Flex Hoses

Presenter:
Joe Rodriguez
Organization/Date:
Orbiter/03-08-05

Agenda:

- Issue
- Background
- Actions
- Certification Verification Findings
- Consequences of Failure/Problem
- Conclusions/Recommendations
- Acceptability Rationale for OPF Rollout
- Remaining Open Items

Flex Hoses

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Organization/Date:
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Issue:

- Failures Have Occurred in Metal Bellows Flex Hoses Used in Sub-systems ECLSS, PRSD, OMS/RCS, MPS and PVD
  - OV-105 Secondary Pressure Control System (PCS) O2 bulkhead flex hose leaked during STS-113 countdown delaying launch. Flex hose was R&R'd, Ref IFA-133-V-01
  - Failure drove the Flex Hose Investigation
- Vehicle Inspections Resulted in PR's Documenting External Damage and Bend Radius Specification Violations
- Suspect Internal Corrosion Found in Spare Metal Bellows Flex Hoses, led to a concern of a possible corrosion threat to Orbiter systems
- Certification Verification Evaluation Questioned Flex Hose Certification

Flex Hoses

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Background:

- Metal Bellows Flex Hose Failure Analyses Have Identified Bellows Cracks Due to Reverse Bending Fatigue
  - External damage was noted on all of the flex hoses
  - The majority of these flex hose failures are believed to be related to collateral damage due to inadvertent personnel contact
- Failure Analysis History Indicates That Metal Bellows Flex Hoses Are Susceptible to Damage That Will Reduce the Fatigue Life Capability and Cause Premature Failure

Flex Hoses

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Metal Bellows Flex Hose Usage

SYSTEM	Criticality					TOTALS
	1/1	1R2	1R3	2	3	
MPS	4	2				6
ECLSS		118	17	13	1	149
PVD			8		2	10
RCS	28				2	30
OMS	4					4
FC/PRSD		9				9
TOTALS	36	129	25	13	5	208

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Actions:

- Performed External Inspections of Vehicle Flex Hoses to Document Damage, Installation Issues and Leakage
  - Flex Hose Vehicle Inspection and Leak Check Requirements were documented and approved via Chits J5670 (ECL,PVD,OMS/RCS, Fuel Cells) and J5669A (MPS)
  - Flex Hose vehicle inspections are complete less the final PVD and MPS inspections which are planned PAD work
  - Tiger team formed to work repairs, replacements and re-designs
  - Summary of the Flex Hose work completed on OV-103 based on vehicle inspections:
    - Replaced 3 ECLSS WCL 1 and 5 WCL 2 Flex Hoses
    - Replaced 3 ATCS Freon Coolant Loop Flex Hoses

Flex Hoses

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Actions:

- Summary of the Flex Hose work completed on OV-103 based on vehicle inspections: (continued)
  - Converted 15 Potable/Waste Water Flex Hoses to Hard Lines
  - Replaced Primary N2 and Secondary O2 and N2 Flex Hoses
  - Replaced 1 WWM Condensate Flex Hose
  - Replaced all 9 Fuel Cell Flex Hoses
  - Replaced all 10 PVD Flex Hoses
  - Replaced 1 Primary FES Feedline Flex Hose
  - Performed external inspections on all FRC3 flex hoses and internal inspections on 11 out of 28 flex hoses
    - No removals required
  - 5 of 6 MPS Flex Hoses will be replaced with spares at the pad, 1 hose will be re-flown
- Replaced the following Flex hoses as a result of the STS-113 IFA investigation
  - Primary O2 and Aux O2 Supply Flex hoses

Flex Hoses

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Actions:

- Inspection of Spare Flex Hoses
  - Evaluate for external discrepancies, suspect corrosion, and screen for best spare candidates
  - Total of 533 Spare flex hoses were identified for inspections
    - All have completed external inspections
    - Total of 98 were delivered to vehicles for installation. All were internally inspected, cleaned and passivated
- Sampling of Vehicle Flex Hoses for Suspect Internal Corrosion, Encompassed All Vehicle Sub-systems Flying Flex Hoses, Approximately 200 Flex Hoses
  - Inspections are complete on OV-103 and substantially complete on OV-104/105 with minimal findings
- Statistically Significant Sampling
  - Inspections have been conducted on over half of orbiter program spares and installed flex hoses with minimal findings

Flex Hoses

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Actions:

- Corrosion Investigation:
  - Suspect corrosion found in spare metal bellows flex hoses raised concern of a possible corrosion threat to orbiter systems
    - Corrosion pitting might contribute to fatigue life reduction
    - Corrosion may be a threat due to perforation of convolute wall
  - Extensive inspection of vehicle and spare flex hoses, evaluation of numerous failure analyses, and review of failure mechanisms ensures that flex hose corrosion is a minimal risk
    - No evidence of corrosion pitting leading to initiation of fatigue failure in over 60 failure analyses
    - Single SCC leakage in fleet history only detectable with mass spec
      - No system effect
    - No evidence of corrosion pitting in vehicle inspections of over 200 flex hoses
      - Vehicle environments are not conducive to corrosion propagation
  - This issue was presented and accepted at the Orbiter DCR

Flex Hoses

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Certification Verification Findings:

- WCL ½" Flex Hoses (MC271-0091)
  - Issue:
    - Previously certified by similarity and did not undergo bend radius testing to magnitude defined in the procurement specification
  - Resolution Plan:
    - Perform Bend Radius Testing to provide:
      - Certification rationale at installation minimum bend radius of 2-inch and service life for low pressure cycling
      - MR rationale for below spec installation minimum bend radius of 1.5-inch
      - Qualitative Assessment of The Effects of Internal Corrosion on flex hose service cyclic fatigue life

Flex Hoses

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Certification Verification Findings:

- Bend Radius Test Results:
  - All 1/2-Inch Flex Hoses Specimens Successfully Passed The 100 Missions Delta Qual
    - Hoses are representative of the WCL system flex hose spares population
    - 100 missions flexure, vibration and pressure cycles
      - 2 inch and above minimum bend radius satisfies specifications requirements
      - 1.5 inch bend radius provides MR rationale for below spec flex hose installations
  - 4 Flex Hose Specimens underwent Destructive Analysis
      - Selected specimens included 2 with reported corrosion and 2 with light or no corrosion
      - No cracks or other possible leak sites identified
      - Anomalies detected included scratches, die marks and suspect corrosion. No significant depth noted

Flex Hoses

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Certification Verification Findings:

- Fuel Cell Flex Hoses
  - Issue
    - Fuel cell bend radius violations found original Certification not representative of the environment seen in the Orbiter
    - Certification for Orbiter use predominantly based on Orbiter requirements similar to Apollo environments
    - Only a vibe test was performed as part of the Orbiter certification effort. Lack of cumulative damage approach, i.e. not one hose was successfully tested to all loading environments
    - Current analysis of existing test data cannot support greater than 6-mission life
  - Recovery Plan :
    - Replaced all 9 OV-103 hoses to avoid potential cert / qual issues
    - Long term plan is to Develop Delta Qual Test Plan & Cost and present to OPO for approval

Flex Hoses

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Certification Verification Findings:

- Radiator Retract Hose Delta Qual Testing
  - Issue:
    - OV-103 Radiator Retract Mechanism flex hose (ME271-0089 3/4") has a minimum bend radius violation (proc spec 3.75" static, installed measurement 3.125")
    - During PRT review of above issue a certification issue with the qualification test was discovered
    - Test subjected hose to 910 flexure cycles which certifies to 20 missions equivalent based on a scatter factor of 4. OV-103 Flex hoses are out of cert
  - Resolution Plan:
    - Perform a Delta Qual test for 42 Mission cycles
      - Test conditions to include vibration, servicing pressure cycles, operating pressure cycles, launch cycles and flexure cycles
      - TRR is complete and testing is underway
      - Preliminary data review at 32 Mission Cycles ECD 4/08/05
      - Preliminary Results will provide flight rationale for STS-114
      - Certification QSA submittal 4/15/05

Flex Hoses

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Certification Verification Findings:

- ECLSS Delta Qualification Testing of ME271-0089/0091 Flex Hoses
  - Issue:
    - Cert verification evaluation questioned flex hose cerfication
    - Original flex hose qualification for all diameters done by similarity to ¼ inch diameter lines
    - Certification update required for ME271-0089/0091 hoses > ¼" in diameter
  - Resolution Plan:
    - Perform Delta qualification testing for 3/8" & ¾" diameter hoses
      - Pressure cycles, vibration, flexure
      - JSC EP Delta Qual test for 3/8" configurations – Complete, Certification QSA submittal ECD 3/14/05
      - Radiator Retract hose Delta Qual testing will satisfy the ¾" requirement- Certification QSA submittal ECD 4/15/05
    - Cert for 5/8" hoses will be enveloped by the 3/8" and ¾" Delta Quals - Certification QSA submittal ECD 4/22/05

Flex Hoses

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Certification Verification Findings:

