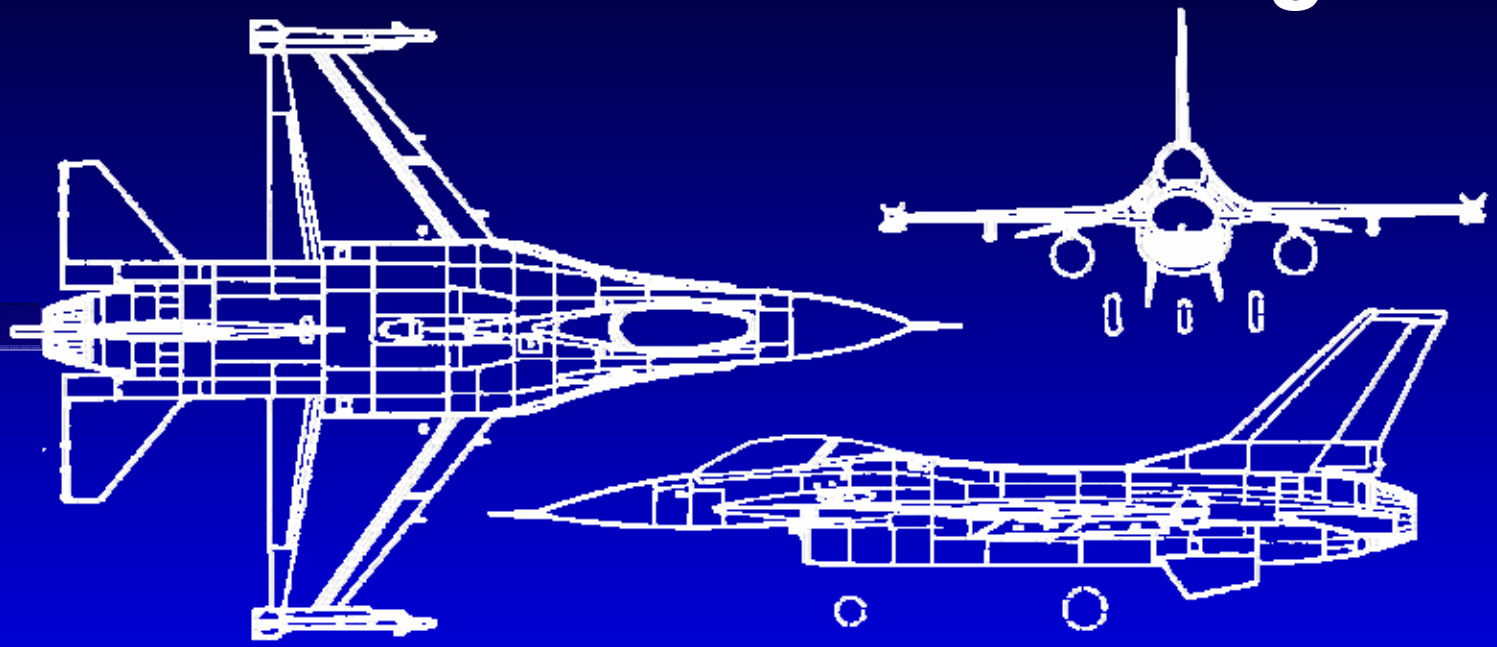
Bonded Repair of a F-16 Bulkhead Flange



David Wieland, Southwest Research Institute

Matt Malkin, Boeing Phantom Works

Background

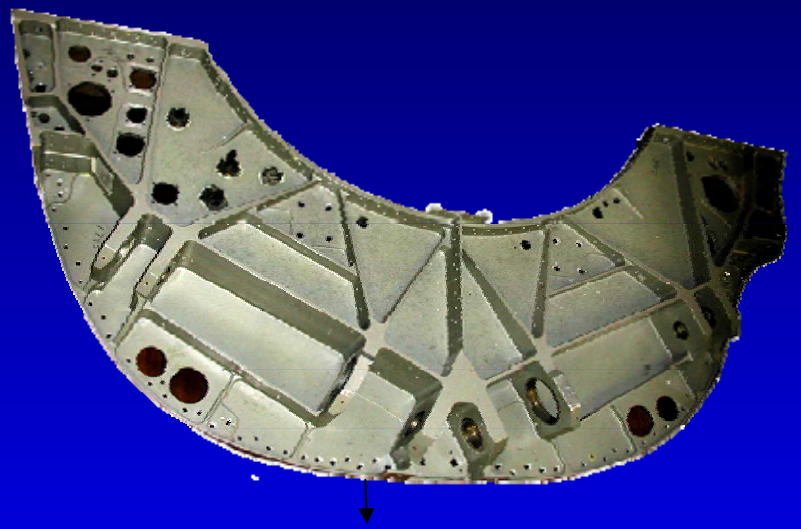
- USAF has a large aging aircraft fleet with age related structural damage
- Inspection and repair of aging fleet is extremely expensive
- Bonded repairs have the potential to reduce repair costs and eliminate component replacements
- SHM systems have the potential to track health of the bond lines and crack growth

Program Objective

- Extend bonded composite patch technology to to thick structures and/or complex geometries
- Using specific aging aircraft structural components
- Early Test of SHM System

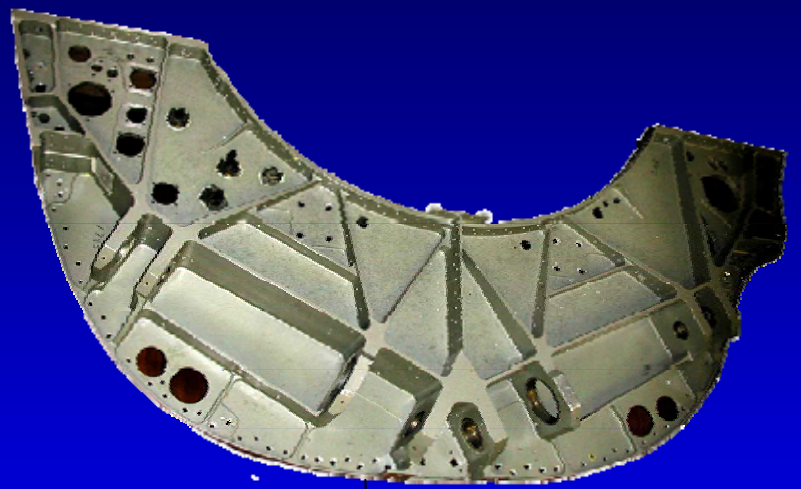
F-16 Bulkhead

- F-16 341 bulkhead flange chosen as the demonstration article for the thick/complex bonded repairs.



