Health Monitoring for Structural "Hot Spots": A Systems Approach

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Presentation Outline

- SHM Level Setting
- Design Space
- Example Applications
- Design Framework
- Closing Remarks

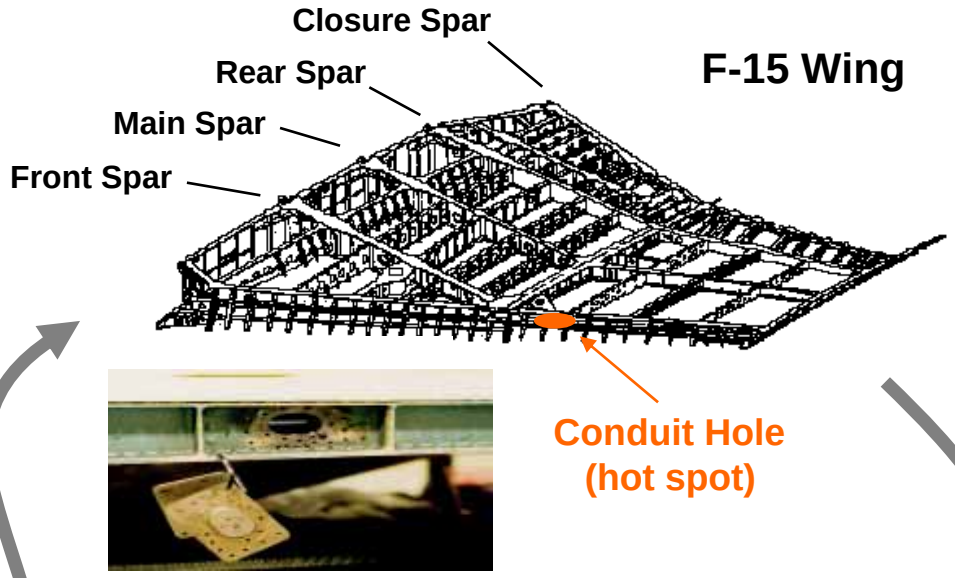
Structural Health Management (SHM) Evolution

- *"Structural safety is an evolutionary accomplishment, and attention to design features is key to its achievement. Acquisition and review of service data and other firsthand information from customer airlines is necessary to promote safe and economic operation of the worldwide Boeing fleet……This paper describes these structural health monitoring approaches".*
  - U. Goranson, Boeing Commercial Airplane Group, Key Note Speech, Stanford Workshop on Structural Health Monitoring, 1997.

Current State: Schedule-Based Maintenance

Structural Design

Problem Areas Identified



Full- Scale Fatigue Testing

Inspection Schedule Constructed

Schedule vs Condition

- Schedule-based maintenance
  - Initially works well
  - However, over time req’ts change
    - Use vehicle systems longer than planned
    - Use for different missions than designed
    - New problem areas identified
  - Results in decreased availability, increased inspection times, and increased O&S costs

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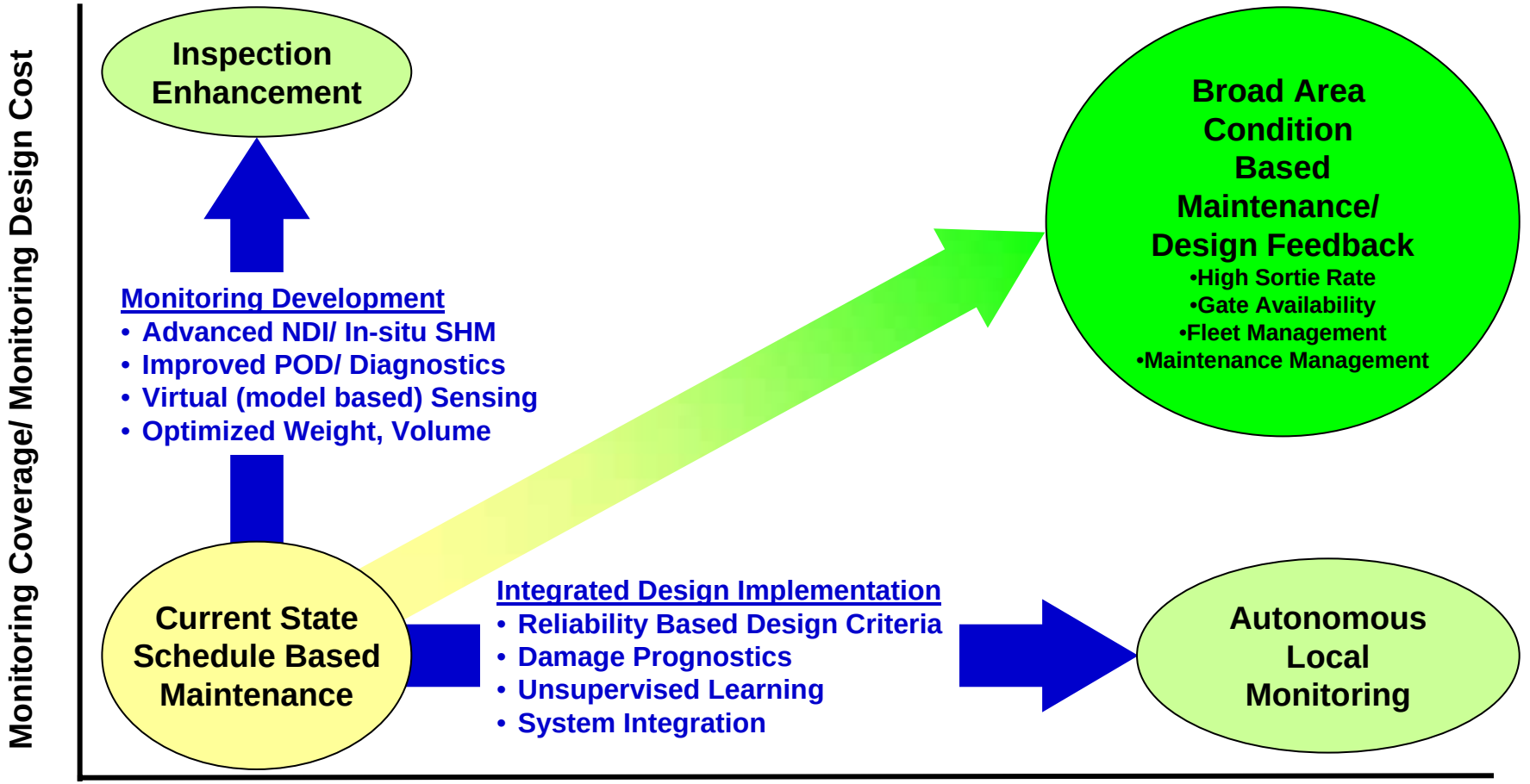
- Condition-based maintenance
  - Increases availability, increases reliability, and decreases O&S costs while maintaining vehicle safety