- ECLSS ME271-0085 Flex Hoses
  - Issue:
    - Cert verification evaluation questioned the certification of ME271-0085 hoses
      - Flex hoses were not tested to the current vibration and deflection requirements and the as installed configuration
  - Resolution:
    - Pressure vs. growth testing, in-situ modal response testing of OV-104 and OV-105 GN2/GO2 hoses, structural characterization testing, metallurgical analysis, and finite model model analyses to evaluate flex hose displacement to loads and stress sensitivity have shown that the –0085 flex hoses have no certification issue
    - Stress and fatigue analysis of the GN2/GO2 bulkhead penetration flex hoses show that the environmental and operational loads do not affect the required service cyclic life
    - Evaluation results show that all other bulkhead dog-bone configurations meet required cyclic service life
      - Significantly lower pressure on all other flex hoses leads to a 67% reduction in stress

Flex Hoses

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Certification Verification Findings:

- **RCS Flex Hoses**
  - Issue:
    - FRCS primary thruster flex hose was originally certified for 5 static deflections
    - 1 static deflection occurs each installation and removal cycle, current preventive maintenance plan increased the number of thruster replacements
    - 3 Flex hoses on FRC3 (F1D, F1L, F2R) have exceeded the originally certified deflections
    - In addition it was noted that the maximum certified bend angle of 45 degrees might be exceeded during thruster installation
  - Resolution Plan:
    - Perform Delta Qualification Test to expand allowable operational usage to a static deflection cyclic limit of 25 and bend angle of 90 degrees
    - Complete qualification to include static deflection, pressure surge cycles, deflection and flexure cycling and random vibration
    - Vibration and Static Deflection testing complete (35 flights)
    - Surge testing preparations on-going, TRR completed 2/25/05, phase 1 testing (35 flights) ECD 3/16/05
    - Flexure testing immediately follows Surge testing ECD 3/18/05
    - Certification by QSA ECD 3/30/05

Flex Hoses

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Additional RCS Test Program:

- Bulge Test of RCS Flex Hose
  - Test Objective:
    - Demonstrate margin for a hose which has exceeded the bulge criteria specified in our inspection chit
    - If successful, the results would enhance our confidence that hoses with a bulge less than collar diameter pose no risk to hose integrity
  - Test article selected from White Sands EI-081 Qualification Test Article (F1F position)
    - Manufactured by Metal Bellows in 1978, 100 mission vibration and 34 equivalent mission duty cycles accumulated
    - Bulge exceeds collar diameter (size of bulge: delta diameter of 0.104” above collar unpressurized, collar diameter is 1.1360) ,
    - Plan to test additional 100 mission equivalent pressure surges (10,000 surge pressure cycles)
  - Results:
    - A leak was noted after 8100 surge pressure cycles. Sub-Car issued 2/24/05
    - FA is in work (ECD 3/18/05), fatigue cracks noted on every convolute crown
    - Boeing Stress & Fluids Analysis analyzing surge pressure cycles (initial results/status 7 Mar 2005)
      - Equivalent firing cycles for tested hose configuration, Effects of common manifold’s thruster firings on hose of interest
    - Discussion on effects to our flight rationale are underway

Flex Hoses

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Consequences of a Flex Hose Failure/Problem:

- Sub-system unique based on criticality and hardware functionality

Conclusions/Recommendations:

- Three major flex hose technical issues have been resolved for STS-114
  - Flex Hose Damage
    - Completed inspections of flex hoses and replacement of damaged hoses
  - Bend Radius Exceeds Specification
    - Bend Radius Testing supports continued use of some flex hoses with bend radii exceeding specification
    - Redesign when required to eliminate bend radius violation not covered by test
  - Flex Hose Corrosion Issue
    - Corrosion investigation concluded a minimal risk, closed at Orbiter DCR
- Completion of Test Programs Will Provide Additional Flight Rationale

Flex Hoses

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Acceptability Rationale for Orbiter Rollout:

- Vehicle inspections have resulted in a small number of flex hoses that were repaired or replaced
  - Tiger team aggressively worked all issues
  - Final Leak Tests to be performed prior to Flight
- Flex hose bend radius issues have been addressed by a combination of repair and life demonstration testing
- Flex hose corrosion issue was addressed by inspection, sampling, life demonstration testing, and destructive analyses
- Pending the Conclusion of the Identified Forward Work the Flex Hose Issue can be Closed for Flight

Flex Hoses

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Forward Work required for Flight Rationale

Item	Responsible Party	Est Completion (task)	Current Status
Radiator Retract Hose Delta Qual Testing	Boeing/USA/NASA	32 Mission results 4/8/05 QSA Submittal 4/15/05	Testing in Work
ECLSS Delta Qualification Testing of ME271-0089 Flex Hoses	Boeing/USA/NASA	3/8" QSA Submittal 03/14/05 3/4 "QSA Submittal 4/15/05	JSC EP 3/8" testing complete, ¾" to be satisfied by Radiator Retract test
ECLSS Delta Qualification Testing of ME271-0091 Flex Hoses	Boeing/USA/NASA	3/8" QSA Submittal 03/14/05 5/8 "QSA Submittal 4/22/05	JSC EP 3/8" testing complete, 5/8" by similarity
RCS Test Program – Delta Qual Testing	Boeing/USA/NASA	Testing comp 3/18/05, Cert QSA 3/30/05	Vibe&static deflection testing (35 flights) complete. Surge testing I/W
RCS Bulge Testing	Boeing/USA/NASA	FA completion 3/18/05	FA in work. Flight Rationale discussions underway

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Flex Hoses	Presenter: Joe Rodriguez
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FLEX HOSES BACKUP

Flex Hoses

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Joe Rodriguez
Organization/Date:
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Flex Hoses
Actions Required

Presenter:
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Organization/Date:
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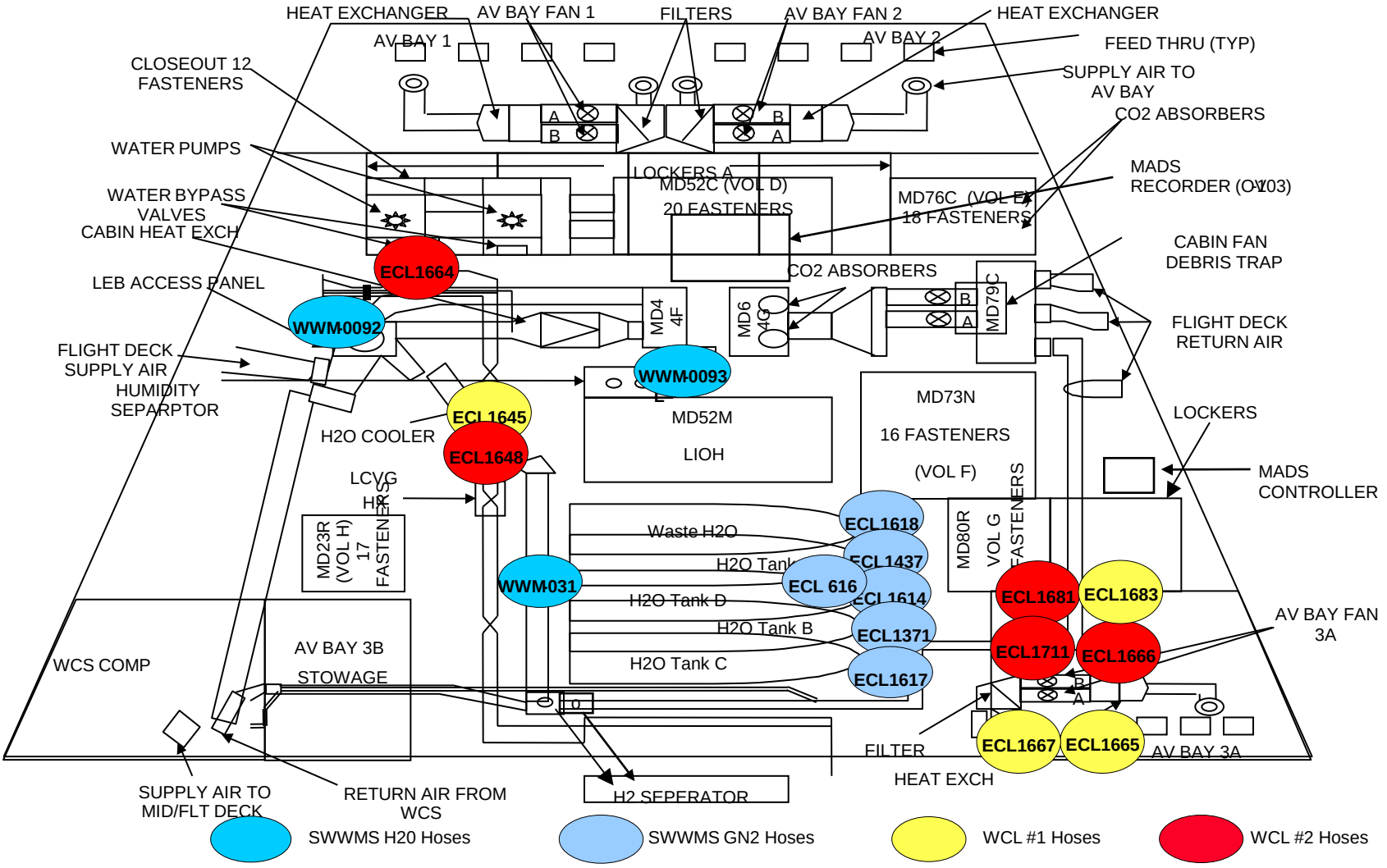

