STS-114 Flight Readiness Review

External Tank (ET-121)

June 29-30, 2005

Agenda

Presenter	S. Coleman/MP31	
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Overview / Introduction	***Sandy Coleman***
Configuration Change	***Mike Quiggle***
Senior Management Review Items	
Certification Status	
STS-114 / ET-121 Readiness Assessment	
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STS-114 / ET-121 Readiness Statement	

Appendices

- ***Class I Changes Reviewed through MP01 FRR or DCR Process***
- ***STS-114/ET-120 Tanking Test Observations***
- ***Waivers / Exceptions***
- ***Accepted Risk Hazards***

External Tank Processing / Review Milestones

Presenter	S. Coleman/MP31	
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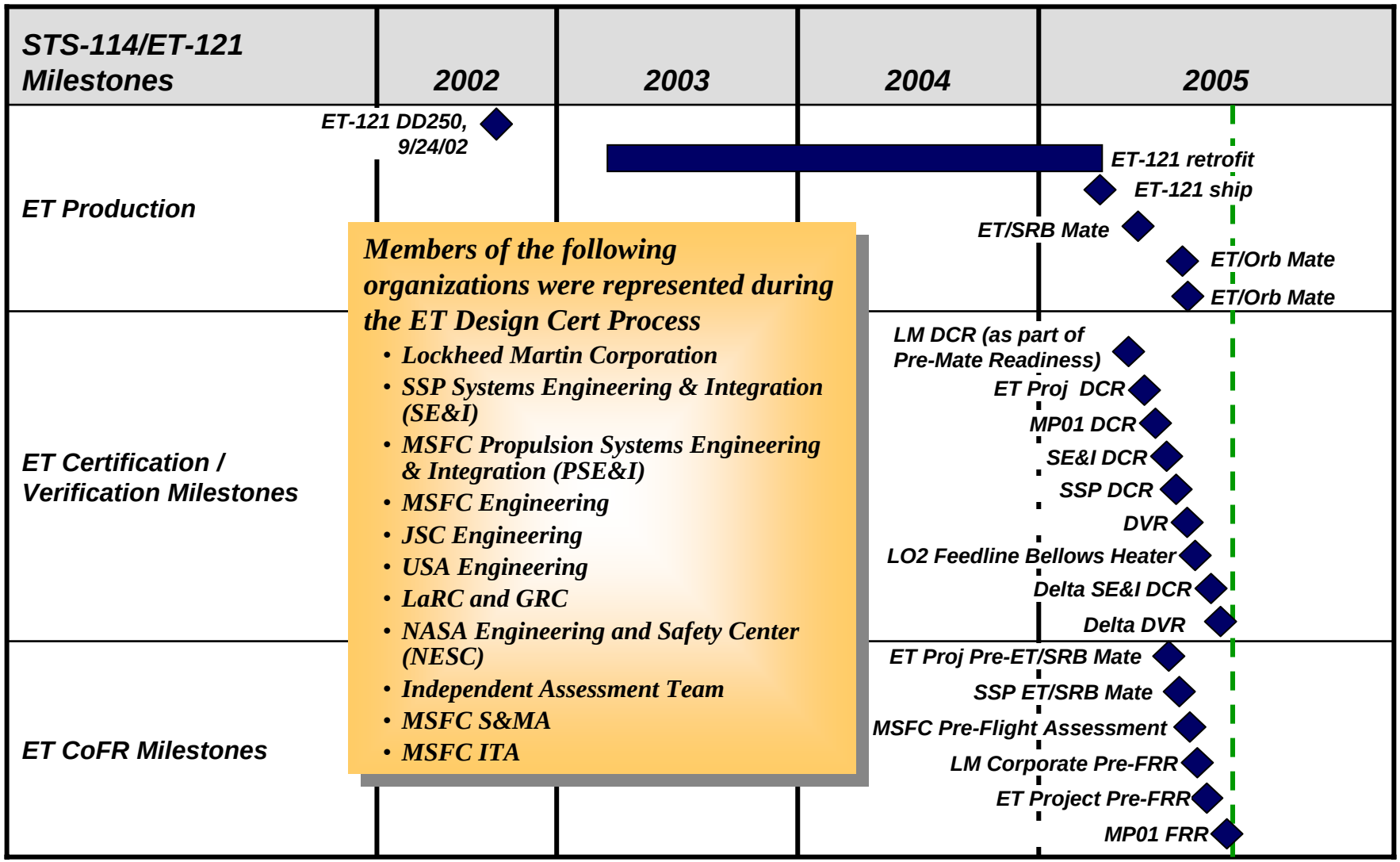

