Structural Health Monitoring and Damage Prognosis at Los Alamos National Laboratory

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The Damage Prognosis Team

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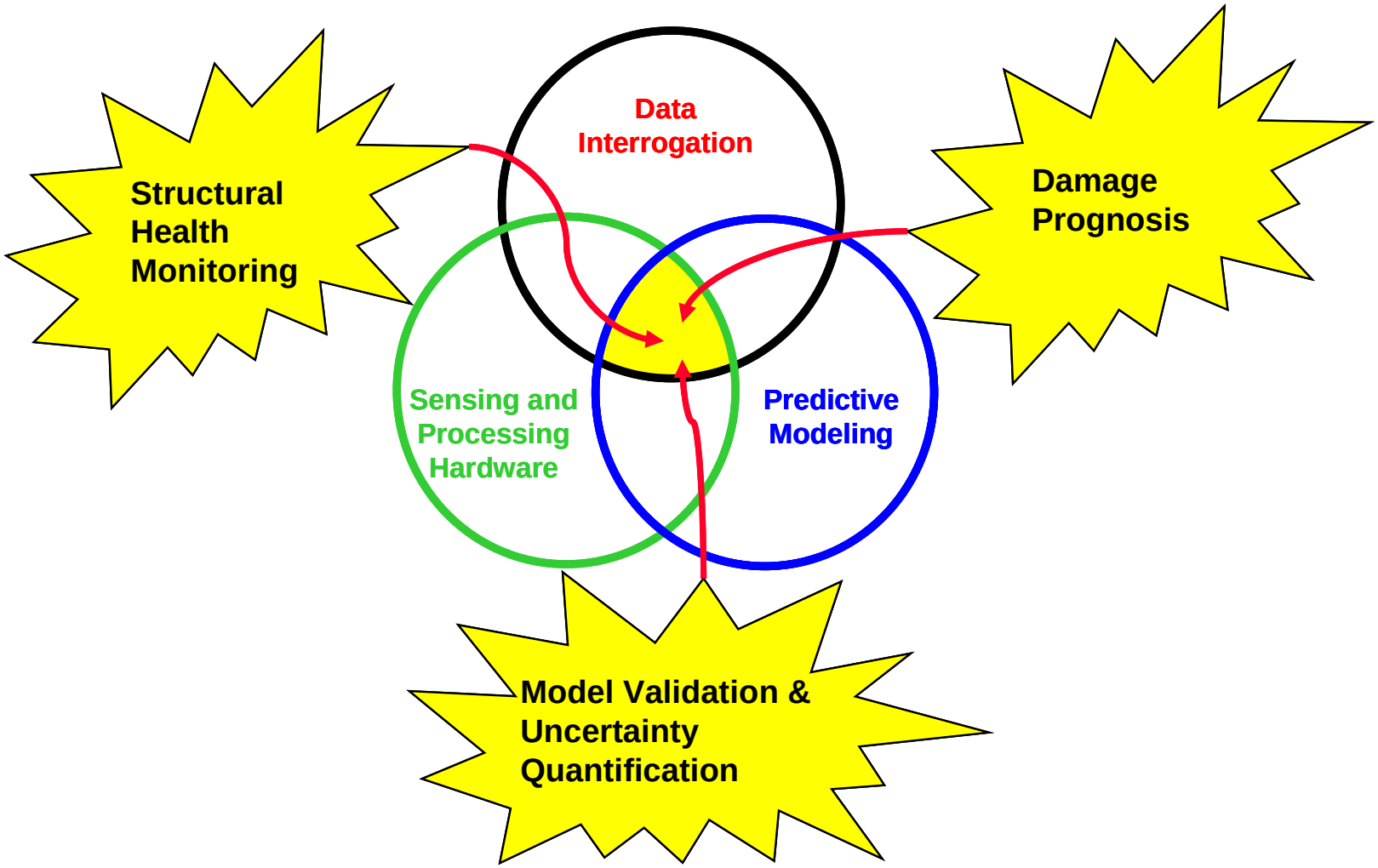
Our Technology

- Our Philosophy for SHM and DP
- Sensing and Data Acquisition
- Data Interrogation Software
- Damage Initiation and Evolution Modeling
- Model Validation and uncertainty Quantification
- Applications & Data
- Publications
- Education

Our Philosophy



The Structural Health Monitoring Process

1. Operational evaluation

   Defines the damage to be detect and begins to answer questions regarding implementation issues for a structural health monitoring system.

2. Data acquisition

   Defines the sensing hardware and the data to be used in the feature extraction process.

3. Feature extraction

   The process of identifying damage-related information from measured data.