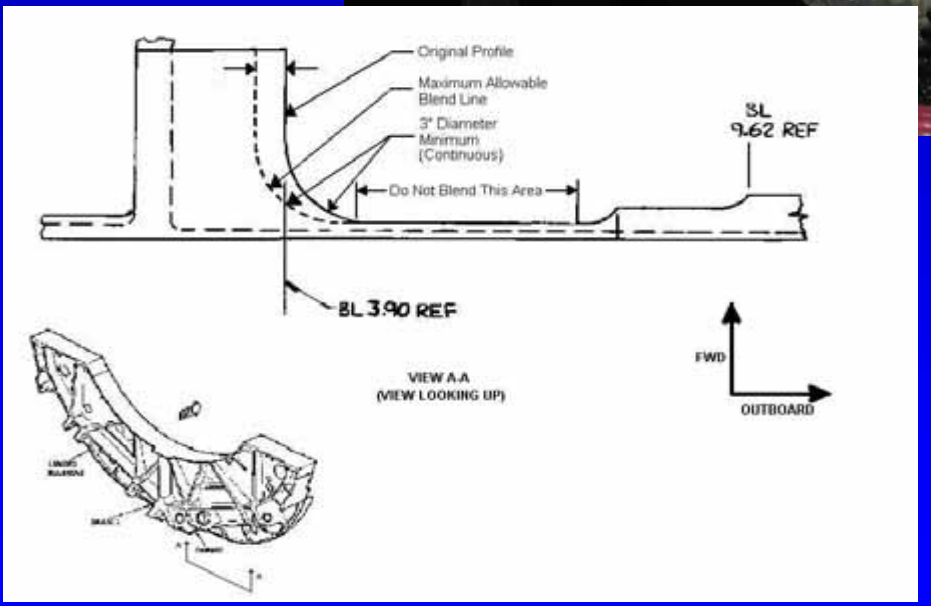
F-16 341 Bulkhead Attach Flange Radii

- Addresses Various Thickness
- Complex Load Path
- Thickness Constraint
- Complex Geometry
- Fastener Holes
- Good ROI



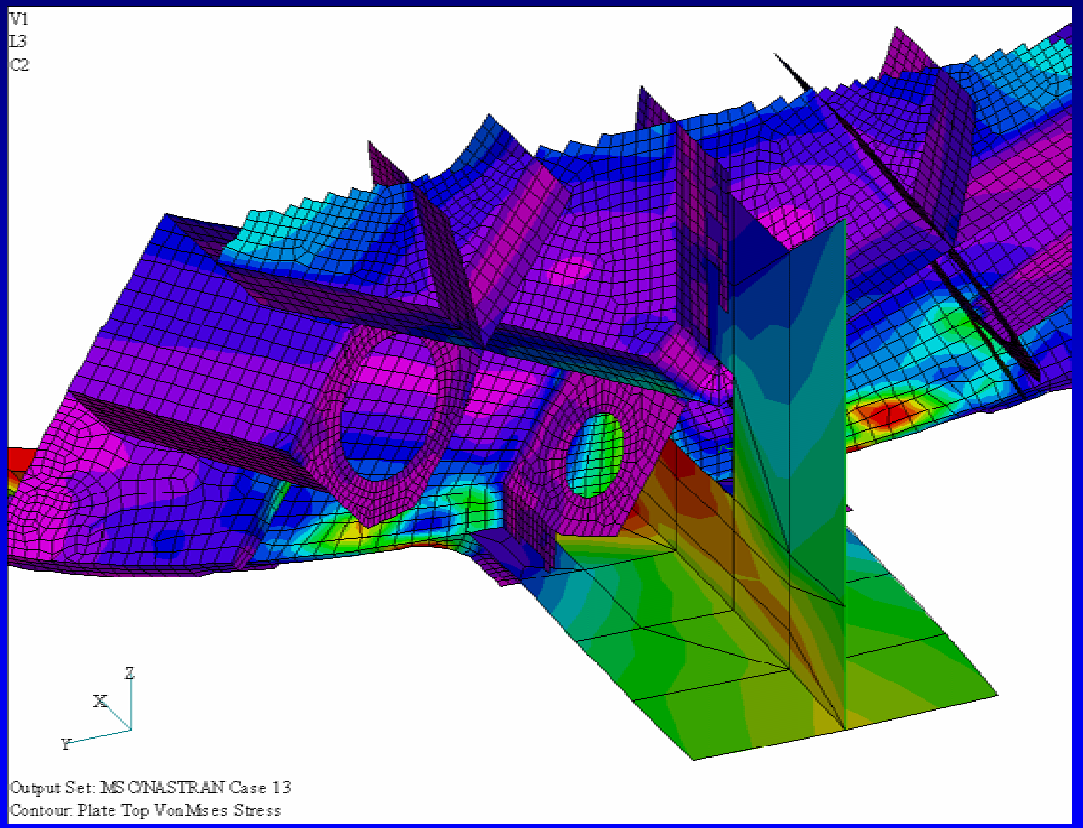
F-16 341 Bulkhead Longeron Attach Flange Radii

- Fatigue crack
- Small radii
- Current repair
  - Blend out crack
  - Replace fitting when cracks to large