Members of the following organizations were represented during the ET Design Cert Process

- *Lockheed Martin Corporation*
- *SSP Systems Engineering & Integration (SE&I)*
- *MSFC Propulsion Systems Engineering & Integration (PSE&I)*
- *MSFC Engineering*
- *JSC Engineering*
- *USA Engineering*
- *LaRC and GRC*
- *NASA Engineering and Safety Center (NESC)*
- *Independent Assessment Team*
- *MSFC S&MA*
- *MSFC ITA*

MSFC ET Project Pre-Flight Review Readiness Statement, June 22

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FLIGHT READINESS STATEMENT
STS-114/ET-121
EXTERNAL TANK PROJECT
PRE-FLIGHT REVIEW

External Tank Project Office — Committed To Safety — Space Shuttle — Marshall Space Flight Center

The Flight Preparation Process Plans for the External Tank Project as documented in NSTS-08117, Requirements and Procedures for Certification of Flight Readiness have been satisfied. External Tank ET-120/STS-114, as identified in the External Tank Project Pre-Flight Review Conducted on June 22, 2005, is considered ready to support flight upon acceptable disposition of Open/Planned Work and/or Open Actions.

Sandra C. Coleman
Manager, External Tank Project, MSFC

For Charles A. Abner
Chief Engineer, Shuttle Processing, KSC

Dominic A. Antonelli
Astronaut Crew Office, JSC

Jack Bullman
Spacecraft and Vehicle Systems Development, MSFC

M. Ralph Carruth
Materials and Processes Laboratory, MSFC

John Chapman 6/22/05
Chief Engineer, Shuttle Propulsion Elements, MSFC

Daniel L. Dumbacher
Safety and Mission Assurance, MSFC

C. P. Jones
Propulsion Systems Development, MSFC

R. Champion
Propulsion Systems Engineering & Integration, MSFC

Paul M. Munafo
Independent Technical Authority, MSFC

P. I. Rodriguez
Test Laboratory, MSFC

Neil Otte
Chief Engineer, External Tank Project, MSFC

MSFC External Tank Project Pre-Flight Review Board Assessed and Approved the Readiness of External Tank 121 to Support Mission STS-114

External Tank-121 / STS-114 Return to Flight Modifications

Presenter	S. Coleman/MP31	
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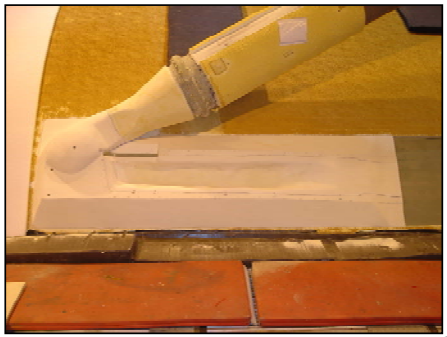
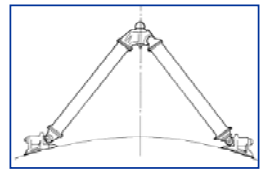


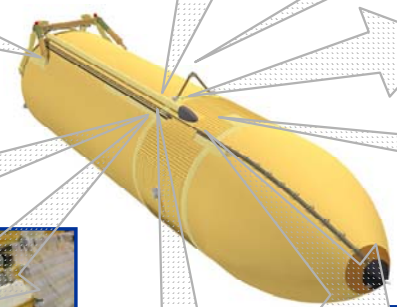
Remove/ Replace Longeron Closeouts

LO2 Feedline Bellows TPS Drip Lip and and Fwd Bellows Heater System

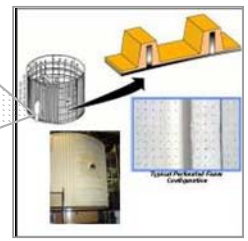


Bipod Strut Hardware (Lubricated thru-bolts)