4. Statistical model development for feature discrimination

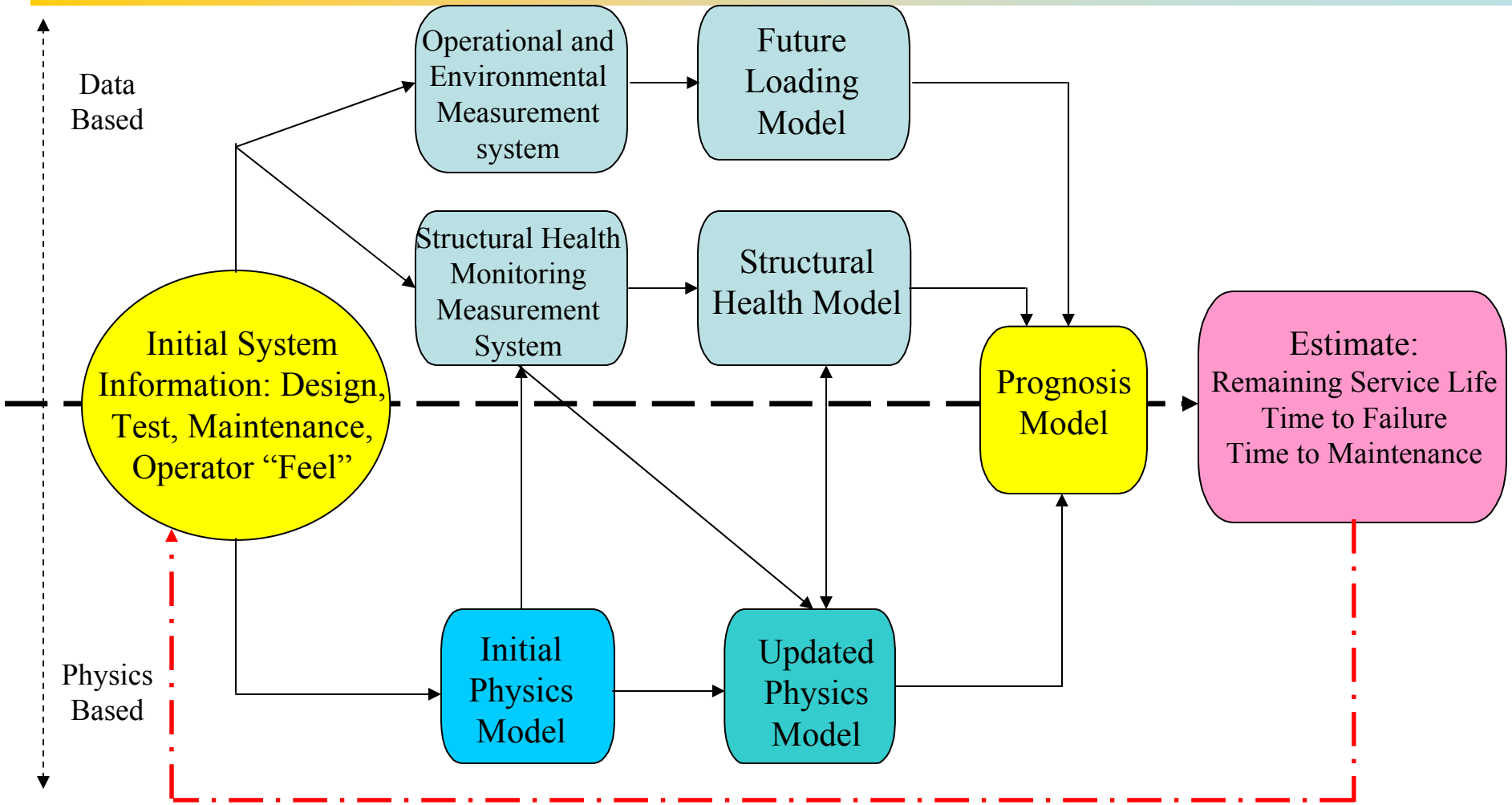
   Classifies feature distributions into damaged or undamaged category.

- **Data Cleansing**
- **Data Normalization**
- **Data Fusion**
- **Information Condensation**

(implemented by software and/or hardware)

