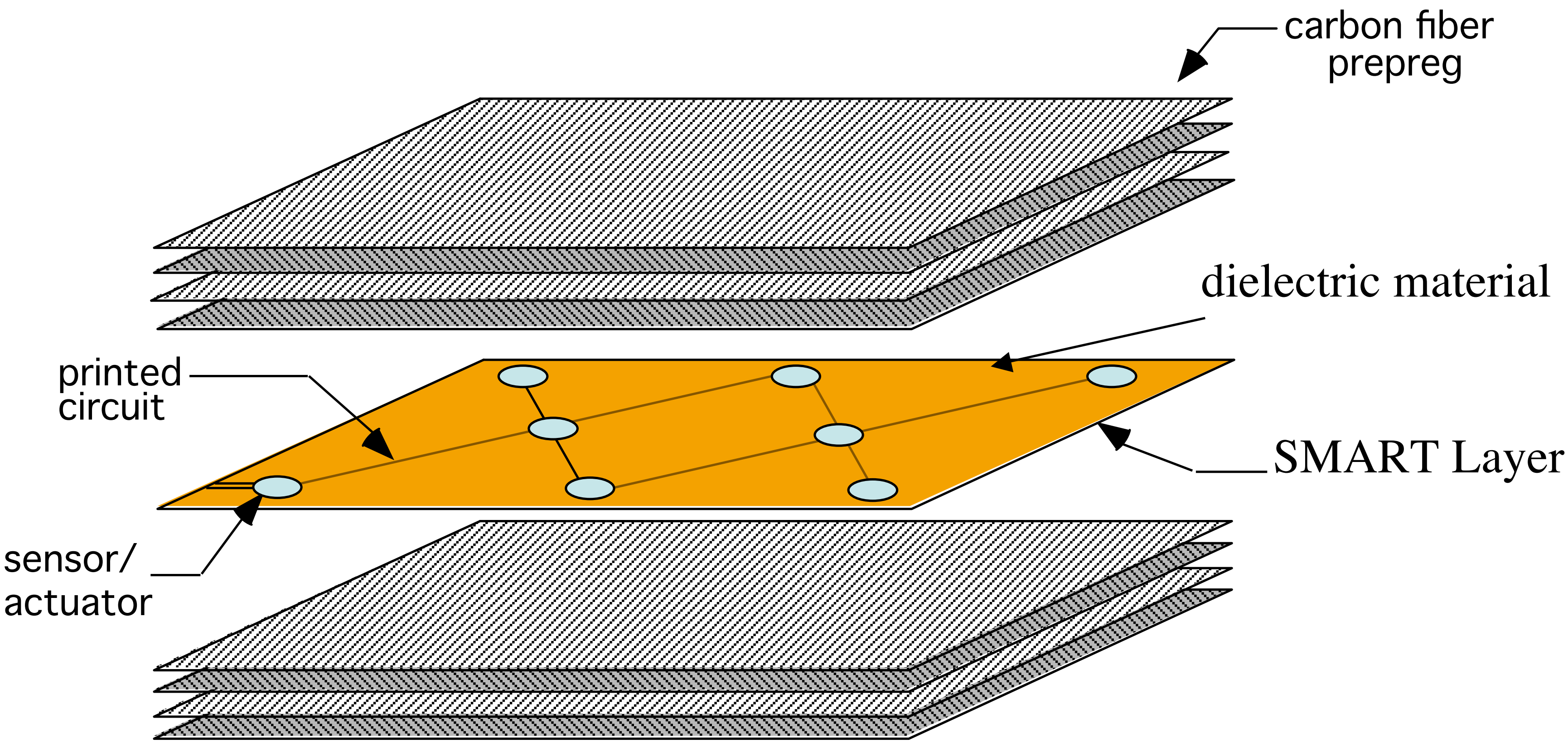


# SENSORS

- PASSIVE (receive signals only)
  - OPTICAL FIBER (Luna Innovations, etc.)
  - STRAIN GAUGE
  - MICROELECTRONIC SENSORS (Microstrain, etc)
  - AE SENSORS (Physical Acoustics, etc.)
  - ETC.
- ACTIVE (receive and generate signals)
  - PIEZOELECTRIC MATERIALS (Acellent Technologies, etc.)
  - SMA
  - ETC.

# Piezo-Sensor/Actuator Network

- FLEXIBLE PRINTED-CIRCUIT BOARD TECHNIQUE



# Prototyping and Testing

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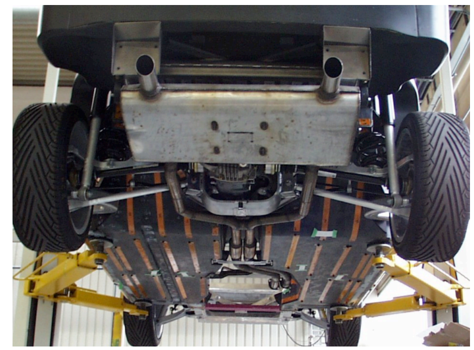
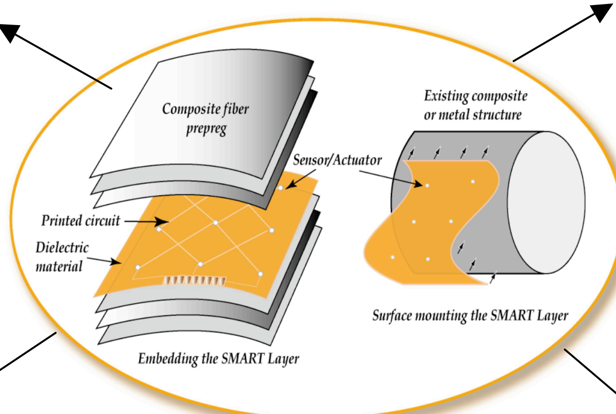
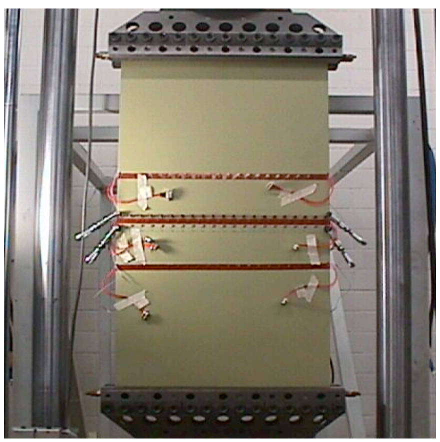
Impact Tests on Composite Barrel