Health Monitoring for Structural "Hot Spots": Design Space

Key technology paradigm shift is from scheduled, hands on inspections to in-situ monitoring, condition based maintenance, and design integration.



SHM for Bonded Repairs (Mark Derriso, AFRL)

Coupon and component testing

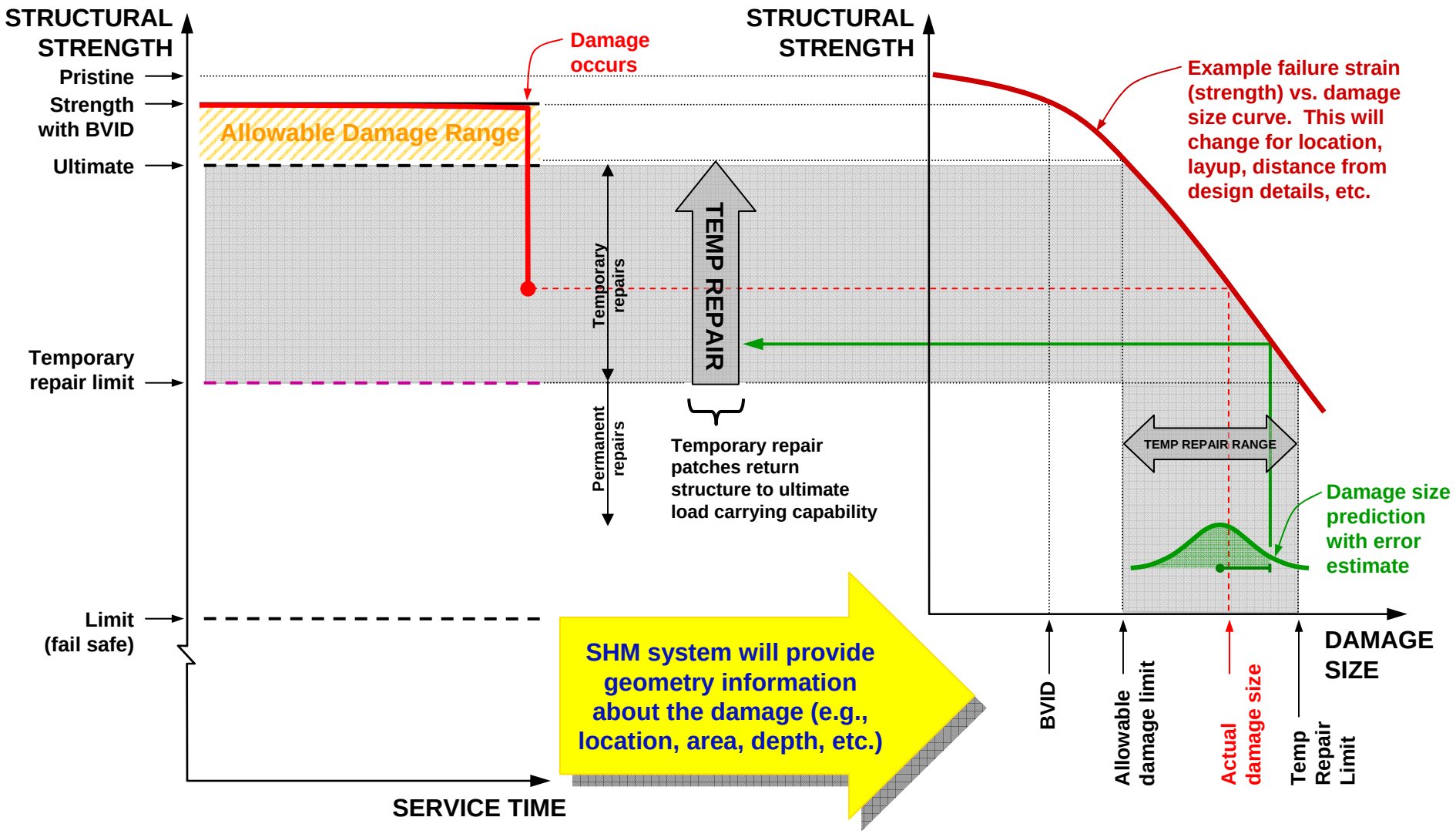
Flight demonstration sensor installation

