PRELIMINARY

Feed Line Liner Fracture Control

- Fracture Control
  - Systematic program of classification, analysis, test, and inspection to preclude catastrophic failure (serious injury, loss of life, or destruction of high value assets) due to crack like defects (known and/or assumed).
  - The feed line liners are classifiable as fracture critical items as certain modes of failure of a liner due to a crack is credibly catastrophic (I.e loss of a piece of liner material into SSME).
  - JSC is the responsible fracture control authority for the feed line liner (ref. To 5007 removed) since JSC is the lead center for the orbiter hardware.
  - Due to visibility of this problem a fracture control assessment team was assembled.
  - Feed line liner fracture control assessment team:
    - MSFC Greg Swanson, POC
      - Wayne Gregg
      - Pravin Aggarwal
      - Preston McGill
      - Doug Wells
      - Jim Newman (NASA retired, MSU Professor, summer faculty at MSFC)
    - JSC Glenn Ecord, POC
      - Royce Forman
      - Keith Beckman
      - Raymond Patin
    - LaRC Scott Forth, POC
      - Bob Piascik
      - Bill Winfree

Feed Line Liner Fracture Control

- Known Cracks
  - Two approaches for dealing with known cracks in fracture critical hardware.
    - "Use-as-is" based on residual life (dealing with crack propagation and the prediction of crack growth)
    - Repair (Dealing with crack initiation and the restoration of fatigue capability)

Feed Line Liner Fracture Control

- Known Cracks, continued
  - "Use-as-is" based on residual life (dealing with crack propagation)
    - Fracture Mechanics analysis using upper bound methodology.
    - Requires loads, cycle counts, material fracture mechanics properties, and detailed crack sizing from inspection.
    - Periodic inspections required to monitor crack propagation.
    - This method is usually not used with high cycle fatigue problems without extensive ground test experience (fleet leader and multiple similar units).
    - Due to limited data available, the large uncertainties in boundary conditions and material properties, and the lack of fleet leader and multiple similar units, this path is not likely to be useful for the feed line liners.

Feed Line Liner Fracture Control

- Known Cracks, continued
  - Repair (Dealing with initiation)
    - Remove or repair all found cracks by best technique (determine by analysis, laboratory testing, and practical assessment of procedures and access to the hardware)
      - (bullets listed here removed since another team is specifically assigned to assessing such techniques)
    - Design test program to appropriate fidelity of the actual hardware
    - If known cracks are repaired, it will take time to re-initialize and grow crack back to the size it was.
    - Periodic inspection, initially every flight.
      - Monitor repairs for cracking.
      - Find new cracks.
      - Find any previously missed cracks that may grow to observable size.
    - Evaluate inspection interval as flight history accumulates.
    - Repair and periodic inspection is preferred when ground test fleet leaders are not available.

Feed Line Liner Fracture Control

- Conclusion
  - Repair is preferred
    - Develop repair test program to appropriate fidelity of the actual hardware
  - Review of repair program should revert to standard NASA review process
    - (Remove bullets that were listed here as anything mentioned here may be viewed by some as "required by the fracture control assessment team". This is not necessarily the case yet b/c the team hasn't met to discuss what portions of the review process are necessary, and what portions may not be.)

PRELIMINARY

Feed Line Liner Fracture Control

- Fracture Control
  - Systematic program of classification, analysis, test, and inspection to preclude catastrophic failure (serious injury, loss of life, or destruction of high value assets) due to crack like defects (known and/or assumed).
  - The feed line liners are classifiable as fracture critical items, failure of a liner due to a crack is credibly catastrophic.
  - JSC is the responsible fracture control authority for the feed line liner (per NASA-STD-5007) since JSC is the lead center for the orbiter hardware.
  - Due to visibility of this problem a fracture control assessment team was assembled.
  - Feed line liner fracture control assessment Points of Contact (POC):
    - MSFC Greg Swanson, POC
      - Wayne Gregg
      - Pravin Aggarwal
      - Preston McGill
      - Doug Wells
      - Jim Newman (NASA retired, MSU Professor, summer faculty at MSFC)
    - JSC Glenn Ecord, POC
      - Royce Forman
      - Keith Beckman
      - Raymond Patin
    - LaRC Scott Forth, POC
      - Bob Piascik
      - Bill Winfree

Feed Line Liner Fracture Control

- Known Cracks
  - Two approaches for dealing with know cracks in fracture critical hardware.
    - "Use-as-is" based on residual life (dealing with crack propagation)
    - Repair (Dealing with initiation)

Feed Line Liner Fracture Control

- Known Cracks, continued
  - "Use-as-is" based on residual life (dealing with crack propagation)
    - Fracture Mechanics analysis using upper bound methodology.
    - Requires loads, cycle counts, material fracture mechanics properties, and detail crack sizing from inspection.
    - Periodic inspections required to monitor crack propagation.
    - This method is not used with high cycle fatigue problems without extensive ground test experience (fleet leader and multiple similar units).
    - Due to limited data available, the large uncertainties in boundary conditions and material properties, and the lack of fleet leader and multiple similar units, this path is not likely to be useful for the feed line liners.