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Flex Hoses
Actions Required

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Flex Hose Investigation Test Program: Environmental Sensitivity Testing

- Most probable cause of flex hoses failing below certified or qualified life has been stated to be collateral damage (repeated flexure/deflection) during vehicle maintenance
- The concern would be the combined effect of mission cycles with collateral damage reducing the life of the hoses with potential to produce a failure during flight
- Determine the sensitivity to reduction in hose mission life from collateral damage
  - Determine relative contribution of pressure cycling of bent hoses and simulated ground handling damage to premature failure
  - Cyclic life – mission pressure plus vibration
  - Cyclic life – Simulated collateral damage
  - Test mission life remaining with various levels of collateral damage
  - All hoses to be destructively analyzed at end of testing
- Assessment of how installation geometry affects pressure and vibration cyclic life
- Assessment of relative contributions of collateral damage and mission cycles to premature failure
  - Gives indication of Mission life remaining vs. number of collateral damage cycles

Flex Hoses
Actions Required

Presenter:
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Organization/Date:
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Flex Hose Investigation Test Program: RCS Test Programs

- Modal Testing
  - Test Objective is to determine whether the FRCS flex hoses are susceptible to low frequency vibration by identifying the natural frequencies of the flex hose over a range of installation angles from 0 to 45 degrees
  - Test articles shipped to Huntington Beach
    - Pre-test leak check resulted in hose failure (CAR AE2807)
    - Replacement hose shipped and received 9/04
    - Technical difficulties have delayed completion (Data Acquisition)
    - Expect to resume testing after completion of Delta Qual testing
- Failure Analysis and Evaluation
  - External leakage detected during pre-test leak check of hose for Delta Qualification
  - F/A determined leakage was due to external corrosion (Boeing Lab record Case #307608)
    - Corrosion due to chlorides - root cause not identified
  - Failure of hose most likely due to failure of process or failure to follow process
    - Most probable cause is isolated case of poor control of etchant
  - Sub-CAR AE2807-012 authorizes destructive evaluation of 5 hoses produced during production run to determine if failure is unique
    - ~~Internal and external inspection, Leak and proof check~~
    - Braid removal and evaluation for signs of external corrosion

Flex Hoses

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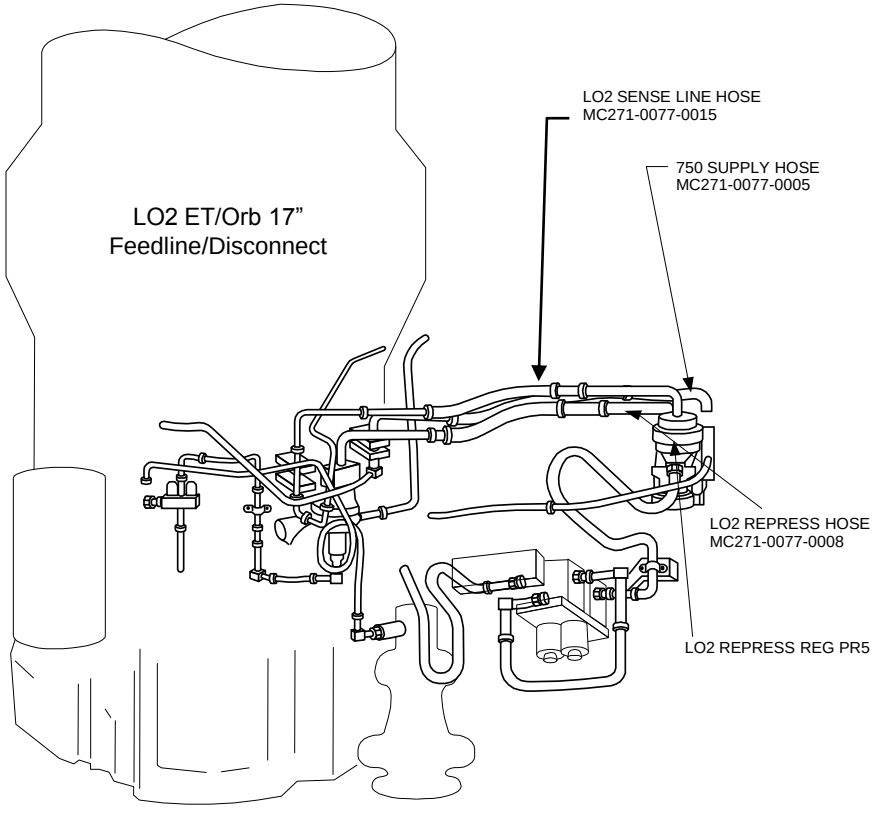
MPS LO2 Disconnect Flex Hoses



Flex Hoses

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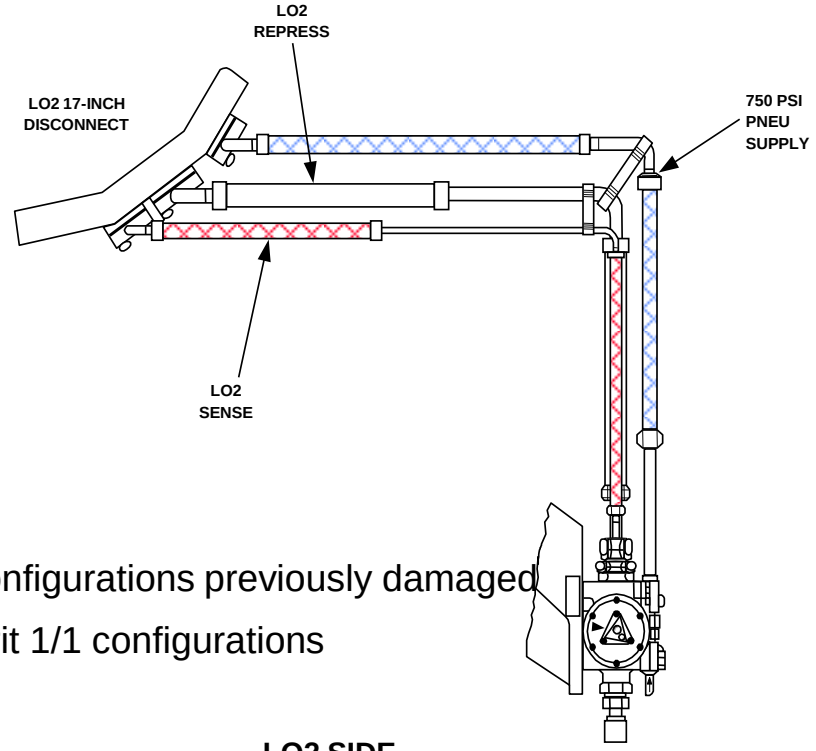
MPS LO2 Disconnect Flex Hoses



14 configurations previously damaged

10 Crit 1/1 configurations

LO2 SIDE

1/4 IN. MANIFOLD SENSE LINE

3/8 IN. PNEUMATIC SUPPLY LINE

1/2 IN. MANIFOLD REPRESS LINE

Flex Hoses

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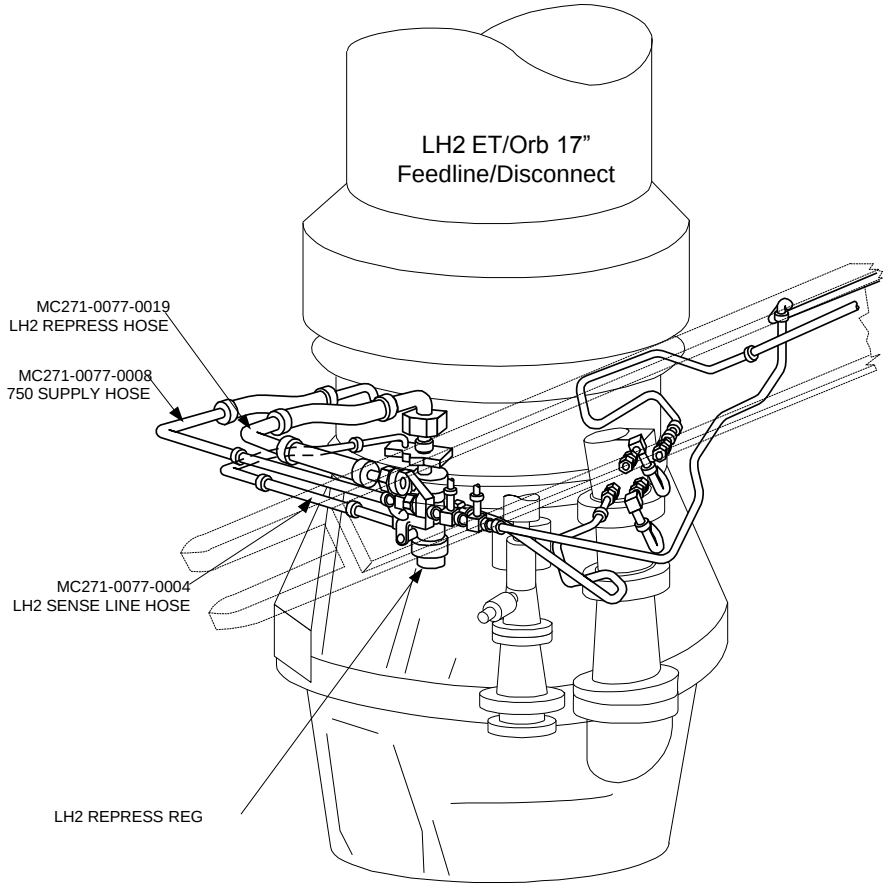
MPS LH2 Disconnect Flex Hoses