Composite Car Misuse Tests



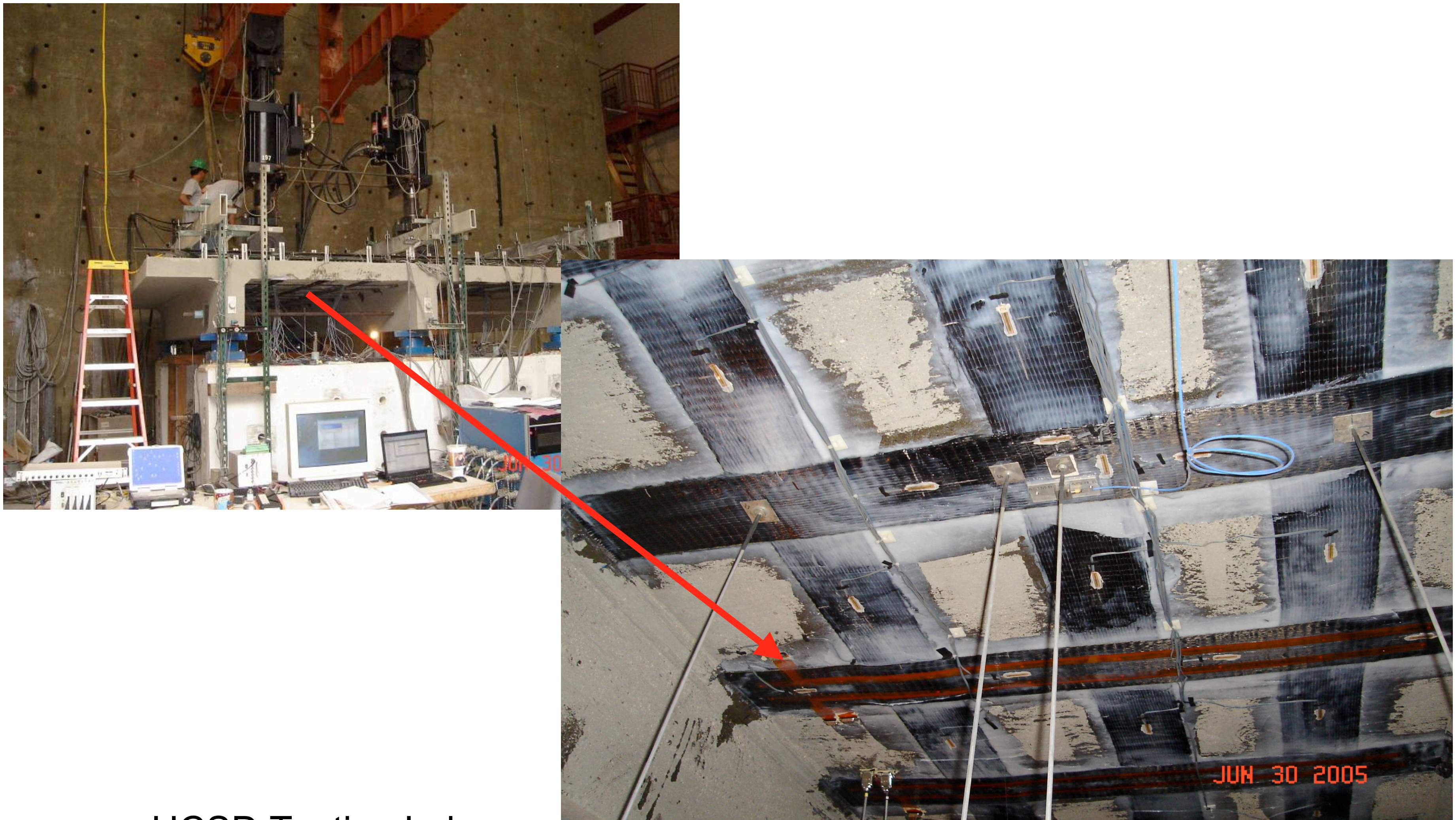


Fatigue Crack Monitoring Tests

Hot spot Monitoring

# Hot Spot Monitoring for Civil Retrofitting



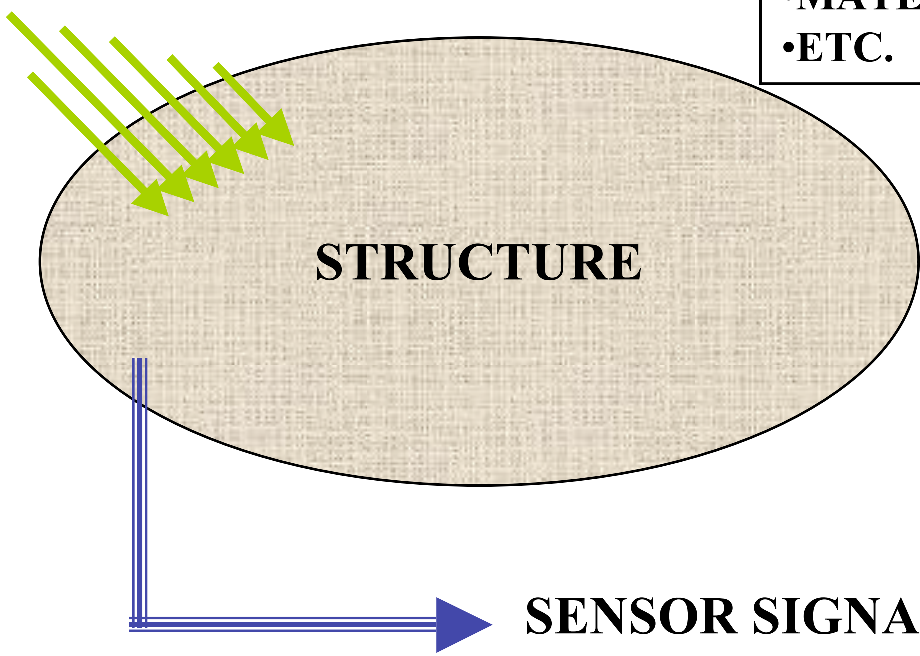

UCSD Testing Lab.

# SHM Inputs & Outputs

**GIVEN SENSOR MEASUREMENTS, DETERMINE EXTERNAL AND/OR INTERNAL PARAMETERS.**

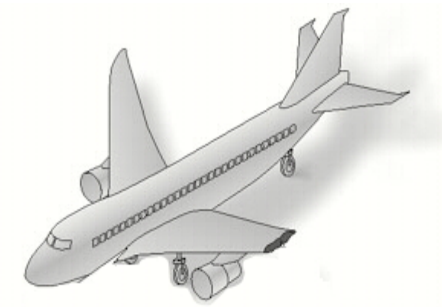
**EXTERNAL:**
- LOAD
- TEMPERATURE
- MOISTURE
- ETC.

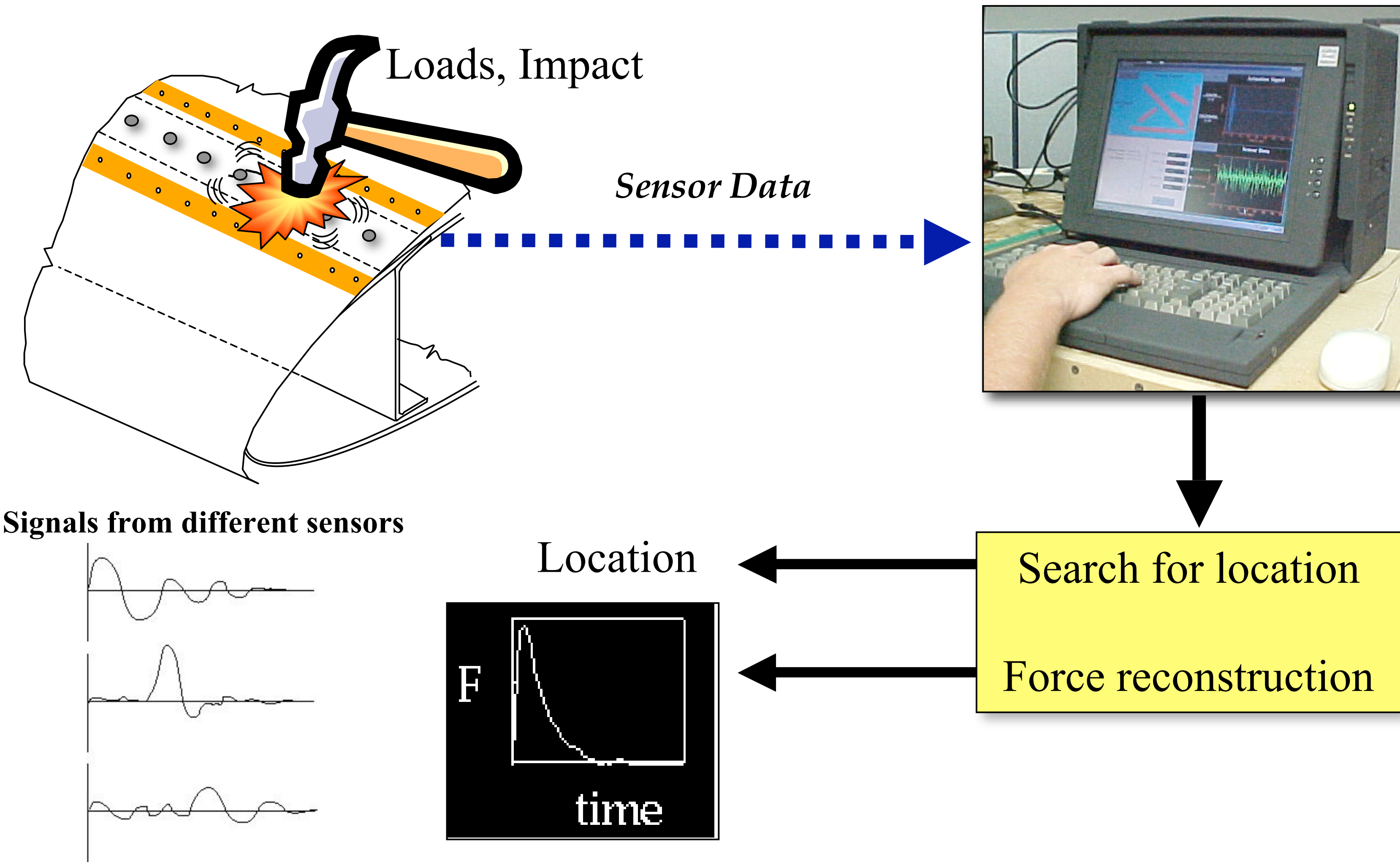
**INTERNAL:**
- DAMAGE LOCATION
- DAMAGE SIZE/TYPE
- MATERIAL PROPERTIES
- ETC.



