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Structural Sensors for Condition Based Maintenance and Prognostics

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- Overview: Condition Based Maintenance and Prognostics (CBM+) Program
- Structural sensor selection/evaluation criteria
- Structural sensor testing
- Path forward

Overview

Whereas

- ASIP ensures safety:
  - MIL-STD-1530C
  - Inspections
  - FSMP

- CBM+ enhances functionality
  - Reliability Centered Maintenance (RCM)
    - Necessary maintenance items
    - On-condition maintenance items
  - Depot scheduling on-condition via
    - Sensors
    - Usage
  - Cost effectiveness via Business Case Analysis

Overview

- Condition Based Maintenance and Prognostics (CBM+) program seeks to:
  - Schedule maintenance based on individual aircraft condition rather than prescribed calendar dates
  - Determine necessary maintenance actions
  - Integrate airframe sensors where effective to identify and prioritize aircraft maintenance needs
  - Increase weapon system availability
  - Increase efficient use of depot resources
  - Increase mission capability rate
  - Reduce unscheduled field maintenance
  - Reduce induced failures

Structural sensor selection/evaluation criteria

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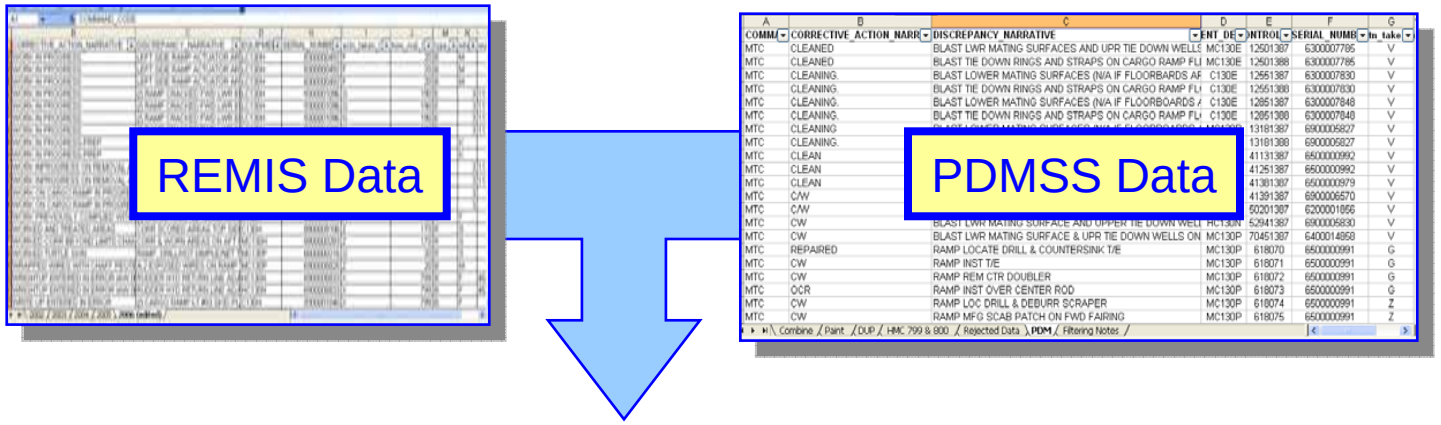

Business Case Analysis

Reliability Centered Maintenance (RCM) Analysis

Sensor Viability Analysis

CBM+ Sensor Package Design

- On-condition tasks suitable for sensors
- Sensor payback
- Viable, feasible, “deployable” sensors

