STS-112 (BI115)
FLIGHT READINESS REVIEW

PROGRAM

September 17, 2002

Solid Rocket Booster

United Space Alliance

TECHNICAL ISSUE - BSM FOREIGN OBJECT DEBRIS

Presenter:
Larry Clark
Organization/Date:
USA-SRB/9-17-02

Issue

- Potential FOD embedded in Booster Separation Motor (BSM) propellant

Concern

- BSM performance
- FOD ejected during BSM firing at SRB separation

Discussion

- Anomaly Resolution Team formed
  - USA - SRB, Integration, Orbiter, GO
  - NASA - KSC, MSFC, JSC, GRC
  - Pratt & Whitney Space Propulsion, Boeing, Lockheed Martin, Hernandez Engineering, Akima Corporation

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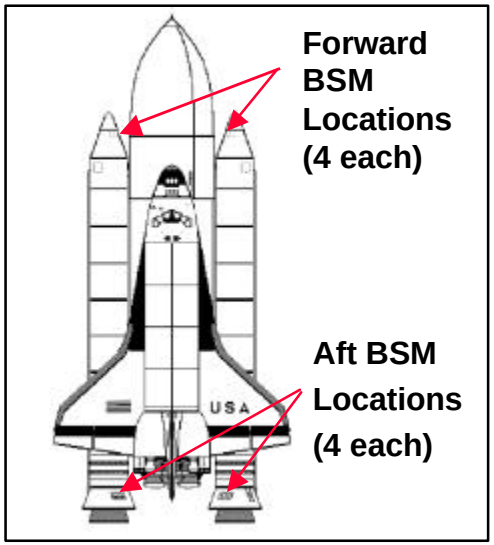
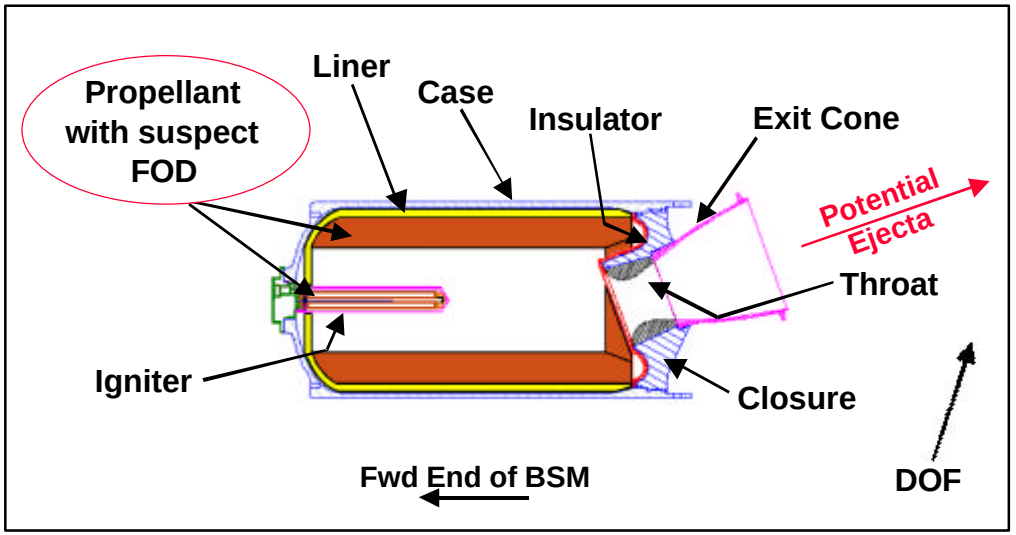
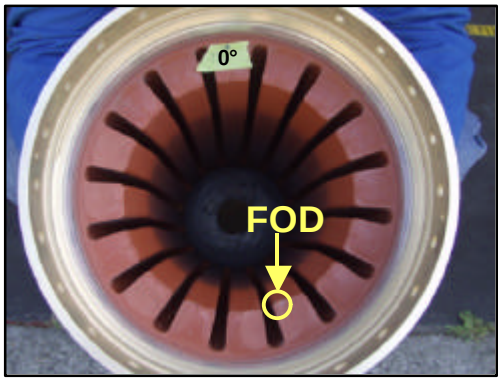
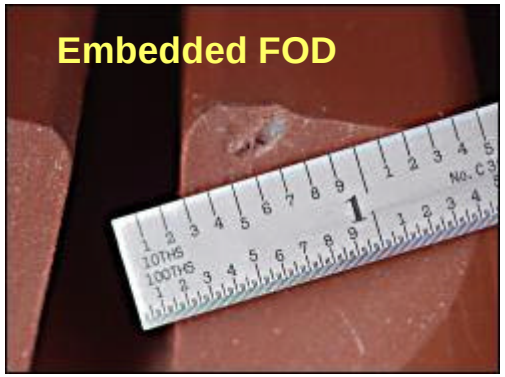