In-service data collection

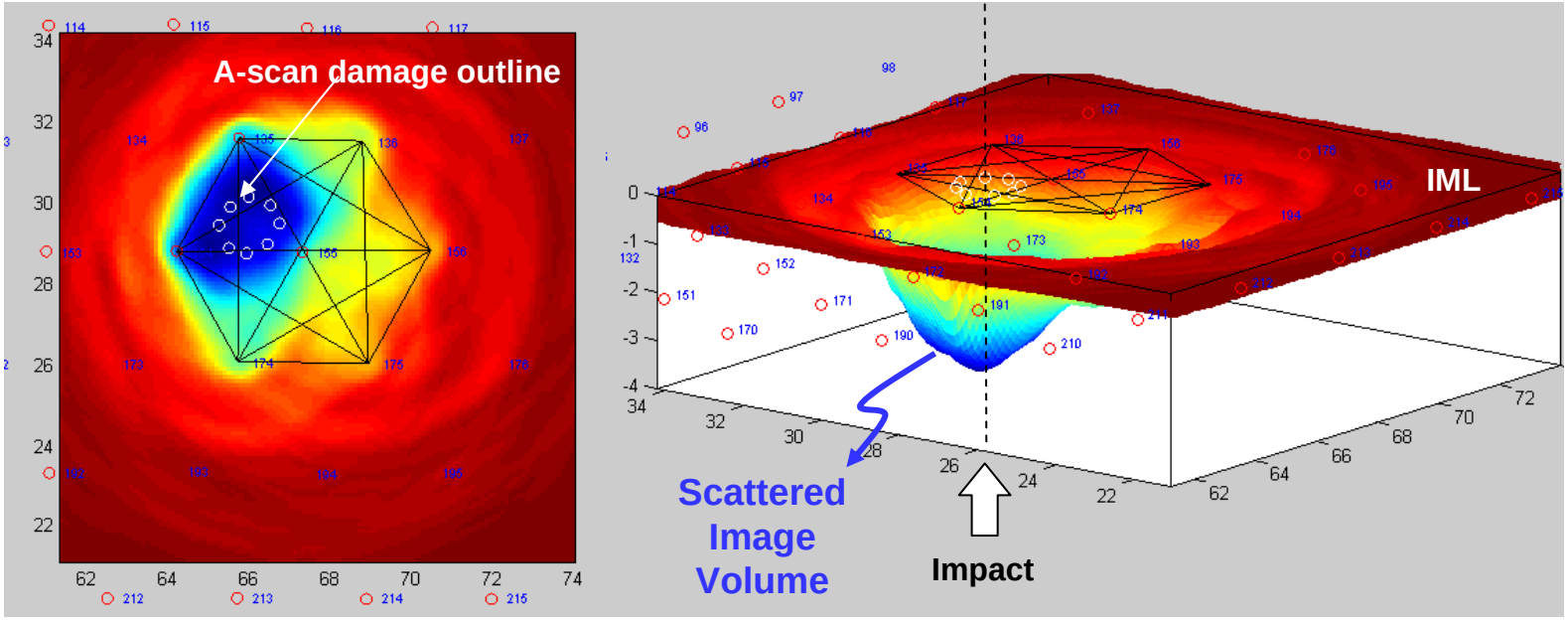
Requirements development with customer

2002	2003	2004	2005	2006	2007

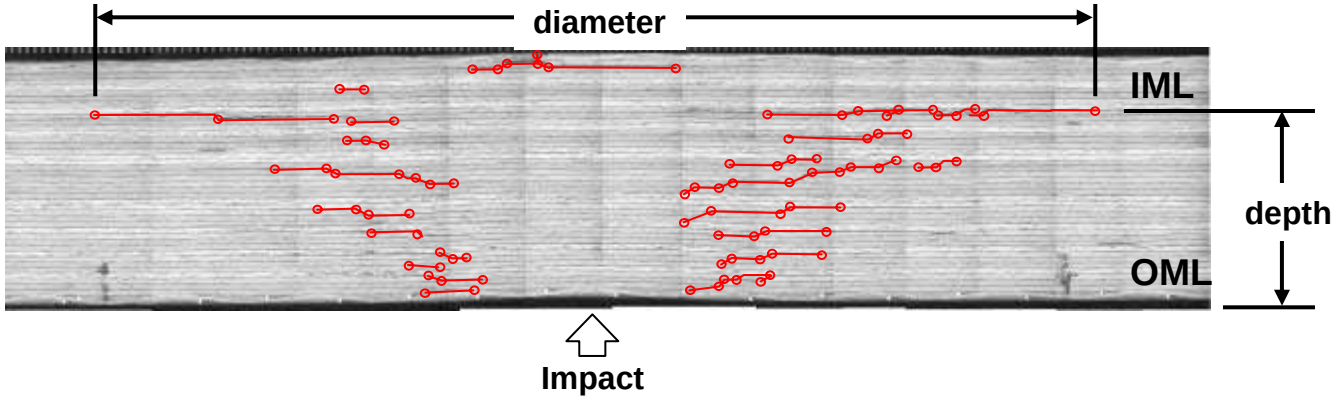
Understanding Requirements from a Systems Implementation Standpoint: Damage Repair Decisions