Structural sensor selection/evaluation criteria

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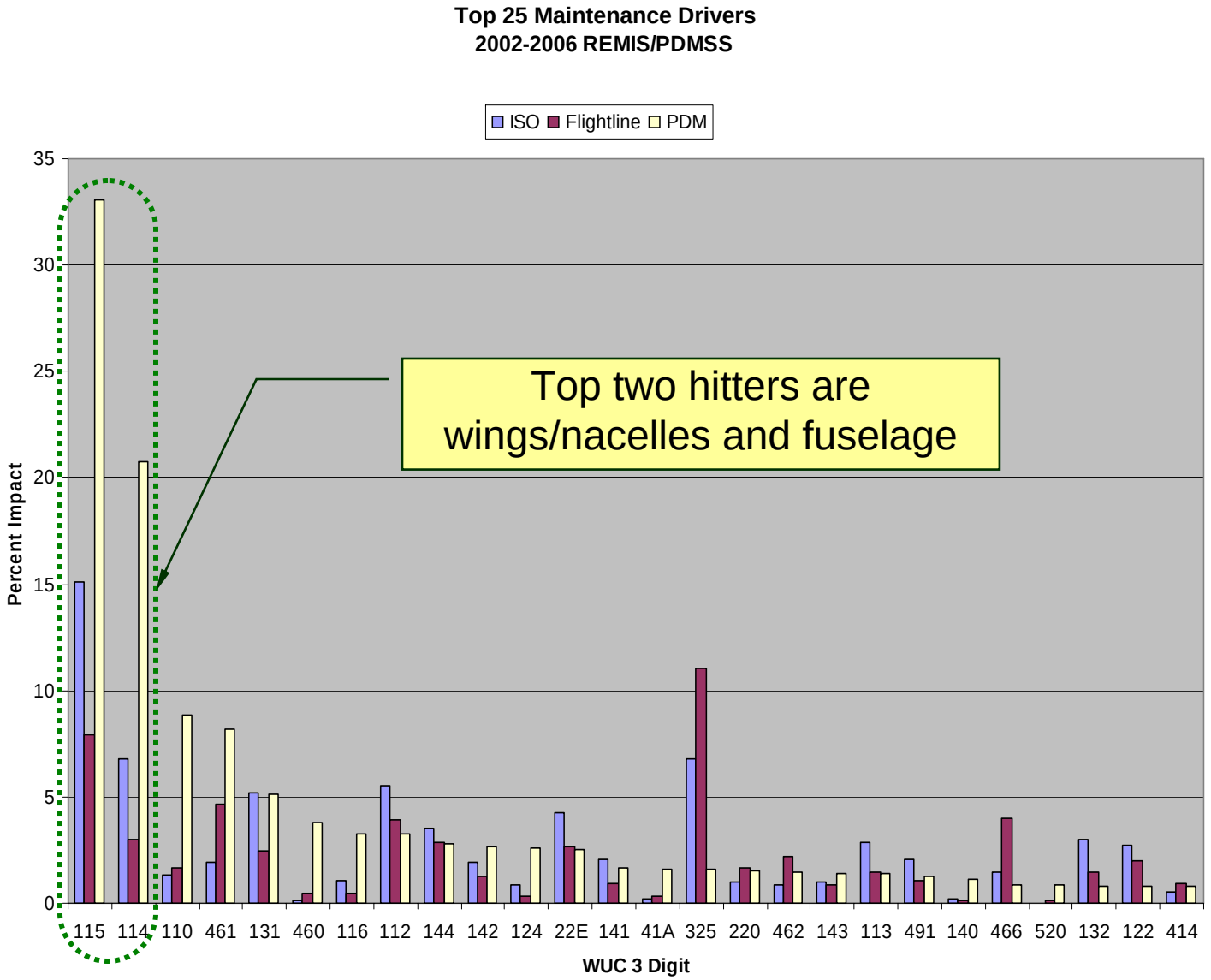

Structural sensor selection/evaluation criteria

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		Cracks	Component Life	Corrosion	Functional
L/ESS	**Usage Sensor**	NDI based on tracked usage, severity, DTA concepts	Cumulative tracked usage, severity, correlation to testing	Usage, severity as SCC drivers	
	Event Sensor	Damage detection sensors at specific locations/ components	Damage detection/ assessment sensors		
	Degradation & Corrosion Sensor			Sacrificial sensors measure cumulative exposure/wash effects	
	Functional System/ Other Sensor				Engine vibration, avionics power consumption

Structural sensor selection/evaluation criteria

- Usage sensors
  - Sensors/flight parameters for flight controls
    - MIL-STD 1553
    - ARINC-429
  - USAF has L/ESS programs underway

- Usage sensor systems
  - Sensor technology largely known, reliable
    - SHMS
    - USCG recorded flight data
    - DFDR
    - Self powered strain gage with memory
  - Recording technology advances make high bandwidth, multichannel, full flight data acquisition feasible and desirable

Structural sensor selection/evaluation criteria

- Usage sensors directly benefit ASIP tasks
  - Individual Aircraft Tracking
  - Inspection Interval
  - Loads/Environment Spectra Survey