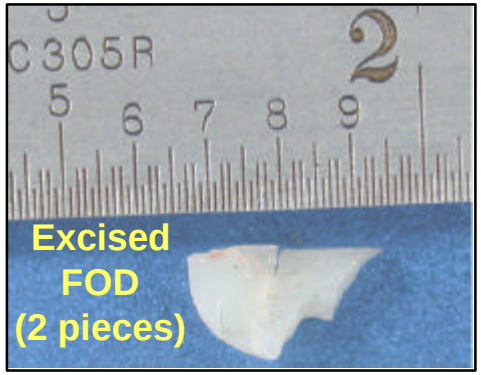
BSM Orientation



Forward BSM Cross-Section







RTV (GE Silicon #1) Sealant in Lot ABT BSM Propellant

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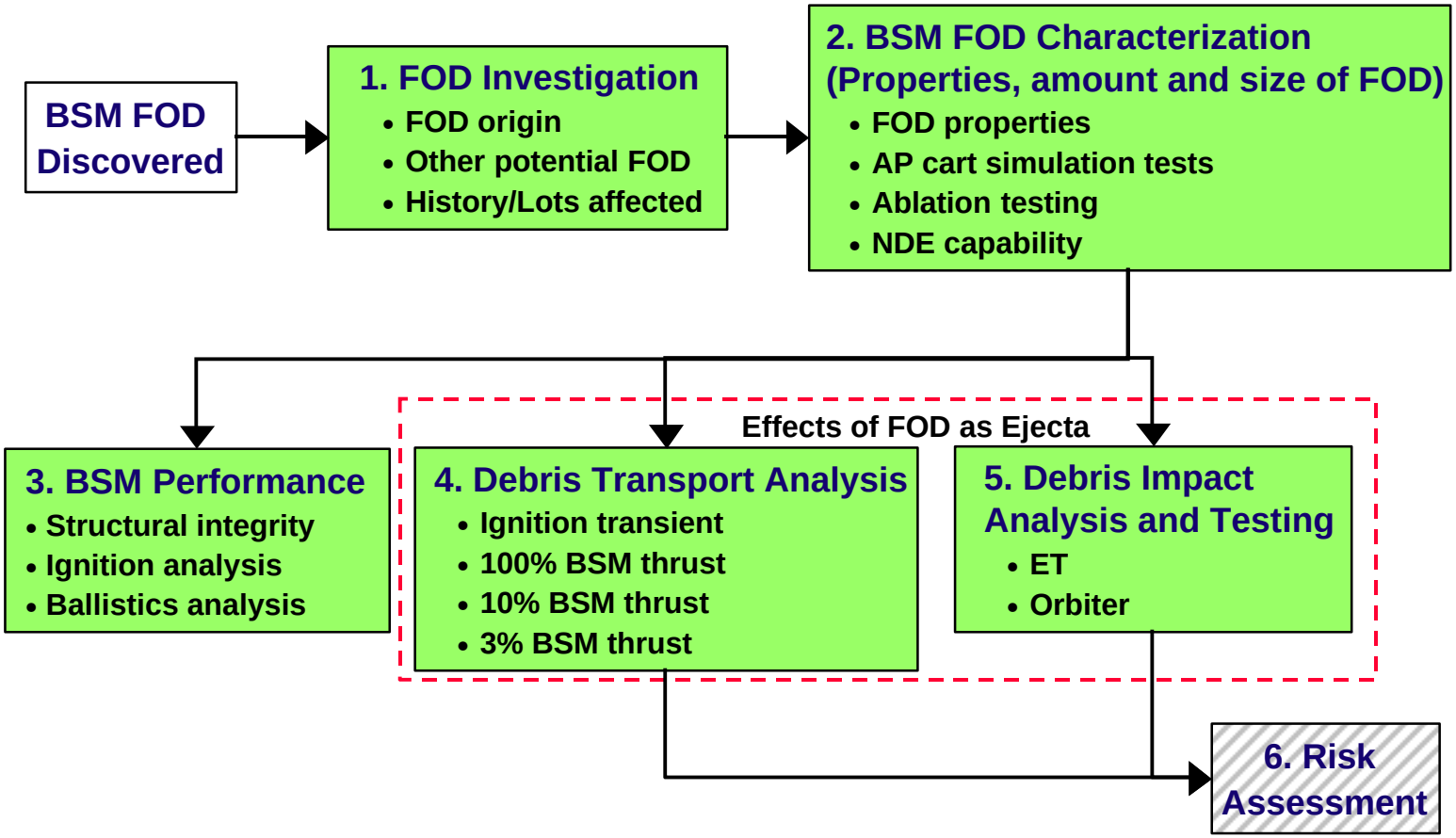