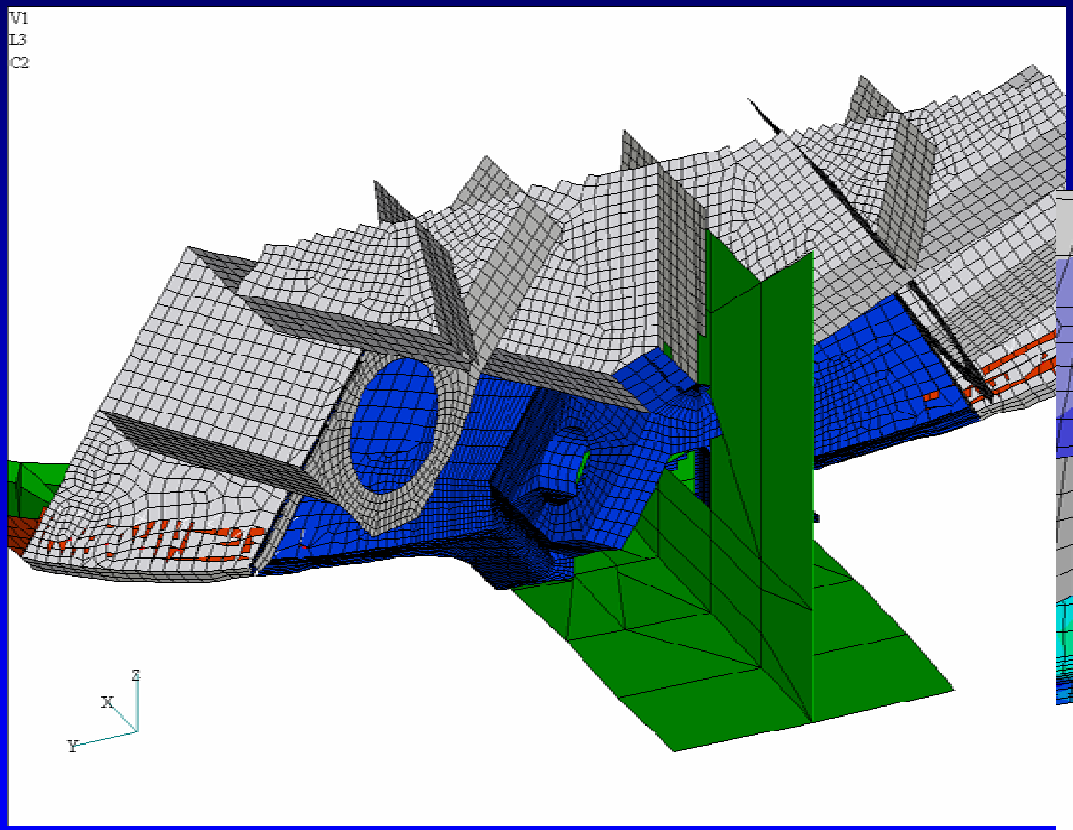


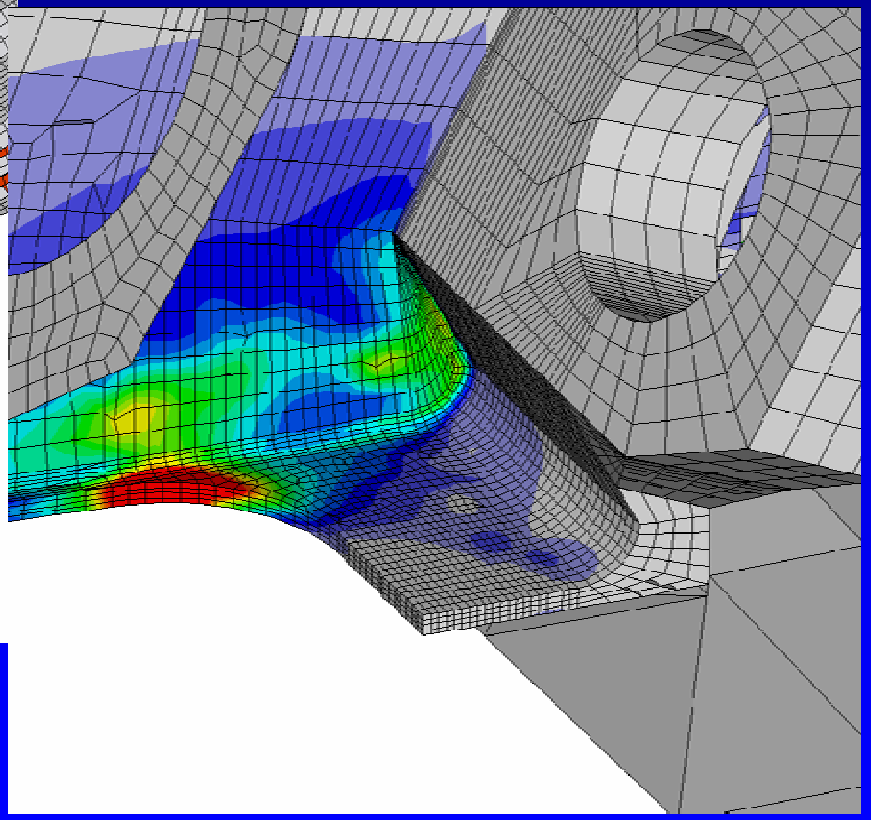
F-16 341 Bulkhead Repair Preliminary Design and Analysis

- Lockheed provided section of bulkhead FEM
- Swri modified Lockheed FEM to include fine mesh model of bulkhead flange



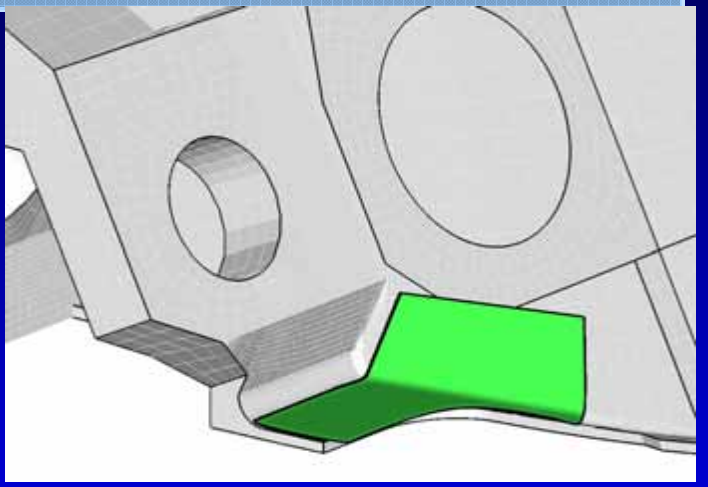
F-16 Continued

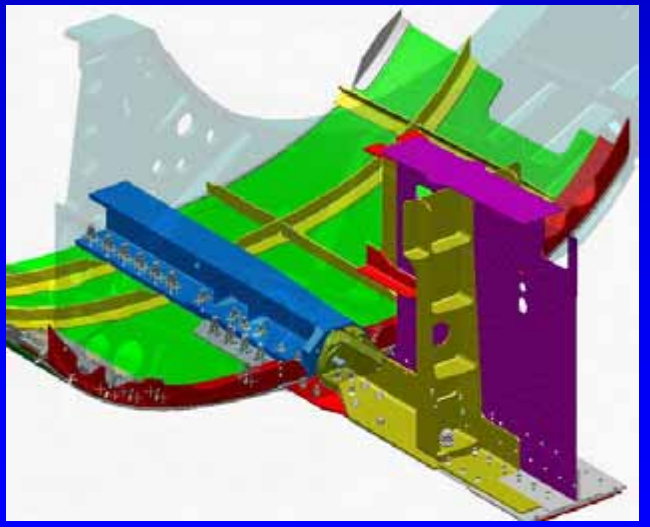


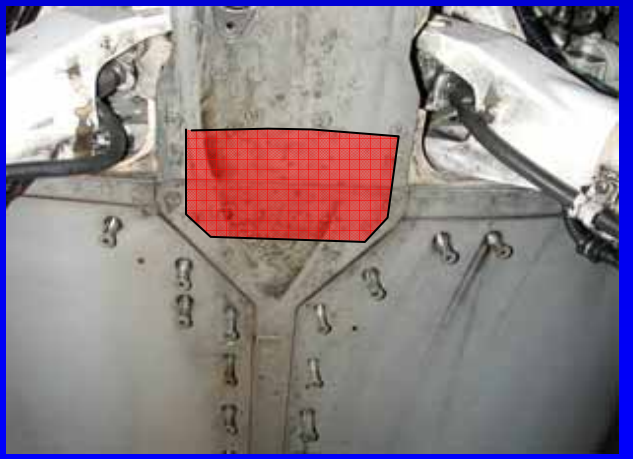


Repair Design

- Blend out Crack in Radius
- Bonded aluminum angle repair with a composite keel patch