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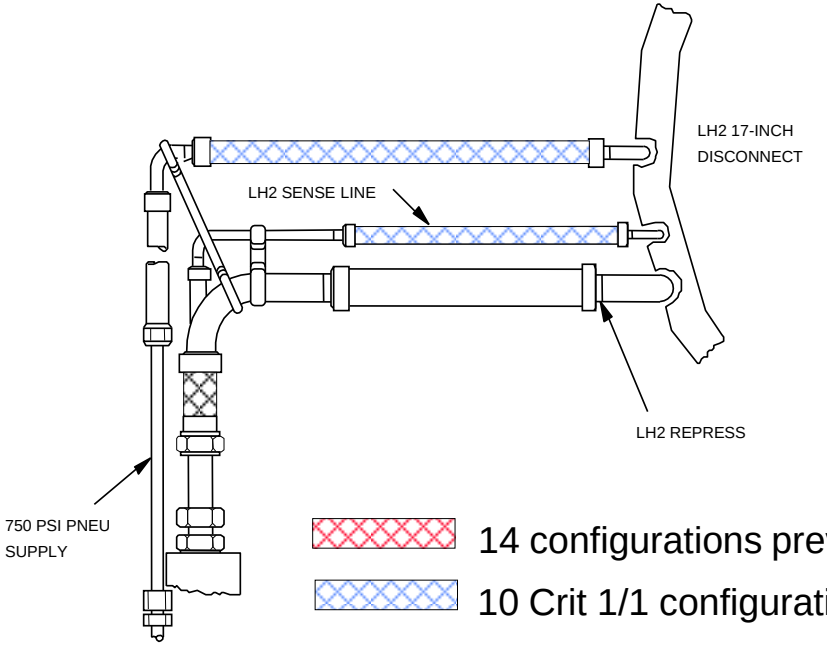
MPS LH2 Disconnect Flex Hoses



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1/4 IN. MANIFOLD SENSE LINE

3/8 IN. PNEUMATIC SUPPLY LINE

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Flex Hoses

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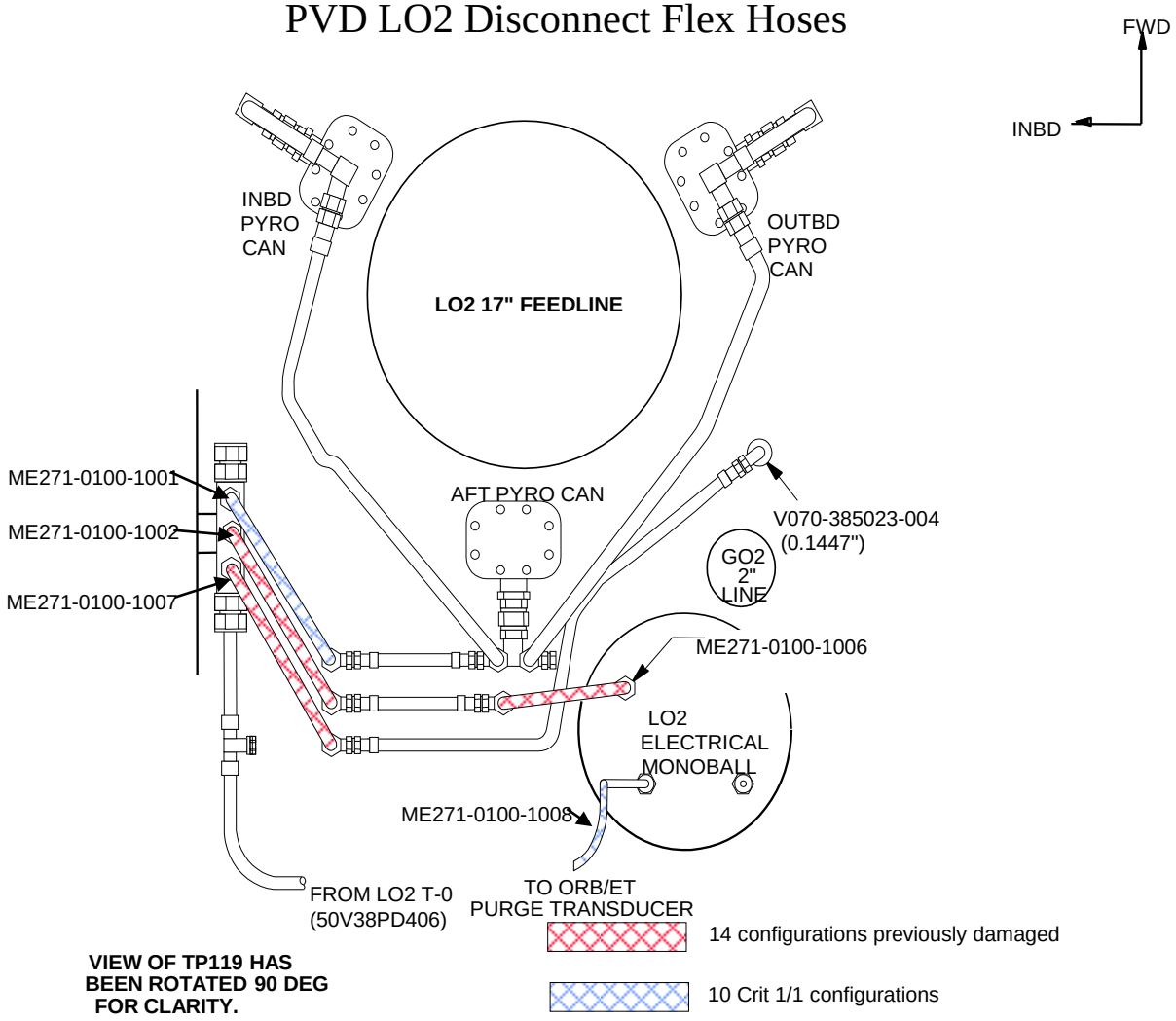
PVD LO2 Disconnect Flex Hoses



VIEW OF TP119 HAS BEEN ROTATED 90 DEG FOR CLARITY.

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Flex Hoses

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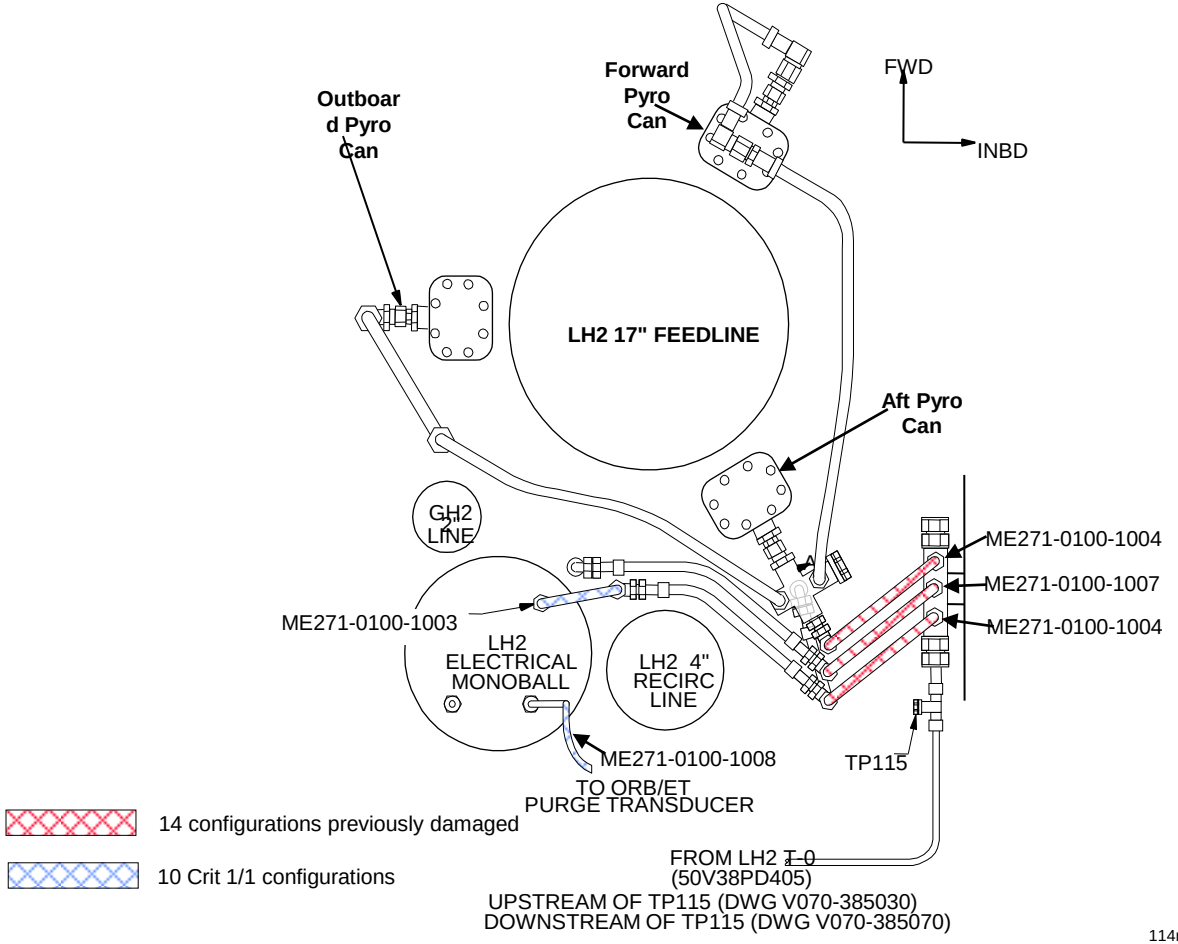
PVD LH2 Disconnect Flex Hoses