Roadmap to BSM FOD Resolution

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1. FOD Investigation

- FOD identified as RTV GE Silicone #1
  - Used to repair leaking Ammonium Perchlorate (AP) transport cart butterfly valve
- All BSM lots potentially affected since 1990

1. FOD Investigation
- **FOD origin**
- **Other potential FOD**
- **History/Lots affected**

AP Cart Butterfly Valve Assembly

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2. BSM FOD Characterization

- Properties determined for FOD
- RTV ablation tests showed no appreciable ablation
- RTV FOD not screened by production NDE techniques
- Defined largest potential particle size: 0.25 x 0.25 x 0.75 inch
- AP cart valve simulation tests performed to determine RTV particle size distribution
  - Applied RTV using vendor's technique, actuated valve, simulated AP flow, categorized particles by size and weight
- Confirmed actual FOD size in-family with test data and bounded by defined largest potential particle size

2. BSM FOD Characterization (Properties, amount and size of FOD)
- **FOD properties**
- **AP cart simulation tests**
- **Ablation testing**
- **NDE capability**

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3. BSM Performance

- For RTV fragments embedded in igniter and/or propellant grain:
  - BSM meets specification performance limits with enveloping assumptions
    - Effect on grain, liner, case and igniter structure
    - Thermal effects
    - Ignition transient effects
    - RTV impact effects on nozzle throat
- No BSM performance issues

3. BSM Performance
- **Structural integrity**
- **Ignition analysis**
- **Ballistics analysis**

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4. Debris Transport Analysis

- Pre-existing Computational Fluid Dynamics (CFD) model
  - Mated configuration
- Revised CFD model
  - SRBs separated
- Included plumes from BSM and upward firing forward reaction control system jets
- Analyzed largest potential particle size and four smaller sizes
- ET debris transport results
  - No impacts during ignition transient and 100% BSM thrust level
  - Impacts predicted for 10% and 3% BSM thrust level
    - Larger particles impact most forward in tank
    - Impact angles in ogive (forward of XT745) less than 40 degrees

4. Debris Transport Analysis
- **Ignition transient**
- **100% BSM thrust**
- **10% BSM thrust**
- **3% BSM thrust**

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4. Debris Transport Analysis (cont.)