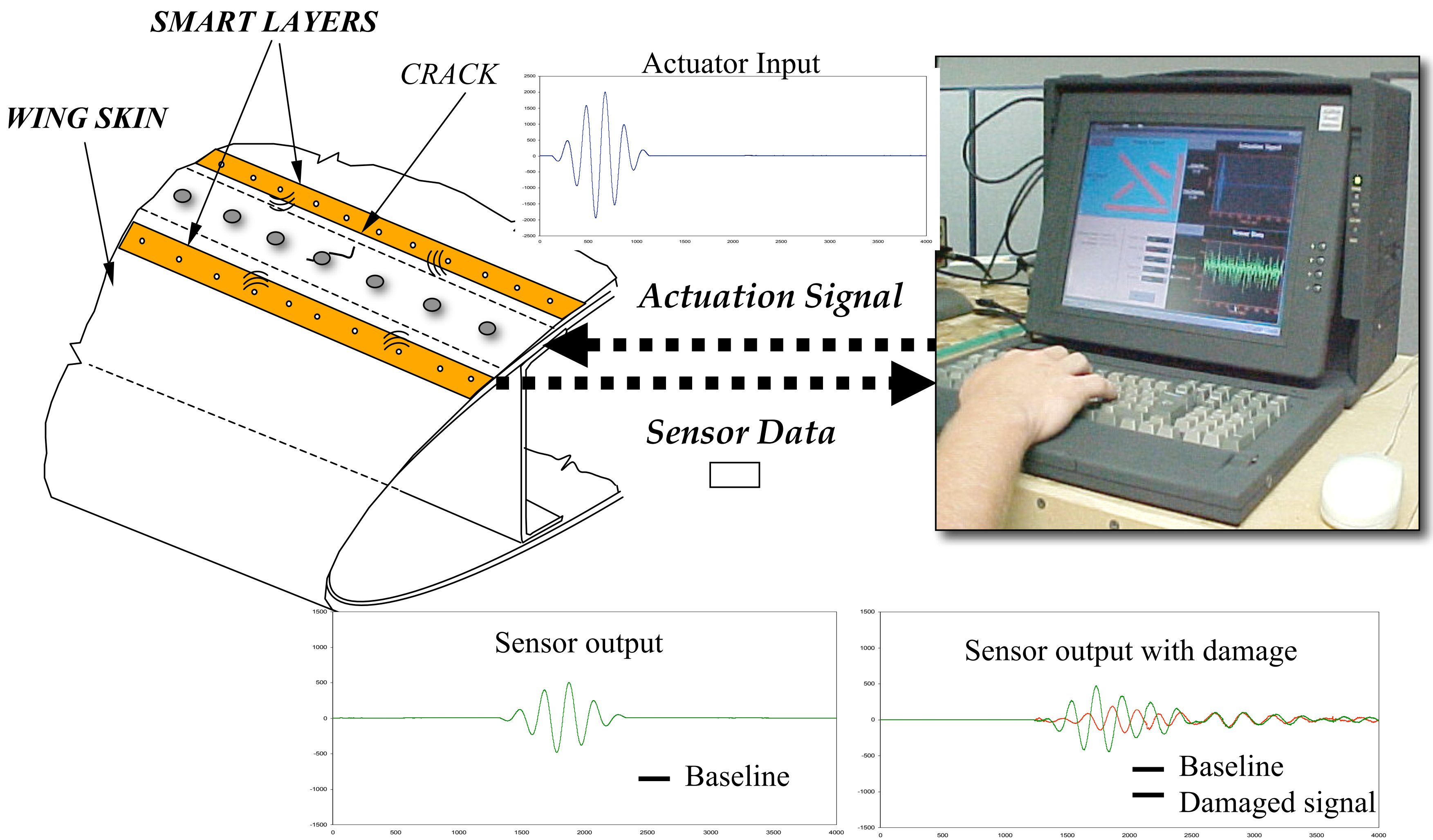

**SENSOR SIGNALS**

# Passive Sensing

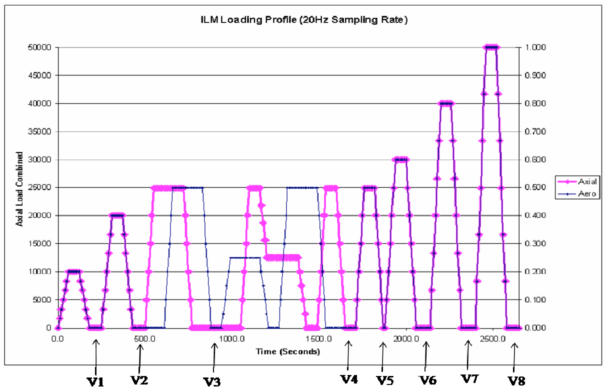




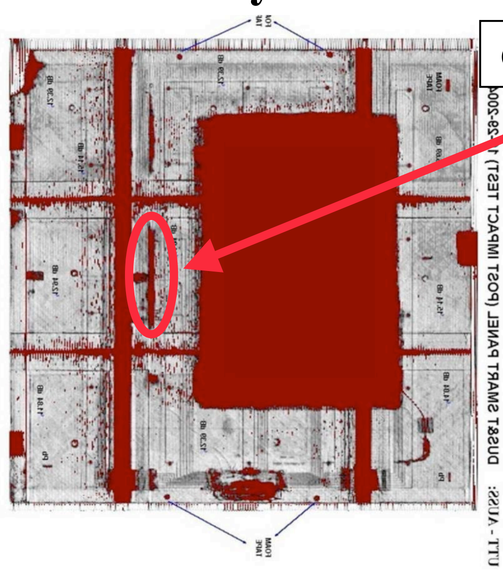
# Active Sensing



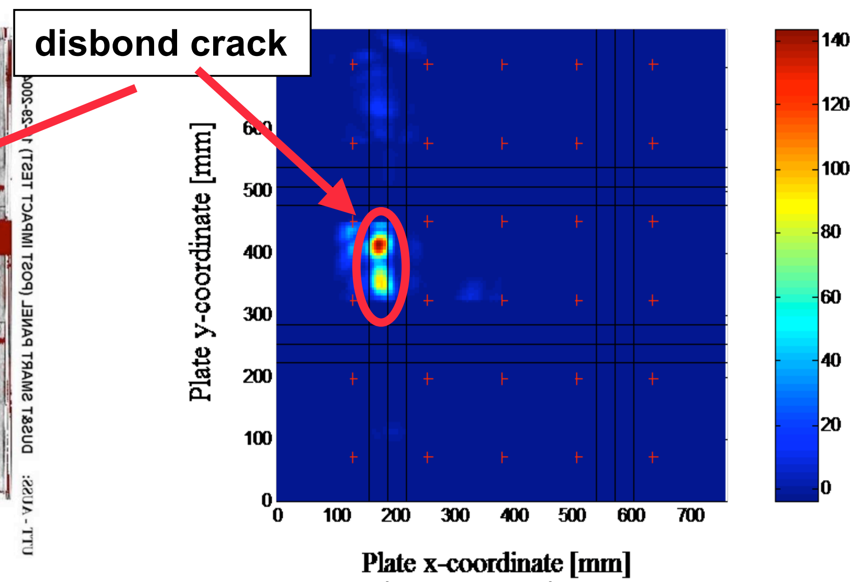
# Diagnostic Imaging for Bonded TPS with Built-In SHM




**Load cycles**



**C-Scan Image**




**Diagnostic Image**

# Inspection for Fatigue Cracks

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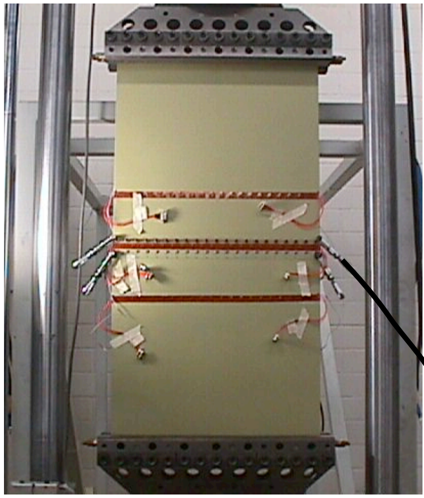
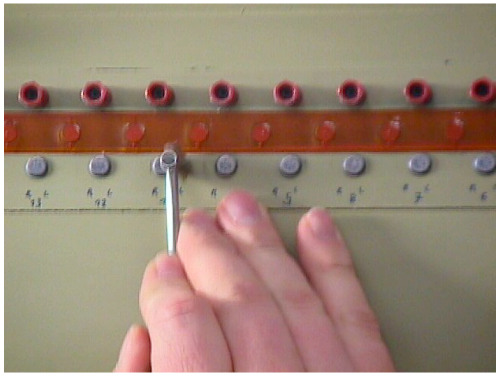
NDT inspection

Smart Patch

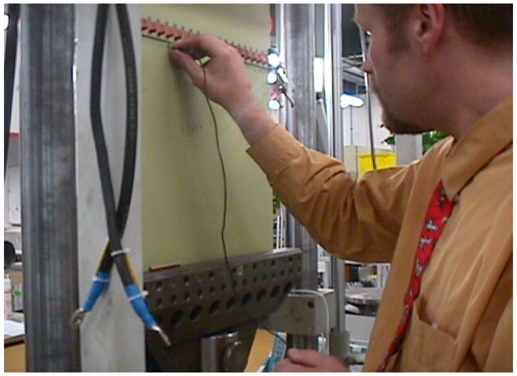


Eddy current



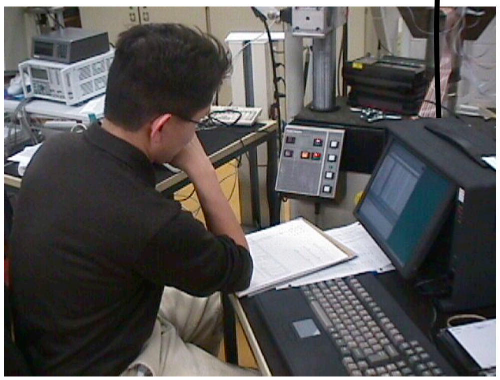
Equipment: Defectoscope AF
Probe: 2.832-01-2520