Composite Impact Damage Estimation Where Damage Sizing is a Requirement

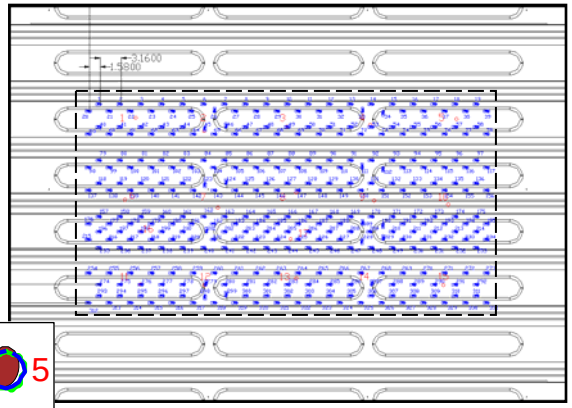


Goals:
Obtain the best prediction of damage delamination *area* and maximum delamination *depth*

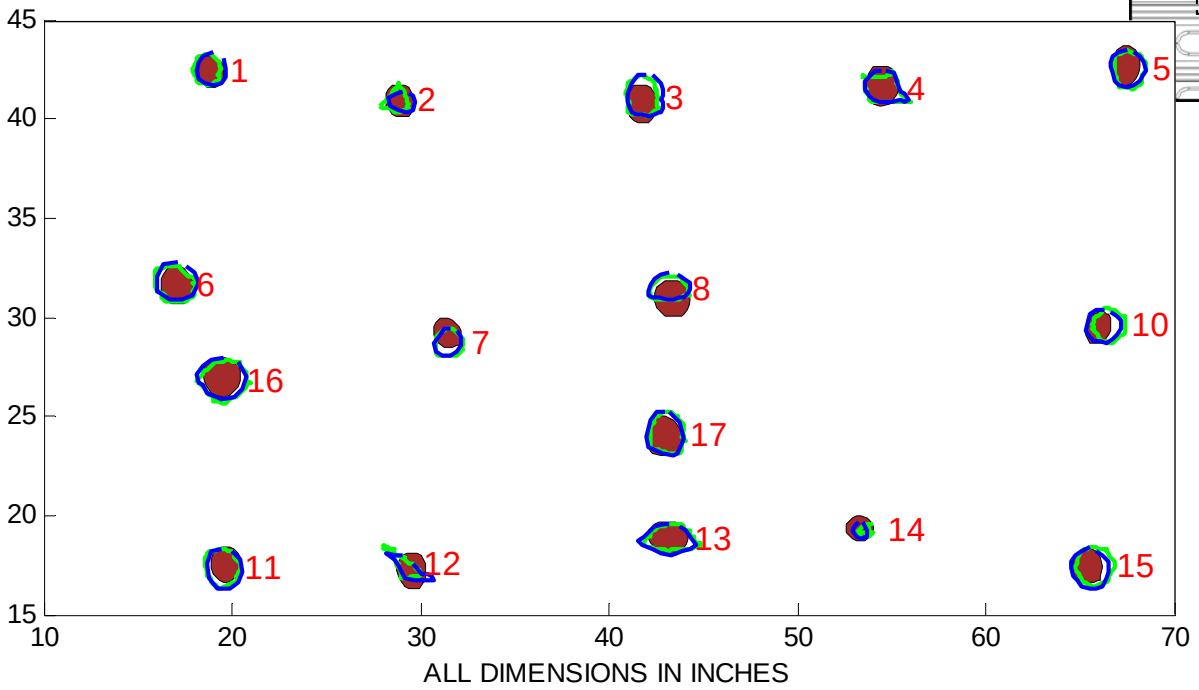


Impact Damage Sizing, Comparison to NDI

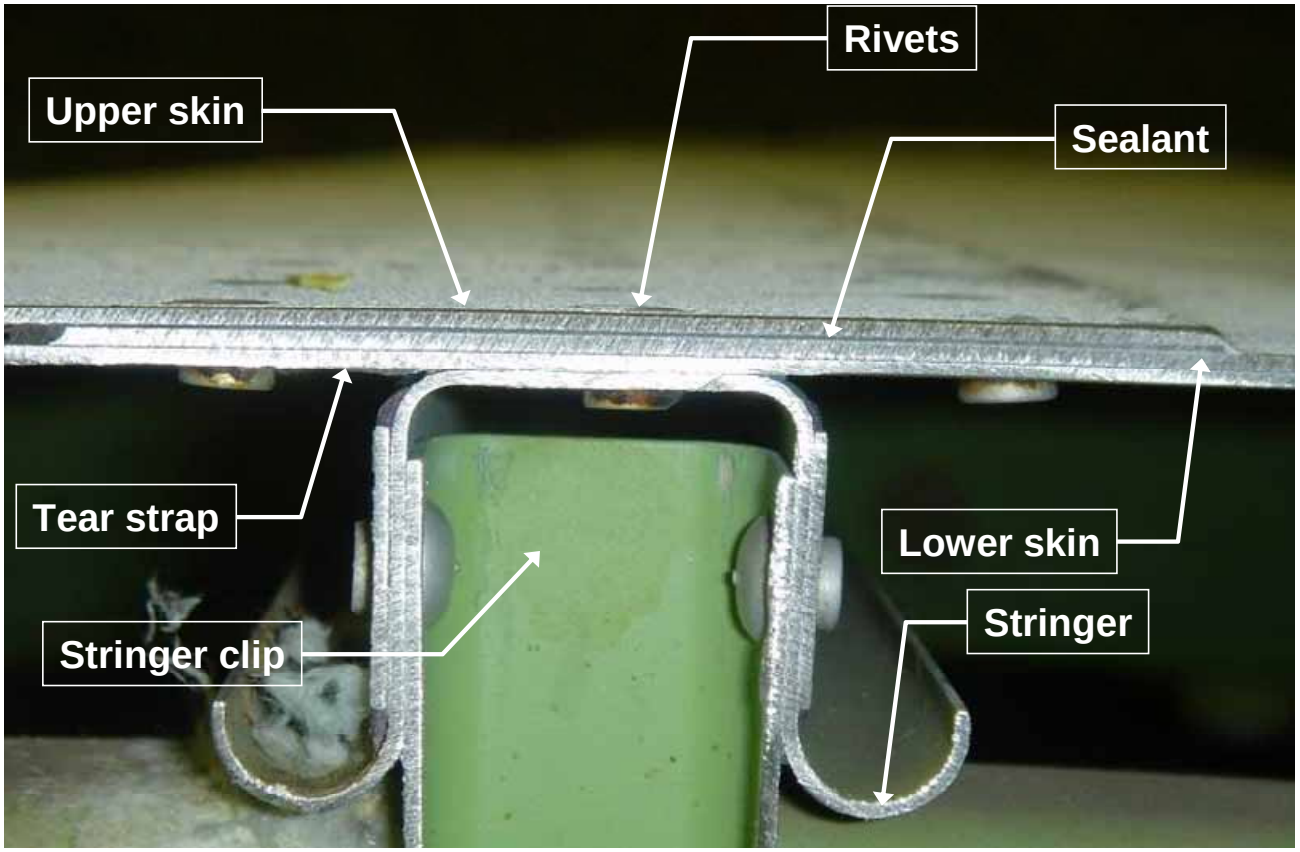
5'x7' Panel



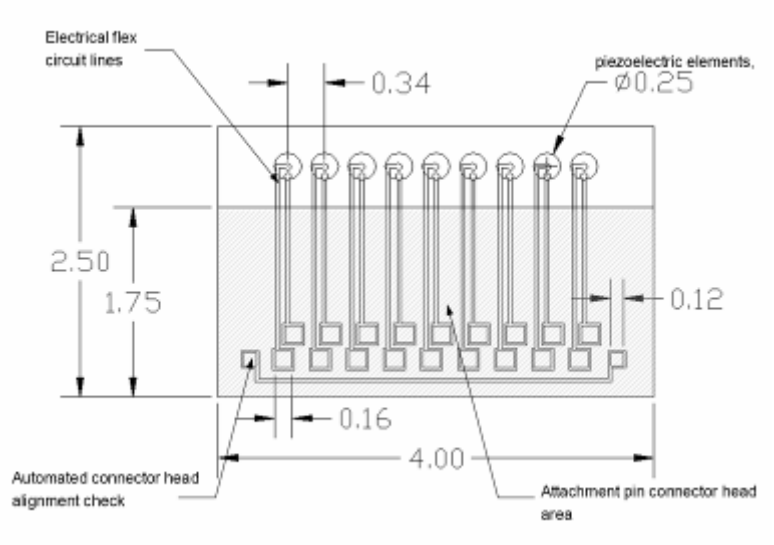
Green: C-scan, Blue: A-Scan, Red: SHM

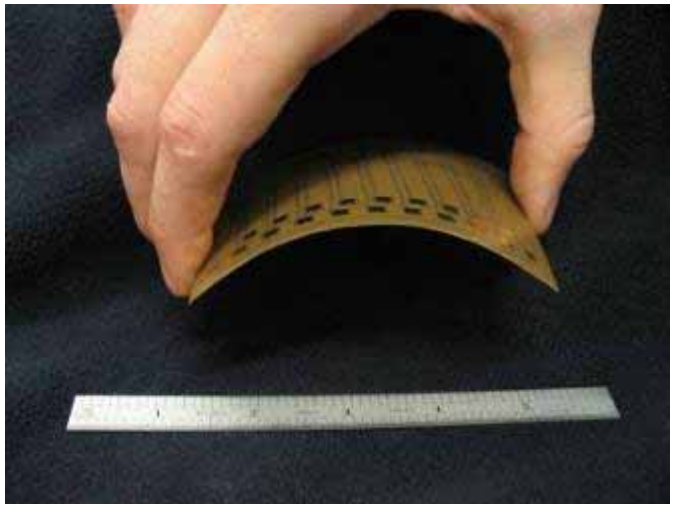


Lap Joint/ Repair Monitoring