- Orbiter debris transport results
  - No impacts during ignition transient, 100% or 10% BSM thrust
  - Impacts predicted at 3% BSM thrust to fuselage, nose reinforced carbon carbon, windows, wing leading edge and wing TPS
- Identified impact locations and velocities for given BSM thrust levels and particle sizes

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5. Debris Impact Analysis and Testing

- Cleared some impacts based on analysis
  - ET tank penetration
  - Catastrophic damage to Orbiter for
    - Fuselage, nose, wing leading edge and wing TPS
- Remaining concerns identified
  - ET impacts in ogive causing early ET breakup
  - Orbiter window impacts affecting survivability during re-entry
- Performed impact testing at Glenn Research Center for Orbiter windows and ET foam panels
  - Multiple RTV shapes and sizes
  - Range of velocities
  - Worst case impact angles
  - Based on debris transport analysis

5. Debris Impact Analysis and Testing
- **ET**
- **Orbiter**

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5. Debris Impact Analysis and Testing (cont.)

- Impact test results
  - ET foam panels
    - Kinetic energy and divot volumes significantly less than previous steel ball and cork test results
    - All RTV projectiles impacted substrate and remained in foam
  - Orbiter windows cleared (no damage) for majority of particle sizes by shooting larger particles at higher than expected velocities
- Subsequent analyses, based on test data, cleared remaining concerns
  - Thermal assessment confirms no early ET breakup due to RTV projectile impacts
  - No damage predicted to windows for smallest particle range

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Programmatic Controls

- Change Request S090912E approved as waiver to NSTS 07700, Volume X, Book 1, Paragraph 3.2.1.1.9.1.1.3
  - "The BSMs shall not release any debris which could damage the Orbiter TPS during separation under conditions specified in Paragraph 3.2.1.1.9.1.3, Design SRB Staging Conditions."

Rationale for Flight

- BSM performance not affected by presence of RTV FOD
- All debris impact concerns cleared by testing and analysis
- No increased risk to flight safety or mission success for identified BSM FOD
- STS-112/BI115 and subsequent flights safe to fly

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Recurrence Control

- Replaced existing cart valve seals and eliminated use of RTV
  - Implemented use of valve cover during transportation of cart
- Walk-down and process audit of all BSM manufacturing areas conducted
- Work instructions updated with inspections and cautions to preclude contamination
  - USA/MSFC Phase II Team approved
- Redesign of valve completed to preclude leakage
  - Implementation planned for future lots

TECHNICAL ISSUE - APU FUEL PUMP INLET PORT CRACK

Presenter:
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Issue

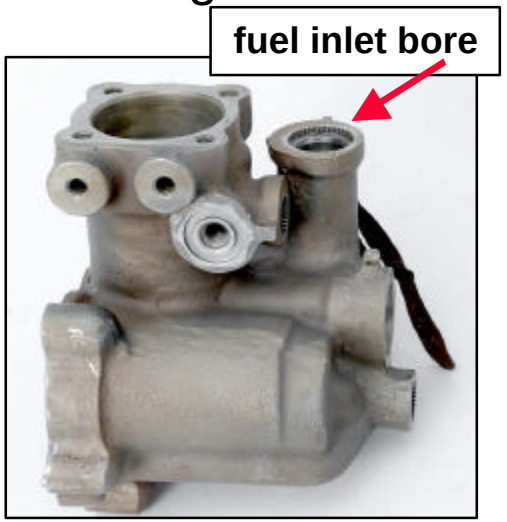
- Radial crack in fuel pump inlet port boss found during Rosan fitting installation at Hamilton Sundstrand
  - Localized corrosion pitting present

Concern

- Fuel pump housing crack can allow external leakage of hydrazine

Worst Case Failure Scenario

- Cracked housing allows external release of hydrazine resulting in fire, explosion and loss of mission, vehicle and crew during flight
  - Criticality 1