- Usage sensors directly benefit CBM+ tasks
  - Higher fidelity correlation of condition with usage
  - Forecasting condition for depot planning
  - Correlation of event sensor data to usage history

Structural sensor selection/evaluation criteria

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- Event sensors
  - Damage detection sensors at critical structural areas
    - Passive acoustic sensors
    - Pitch-catch acoustic sensors
    - Residual plastic strain indicators
    - MWM methods
- Degradation and corrosion sensors
  - Environmental sensors in multiple locations
    - Sacrificial environmental exposure devices
    - Acoustical sensors
- Functional systems
  - Vibration sensors for engines/power trains/props
  - Hydraulic pressure / temperature sensors

Structural sensor selection/evaluation criteria

- Sensor functionality
  - Do they detect desired events?
  - Do they detect them at advantageous thresholds?
  - Are detections conveyed in a timely manner?

- Sensor costs
  - Cost of the transducer and other on-board equipment
  - Ground support infrastructure
  - Cost to acquire the data, store, and evaluate
  - Cost of status quo
    - For example, wing inspections cost approx. 400k$ and 10-12 months to extend wing service life from 38k EBH to 45k EBH

Structural sensor selection/evaluation criteria

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- Sensor added value
  - Can sensors prioritize, delay component replacements?
  - Can sensors augment new components?
  - Can sensors detect cracks between scheduled inspection intervals?

- Sensor “deployability”
  - Packaged for flight/field versus lab
  - Skill level/training required to use
  - Reliable
  - Maintainable
  - Fit in available spaces
  - Placement both accessible and functional

Structural sensor selection/evaluation criteria

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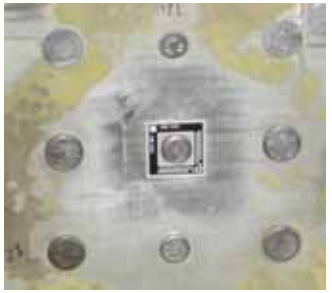
- Technology identification/viability assessment
  - Transducer intersects with CBM+ needs
  - Functional in a field environment
  - History of application
    - NAVAIR, AFRL, AFMC and others
  - Available
- Lab tests on full scale parts, full scale loads demonstrate
  - Form, fit, function in available space and existing constraints
  - Suitability for flight test considerations
- Infrastructure for data retrieval, interpretation, and management

Structural sensor selection/evaluation criteria

- Lab testing currently focused on these sensors:
  - Direct Measurements Incorporated
    - Residual plastic strain indicator
    - Requires camera to capture image, compare to reference state
    - Also provides IUID capability



  - Ultra/AAIMS
    - Acoustic sensor array
    - Packaged for flight, includes data recorder
    - Functional in several field tests already

  - Physical Acoustics
    - Acoustic sensor technology
    - AFRL funded research underway at Penn State