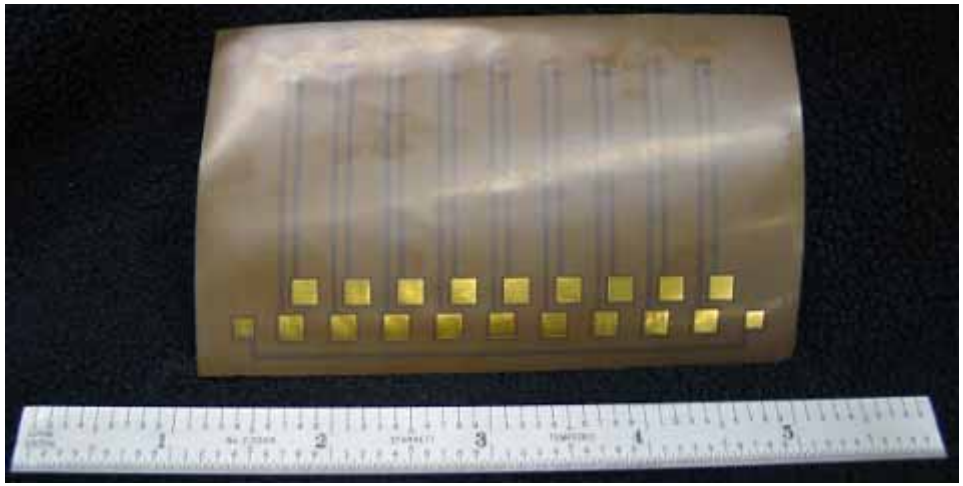


Phased Array Design to Meet Application Requirements



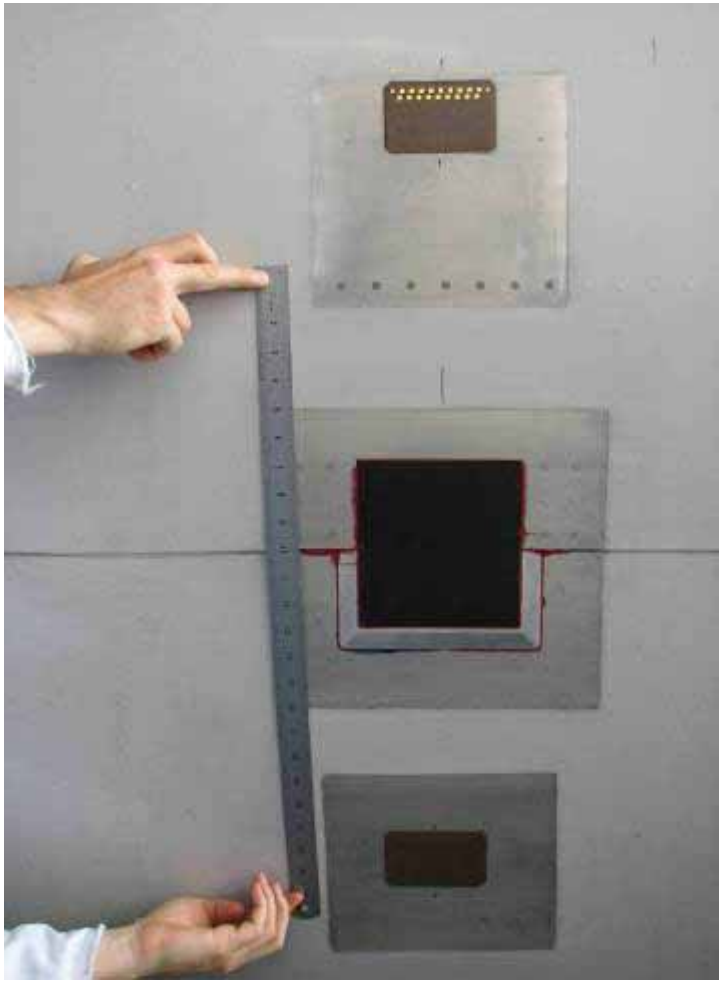


Phased Array approach helps meet requirements and cost targets for a linear application like a lap splice



Phased Array Design Implementation

Prototype Flight Installation for Proof of Concept



Hard Landing Assessment Example

LANDING EVENT

GOALS - Reduce aircraft schedule interrupts by:

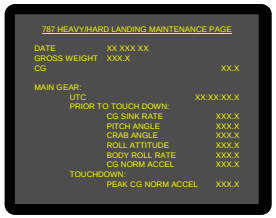
1. Reducing number of falsely reported hard landings
2. Aiding the maintenance process

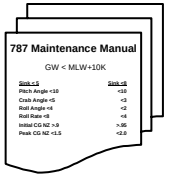
MAINTENANCE MANUAL

CURRENT APPROACH

- Pilot "by feel" initiated inspection
- Limited flight data usage with AMM
- Large number of false positives

MAINTENANCE PAGE



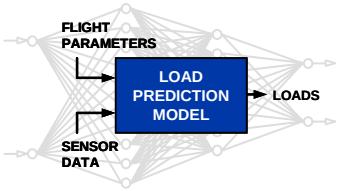


PHASE 1 APPROACH

- Pilot "by feel" initiated inspection
- Maintenance page provides flight parameters at touchdown
- Lookup table used to determine maintenance action