SHM is a Problem in Pattern Recognition

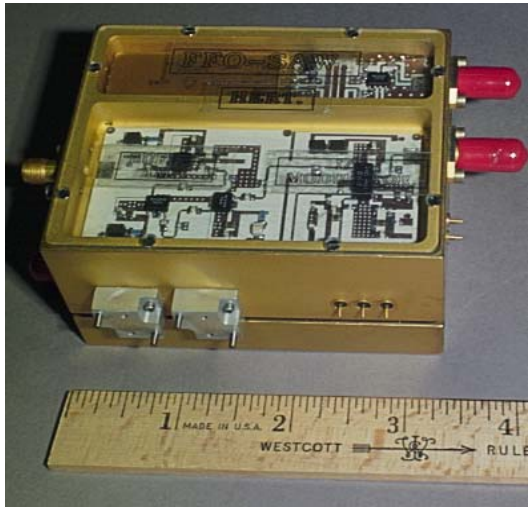
The Damage Prognosis Process



Considerations for SHM Data Acquisition System

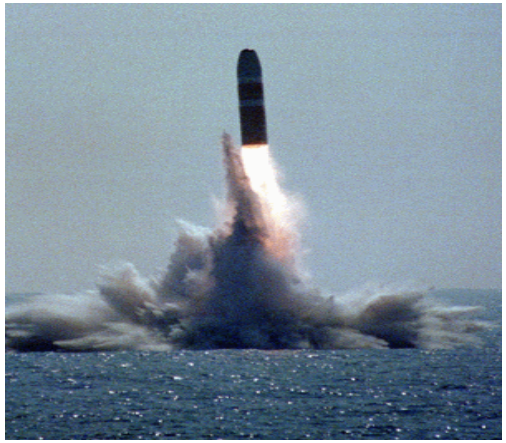
- **THERE IS NO SENSOR THAT MEASURES DAMAGE! (and there never will be!!)**
- **However, can't do SHM without sensing**
- Define data to be acquired and the data to be used in the feature extraction process.
  - Types of data to be acquired
  - Sensor types, number and locations
  - Bandwidth, sensitivity (dynamic range)
  - Data acquisition/transmittal/storage system
  - Power requirements
  - Sampling intervals
  - Processor/memory requirements
  - Excitation source (**active sensing**)
  - Sensor diagnostic capability
- **CAN NOT develop the sensing/processing system independent of the feature selection and statistical model development portions of the process.**

HERT System

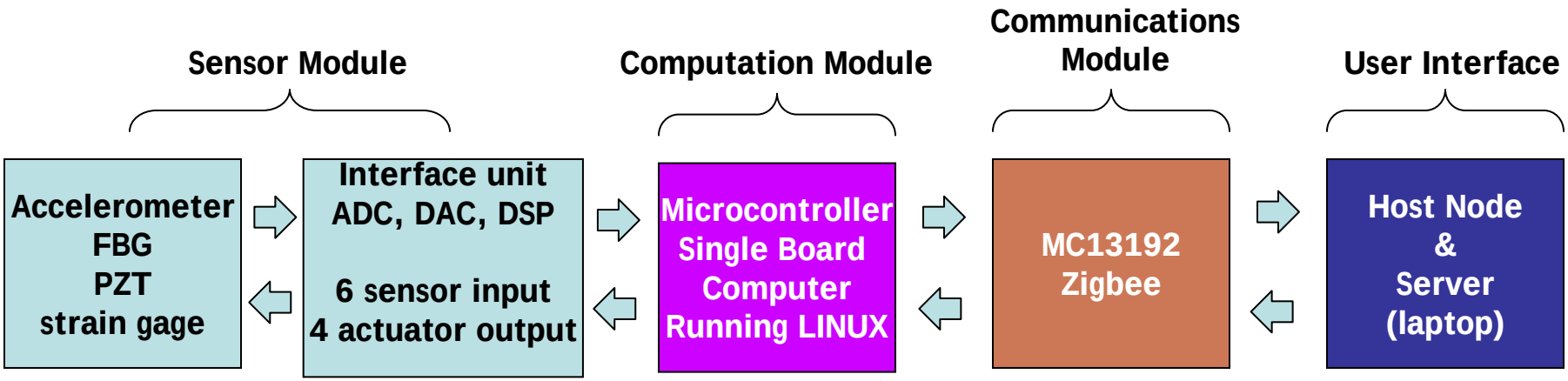


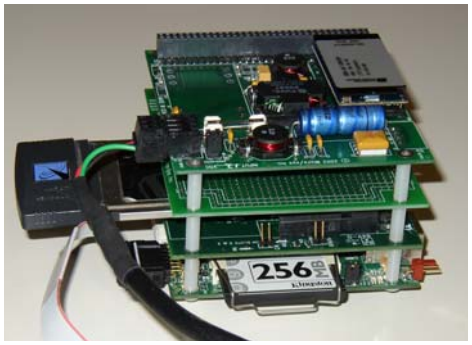
HERT Mark II with 10 watt power amplifier

- 64 optical inputs
- 10 ns resolution
- Approximately 2.2 Kg
- Field Programmable Gate Array for onboard data processing
- 100 Mbit/s data transmission
- Flight hardened!!



System Integration: Motorola/LANL SHM System

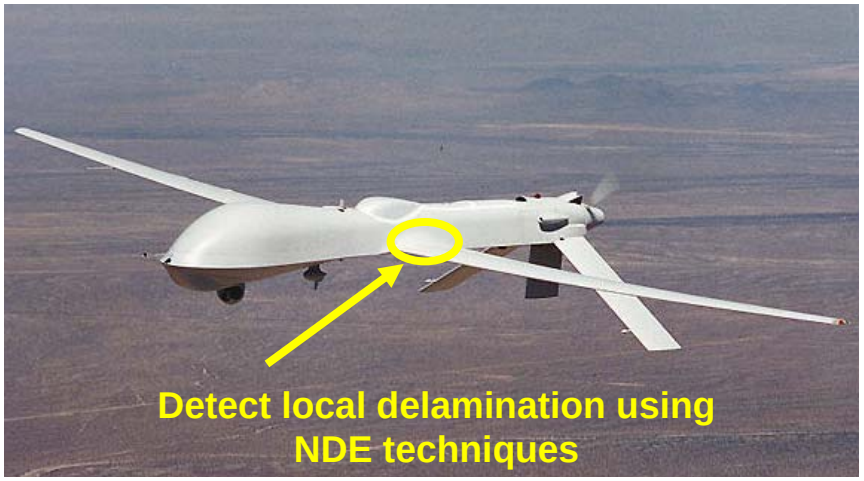




Primary Design Concern: the ability to translate data into information (requires enhanced processing capability and interfaces with DIAMOND II SHM software)