Fuel Pump Housing

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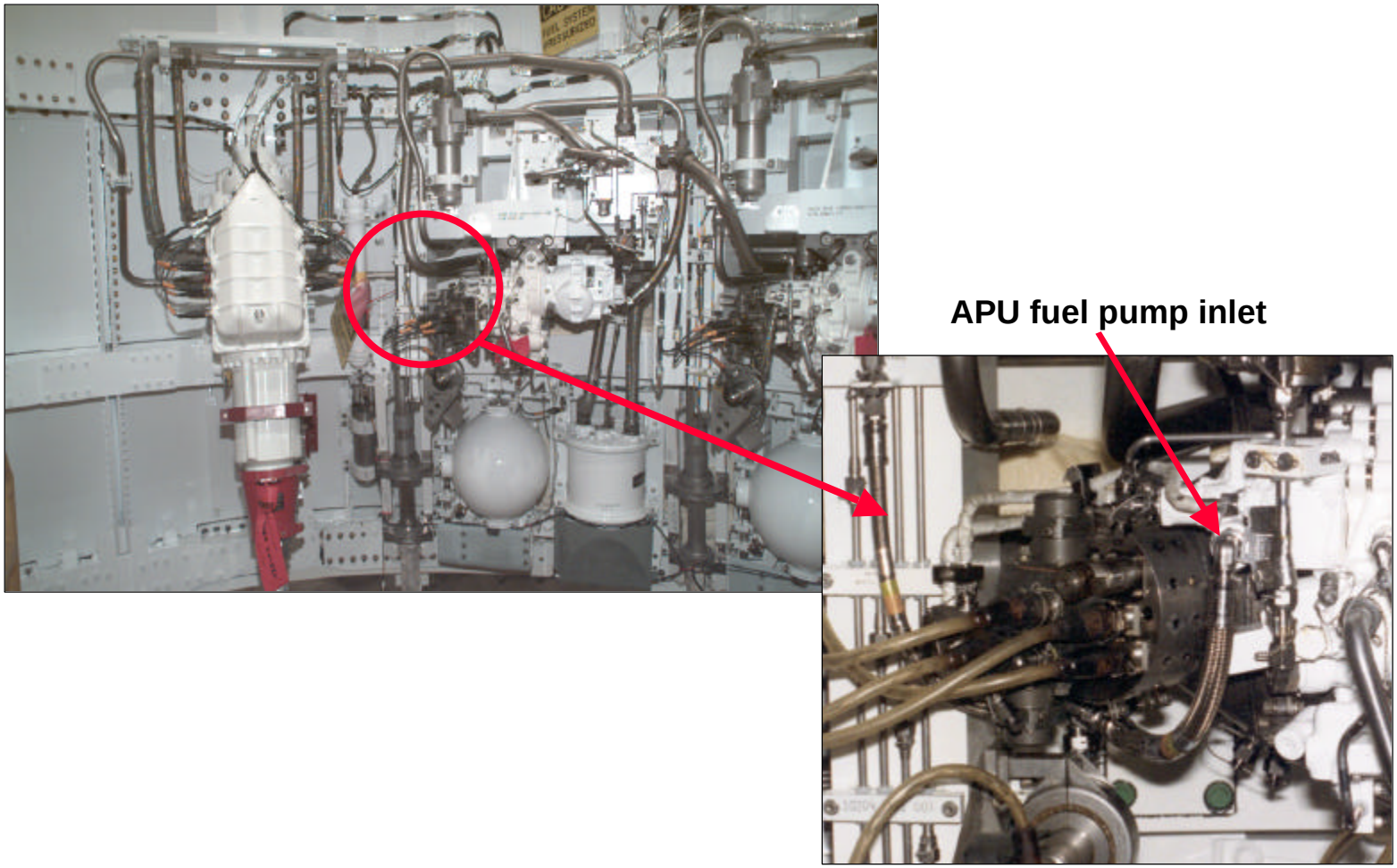