INSPECTION

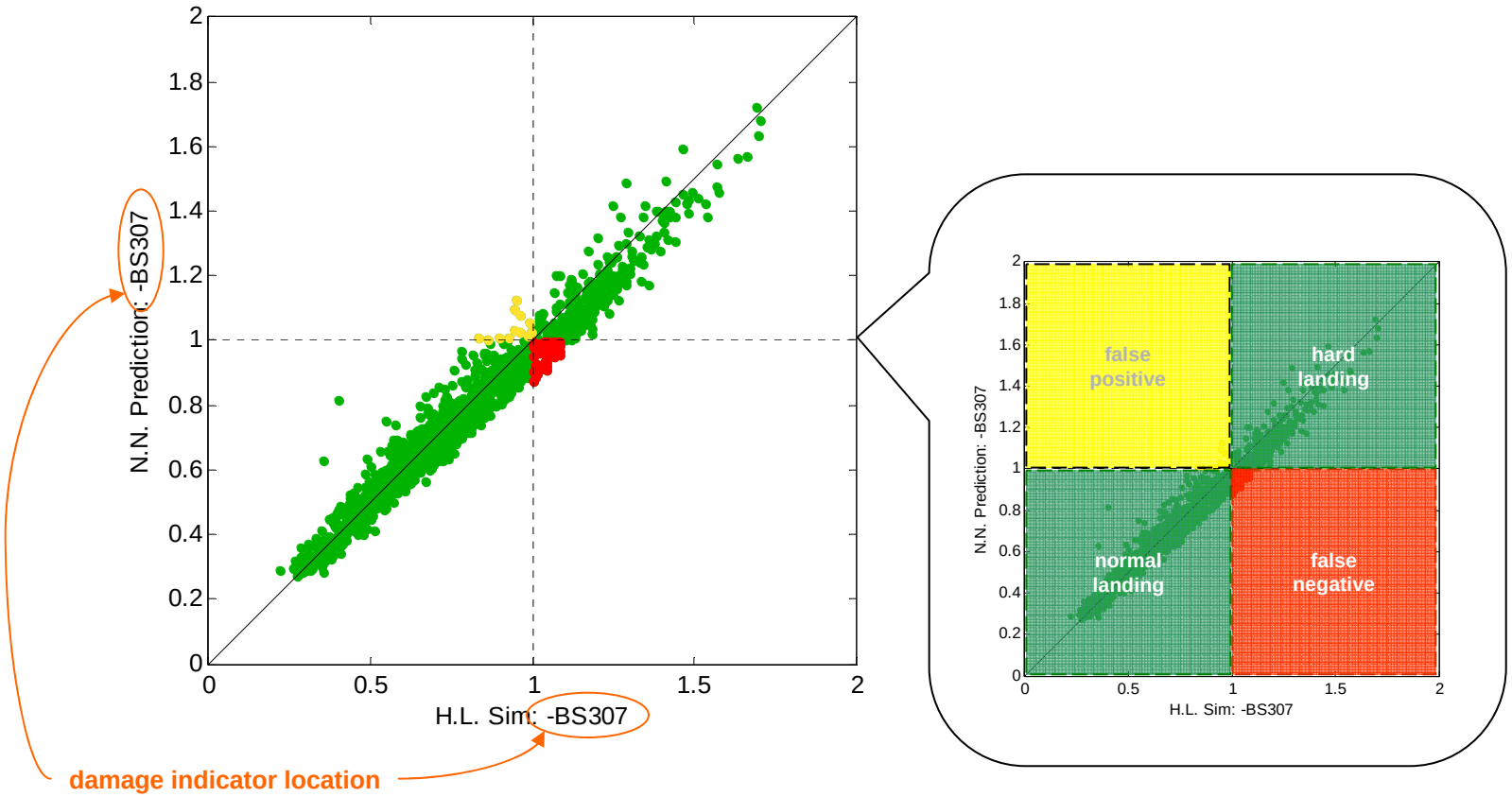
AUTOMATED LOAD PREDICTION



PHASE 2 APPROACH

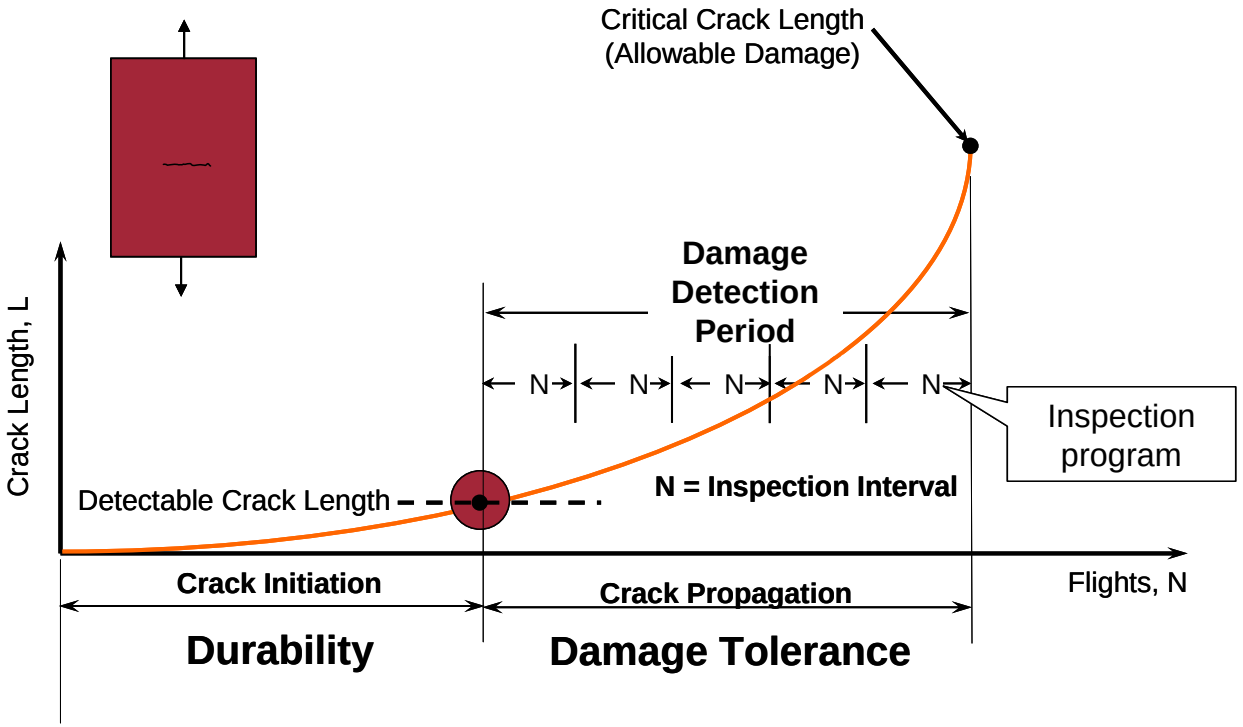
- Pilot "by feel" initiated inspection
- Flight parameters and sensor information used to predict detailed load information in critical structural areas
- Recommend maintenance action
- Aid maintenance procedure