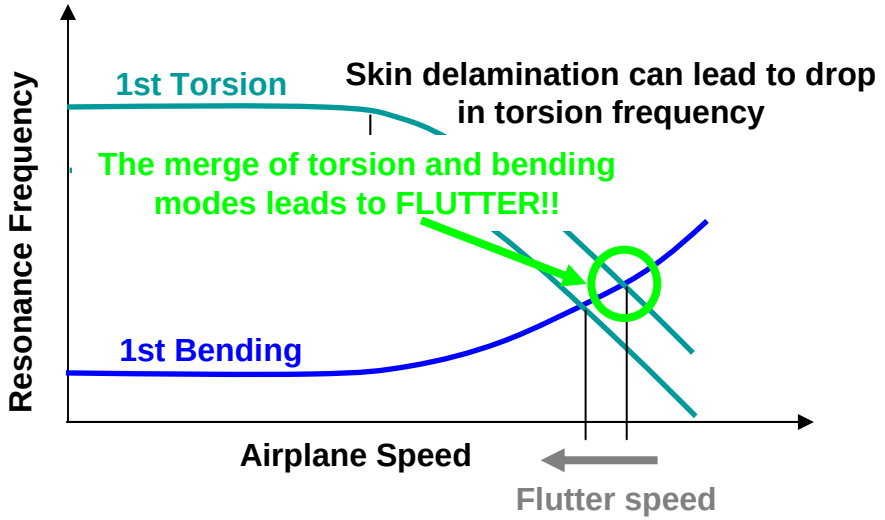
Integrating Global SHM and Local NDE Techniques

- Active Local SHM
  - High frequency response
  - Local damage identification
  - Active sensing



  - Lamb wave propagation
  - Impedance method
  - Time reversal analysis

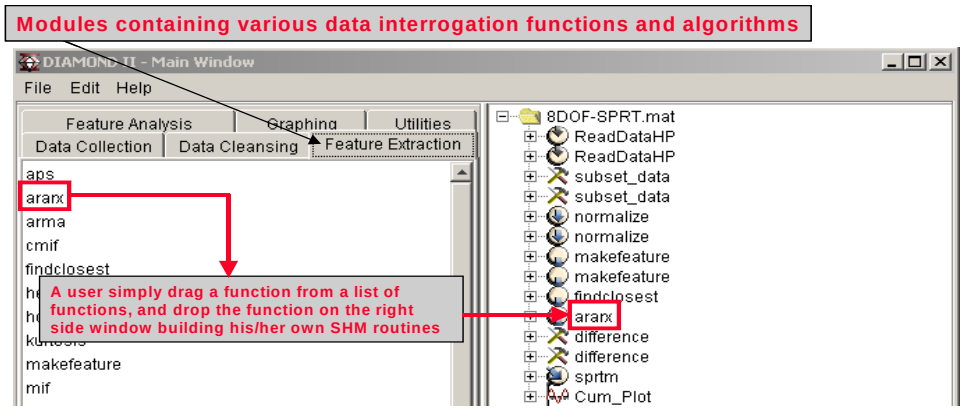
- Passive Global System Response
  - Low frequency response
  - Global vibration based monitoring
  - Passive sensing



  - Modal testing & analysis
  - System identification
  - Operational and Environmental monitoring

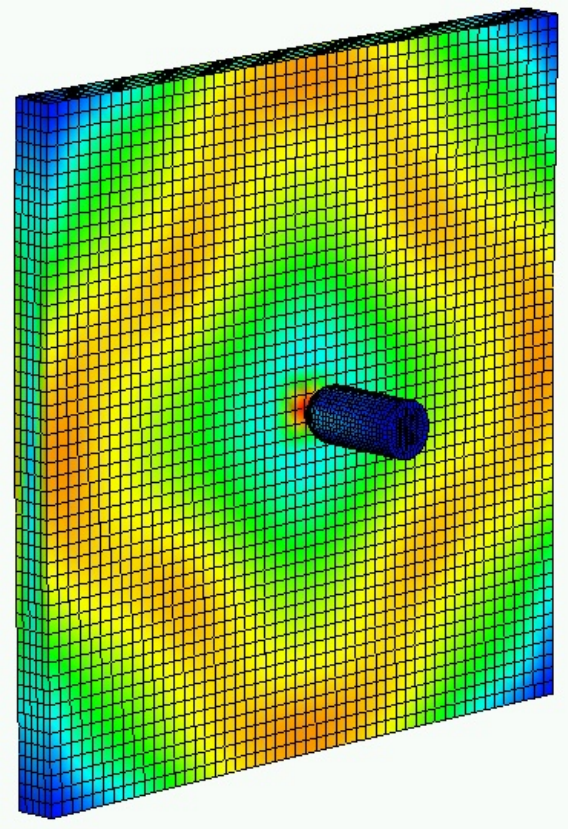
Structural Health Monitoring Software: DIAMOND II