Structural sensor selection/evaluation criteria

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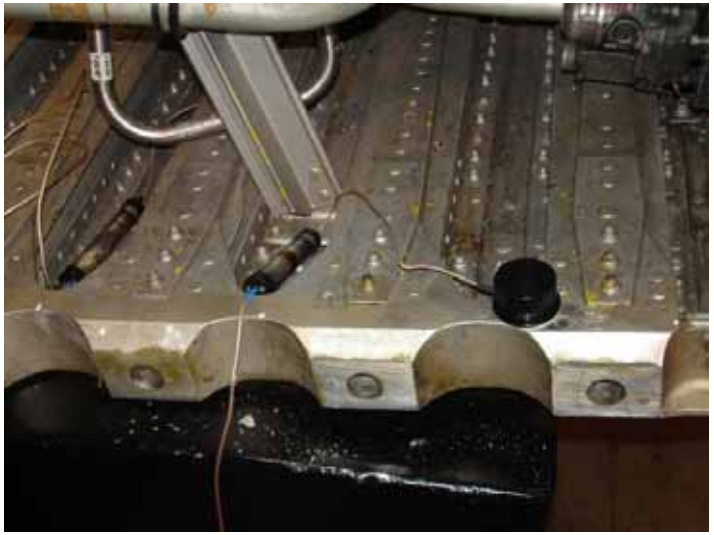
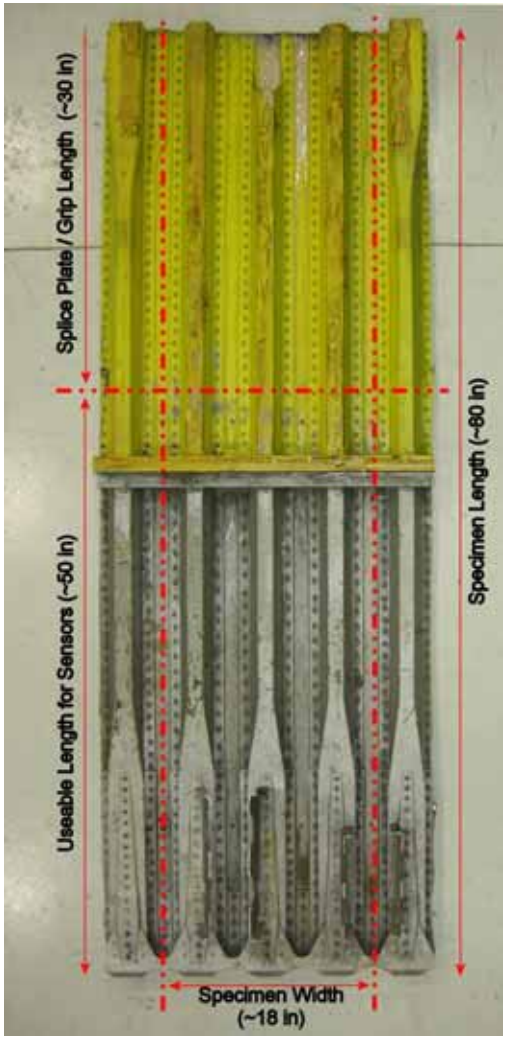


Structural sensor selection/evaluation criteria

- Wing lower surface assembly selected for test article
  - Structure, loading, cracking locations well known
  - Includes fittings, stringers, panel
  - Eddy current scans of test article revealed no cracks
- Sensor technologies not exclusively focused on wing panel structures
  - Conclusions of sensor effectiveness or ineffectiveness are applicable to other structure besides wing lower surface
- Test simulates operational loads to evaluate sensor viability
  - Can the sensors detect real cracks on real structures?
  - Not a service life test
  - Not a POD test



Structural sensor selection/evaluation criteria

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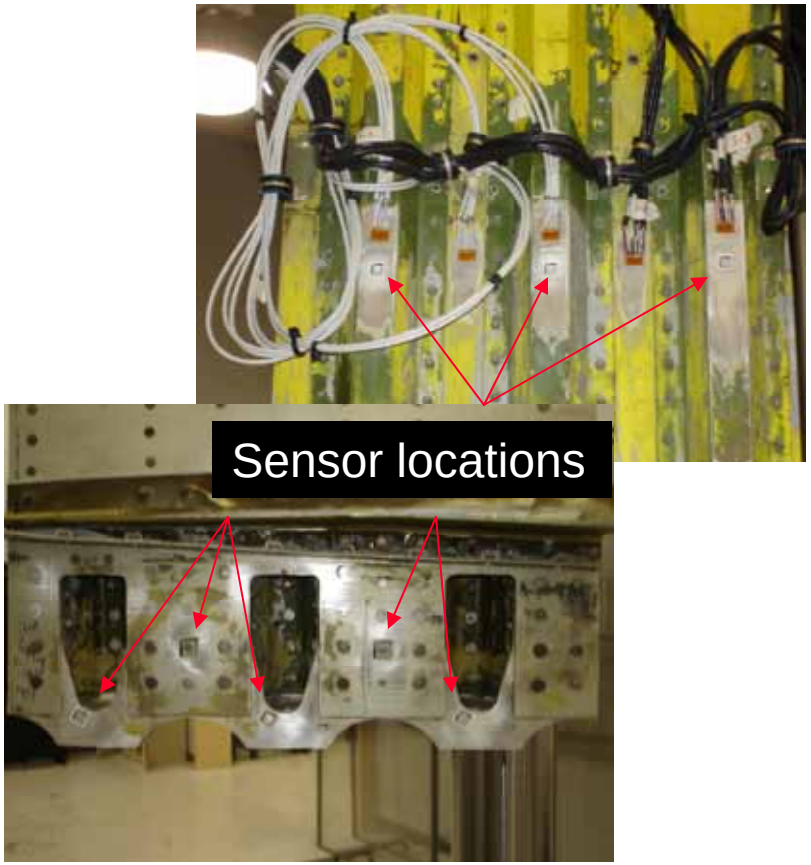
- MERC Test Facility