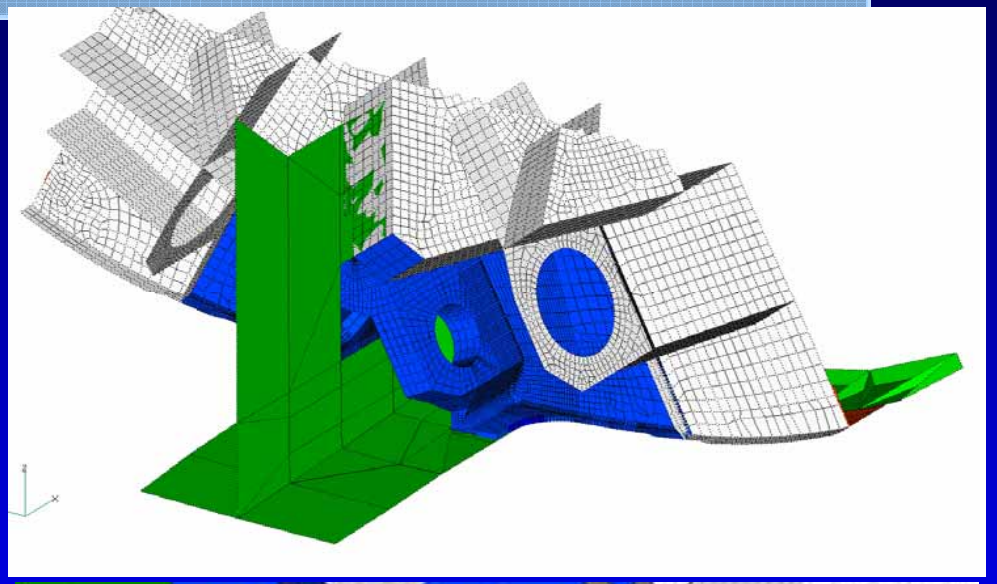


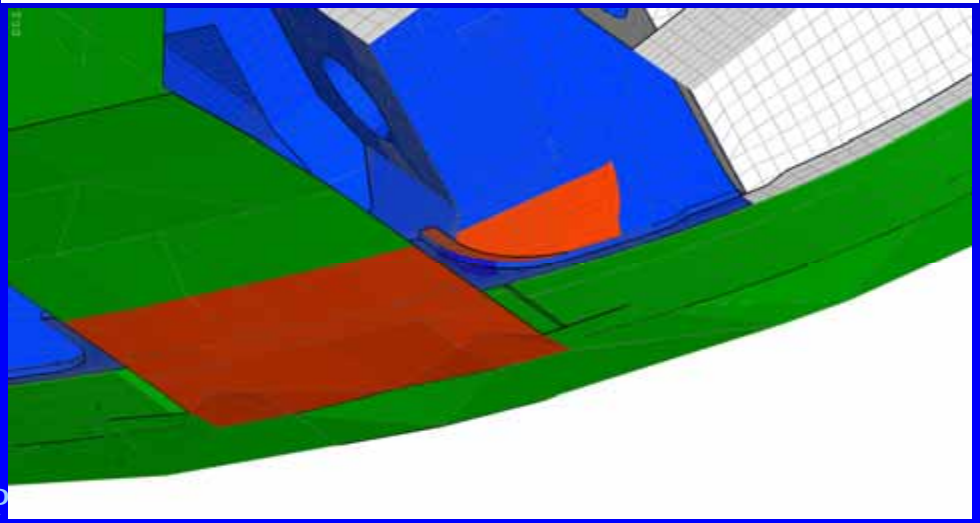




Updated FEM

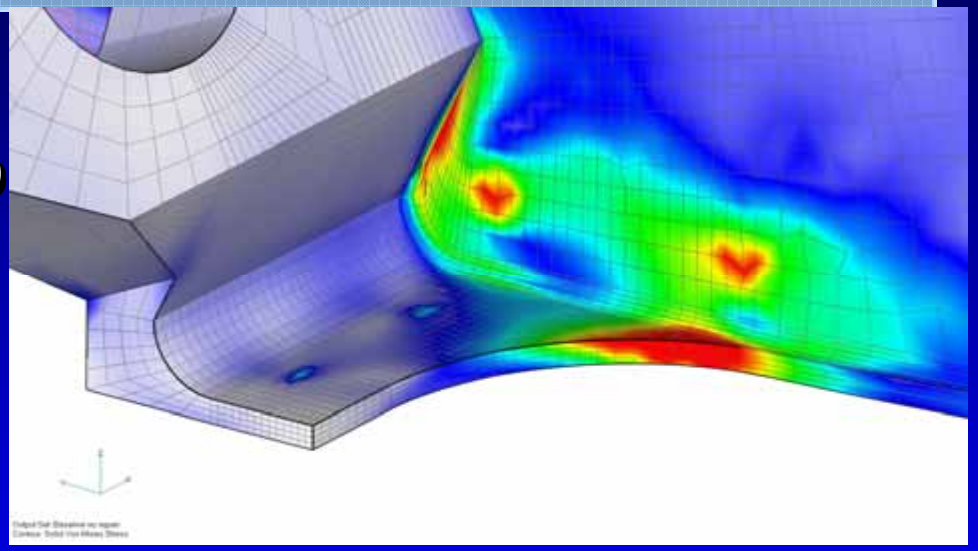
- Baseline FEM updated
- Removed flange material
  - Simulate a blended repair with 1.5” Radius
- Aluminum doubler extended to original bulkhead geometry with 1.5” radius