- A suite of data interrogation algorithms for damage diagnosis, prognosis and model validation is being developed in the format of GUI software called DIAMOND II. (LA-CC-01-69, **patent disclosure filed**)



- DIAMOND II facilitates users to construct their own SHM process by providing built-in modules, and permits users to add their own functions.
- Contains algorithms for **data normalization, cleansing, compression and fusion,** feature extraction, **statistical modeling** and **sensor diagnostics**.
- JAVA front end running MATLAB.

Damage Modeling

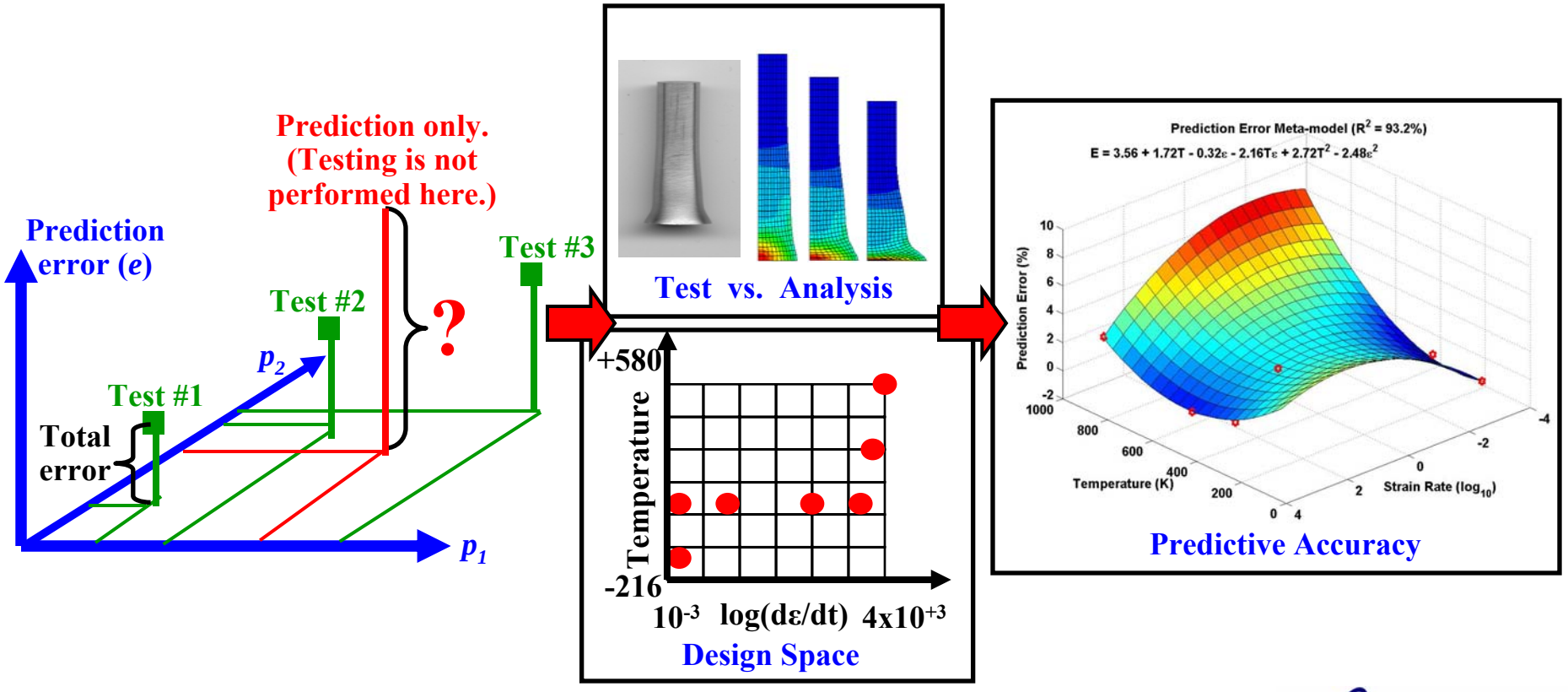


- Multi-length scale structural analysis framework (Began with GE-90 Fan Blade CRADA)
  - Homogenization at fiber/matrix level
  - Generalized multilength scale plate theory/Multilength scale finite element theory (MSFE)
    - Global and local components to the fields
    - Accurate representations of local fields
    - Explicitly models existence of each lamina and the associated interfaces
    - Formulated to accept any cohesive zone model
- Cracking modeled using cohesive zone models (CZMs)
  - Debonding between fiber and matrix, Ply splits, Delaminations