Redesigned Bipod Fitting



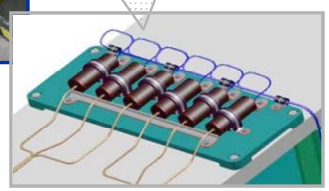
Intertank / LH2 Tank Flange Closeout Enhancement



Increase Area of Vented Intertank TPS

Partial LH2 PAL Ramp Replacement

ET Camera in LO2 Feedline Fairing



RTF Instrumentation

ET Ground Umbilical Redesign

ET/SRB Bolt Catcher Inserts

Eliminated the proximate cause of STS-107 In-Flight Anomaly (STS-107-T-01)

STS-114 / ET-121 Class I Changes

Presenter: S. Coleman/MP31
Date: June 29, 2005

Changes — *Note: Items reviewed through DCR and MP01 FRR included in Appendix A*	*STS-114/ ET-121*	*STS-300/ ET-120*	*Reviewed at Program DCR*	*Reviewed at MP01 FRR*
• ***In-Line Configuration Changes***				
• **Redesign thrust strut assembly (B02062)** ***Present at FRR per MP01 Board Recommendation***	X	X		√
• ***In-Line Changes (No configuration change)***				
• Revise LO2 Feedline Flange Material Spec Revision (B02053B)	X	X		√
• Replace Zinc Chromate Primer (B02027)	X	X		√
• Delete LO2 low level pressure transducer test (B02076)	X	X		√
• Requalify GH2 Pressline Fairing Resin Catalyst (B02067)	X			√
• "Make" SLWT Intertank at MAF (B02040)	X			√
• Change GH2 Vent Line Supplier (B02053B)	X			√
• ***RTF Retrofit Changes***				
• Eliminate foam ramp over bipod fittings (B02093A)	X	X	√	
• Enhance Intertank / LH2 tank flange TPS closeout and re-spray partial LH2 PAL ramp (B02093A)	X	X	√	
• Redesign Longeron TPS closeout (B02093D)	X	X	√	
• Expand Intertank TPS vented TPS area (B02093A)	X	X	√	
• Implement ET camera system (B02093A)	X	X	√	
• Replace lubricated thru bolts on bipod struts (B02089)	X	X	√	
• Redesign ET portion of ET/SRB bolt catcher (B02085)	X	X	√	
• Redesign ET ground umbilical (B02091)	X	X	√	
• Install RTF Instrumentation (B02096A)	X		√	
• Redesign LO2 feedline bellows TPS (B02093A)	X	X	√	
• Install heater system on forward LO2 feedline bellows (B02093D)	X	X	√	

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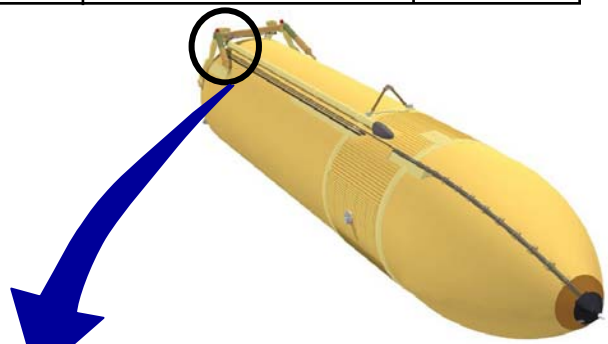
Item	***Presenter***
Overview / Introduction	*Sandy Coleman*
Configuration Change	***Mike Quiggle***
Senior Management Review Items	
Certification Status	
STS-114 / ET-121 Readiness Assessment	
STS-300 (LON) Readiness Assessment	
STS-114 / ET-121 Readiness Statement	
Appendices	