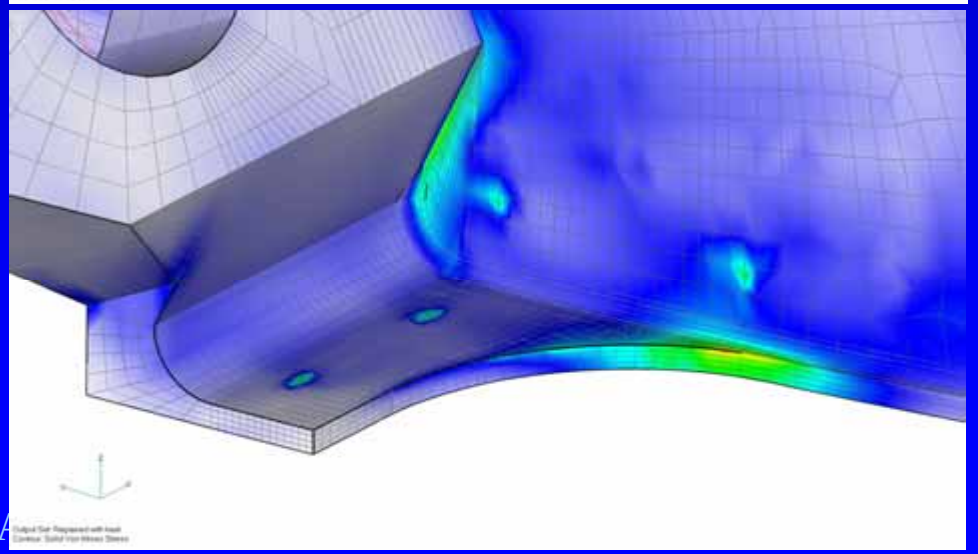




Updated FEM

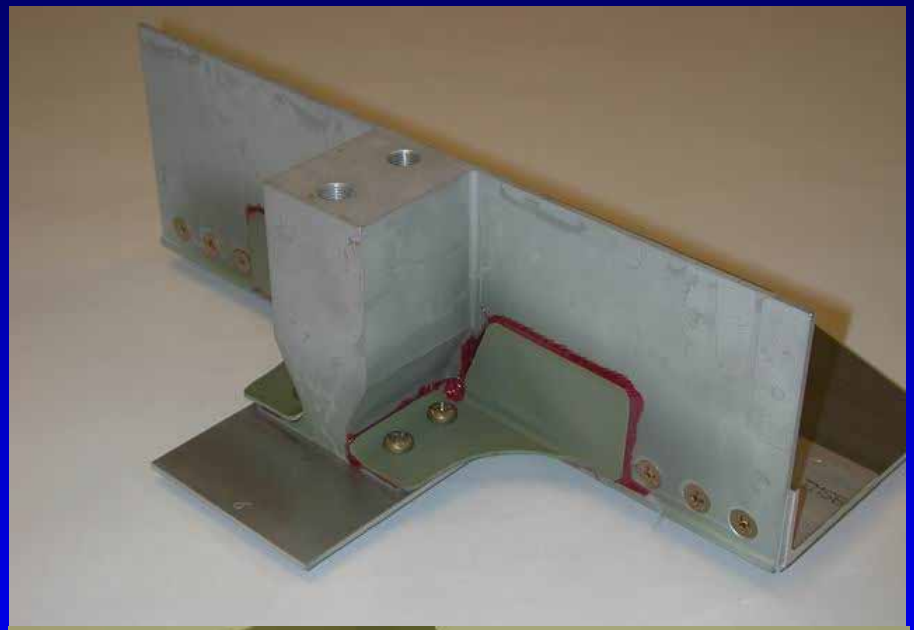
- Reran FEM baseline to determine test radius target stress
- Compared baseline to repaired stress analysis
- 60% reduction of stress at crack
- Finalized design
- Repair not shown for clarity





Repair Redesign Coupon

- 0.08 inch thick 2024 aluminum doubler with 1.5 inch radius
- Composite keel patch
- Surface preparation
  - Grit Blast Sol-gel
    - AC130 Kit
  - Bonding Primer
    - Cytec BR 6747-1

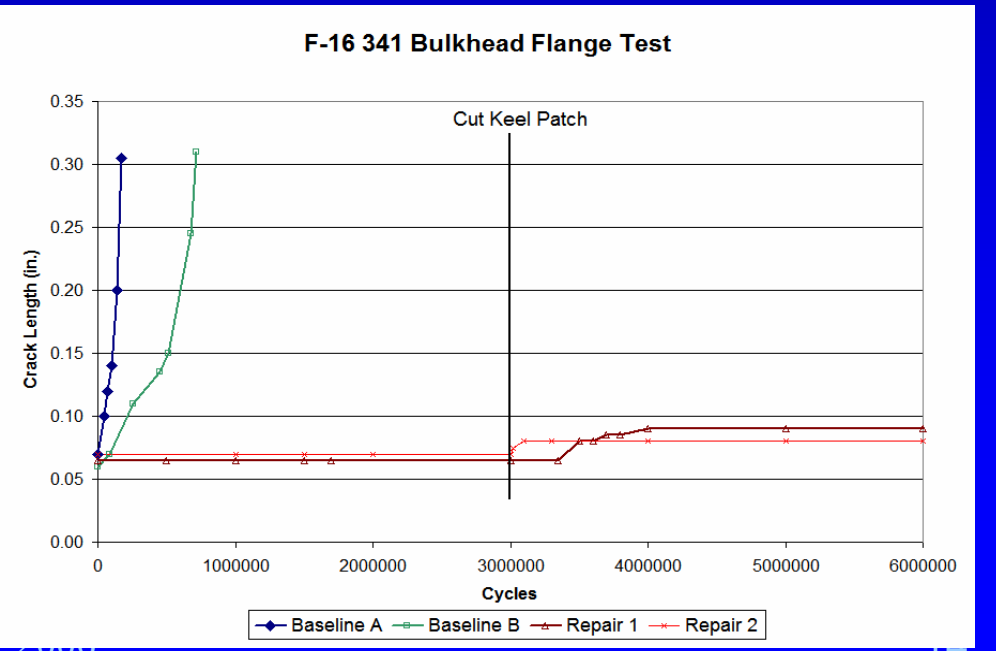


Repair Testing

- Coupons tested with 0.05 inch initial flaws
- Out of plane test constraints
- Spectrum loading
- 2 unrepaired baseline tests
- 2 repaired test

Repair Testing Continued

- Final Repair Designed
  - 0.08 inch thick 2024 aluminum doubler with 1.5 inch radius
  - Boron keel patch
  - Surface preparation
    - Grit Blast Sol-gel
    - AC130 Kit
    - Cytec BR 6747-1 Bonding Primer
- Testing Indicated greater than a 6 to 1 life improvement



Prototype F-16 Repair Installation

- Based on analytical and test results, repair approved for prototype installation
- Repair installed at Hill AFB
- Will monitor repair performance for 12-18 months
- In active service since March 2006

Prototype Repair Installation










Bonded Repair First Flight

- SwRI, Boeing and Hill AFB engineers were present for first flight
- Repair inspected for indications of damage

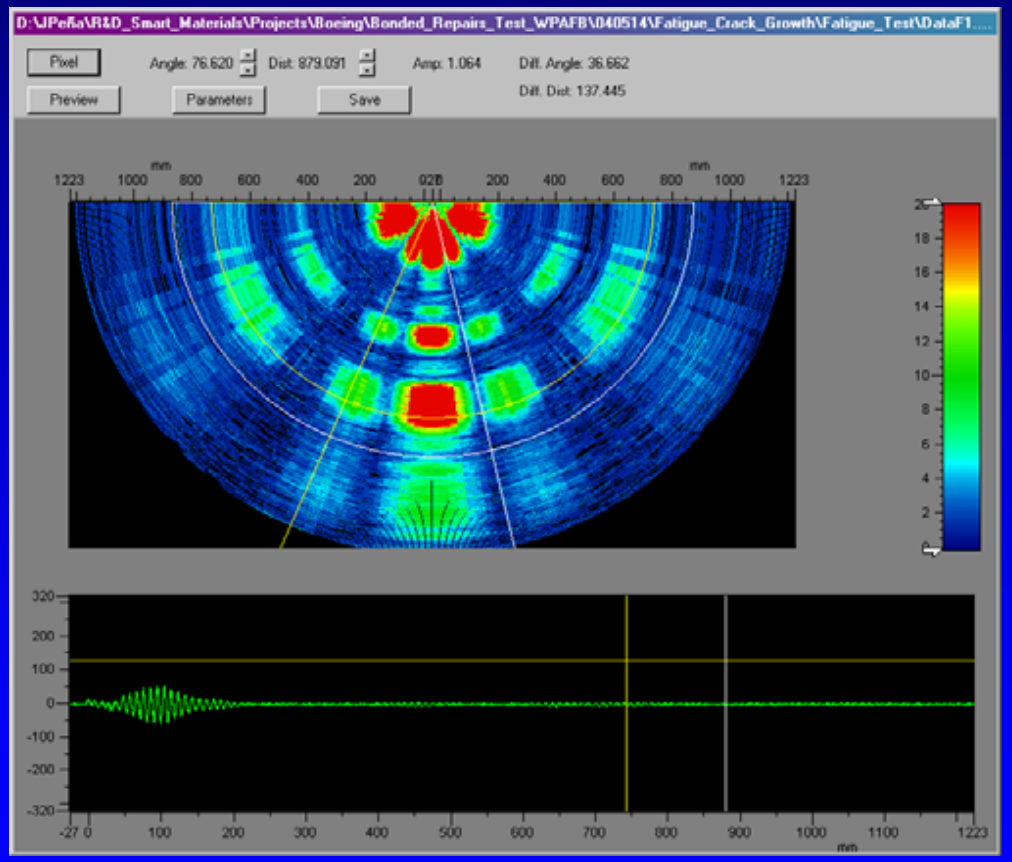
Repair Status

- Installed prototype repair on an F-16
- Repair currently flying in normal usage environment
- Using a SHM System to Monitoring Repair