185.5g, 2.5-cm-dia. projectile impacting a composite plate

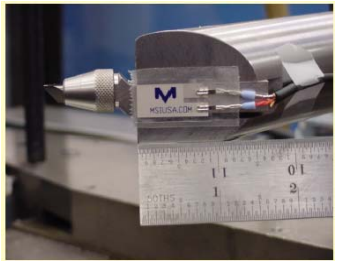
Model Validation and Uncertainty Quantification

- **Model validation provides an assessment of *predictive accuracy* (expected error and its uncertainty estimate) throughout an operational domain.**

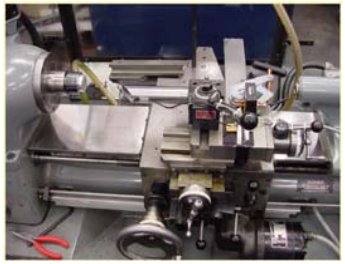


Some of Our Applications

Composite Wings of Unmanned Aerial Vehicle

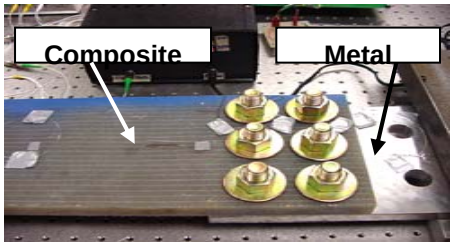


(a) Close-up of Cutting Tool and Sensor



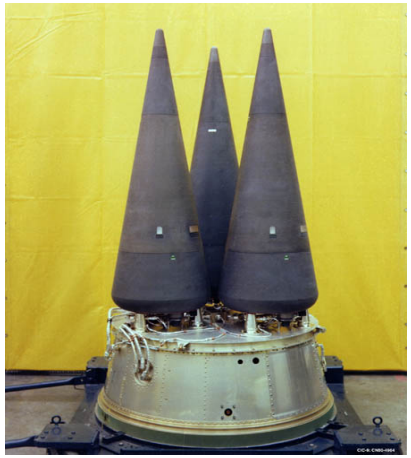
(b) Experimental Setup

Machine Tool Operation



Composite-to-metal lap joint for Navy Destroyer

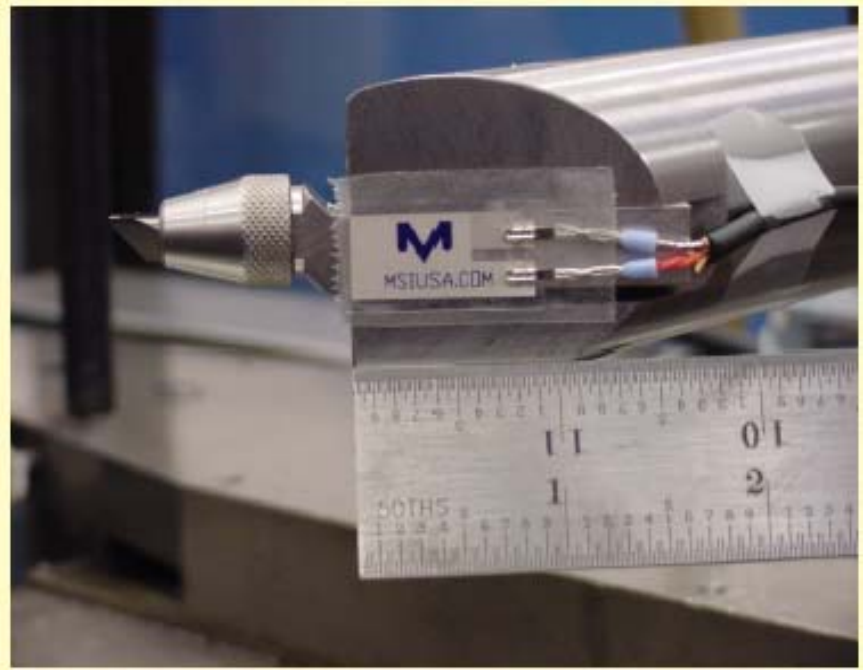
Amusement Park Rides



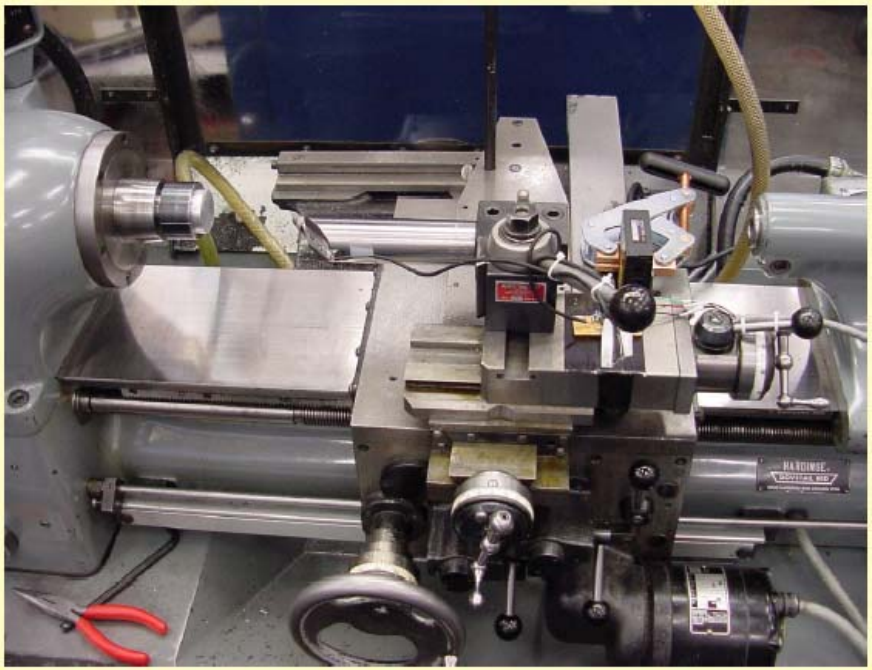
NNSA Hardware

Highway Bridge

Our Future Applications



(a) Close-up of Cutting Tool and Sensor



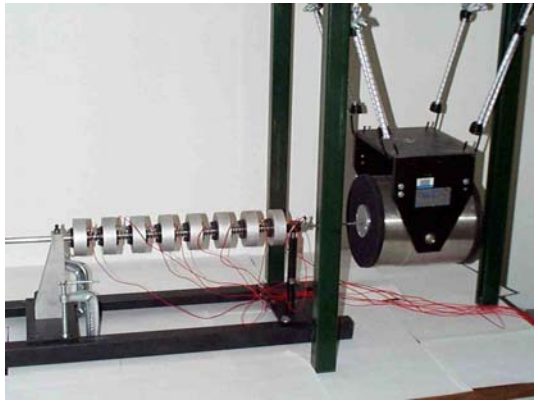
(b) Experimental Setup

Machine Tool Operation

New Paradigm: Implement SHM beginning with component manufacturing and ending with complete systems deployed in the field