TVC System in Aft Skirt

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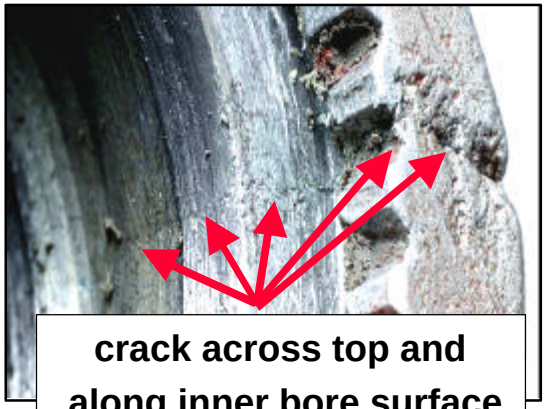
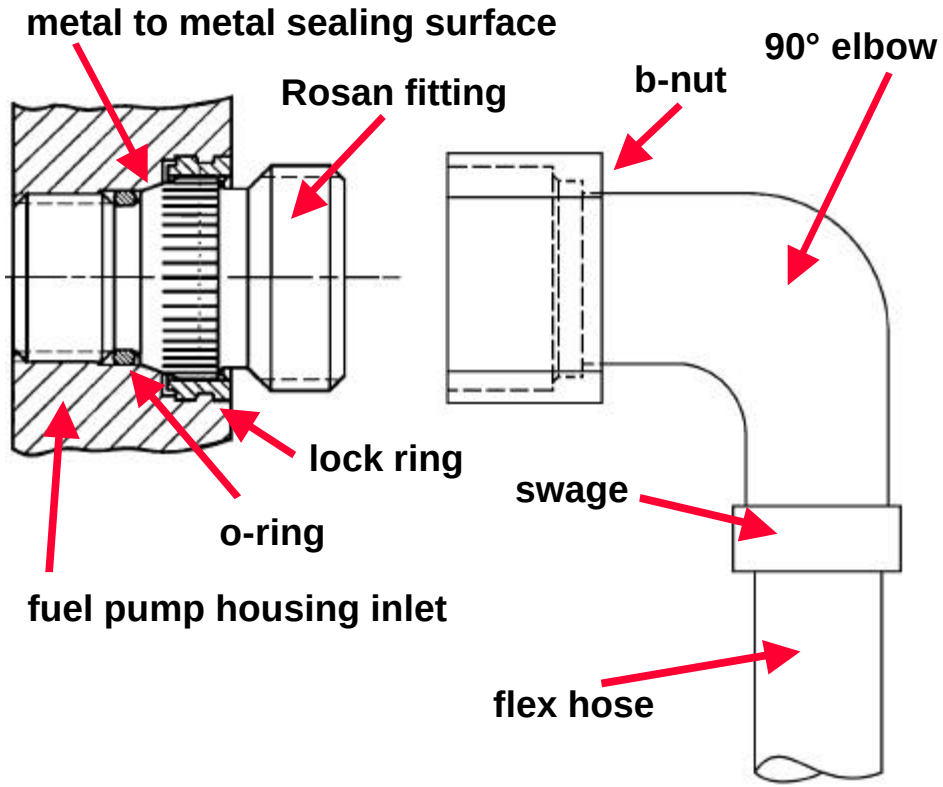
Outer Bore Surface



Inner Bore Surface



Installed Rosan Fitting Cross Section

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Background

- Fuel pump refurbished at Hamilton Sundstrand following every flight
- Subject housing manufactured in 1986 and flew on STS-86 (1997) and STS-102 (2001) as part of APU S/N 156
  - Rosan fitting not removed following STS-86 flight
  - Defect found during STS-102 refurbishment Rosan installation
    - Rosan fitting removed to implement Chem film corrosion protection and Krytox grease replacement of Apiezon grease