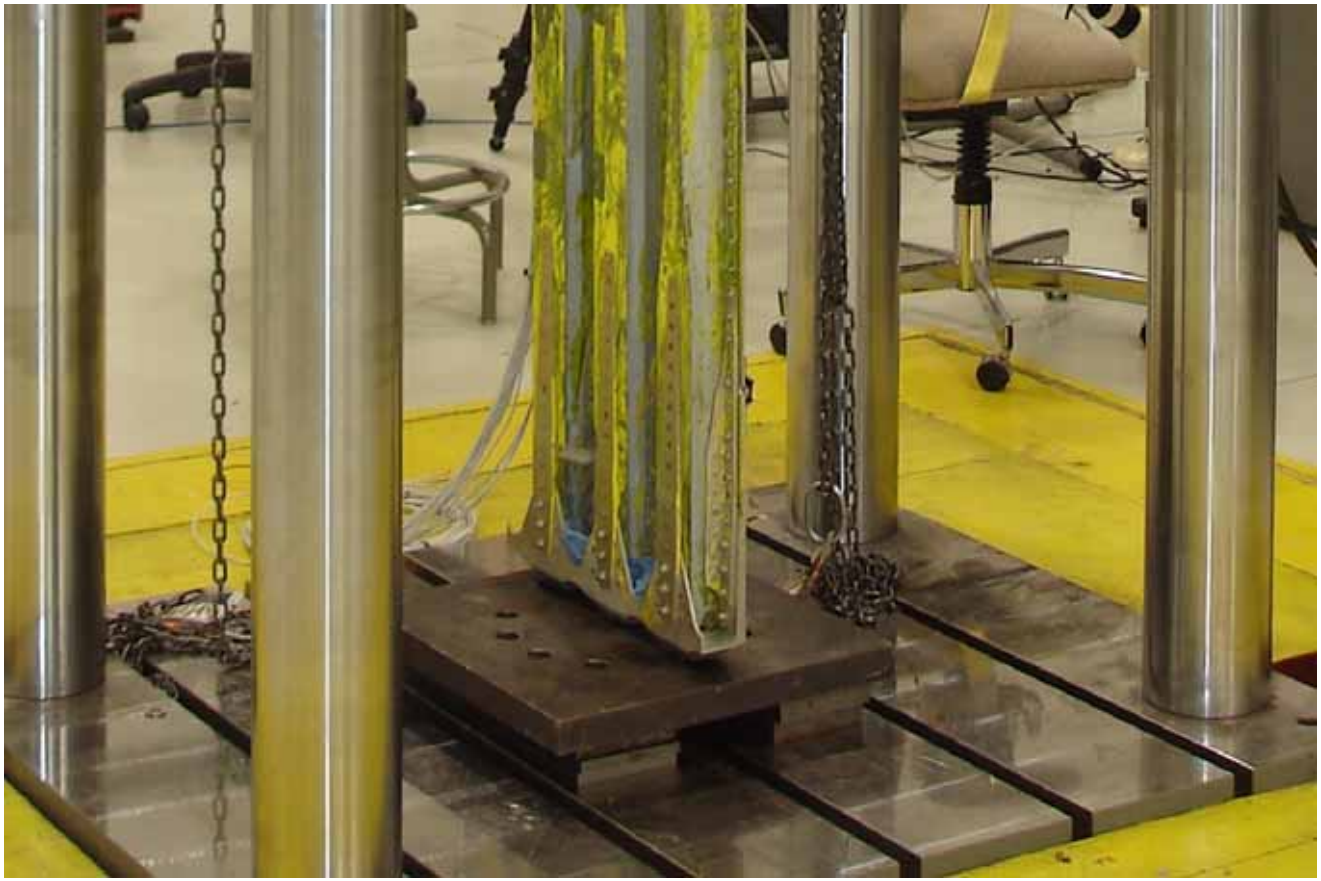


Structural sensor selection/evaluation criteria

- Grips are stepped leaves to smoothly and uniformly transfer test load into the test article panel and stringers