Data Sets Available

- Available at www.lanl.gov/projects/damage_id
  - I-40 Bridge
  - UC-Irvine Concrete Columns
  - 8 DOF test structure
  - Surface Effects Fast Patrol Boat (soon)



Publications

- See www.lanl.gov/projects/damage_id
- Two Extensive literature reviews on SHM
- Numerous LA-MS reports on SHM and DP
- 100s of conference papers and journal articles on SHM, DP and MV&UQ
- In the works:
  - Special issue of Philosophical Transactions of the Royal Society on SHM (2005)
  - *Structural Health Monitoring: A Statistical Pattern Recognition Approach,* John Wiley (2005)

The Engineering Institute

A Multi-Disciplinary Engineering Research & Development AND Educational Collaboration with the University of California - San Diego

R&D Focus and Products

Damage Prognosis Technology

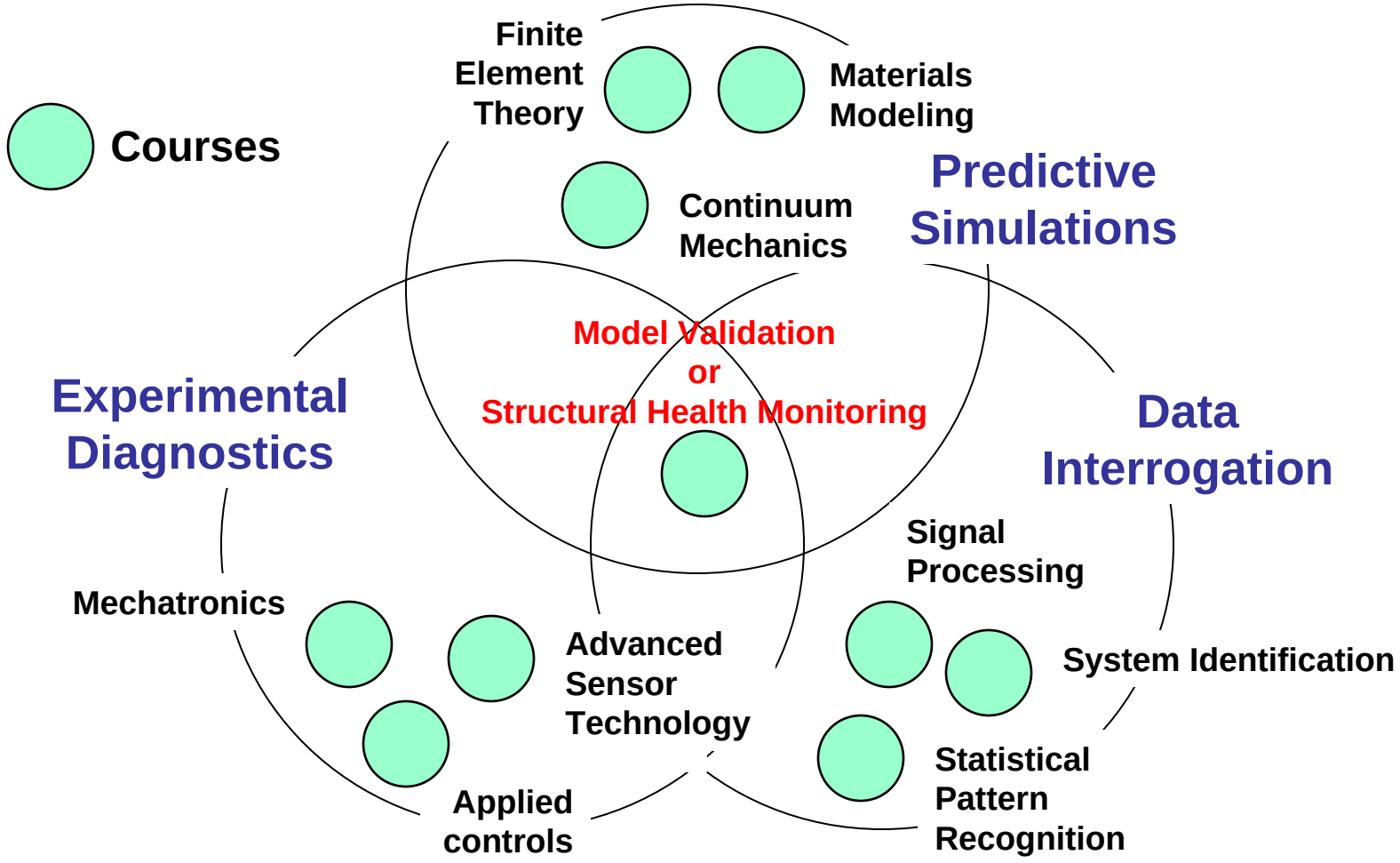
- High-Fidelity Predictive Simulation
- Advanced Sensing and Diagnostics
- Novel Data Interrogation