Rosan Fitting

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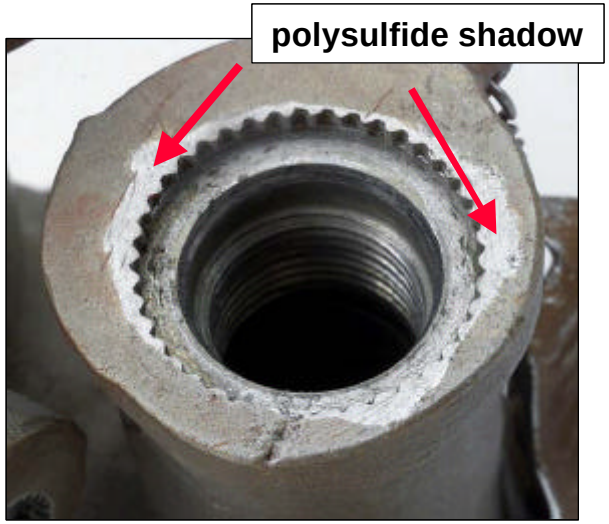
Investigation

- Visual inspection showed corrosion pitting coincident with crack on port flange
  - Minimal polysulfide shadow present
- Chemical analysis verified material C355 aluminum per print
- Material evaluation reverified casting integrity
- Evaluations determined fuel pump housing corrosion unique event
  - 104 housings inspected at vendor including 48 unpainted housings
  - No other indications of corrosion
  - PR historical search indicated no other occurrences



Inlet Bore

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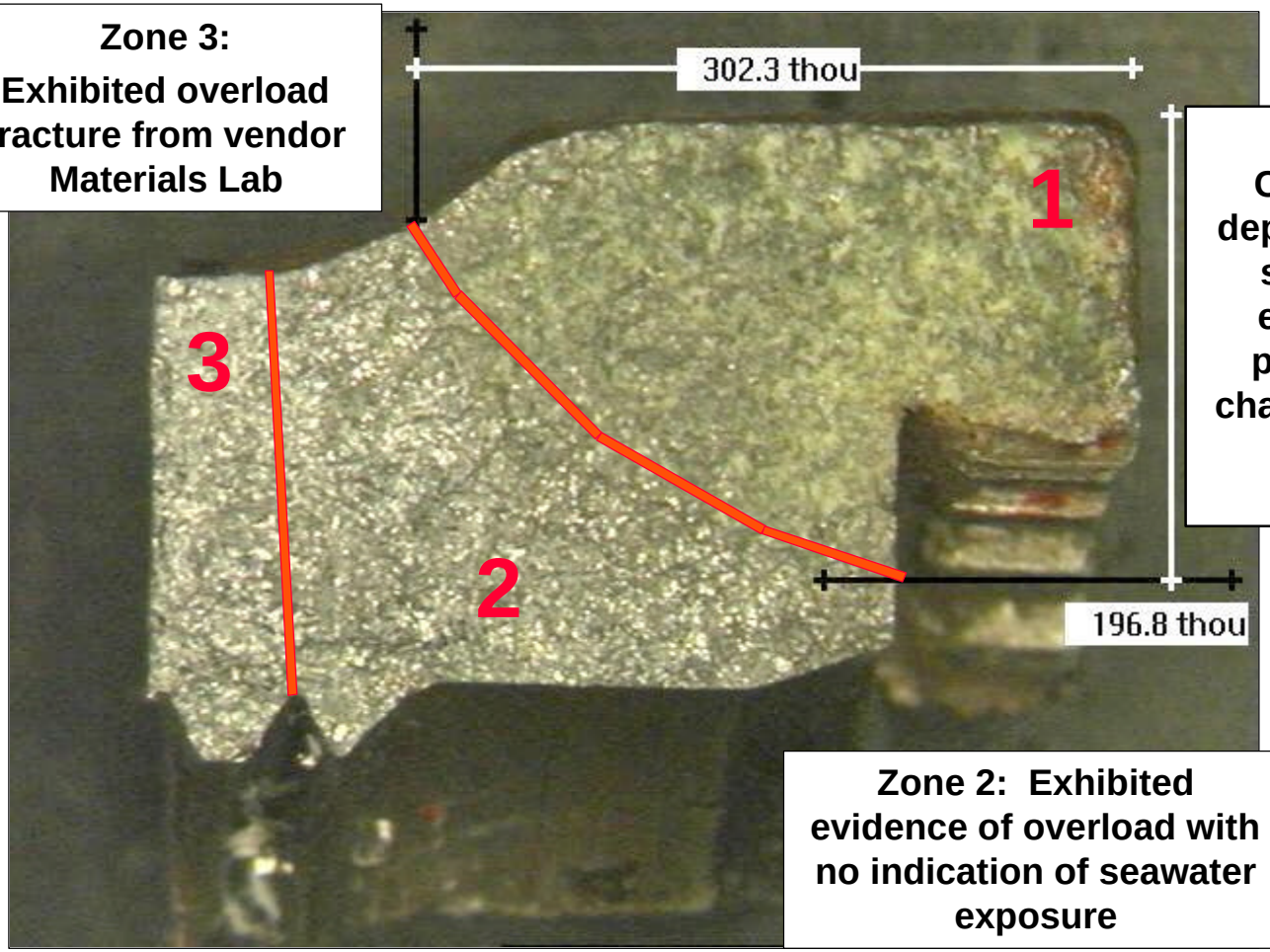
Zone 3:
Exhibited overload fracture from vendor Materials Lab