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Flex Hoses

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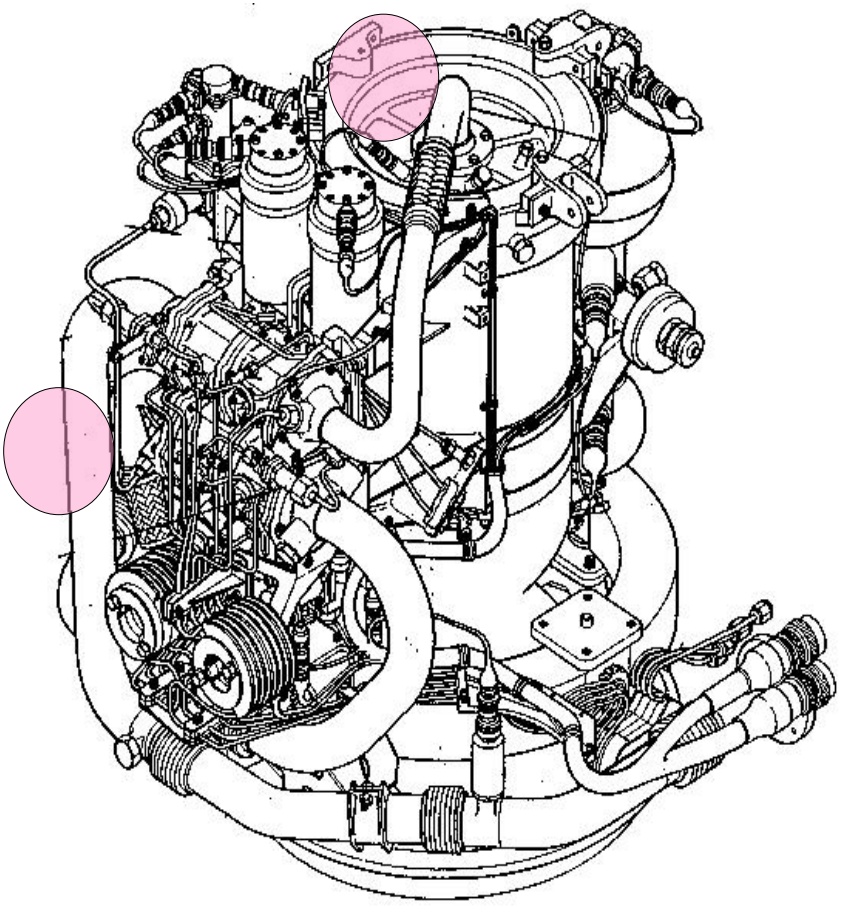
OME Flex Hoses



Flex Hoses

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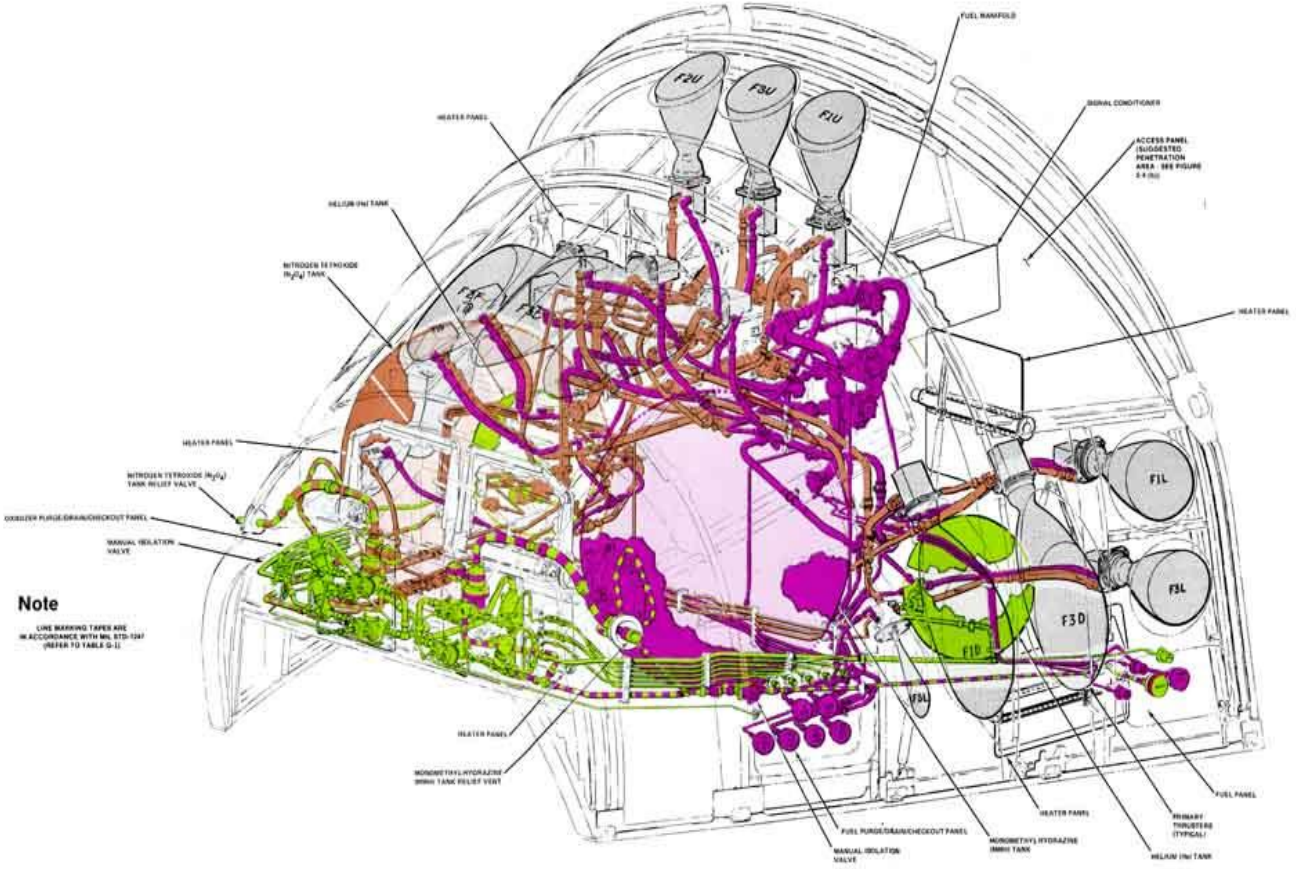
RCS Flex Hoses