Structural Health Monitoring (SHM) Sensor

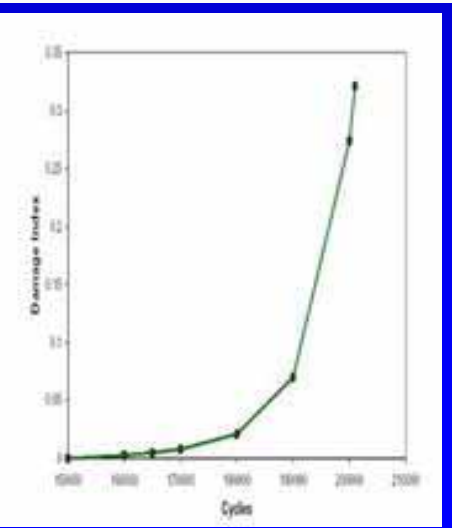
- Coupon testing
- Boron/epoxy patches on aluminum plate
- 3 rounds of tests, using multiple sensor types
- Evaluated sensor system

Flat Coupon Testing Results



*** SHMER Component Test Results ***
Sensor System: SMART Layer
Specimen Configuration: Disbond Growth
Specimen Number: 1

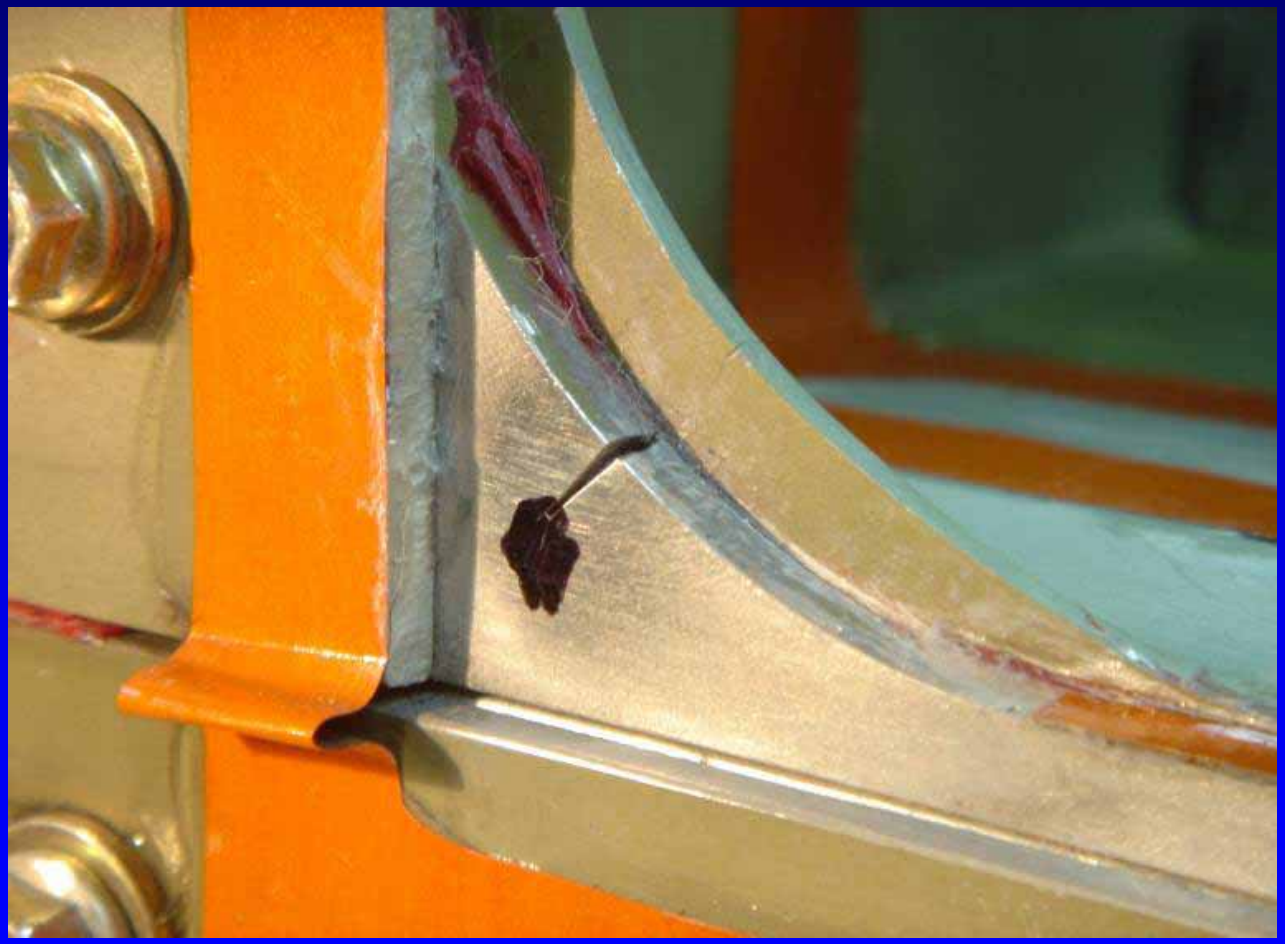
Date	Time	Cycles	Measured Disbond Area	Estimated Disbond Area	Uncertainty
01/06/05	05:46:52	10500	0.125	------	------
01/06/05	05:57:46	11000	0.125	------	------
01/06/05	06:11:14	11500	0.188	------	------
01/06/05	06:48:26	12000	------	0.255	±0.151
01/06/05	07:11:38	12500	------	0.272	±0.170
01/06/05	07:28:12	13000	------	0.438	±0.360
01/06/05	07:40:32	13500	------	0.710	±0.672
01/06/05	07:55:10	13800	------	2.154	±2.545