Zone 1: Corrosive deposits from seawater exposure prevented characterizing fracture surface

Zone 2: Exhibited evidence of overload with no indication of seawater exposure

Fuel Pump Housing Fracture Surface

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Investigation (cont.)

- Fault tree utilized to identify and eliminate potential causes
  - Most probable cause attributed to unique combination of high joint stress due to applied loads and local stress concentration resulting from corrosion pitting
    - Initial high loading event occurs with Rosan fitting installation
    - Water impact can induce additional joint loading
    - Corrosion most likely caused by insufficient application of polysulfide coating
    - Stress concentration can drive loading past material ultimate capability
- Testing performed to characterize material properties and refine analytical models
  - Material properties within specification limits
    - Yield strength, ultimate strength and elongation
  - Torque tension testing revealed yield with worst case design conditions

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Investigation (cont.)

- Flight induced loading insignificant relative to installation loads
  - Negligible flight crack growth
- External leakage requires crack growth beyond secondary o-ring seal
- Boss failure most likely to occur due to overload not fatigue crack growth

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Risk Assessment

- Fuel pump crack specific event sequence and risk assessment developed
- Vehicle level catastrophic event resulting from fuel pump crack probability less than 1 in 10,000,000

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Rationale for Flight

- Cracked fuel pump housing allowing external leakage will be screened by multiple leak verifications both at supplier and KSC
  - Sundstrand hotfire encompasses flight loading
  - 380 psi GHe leak test following fuel hose connect
    - Verifies port integrity to 10^{-6} standard cubic centimeters per second
  - ACO hotfire demonstrates operability
    - Subsequent inspections and sniff checks verify housing integrity
- Minimal risk of crack growth during flight
  - Analysis shows flight loads very small in area of Rosan fitting relative to installation loads
- External leakage requires crack growth beyond secondary o-ring seal

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Rationale for Flight (cont.)

- History indicates high demonstrated reliability of fuel pump configuration over life of program
- Investigation results substantiate unique occurrence mitigating fleet wide concerns
- Currently installed fuel pump housings do not increase risk to mission success or flight safety
- STS-112/BI115 and subsequent flights safe to fly

Recurrence Control

- Vendor processing documentation modified to enhance inspection and assembly operations

STS-112 (BI115) Flight Readiness Review

Pending completion of normal operations flow, we certify the Booster Assembly hardware ready to support the launch of STS-112

Original signed by Lloyd Gregg

Gordon P. Nielsen
Associate Program Manager/USA
SRB Element

Original signed by Joe Lusk

A. A. McCool
Acting Manager,
SRB Project Office

United Space Alliance