Ultrasonic

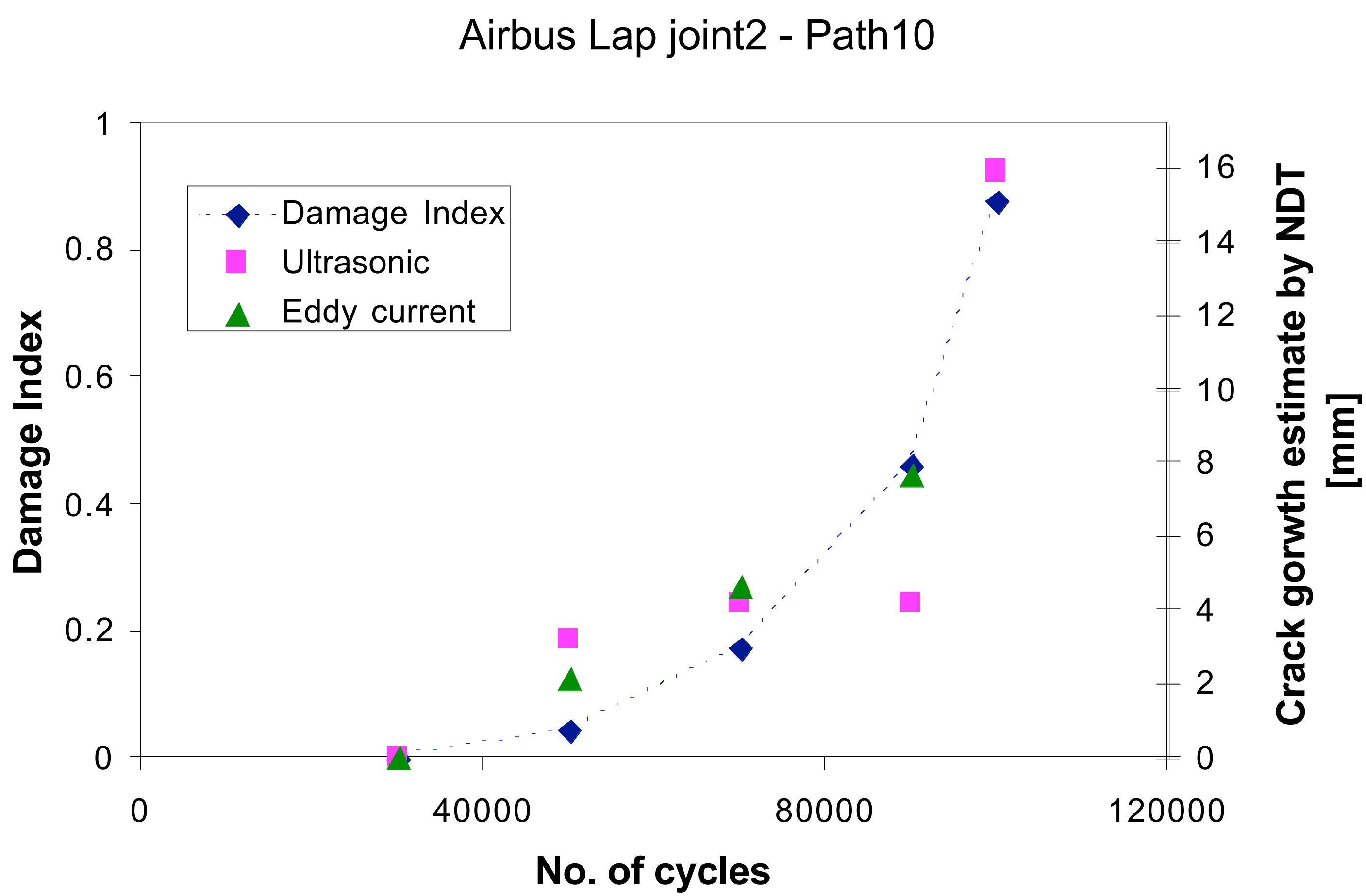


Equipment: USM 25
Transducer: SMWB 70 w/ 70 degree angle

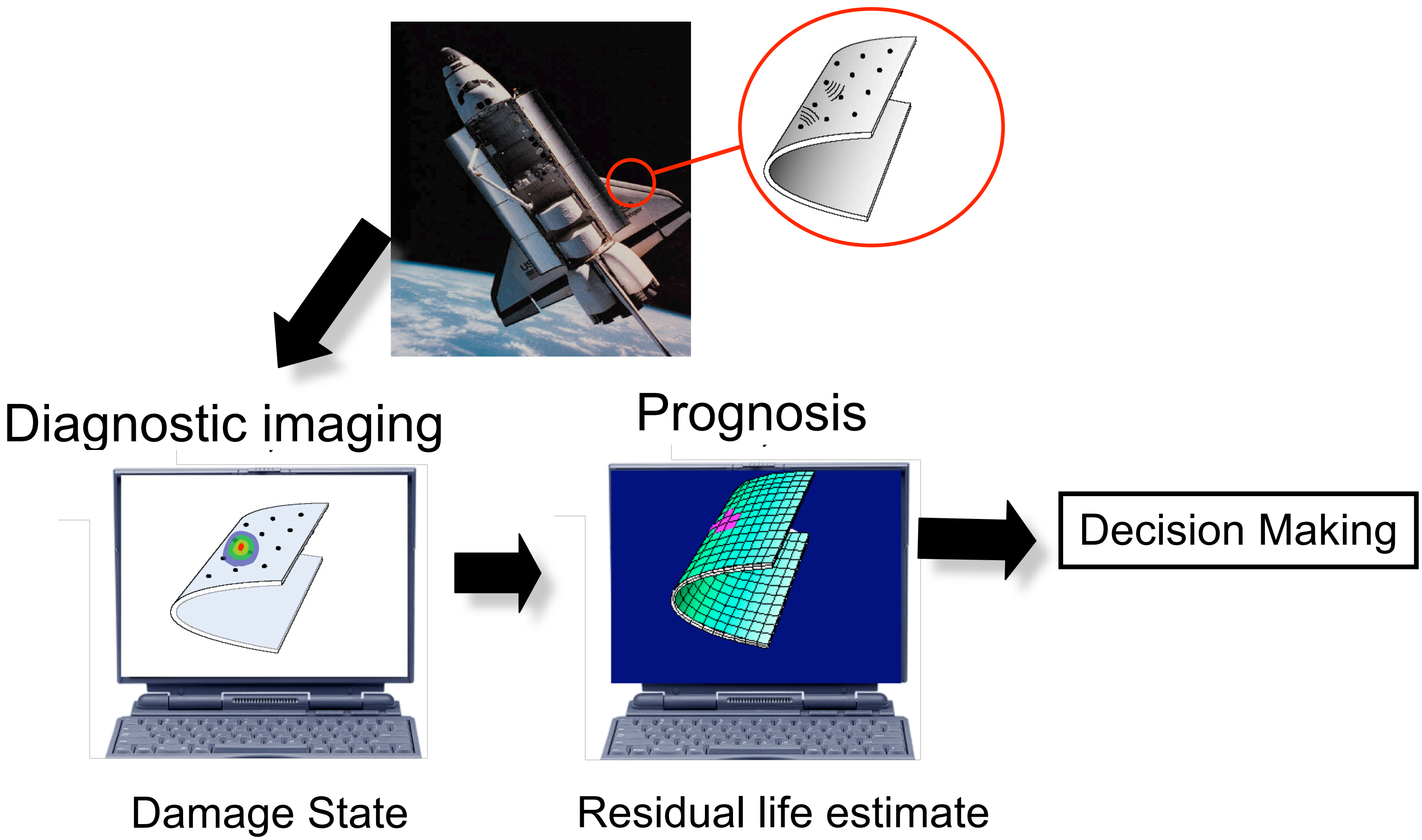
A click….