Structural sensor selection/evaluation criteria

- Test article rainbow fitting anchored to base plate at bottom of test fixture



Structural sensor selection/evaluation criteria

- Dial indicator for measuring lateral movement under load

Structural sensor selection/evaluation criteria

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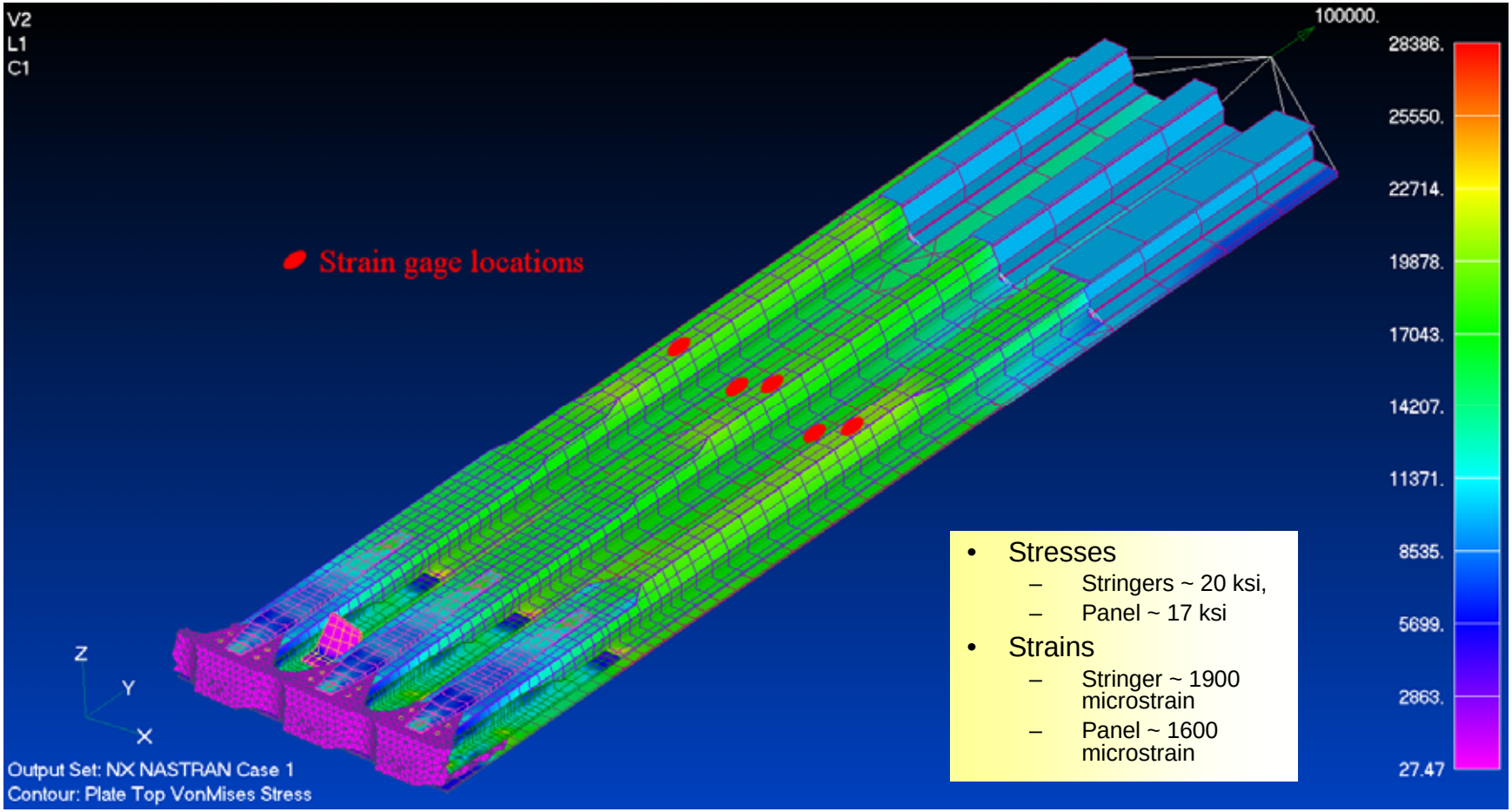
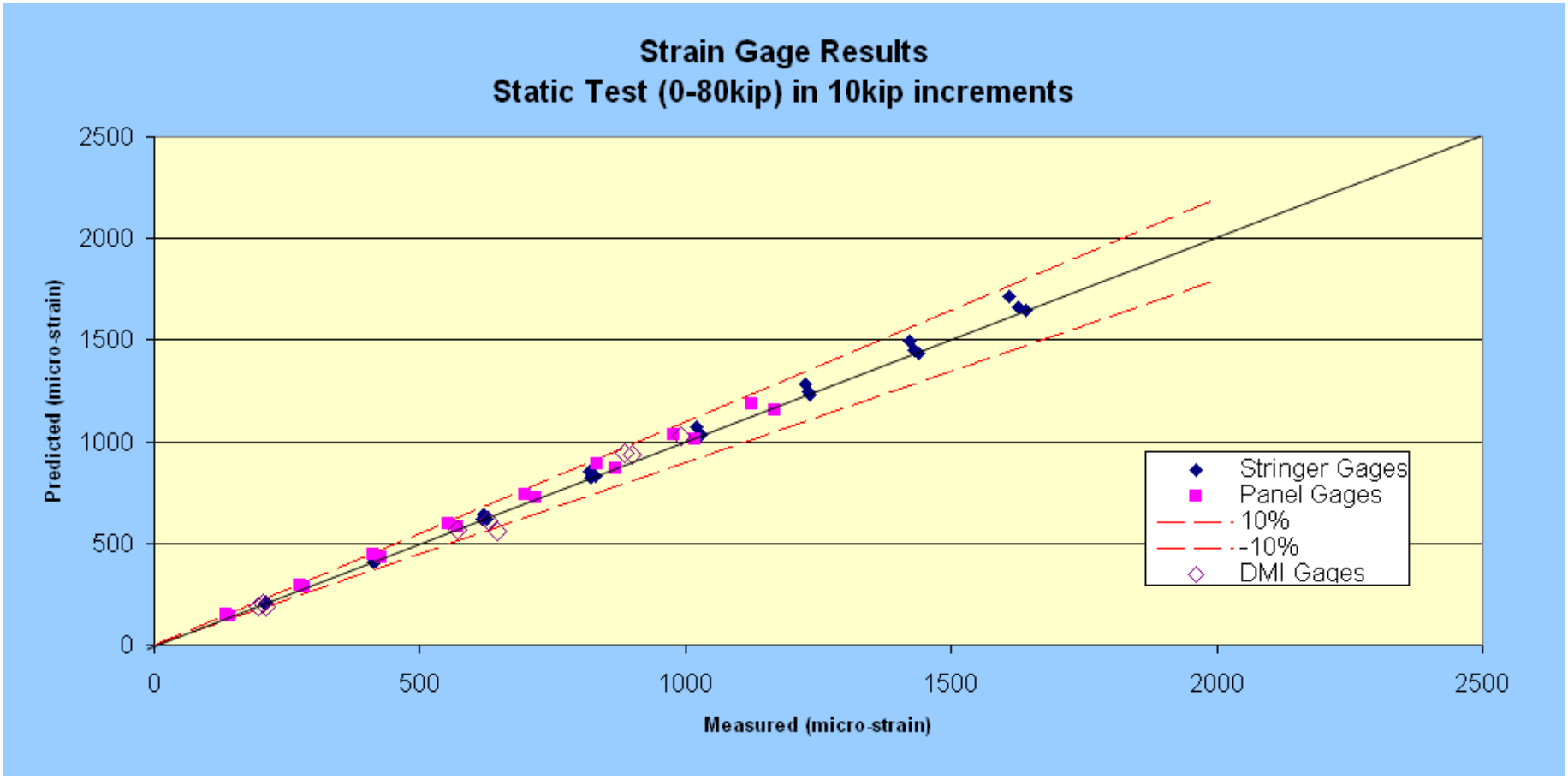