Flex Hoses

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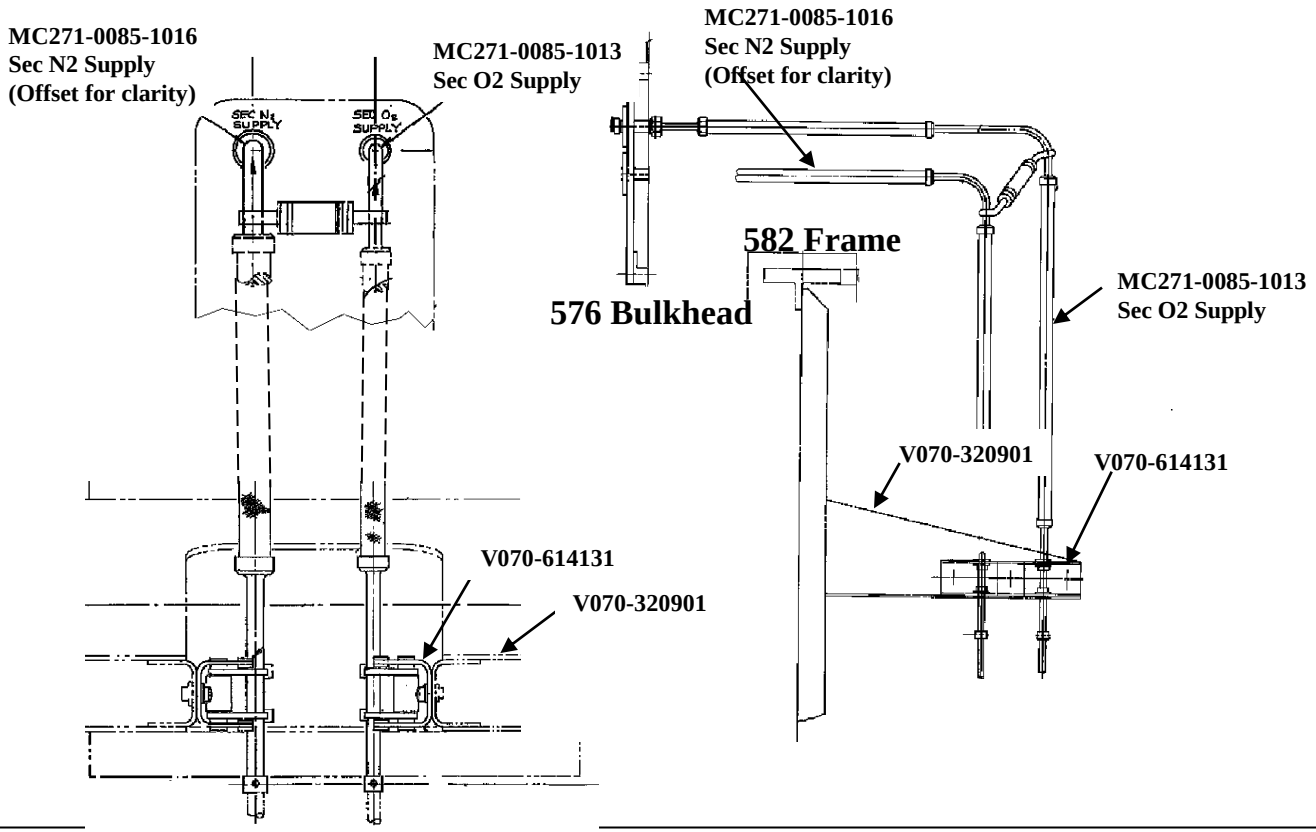
MC271-0085-1013 Secondary O2 Supply

MC271-0085-1016 Secondary GN2 Supply



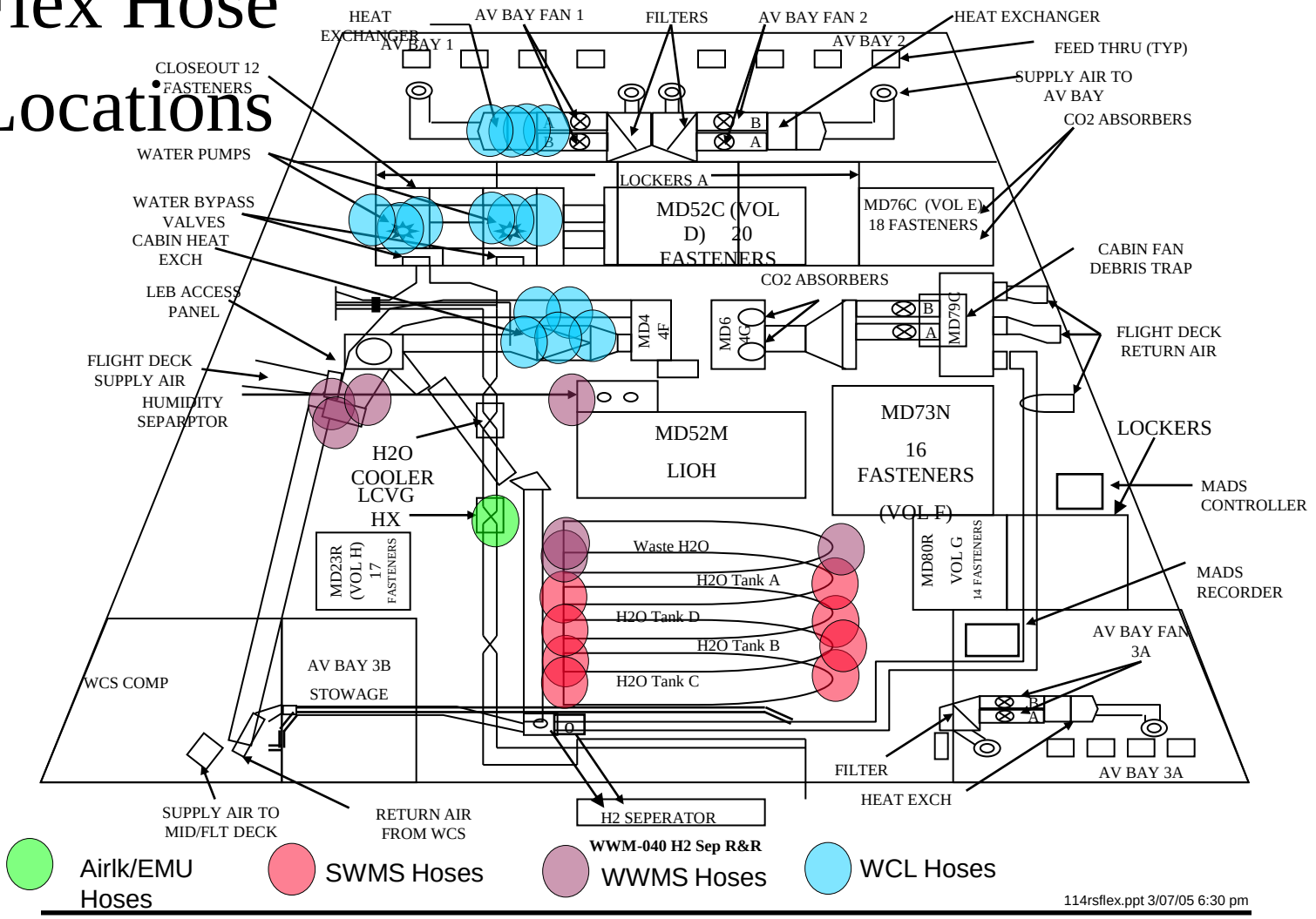
ECLSS O2/N2 Secondary Flex Hoses

ECLSS Bay Flex Hoses

Presenter: Joe Rodriguez

Organization/Date: Orbiter/03-08-05

Flex Hose Locations



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Flex Hoses

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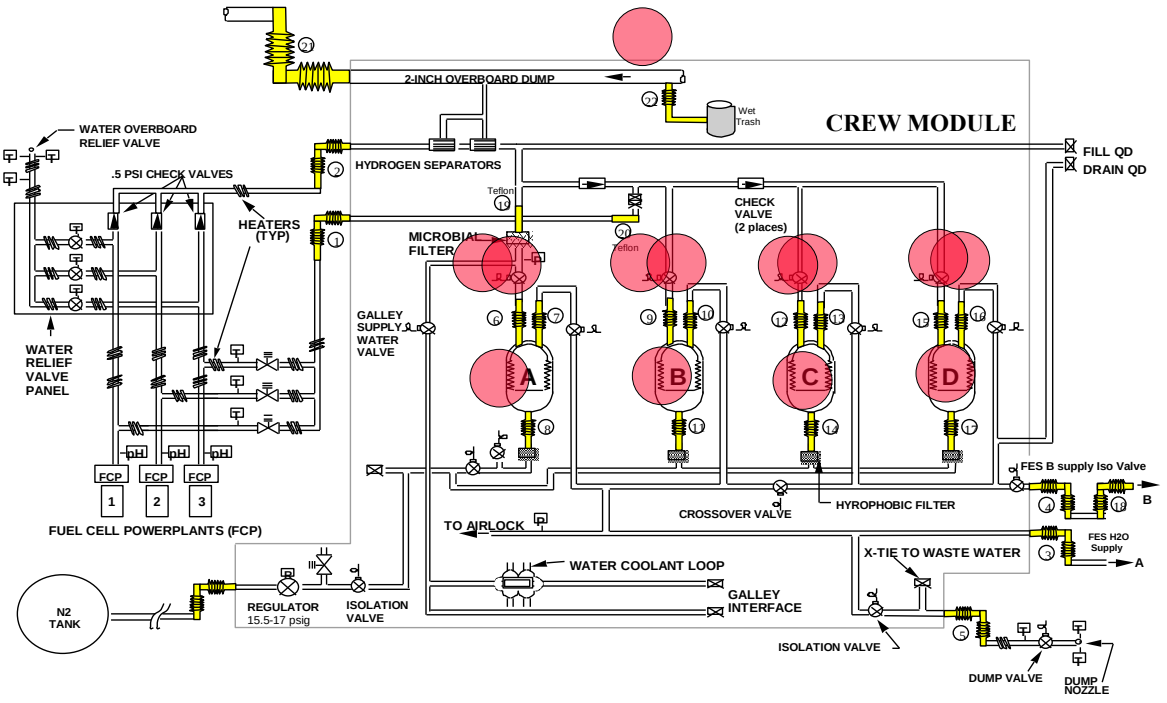
Supply Water Management System