Sample Hard Landing Trade Results



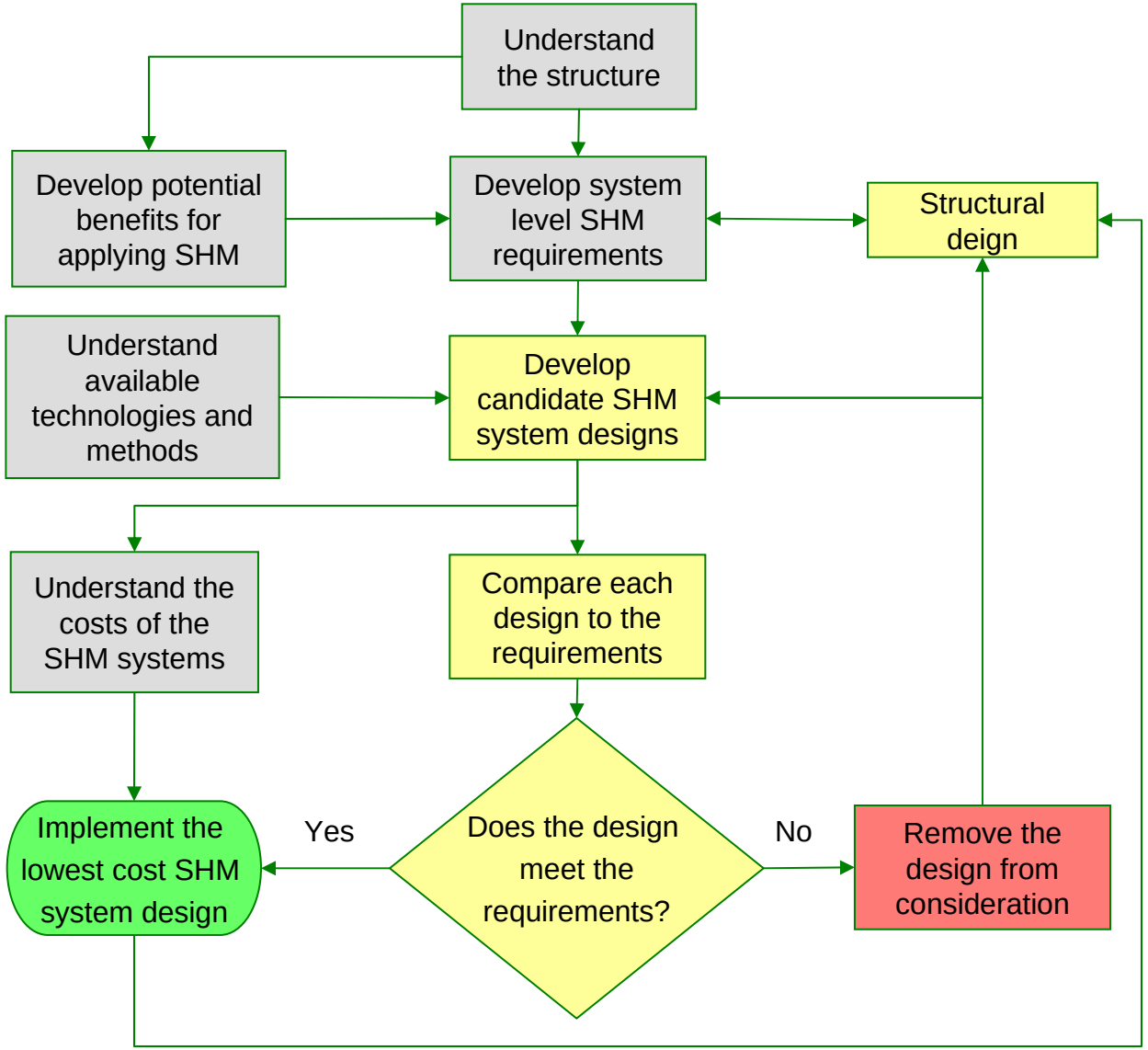
- **Composite plot of predicted versus simulated (i.e., truth) normalized damage indicators.**
- **Adjust threshold to eliminate false negatives, but at a cost of increasing false positives.**
- **Adding physical sensors increases performance to a point.**

Load Monitoring for Condition Based Maintenance



- **Operational load data can be used to determine inspection thresholds and intervals based on durability and damage tolerance methods.**
- **Approach must show significant maintenance cost improvement over scheduled inspection approach, while maintaining or improving reliability.**
- **This is a key component of an overall systems, condition based maintenance approach.**

Hot Spot Monitoring and Design Framework (AFRL)



Closing Comments

- Implementation requires clear understanding of benefits and requirements.
- Understanding of impact to overall design and design criteria is critical to understanding the implementation time frame.
- A design framework that allows SHM systems to be designed in the context of the overall system (structures, systems, support) is critical to implementation success.

SHM End-to-End Flow: Damage Detection Example