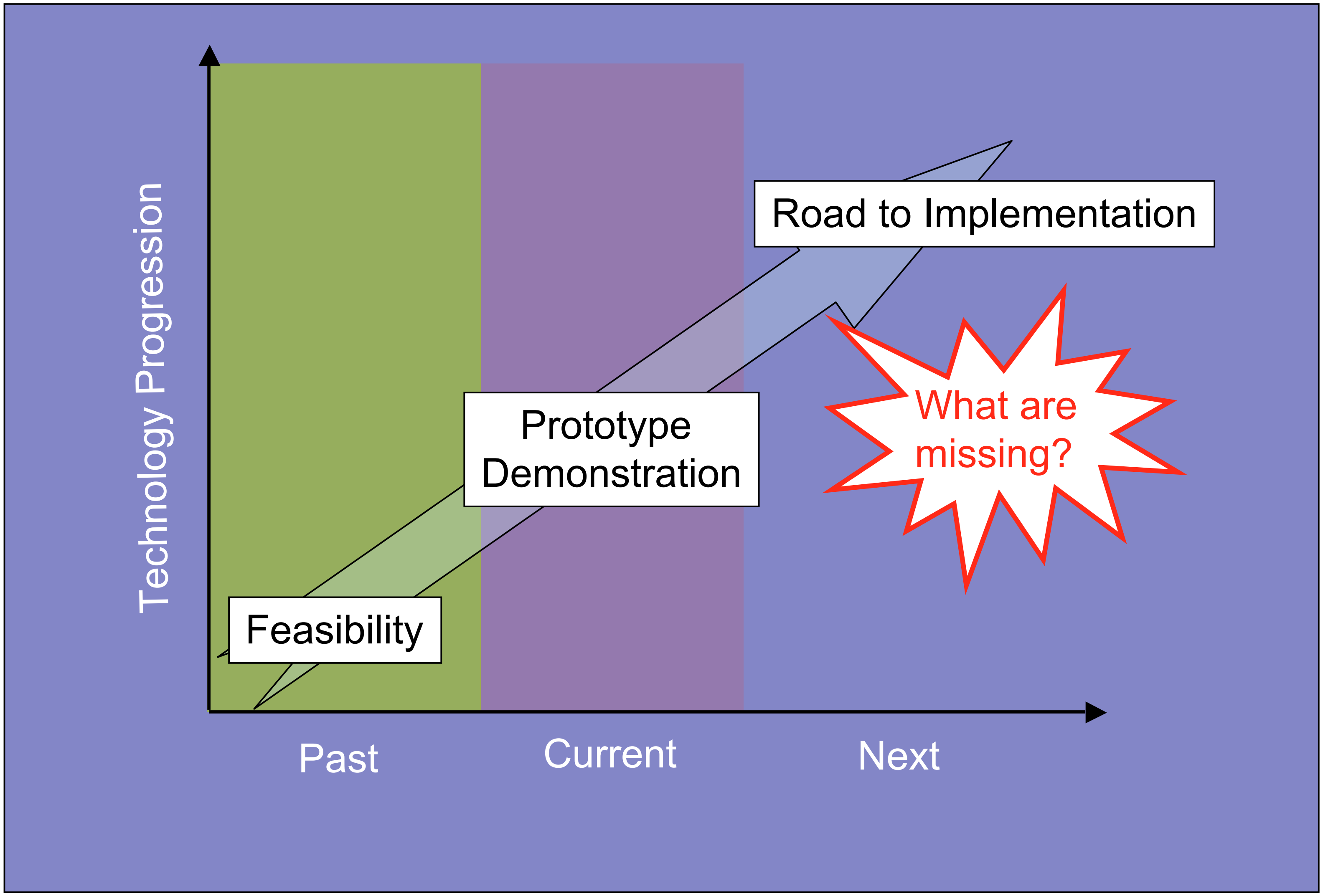
# Damage Index vs. Ultrasonic



# SHM-Embedded Design



# SHM Technology Progression



# Road to Implementation

- Quantification
- Validation
- Scalability
- Reliability/Durability

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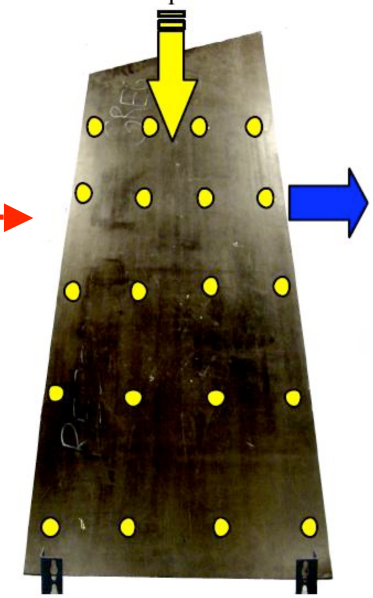
# How to Quantify SHM Performance ?

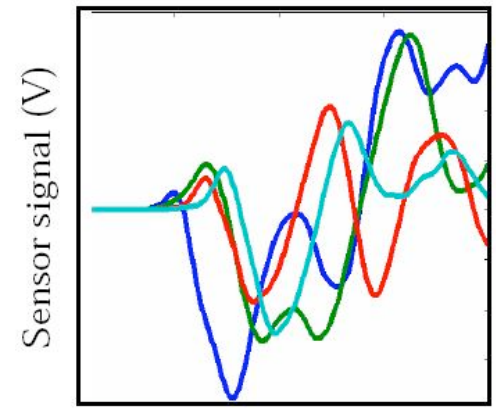
## Probability of Detection (POD)

- Level I: Detection of Event (POD)
- Level II: Detection of Location (POD)
- Level III: Detection of Size, Magnitude (POD)
- Level IV: Detection of Effect (POD)

# How to Quantify a Passive System ?

**Structure with sensors**




**Algorithms**

**Information about impact**

# Probability of Detection (POD)

Design Variables:

- Sensor types
- Sensor location
- Sensor number
- Software
- Calibration (structure)

# SACL Problem: $\underset{sensornumber}{Min}\left[\underset{sensorlocation}{Max}\left(POD_{network}\right)\right]$

**Optimization problem:**

**Design variables**: sensor locations $x_i = [x_1, x_2, \ldots, x_n]$

**Objective**: Find sensor location such that $\underset{sensorlocation}{Max}\left(POD_{network}\right)$

**Constraint:** Sensor only in certain regions allowed: $x_i \in [x_{\min}, \ldots, x_{\max}]$

**Objective function**: $POD_{network} = \frac{1}{m}\sum_{i=1}^{n}\sum_{j=1}^{m} POD_{ij}$

m: number of impacts
n: number of sensors

$$POD_{ij} = \begin{cases} 1 & \text{if} \quad \varepsilon_j(x_i) \geq \varepsilon_{\min} \\ 0 & \text{if} \quad \varepsilon_j(x_i) < \varepsilon_{\min} \end{cases}$$

$\varepsilon_{\min}$ : min. measurable strain during contact
$i$ : sensors
$j$ : impacts

$$\varepsilon_j = \varepsilon_{xx} + \varepsilon_{yy} = \frac{\partial u_j}{\partial x} + \frac{\partial u_j}{\partial y}$$

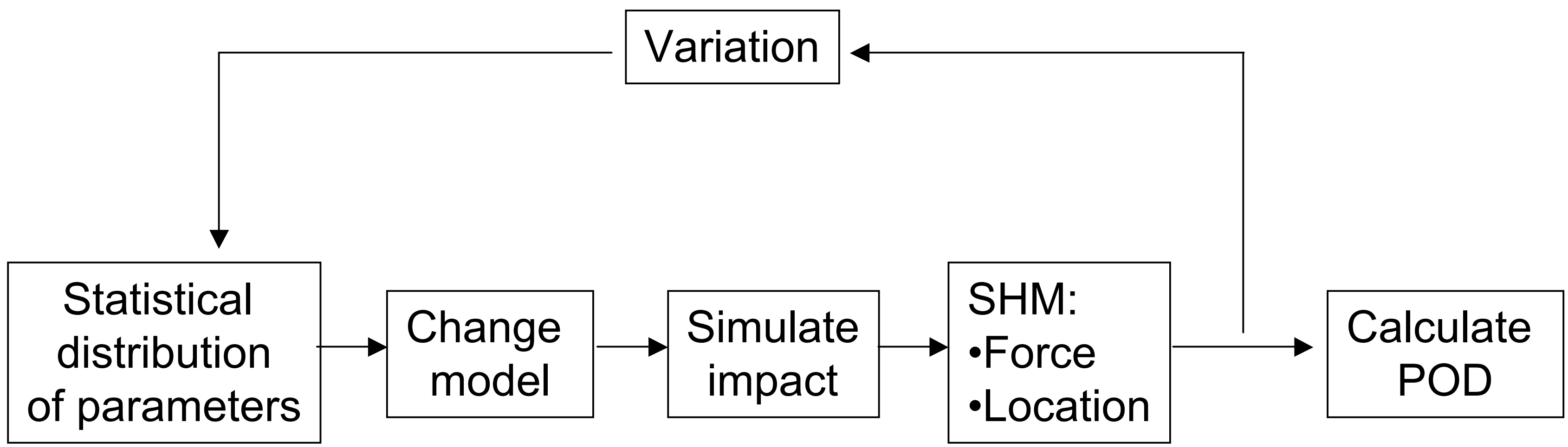
local strain

$$\mathbf{M}\frac{\partial^2 u_j}{\partial t^2} + \mathbf{K}\frac{\partial u_j}{\partial t} = \mathbf{F}_j$$