Educational Focus and Products

Structural Dynamics with emphasis in Validated Simulation

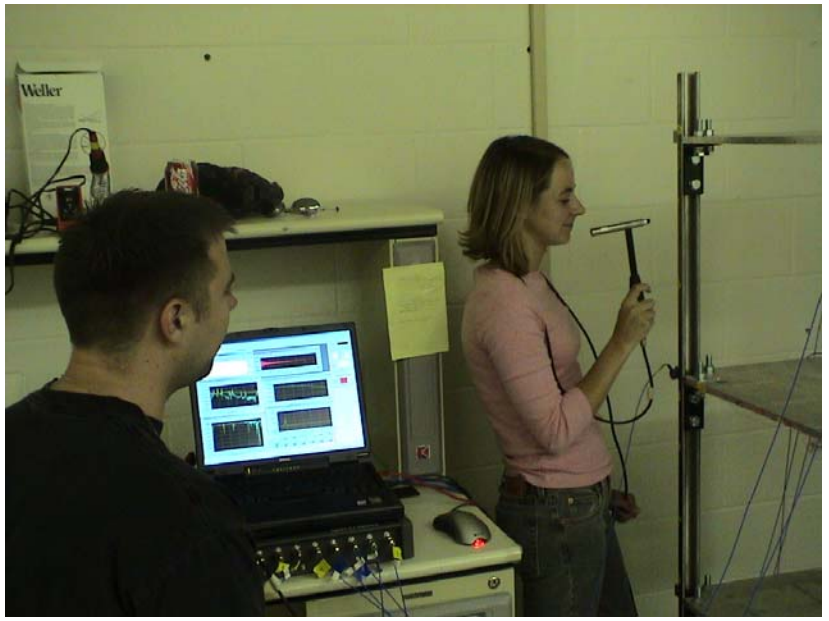
- Joint LANL/UCSD Degree
- Dynamics Summer School
- Short Courses

Joint LANL – UCSD Degree Program



THE LOS ALAMOS DYNAMICS SUMMER SCHOOL

- Proactive approach to **recruitment** of top students through an intense 8-week summer school program.
- Program goal: Get top US-citizen undergraduate engineering students to enroll in graduate school.
- 72 students in 2000- 2004 classes had an ave. GPA of 3.75
- To date, LANL has hired 7 Staff Members from this program



- Five former LADSS alumni at enrolled in graduate school at UCSD.
- This year two students from 2003 summer school won NSF graduate fellowships, three were honorable mentions and one is a finalist for Hertz Foundation Fellowship. Two former students at UCSD won National Defense Engineering and Science Fellowships

Other Educational Activities

- Five Students have received Los Alamos Engineering Institute Fellowships at UCSD.
- NATO sponsored SHM, DP and MV&UQ lecture series to Norwegian Defense Ministry.
- LANL staff and UCSD Faculty provided 6 tutorials at NSF sponsored Pan American Advanced Study Institute on Damage Prognosis, Brazil.
- LANL staff and UCSD Faculty teaching short course *Structural Health Monitoring: A Statistical Pattern Recognition Approach* at NASA-Marshall Space Flight Center. Course has been taught ten times since 1997.
- Five 40% time education appointments for LANL early-career staff (e.g. MS level engineers working on Ph. D.)
- LANL staff teaching new course “Principles of Structural Health Monitoring” SE 165 at UCSD starting January, 2005 Winter Quarter