- Stresses
  - Stringers ~ 20 ksi,
  - Panel ~ 17 ksi
- Strains
  - Stringer ~ 1900 microstrain
  - Panel ~ 1600 microstrain

Structural sensor selection/evaluation criteria



Structural sensor selection/evaluation criteria

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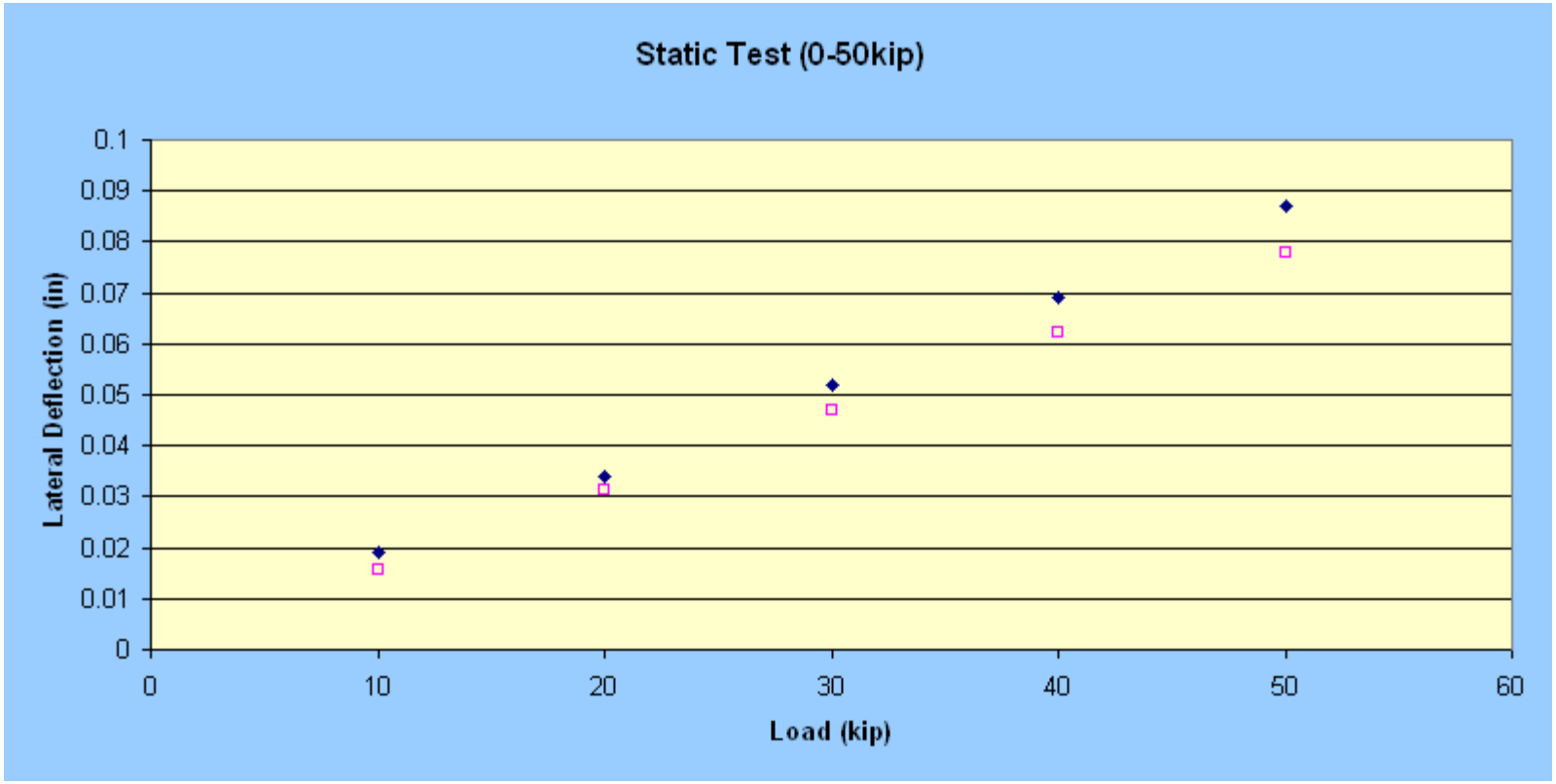

Structural sensor selection/evaluation criteria

- Run the load profile with periodic inspections
  - Compare sensors with visual and eddy current measurements

Path forward

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- Complete viability evaluation
  - Lab testing on center wing sections with full scale loads
  - Matrix of sensor characteristics/trades, reliability concerns
  - Identifying/verifying whether or not the sensors detect cracks
- Cooperative alliance with NAVAIR, AFRL for identifying best technologies
- Identify technologies to fulfill needs identified in RCM analyses
- Sensor flight test considerations
  - Sensor system specs
  - MACC
  - CCB requirements
  - Flight test plan

Questions?