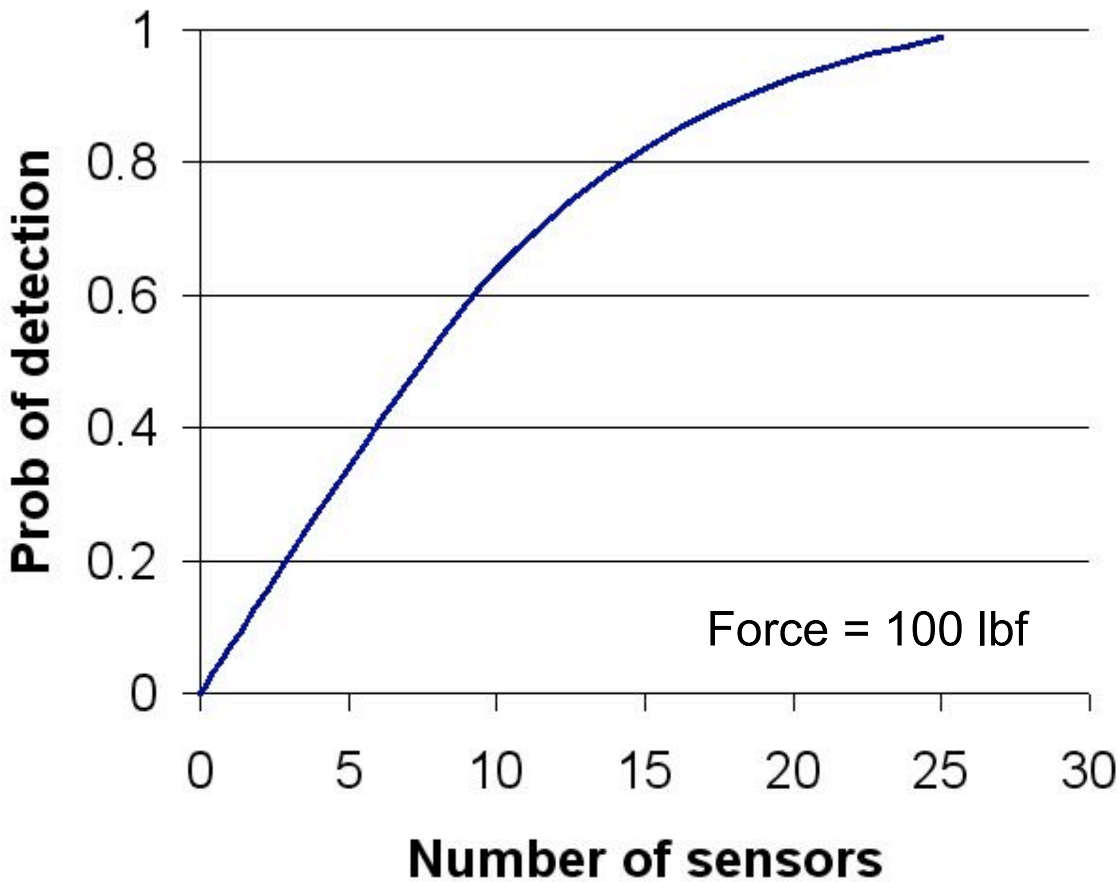
Contact force and contact time from SHM

# System Quantification

## Monte Carlo Simulation



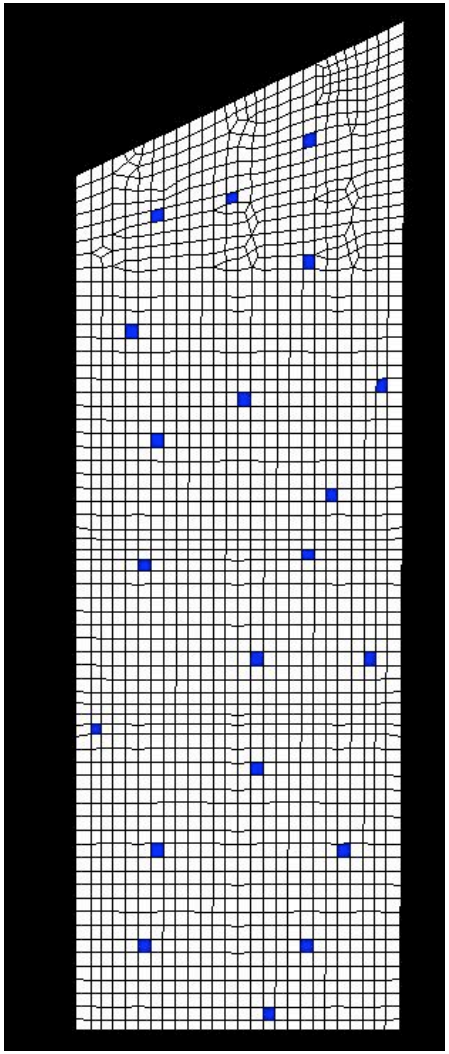
# Max. POD / Number of Sensors



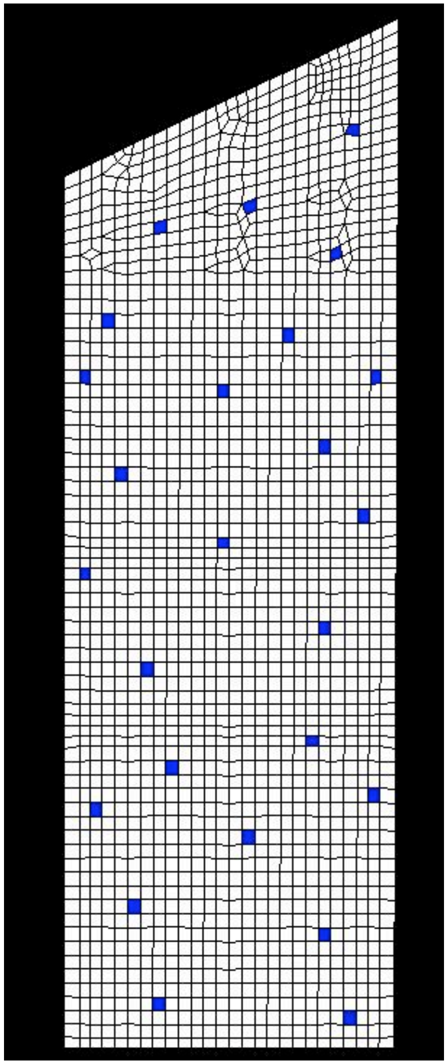
# Optimal sensor locations (examples)

**Force= 100lbf**

20 Sensors
Prob. of detection: 93%



25 Sensors
Prob. of detection: 99%



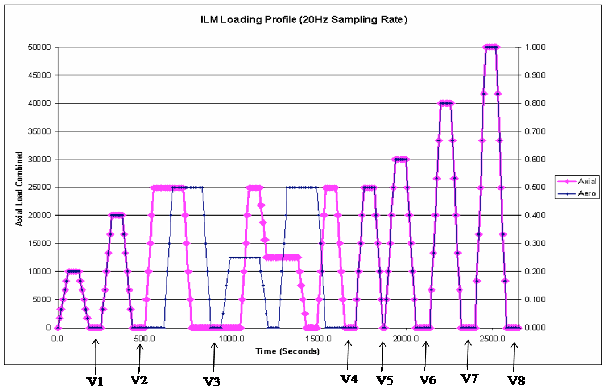
# Basic SHM Requirements

•Quantification - Probability of Detection (POD)

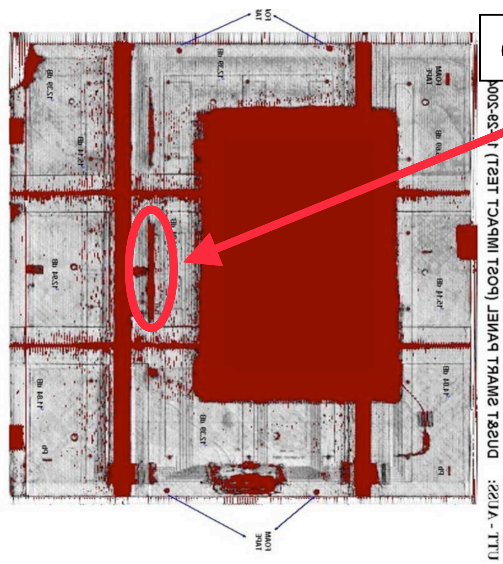
•Reliability - Self-diagnostics

•Acceptance -  Validation

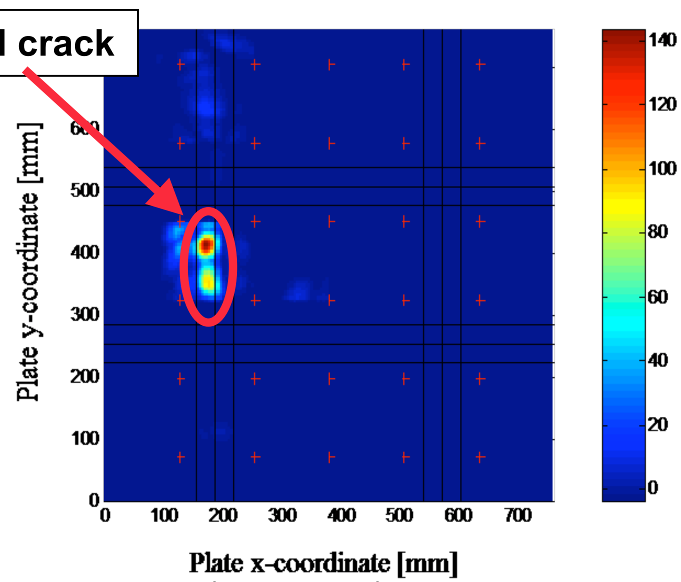
# How to Quantify an Active System ?




Load cycles



C-Scan Image




Diagnostic Image

# SmartComposite™ System

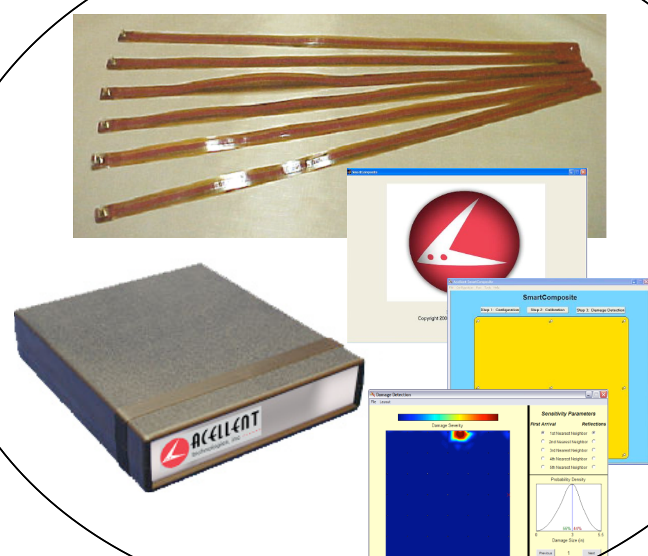
*For detecting damage in large composite structures*

| The Most Advanced Active Diagnostic System Available ! |
|---|

Step-by-step sensor installation

Automated damage detection

Area-computed POD curves



Standard output formats

Sensor self-diagnostics

Automated calibration

Robust / repairable

Sensor install/repair kit

Temperature compensation

Built-in adaptive algorithms

Easy to interface with other systems

Damage sizing with uncertainty values

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# Key Requirements for Sensors/Actuators/Network

Actuator/Sensor and Network:

High strain to failure

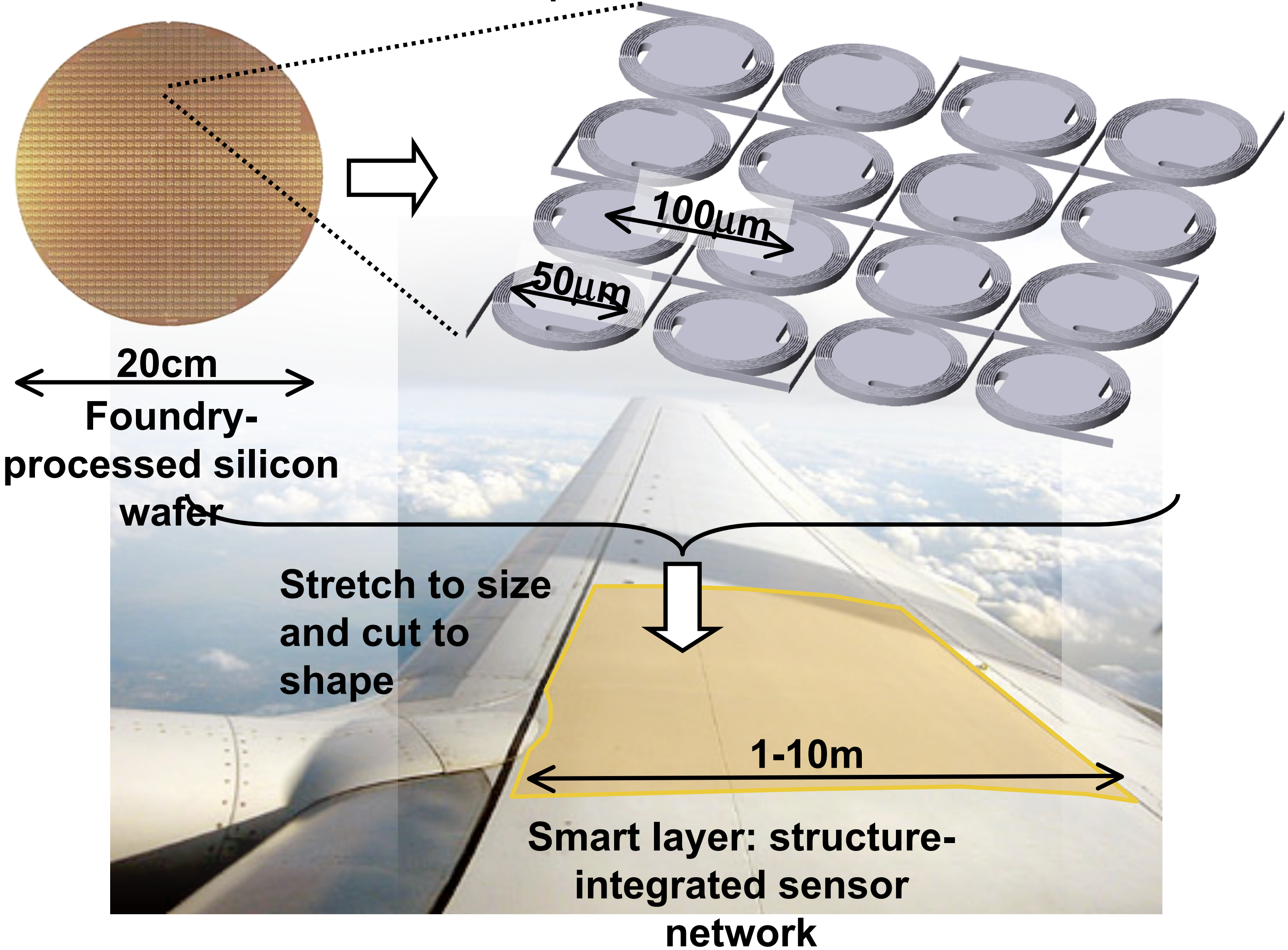
Damage tolerance

Survival to harsh environment

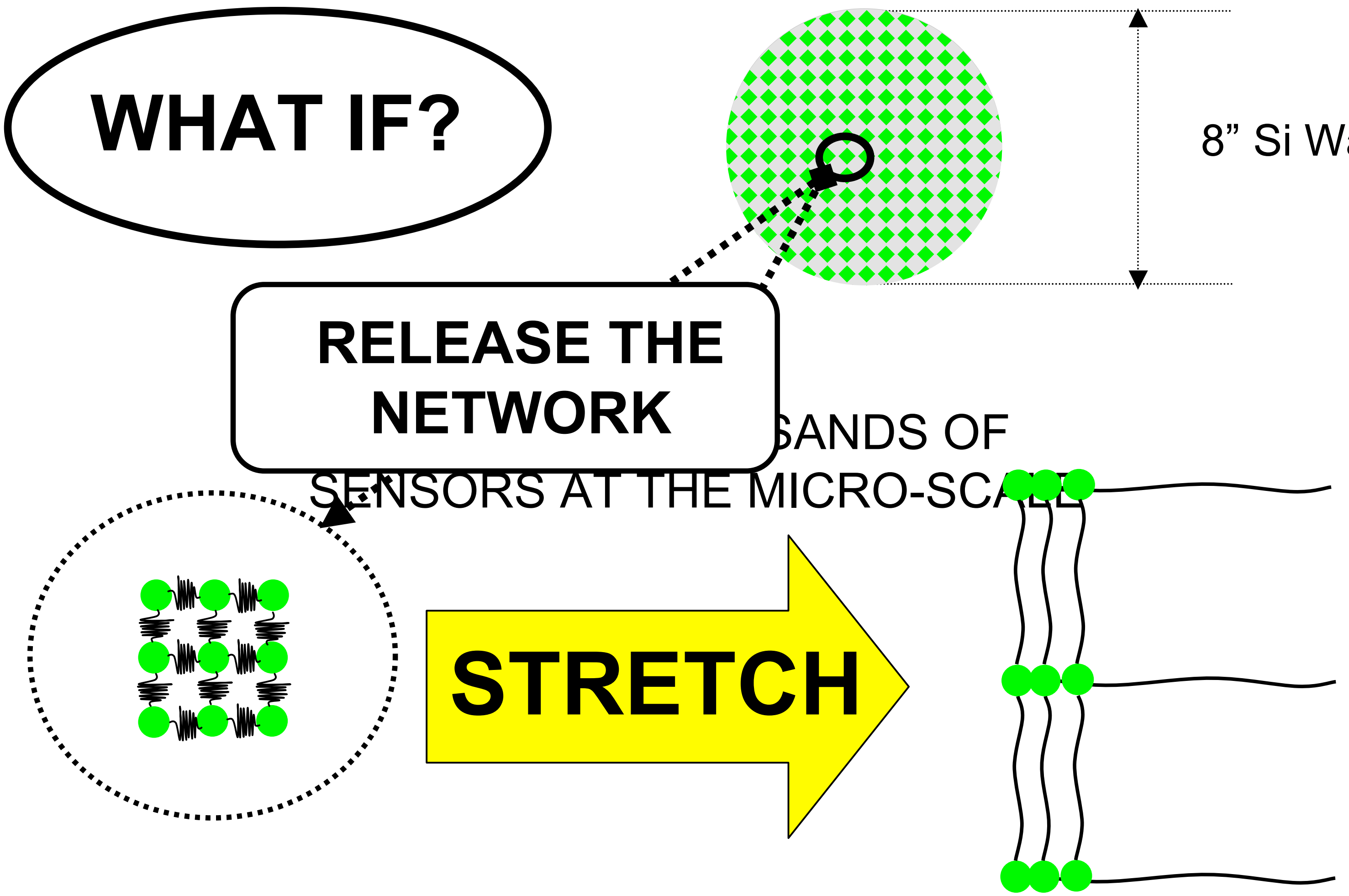
Scalability

Strong interface bond

# Stretchable, and reconfigurable silicon-based piezo- sensor network ?



# Stretchable Network



# The Individual Node

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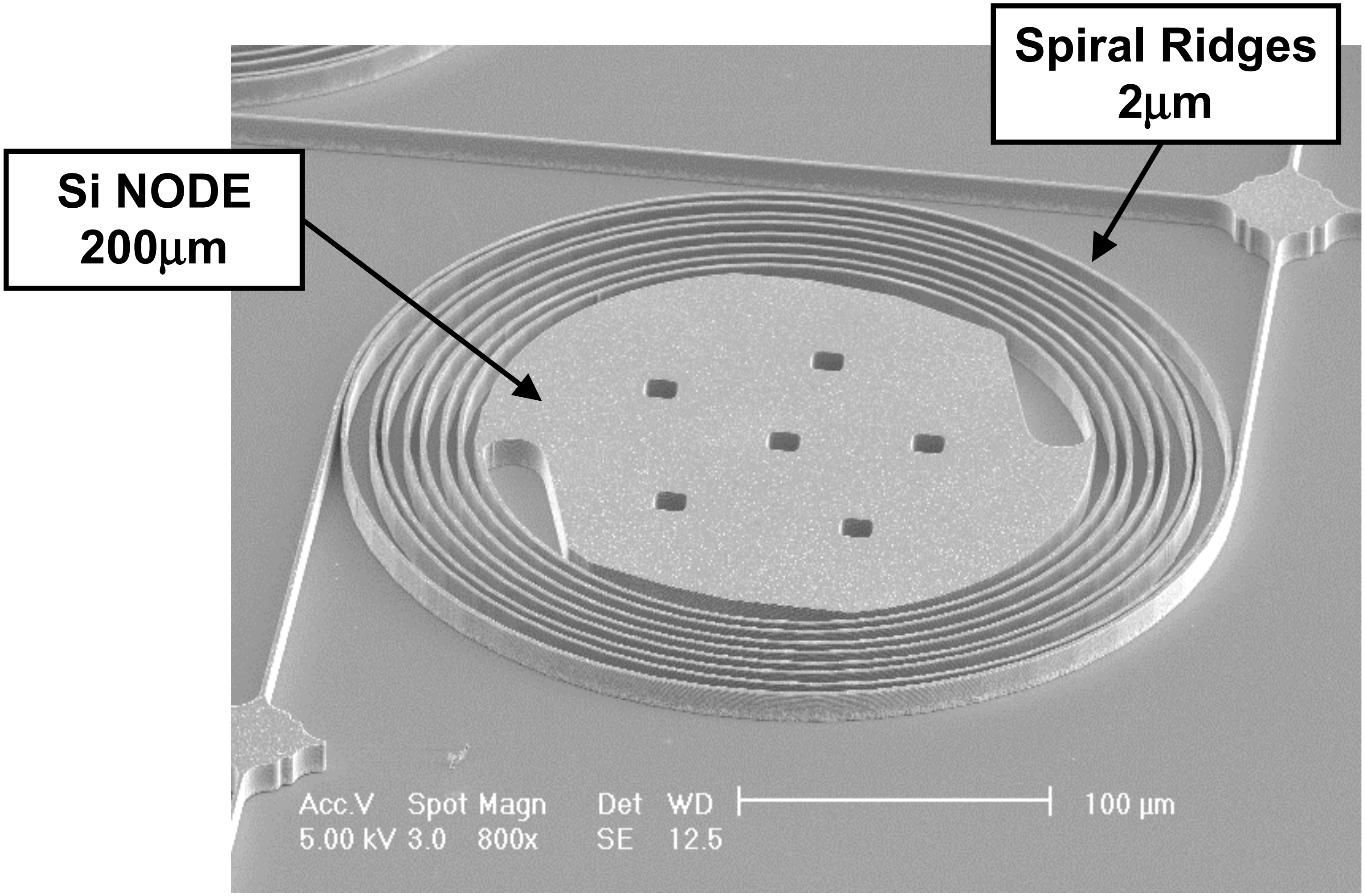
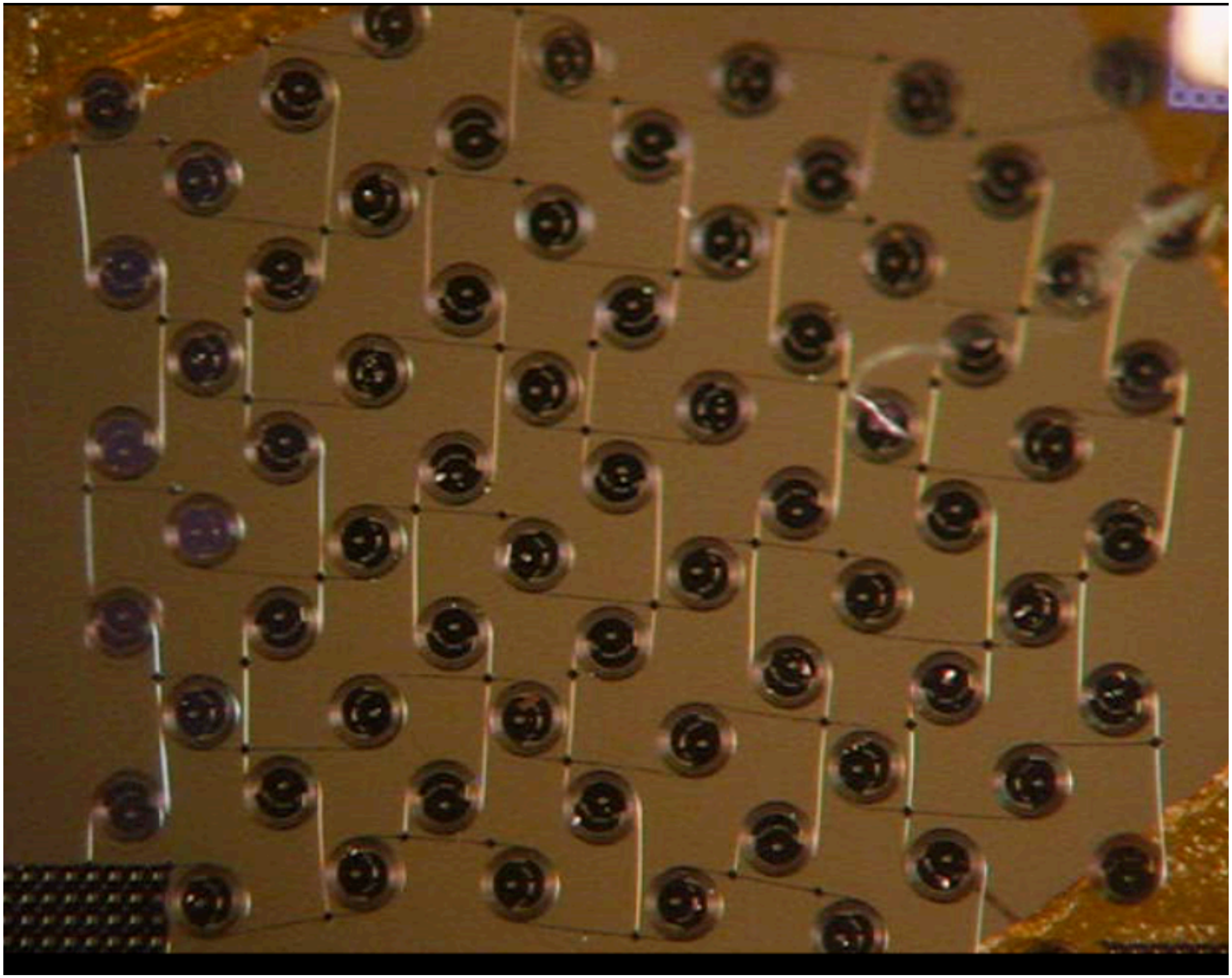
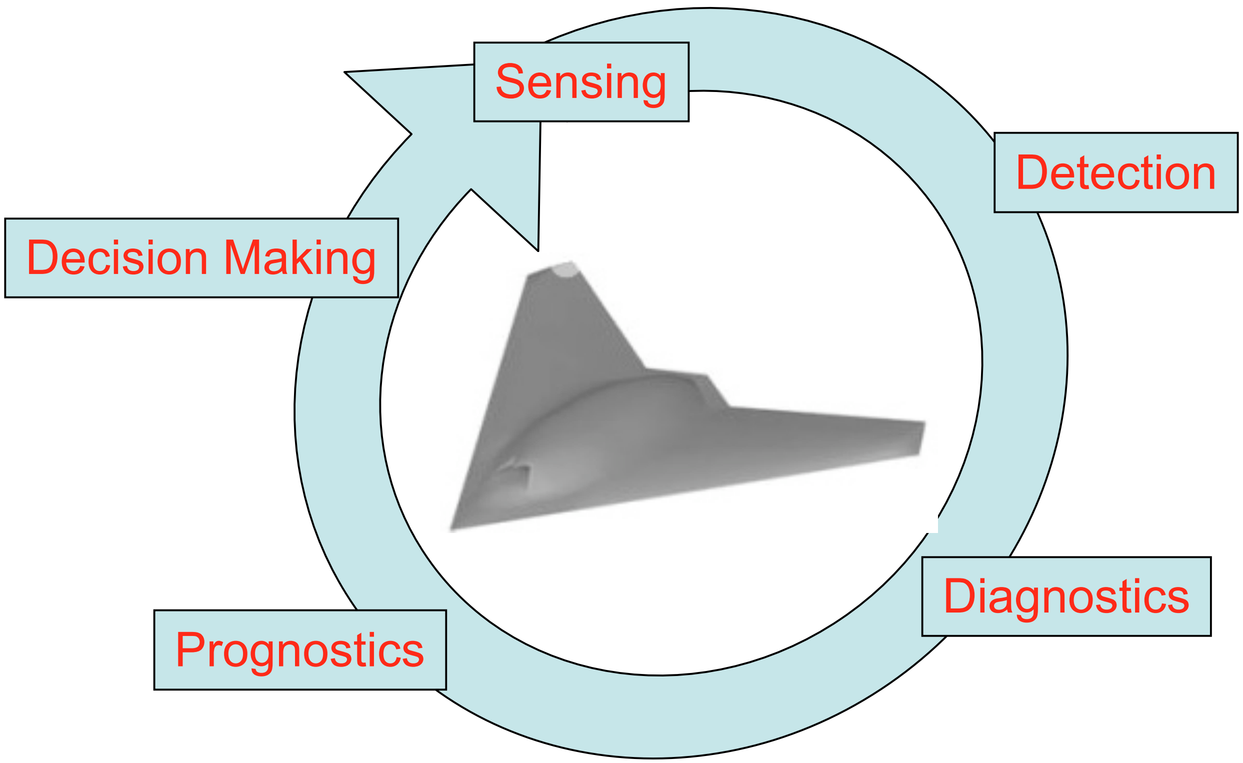


# A Freestanding 71 Nodes Network



# Testbed Study:




To develop Certification and Standardization Procedures

# Announcement of AISC SHM Charter

## Aerospace Industry Steering Committee (AISC)
## for
## Structural Health Monitoring (SHM)

# SHM AISC Mission

- The mission of the SHM AISC is to provide an approach for standardizing integration and certification requirements for SHM of Aerospace structures, which will include system maturation, maintenance, supportability, upgrades and expansion. The final goals will be to develop a guidebook specifying approach for SHM usage on Air and Space vehicles and to identify technology gaps leading to SHM utilization.

# Conclusions

- SHM holds promises with many challenges.
- New and innovative SHM techniques are demanded.
- SHM reliability and durability must be quantifiable.
- New and innovative integrated design methods must be developed for SHM.
- New SHM validation procedures must be developed.
- Certification and standardization are needed.