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Flex Hoses

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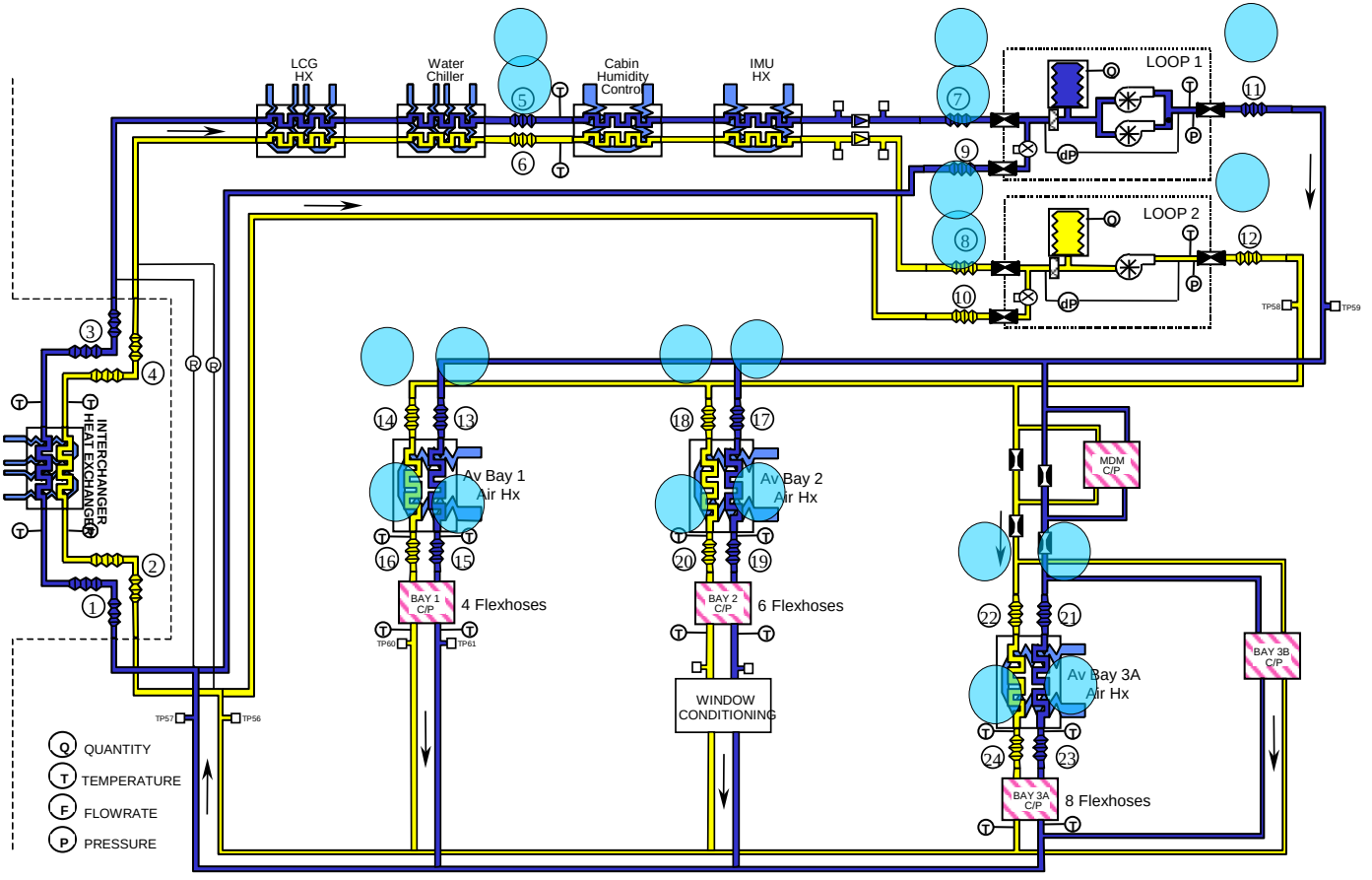
ECLSS Bay Flex Hoses

Orbiter Water Coolant Loop (WCL)



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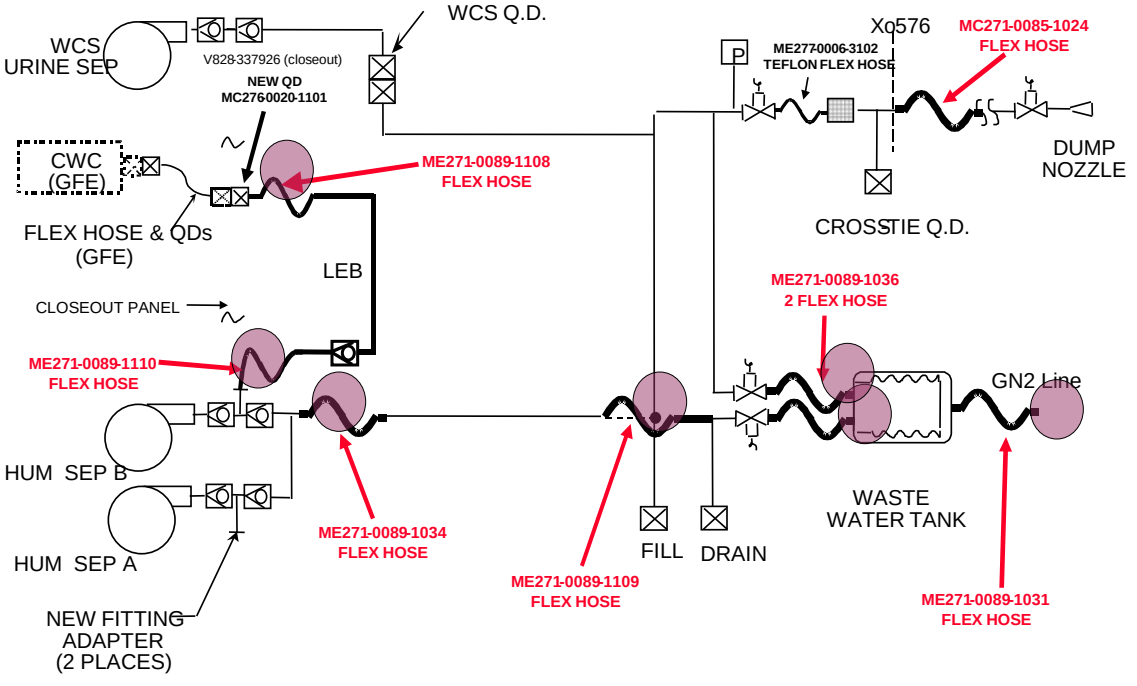
ECLSS Bay Flex Hoses

Waste Water Management System



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BOEING

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Flex Hoses

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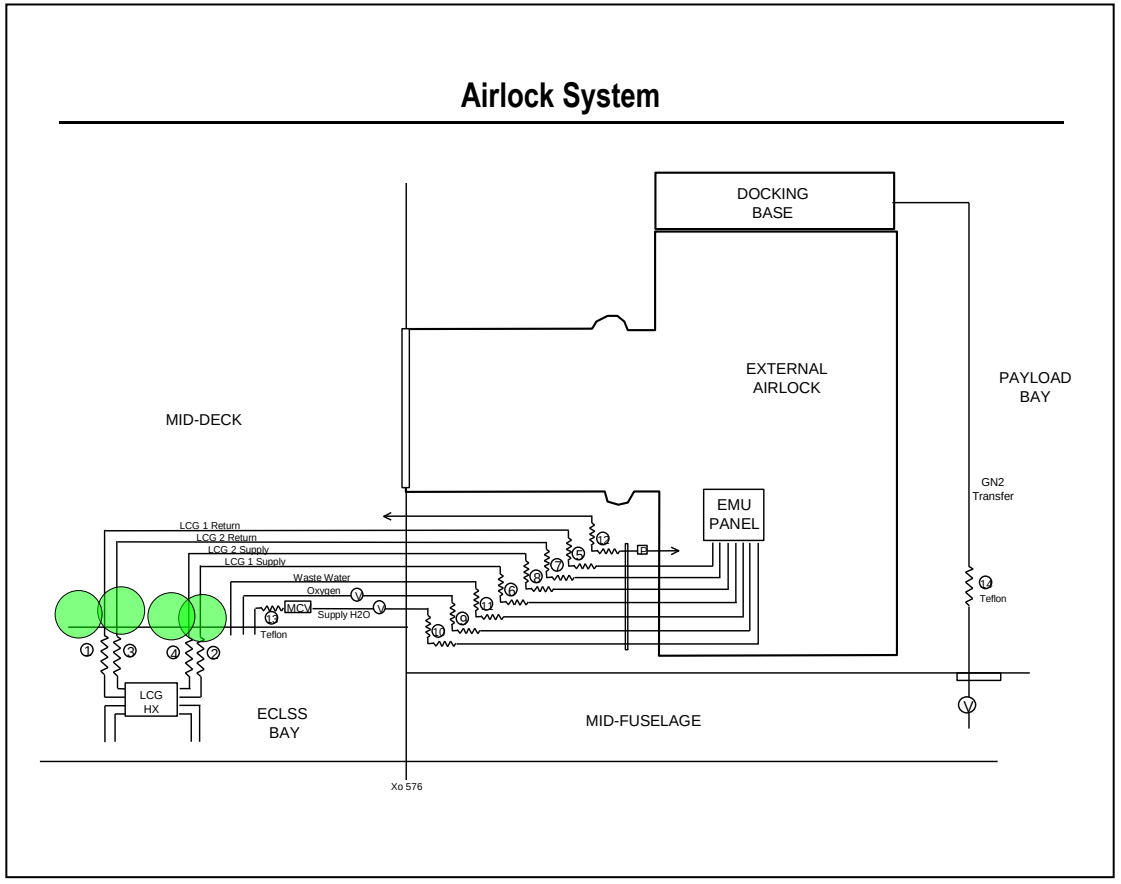
ECLSS Bay Flex Hoses (Airlock/EMU Hoses)