Feed Line Liner Fracture Control

- Known Cracks, continued
  - Repair (Dealing with initiation)
    - Remove all found cracks by best technique (determine by analysis, laboratory testing, and practical assessment of procedures and access to the hardware)
      - stop drill
      - weld
      - keyhole
      - surface improvement (polish, peen, laser shock peen, …)
      - etc.
    - Design test program to appropriate fidelity of the actual hardware
    - Known cracks are repaired, it will take time to re-initialize and grow crack back to the size it was.
    - Periodic inspection, initially every flight.
      - Monitor repairs for cracking.
      - Find new cracks.
      - Find previously missed cracks that have grown to observable size.
    - Evaluate inspection interval as flight history accumulates.
    - Repair and periodic inspection is preferred when ground test fleet leaders are not available.

Feed Line Liner Fracture Control

- Conclusion
  - Repair is preferred
    - Develop repair test program to appropriate fidelity of the actual hardware
  - Review of repair program should revert to standard NASA review process
    - Material Review Board
    - Configuration Control Board
    - Preliminary Design Review
    - Etc.

Feed Line Liner Fracture Control

Scott Forth, LaRC, comments:

- If an accurate stress analysis can be performed, damage tolerance lifing of the part seems feasible, as none of the parts need to be removed. There are many instances of HCF components being flown without a fleet leader.
- Further, the DT approaches called out by the NASA standards are grossly conservative, in most cases, in an HCF environment. I looked at the In718 data in NASGRO for low temps, there is no threshold data even at room temp. However, the liquid nitrogen and liquid hydrogen data at R=0.1 was similar. So if we could get threshold data using nitrogen it may give us an idea of fatigue life.
- If a fix is required, I would prefer a fix of welding the cracks than a keyhole approach. I would think a friction plug weld should cover the area, if FSW of In718 is feasible. Finally, I think the welds should be subsequently peened, most likely a light shot or laser so as not to disturb the fluid flow significantly.
- Otherwise, I mostly agree with Greg's presentation.

PRELIMINARY

Orbiter Main Propulsion System Feedline Flowliner Fracture Control

- **Fracture Control**
  - Systematic program of classification, analysis, test, and inspection to preclude catastrophic failure (serious injury, loss of life, or destruction of high value assets) due to crack like defects (known and/or assumed).
  - Because failure of a liner due to a crack is credibly catastrophic, the flowliners may be classified as fracture critical.
  - JSC is the responsible fracture control authority for the flowliner (per NASA-STD-5007) since JSC is the lead center for the orbiter hardware.
  - Due to visibility of this problem a fracture control assessment team was assembled.
  - Flowliner fracture control assessment Points of Contact (POC):
    - JSC Glenn Ecord, POC
      - Royce Forman
      - Keith Beckman
      - Raymond Patin
    - MSFC Greg Swanson, POC
      - Wayne Gregg
      - Pravin Aggarwal
      - Preston McGill
      - Doug Wells
      - Jim Newman (NASA retired, MSU Professor, summer faculty at MSFC)
    - LaRC Scott Forth, POC
      - Bob Piascik
      - Bill Winfree

Orbiter Main Propulsion System
Feedline Flowliner Fracture Control

- **Known Cracks**
  - Two approaches for dealing with known cracks in fracture critical hardware
  - **"Use-as-is" based on risk assessment and residual life analysis**
    - Fracture Mechanics analysis using upper bound methodology.
    - Requires loads, cycle counts, material fracture mechanics properties, and detail crack sizing from inspection.
    - Periodic inspections required to monitor crack propagation.
    - Assessment of cracks for use-as-is disposition relies heavily on ground test experience, material test data, flight history, and other forms of empirical support.
    - Due to limited data available, the large uncertainties in boundary conditions and material properties, analytical assessment is not likely to be useful for the flowliners.
    - The lack of a meaningful fleet leader and multiple similar units further complicates a purely risk-based assessment.
  - **Repair and risk assessment**
    - Remove known cracks by best technique (determine by analysis, laboratory testing, and practical assessment of procedures and access to the hardware)
      - –stop drill
      - –weld
      - –keyhole
      - –surface improvement (polish, peen, laser shock peen, …)

Orbiter Main Propulsion System
Feedline Flowliner Fracture Control

- **Known Cracks, repair and risk assessment - continued**
  - Design test program to appropriate fidelity of the actual hardware
  - Once repaired, cycles are required to re-initialize and grow crack back to previous size
    - Forms a basis for flight-by-flight rationale
  - Periodic inspection, initially every flight.
    - Monitor repairs for cracking.
    - Find new cracks.
    - Find previously missed cracks that have grown to observable size.
  - Evaluate inspection interval as flight history accumulates.
  - Evaluate risks associated with repair
    - Re-initiation life
    - Residual stresses associated with welding
    - Flow changes due to slot cut-outs
    - Contamination

Orbiter Main Propulsion System
Feedline Flowliner Fracture Control

- **Conclusion**
  - At this time, repair scenarios appear favorable due to uncertainties in analytical assessment and the lack of a meaningful fleet leader
  - Develop repair test program to appropriate fidelity of the actual hardware
  - Evaluate efficacy of use-as-is solely by risk assessment on a case-by-case basis as repair scenarios, test data, and understanding develop
  - Review of repair program should revert to standard NASA review process
    - Material Review Board
    - Configuration Control Board
    - Preliminary Design Review
    - Etc.