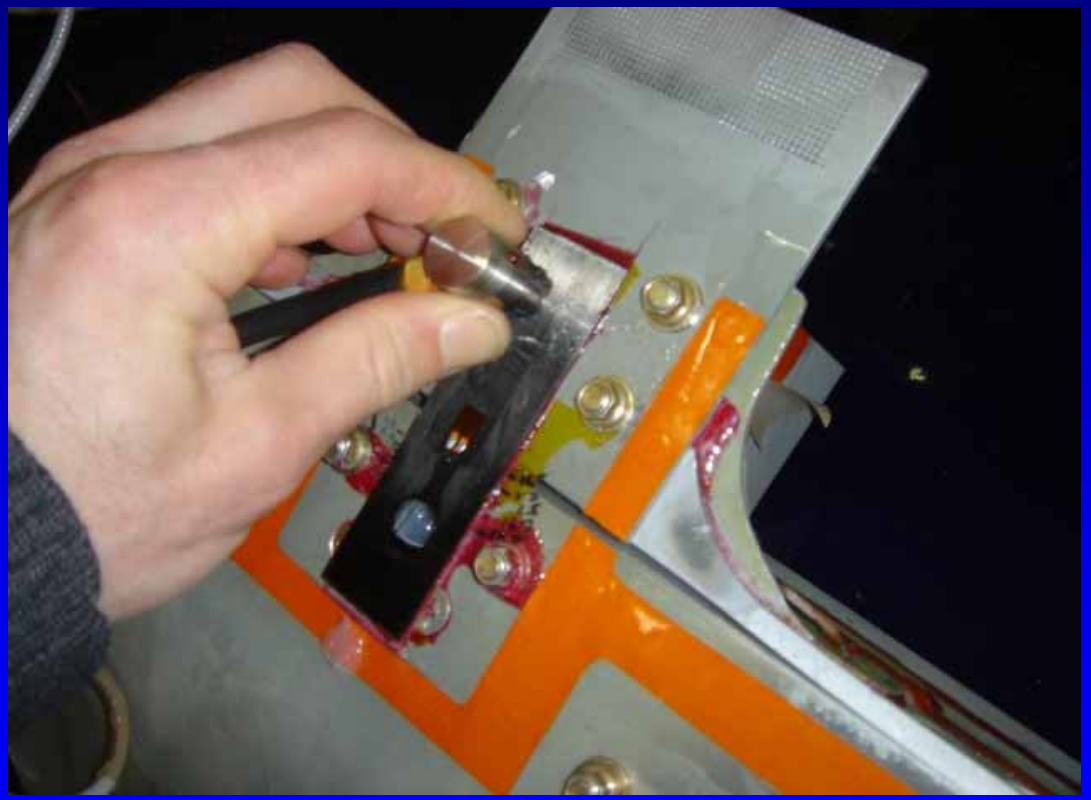
F-16 Bulkhead Coupon

SHM Sensor on F-16 Coupon

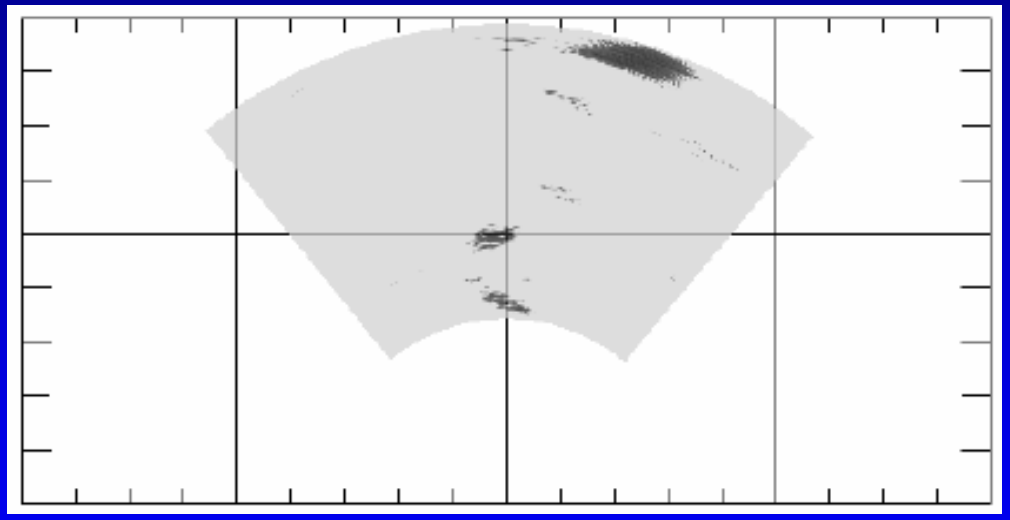
F-16 Coupon Testing



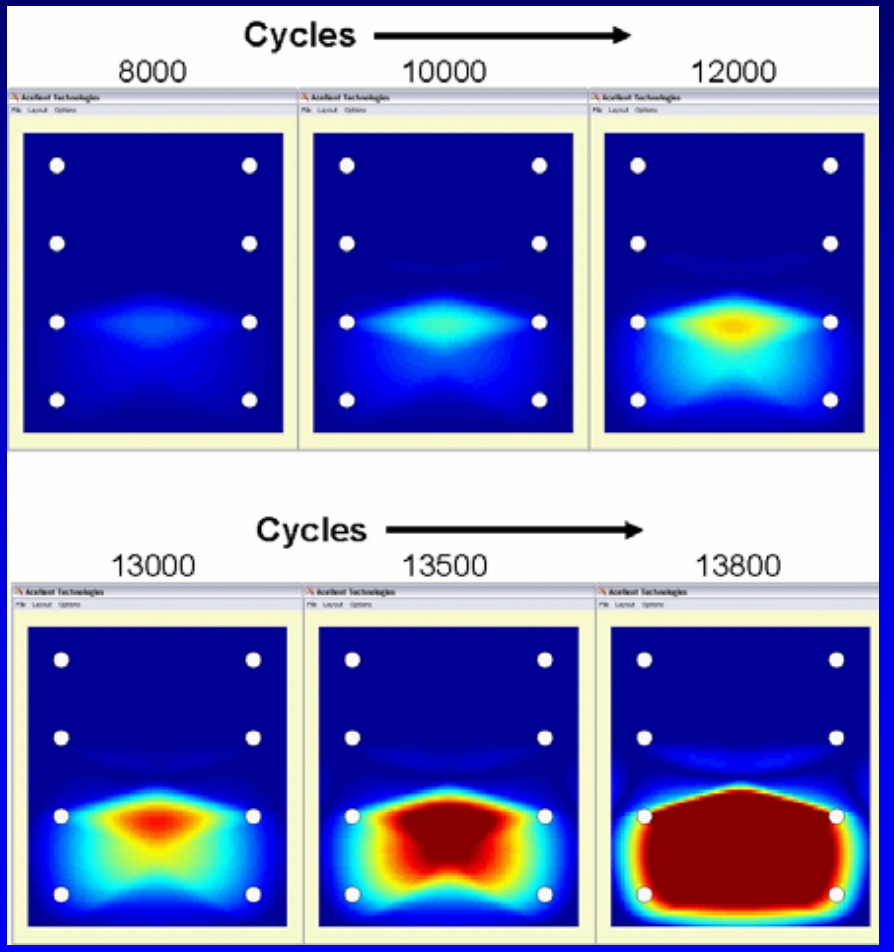
Conventional NDI



SHM Sensor Results

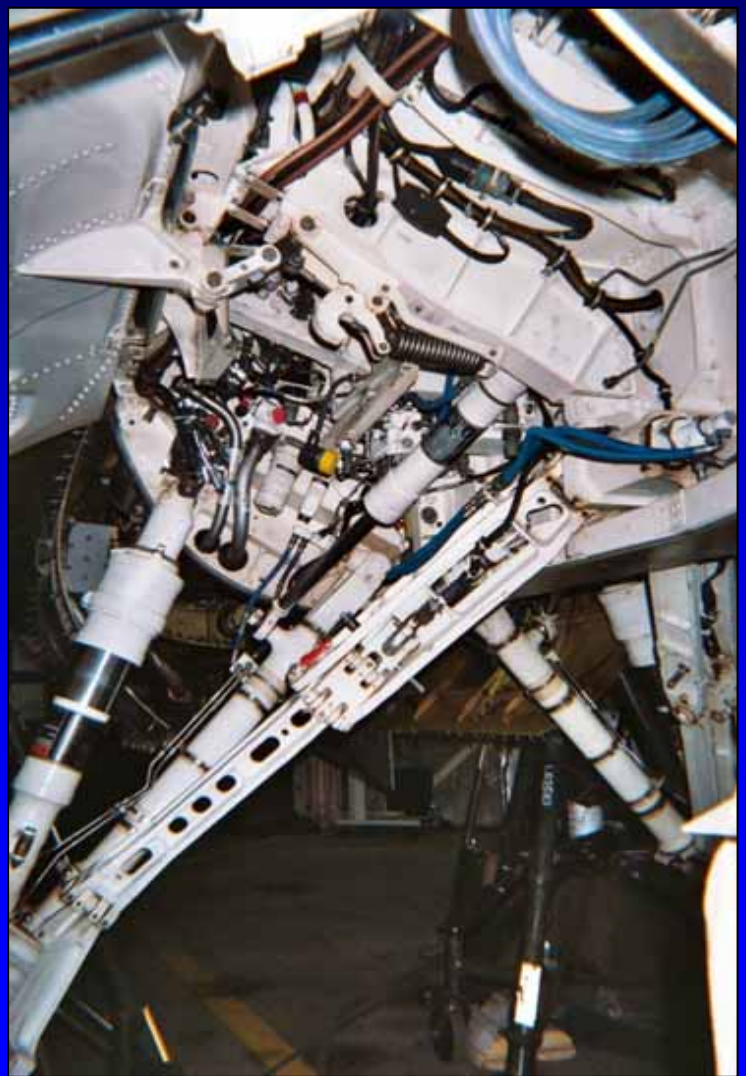


Piezoelectric phased array

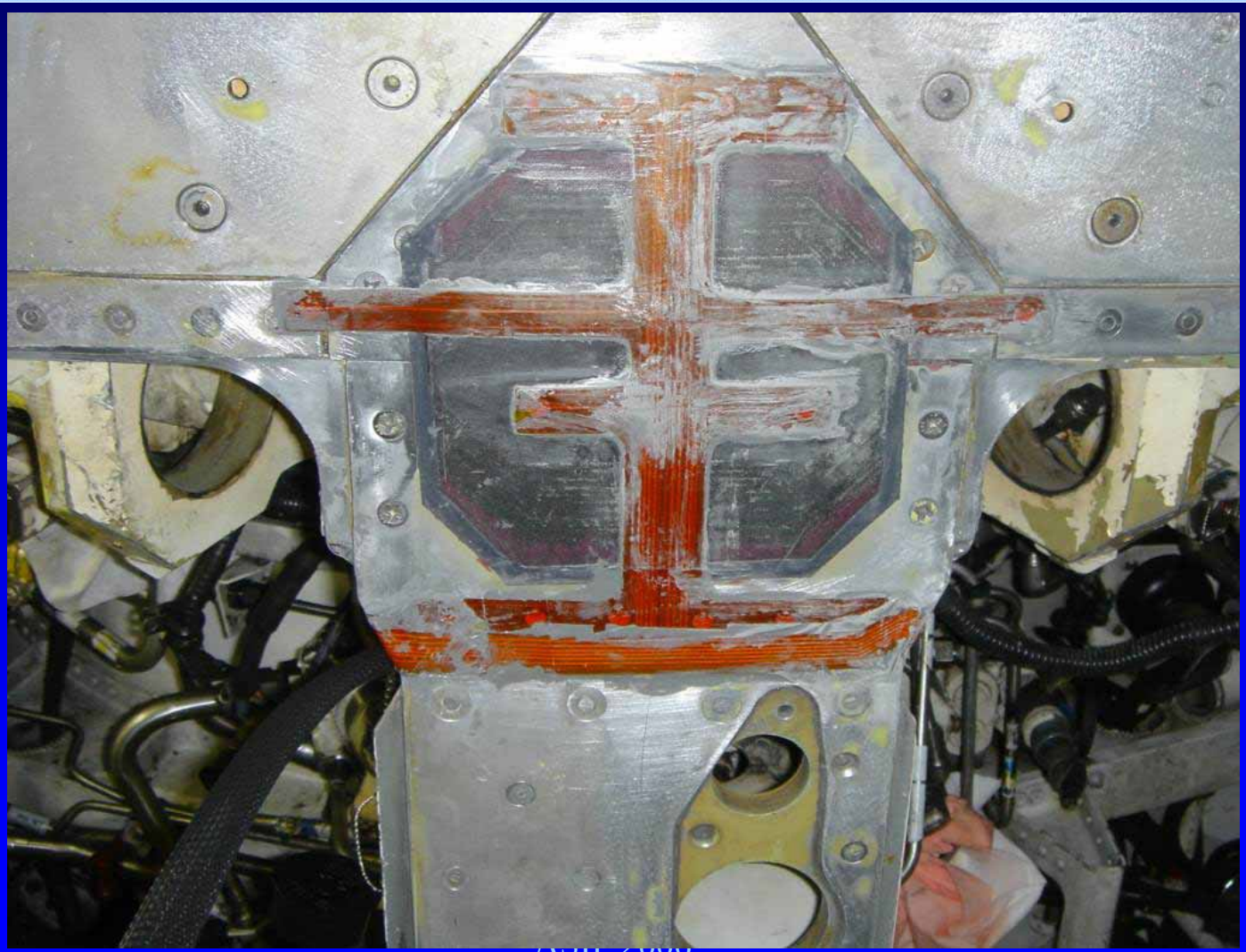


Piezoelectric pitch-catch

F-16 Main Gear Wheel Well



SHM Sensor Installed on Bonded Repair



SHM Sensor Installation (Continued)

SHM Sensor Installation (Continued)

In service SHM

In-Service Experience

SHM Conclusion

- **Capabilities**
  - A. Operation in difficult environment.
  - B. Sensor durability once installed.
  - C. System operation in a realistic environment.
  - D. Multiple output methods.
- **Limitations**
  - A. Correlation between structural change and physical phenomena (accuracy, resolution).
  - B. Reliability of wiring connections.
  - C. Wire weight and complexity.
  - D. Sensor density.
  - E. Fragile transducer elements.
  - F. Data acquisition size and complexity.
  - G. Sensitivity.
  - H. Acceptance by maintenance and certification community.

SHM Future Work

- Wireless sensors.
- Environmental testing.
- New sensing materials/methods.
- Sensor density studies.
- Miniaturization and strengthening of data acquisition equipment, user interface.
- Algorithm development.
- Study effects of noise sources.
- Further development of support philosophy and actions.