CORROSION INVESTIGATION
Flex Hoses

Presenter:
Joe Rodriguez
Organization/Date:
Orbiter/03-08-05

Concern #1: Corrosion Pitting Might Contribute to Fatigue Failure of Flexible Hoses

- Vehicle History
  - No Reports of Corrosion Contributing to Any Fatigue Failure on Flexhoses
  - One Report of Corrosion in a Vehicle Flexhose
    - ECLSS Radiator Jumper Hose Minor Leakage Determined to Be As a Result of Stress Corrosion Cracking
    - No Evidence of Fatigue Initiation at SCC Defect
- Failure Analysis History
  - 60+ Failure Analysis Conducted on Flight Hoses
    - No Corrosion Noted (Except Radiator Jumper Hose Mentioned Above)
    - Tooling Marks Were Noted but Were Not Contributory to Failures
  - Ground and Facilities System Flexhose Experience
    - Several Hoses Failed Via Pitting Corrosion Through the Wall
    - Hoses Did Not Unzip, There Was No Evidence of Fatigue Initiating at the Pit
      - GSE Hoses Do Not See Launch or Flight Vibrations
      - Do See Pressure Cycles and Ground Handling

CORROSION INVESTIGATION **Flex Hoses**	**Presenter:** Joe Rodriguez
	Organization/Date: Orbiter/03-08-05

Concern #1: Corrosion Pitting Might Contribute to Fatigue Failure of Flexible Hoses

- Tooling Marks
  - Fatigue Sees Tooling Marks As Similar to Corrosion Pits
    - Both are localized stress concentrators
  - Full Qual Level Test and Then Some Done on WSTF Fleet Leader – No Failures
    - One Hose Was Selected for Destructive Analysis
      - No Corrosion Detected, However Numerous Tooling Mark Defects Were Present on the Hose As Deep As 0.002”
      - No Evidence of Fatigue Initiating at These Pit-like Defects
  - Tooling Marks Do Not Contribute To, Nor Interact With, LCF Failures
    - Past Failure Analysis Have Noted Pit-like Tooling Marks Adjacent to Fatigue Cracks
      - These Tooling Marks Did Not Contribute to the Eventual Low Cycle Fatigue Failure

CORROSION INVESTIGATION
Flex Hoses

Presenter:
Joe Rodriguez
Organization/Date:
Orbiter/03-08-05

Concern #1: Corrosion Pitting Might Contribute to Fatigue Failure of Flexible Hoses

- Failure Mechanism
  - Low Cycle Fatigue (LCF) Of Flex Hoses Creates Thousands Of Fine Cracks In The Exterior Surface of the Root, That Grow Together Into A Large Fatigue Crack Which Then Grows In Depth
    - The Resulting Crack Can Cover A Large Portion Of The Periphery
    - To Date All LCF Failures Have Been Caught By Leak Testing Prior To Flight
    - A Pit May Serve to Initiate One of Those Thousands of Microcracks Mentioned Above
    - However, the Rest of the Thousands Still Need to Initiate to Join in
    - Result Is No Change to Low Cycle Fatigue Life Due to Pitting
  - High Cycle Fatigue (HCF) Failures Occur On The Inner Surface Of the Crown
    - HCF failures were experienced during the original development testing
    - There Have Been No HCF Failures of Flexhoses on Orbiter
    - No Evidence of HCF on WSTF Fleet Leader Hose and on Other Qualification Tests With Pit-like Tooling Marks Present

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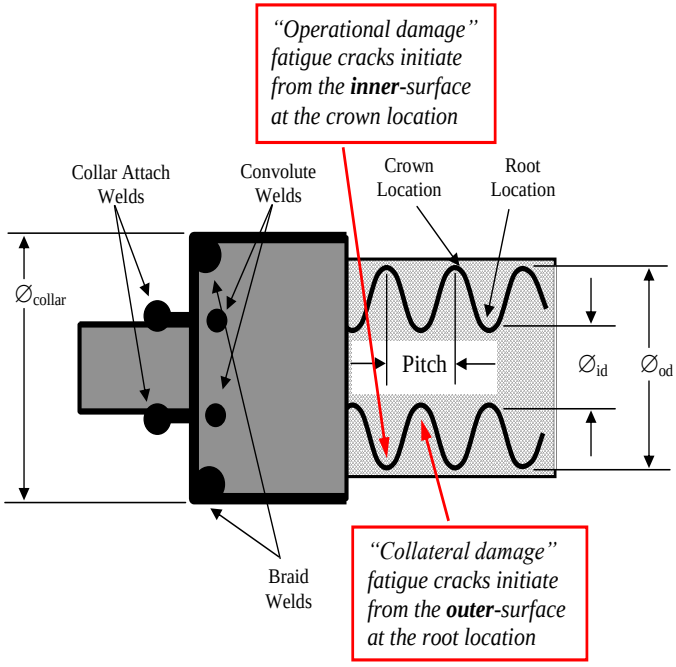
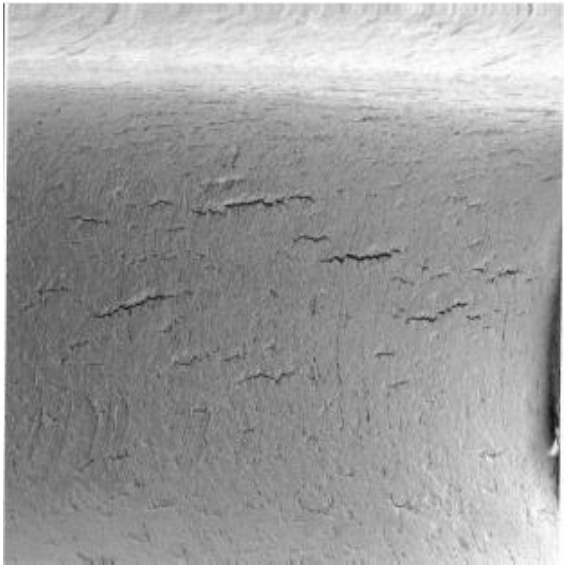
Concern #1 : Corrosion Pitting Might Contribute to Fatigue Failure of Flexible Hoses

- Based upon observations from failure analysis, failure mechanism, and flight history
  - Apparently, stresses from handling (LCF) are sufficiently high enough to drive crack initiation and propagation independently from corrosion pit stress concentrations
  - Apparently, stresses form operation (HCF) are sufficiently low enough as not to significantly affect the operational fatigue life





CORROSION INVESTIGATION
Flex Hoses

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Organization/Date:
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Concern #2: Corrosion, Itself, May Be a Threat Due to Perforation of Convolute Wall

- Vehicle History
  - No significant corrosion problems in fluid system Flexhoses reported in 23 years of flight
  - Over 200 flex hose inspections on vehicle hoses have been planned
    - To date, inspection of over 100 on-vehicle hoses have found normal contamination – no corrosion and no surface material loss
- Spares History
  - Out of ~300 spare flexhoses inspected
    - 2 Flexhoses found with internal corrosion
    - 1 spare RCS hose had corrosion pitting that originated on the outer surface
    - Level of corrosion was out of family as compared to other hoses
- Failure Analysis History
  - Failure analyses of 60+ Orbiter flex hoses found 3 examples of pitting corrosion (The spare hoses mentioned above)
    - Two spares had internal pitting corrosion up to 0.0014” deep
    - One spare had pitting corrosion, through the wall, originating on the exterior

CORROSION INVESTIGATION
Flex Hoses

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- Tooling Marks From Manufacturing Do Not Significantly Reduce Fatigue Life
  - Tooling Mark Defects Have Been Characterized
    - "Tool Marks Are Surface Irregularities That Are Generated by Tools During the Forming Process"
    - Flexhose Manufacturers Have Limits on Tooling Marks of 0.002". This Is Standard Industry Practice. Our Fatigue Factors Cover Any Scatter in Failures Due to Tooling Marks
    - Stress Concentration From Tooling Marks Vs. Corrosion Pits Expected to Be Similar
    - Failure Analysis of Orbiter Flexhoses show no detrimental effects from tooling marks
- Test Programs Have Demonstrated That Tooling Marks Do Not Effect Fatigue Life in Orbiter Environments
  - Original Flexhose Qualification Programs
    - Original Orbiter Certification Testing Included Tooling Marks – No Failures
      - –Statistical Variability of Tooling Marks Limited to Size of Test Population
  - WSTF Fleet Leader Testing
    - Full Qual Level Test and Then Some Done on WSTF Fleet Leader – No Failures
    - One Flexible Hose Selected for Destructive Analysis
      - No Corrosion Detected, However Numerous Tooling Mark Defects Noted on Hose As Deep As 2 Mils
      - No Evidence of Fatigue Initiating at These Pit-like Defects
  - Boeing Huntington Beach "Bend Radius Test"
    - Full Qual Level Testing + Bend Radius Cycling – No Failures