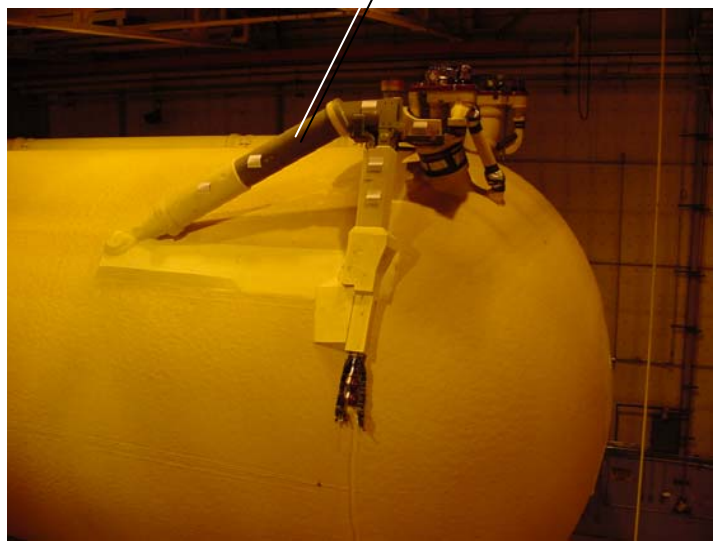
- *Class I Changes Reviewed through DCR Process*
- *STS-114/ET-120 Tanking Test Observations*
- *Waivers / Exceptions*
- *Accepted Risk Hazards*

Redesign ET Thrust Strut Assembly (B02062)

- *Change*
  - Increased thickness on thrust strut lower flange (Al 7050) and end fitting flange (Al 2219)
    - No change to material or process
- *Reason for Change*
  - Contingency abort study identified loads that exceeded ET design capability
    - 'Black Zone' condition identified during early 3 SSME-out condition
    - ET Project directed to redesign thrust strut hardware to support elimination of 'Black Zone' condition
- *Details of Change*
  - Thrust strut lower flange thickness increased from 0.500" to 0.625"
  - End fitting flange thickness increased from 0.500" to 0.675"
  - Weight impact ~ 8 lbs



-Y Thrust Strut (TPS applied)



Redesign ET Thrust Strut Assembly (B02062)

- ***Basis for Certification***
  - **Design condition verified by test and analysis**
    - **FS design = 1.85 (FS req'd = 1.40)**
      - **Test demonstrated FS = 1.46**
  - **Contingency abort condition verified by stress analysis**
    - **FS = 1.14 (FS req'd = 1.0)**

- ***Certification / CoFR Assessment***

System Safety

System Safety Assessment
Decrease in risk

Certification Impacts

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
F/C Impact	No impact	No impact	S516 - √	None

CoFR Assessments

SSP DCR	EAR	ET/SRB Mate	LM Corp PFR	Project PFR	MP01 FRR	FRR
N	N	Y	Y	Y	Y	Y

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- *Waivers / Exceptions*
- *Accepted Risk Hazards*

STS-114/ET-121
Senior Management Review Items

SMR	STS-114/ ET-121	STS-300/ ET-120
• ET-121 LH2 Tank Out of Position Build (SMR 02-002)	X	
• Conathane TPS Tie-Coat Adhesive Acceptability (SMR 04-001)	X	X
• Camera System Battery Replacement (SMR-04-002)	X	X

ET-121 LH2 Tank Out of Position Build (SMR 02-002)

