REPLICA-BASED CRACK INSPECTION

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INTRODUCTION

• Cracks found in Space Shuttle Main Engine LH$_2$ feedline flowliners (2002)
  – Ranged from 0.1 inch to 0.6 inch long
  – Weld repaired, polished, and recertified for flight
  – NDE: no cracks >0.075 inches long exist

• Revisited in 2004
  – Unable to show flight rationale with a crack 0.075 inches long
FLOWLINER DESCRIPTION

Orbiter aft

Engine cavity

LH₂ feedline

Flowliners
FLOWLINER DESCRIPTION

- LH$_2$ consumption
  - 385,000 gallons
  - 8.5 minutes
  - Each engine consumes 15,000 gal/min
  - Flow induced stress cycles in kHz range
  - Millions of stress cycles per flight
PROBLEM

- Analysis: unsafe conditions may occur for multiple cracks > 0.005 inch long
- Improved eddy current unable to detect 0.005-inch-long cracks
- Need an NDE method able to find cracks down to 0.005 inch long
PROPOSED SOLUTION

• Use surface replicas as an NDE method
• Surface replicas used for decades to monitor small cracks (<0.005 inch)
• Recently-developed silicone-based replicas better suited for inspection
EXPERIMENTAL PLAN

• Feasibility study:
  – Generate fatigue cracks in laboratory specimens
  – Compare crack lengths from
    • Silicone-based replicas (zero load)
    • Acetate-tape replicas (maximum load)
    • Destructive exam (zero load)

• Determine reliability of silicone-based replicas relative to acetate-tape replicas
FATIGUE TESTING

• Specimens used to simulate flowliner slot geometry and stress state
  – $P_{\text{max}} = 3.4$ kips, $R = 0.1$

• Testing interrupted periodically for slot surface replication
  – Acetate-tape replicas
  – Silicone-based replicas
REPLICA ANALYSIS

- Replica preparation
  - Sectioned in 4 pieces
  - Grounded on metallic slide
  - Coated with metallic material
- Examined in an SEM
- Initial scan at 50-100X
  - Surface finish, scratches, etc.
- Crack scan at 400-700X
EXPERIMENTAL RESULTS

- Crack found after 50,000 cycles
  - Surface crack
  - 0.008 inches long
CRACK LENGTH COMPARISON

Acetate replica (loaded) – 163 µm

Silicone replica (no load) – 199 µm

Specimen (no load) – 194 µm
EXPERIMENTAL RESULTS

• 3 cracks found after 50,000 cycles
  – 2 surface cracks
  – 1 corner crack

Crack #1 – 0.012”
Crack #2 – 0.004”
Crack #3 – 0.001”
CRACK LENGTH COMPARISON
(Crack #1)

Acetate replica (loaded) – 280 µm
Silicone replica (no load) – 343 µm
Specimen (no load) – 350 µm
CRACK LENGTH COMPARISON
(Crack #2)

Acetate replica (loaded) – 81 μm
Silicone replica (no load) – 104 μm
Specimen (no load) – 110 μm
CRACK LENGTH COMPARISON
(Crack #3)

Acetate replica (loaded) – 20 µm
Silicone replica (no load) – 26 µm
Specimen (no load) – 27 µm
CRACK DETECTION AFTER POLISHING

• Flowliner slots were polished after cracks detected in 2002
• One orbiter has not flown since flowliner slot polishing
• Concern about post-polishing crack detection
  – Crack mouth potentially filled with material
POLISHED CRACK DETECTION

Initial crack

After polishing

After polishing + 1 load cycle
SURFACE FINISH QUALITY

- Pit-like damage from punching not completely removed by polishing
- At least 7 fatigue cracks initiated by 50,000 cycles
- Quality of surface finish is important

200 µm
OTHER TYPES OF DAMAGE

- Pit damage
- Tool mark
- Abrasion and scratches
- Tool marks/dents
**REPRODUCIBILITY**

- Concern: Repeated replication may fill crack mouth
- Repeated replicas taken on several cracked specimens
  - Example: 0.006-inch-long surface crack
- No degradation in crack detection
APPLICATION

• Replica-based inspection method approved for use on flight hardware
• Found 55 cracks in 3 orbiters
  – Ranging from 0.004 to 0.040 inches
• Confirmed repair by second round of replicas
Replica-based crack inspection may be well-suited for other applications:
- Improved crack detection could make damage tolerance life management practical for additional components:
  - Rotorcraft?
  - Propellers?
  - HCF engine components?
## PROS AND CONS

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<th>PROS</th>
<th>CONS</th>
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<tr>
<td>• Much better resolution than traditional NDE</td>
<td>• More labor intensive than traditional NDE</td>
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<td>• Little training required to make replicas</td>
<td>• Limited to surface flaws</td>
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<td>• Limited equipment needed in field</td>
<td>• Dependent on surface condition</td>
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<td>• Limited to small areas</td>
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<td>• No immediate feedback</td>
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SUMMARY

• Analysis of silicone-based replicas
  – Find cracks below 0.005 inches
  – Find pits/defects down to 0.001 inches

• Method approved for use on flight hardware
  – Found 55 cracks in 3 orbiters (684 slots)
  – Identified unacceptable levels of damage
  – Repair confirmed by second round of replicas