Presenter	M. Quiggle/LM-ET	
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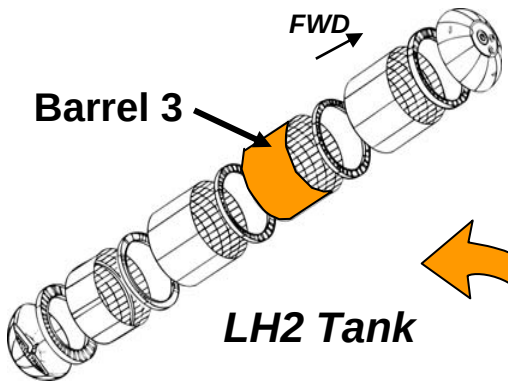
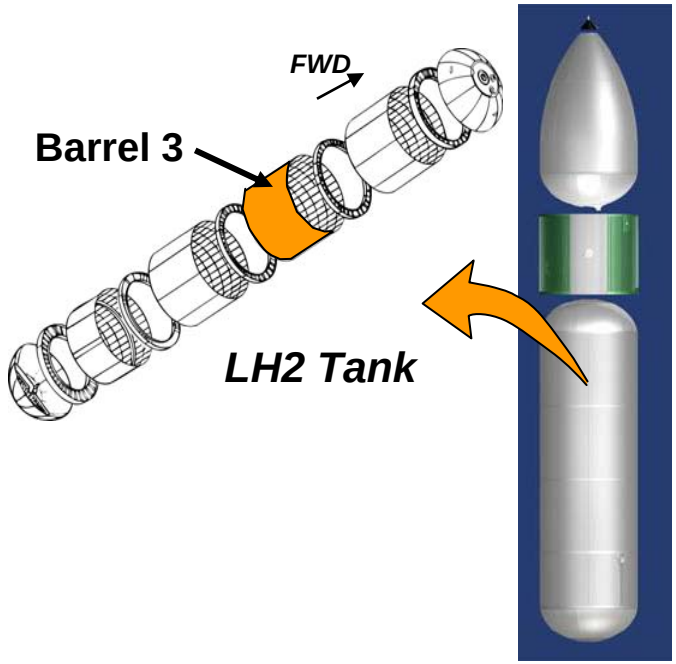


- ***Issue***
  - **Out of position build of ET-121 LH2 tank**
- ***Background***
  - **ET-121 LH2 tank built using partial LH2 tank (domes and barrels 1, 2, and 4) reallocated from ET-117**
    - **Barrel 3 welded to assembly out of position**
- ***Discussion***
  - **Out of position build plan developed**
    - **Modified tooling, weld schedules and flight components to maintain overall length**
    - **Barrel 3 and ring frame between barrels 2 and 3 modified (oversized) to compensate for material loss during removal of discrepant barrel**
  - **Tank reassembled using modified manufacturing process and tooling**
  - **Re-built tank assessed against geometry requirements**
    - **Out of tolerance conditions accepted per MRB - No effect on final fit-up and assembly of hardware**
      - **Cable tray alignment: OOT by 0.018”**
      - **Feedline alignment: OOT by 0.004”**

ET-121 LH2 Tank Out of Position Build (SMR 02-002)

Presenter: M. Quiggle/LM-ET
Date: June 29, 2005

- ***Rationale for Acceptance***
  - **Successful proof test**
  - **Analysis**
    - **Minimum design FS unaffected**
  - **Inspection – No issues**
    - **Visual**
    - **Final assembly of rebuilt hardware**
    - **Post proof NDE**



- ***Disposition: Use as repaired***
  - **LM review, 06/19/02**
  - **MSFC conducted an informal review in addition to the independent NCD review – No issues**

- ***Certification / CoFR Assessment***

System Safety

System Safety Assessment
No change in risk

Certification Impacts

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
No impact	No impact	No impact	No impact	None

CoFR Assessments

SSP DCR	EAR	ET/SRB Mate	LM Corp PFR	Project PFR	MP01 FRR	FRR
N	N	N	Y	Y	Y	Y

Conathane TPS Tie-Coat Adhesive Acceptability (SMR 04-001)

- ***Issue***
  - **Conathane, a two-part tie-coat adhesive material, did not meet the STM 723 (material specification) requirements**
    - **Tensile strength**
    - **Component "A" viscosity**
- ***Background***
  - **Conathane is used to bond foam to a foam substrate**
  - **Qualification tests were required for new sub-tier supplier Component 'A' catalyst**
    - **Catalyst is totally consumed in the formation of Component 'A'**
    - **Tensile strength was below requirement**
    - **Viscosity test violated requirement at the low end of temp range (25±2°C)**
- ***Discussion***
  - **Reviewed qualification requirements**
    - **Tensile requirement (1200 – 1400 psi) was based on early supplier literature**
    - **Supplier tensile tests indicated mean value of 800 psi (no MEK added)**
  - **Instrumental analysis of old and new catalyst detected no discernible differences**
  - **Joint NASA / LM team identified no changes in materials, processes, or testing**
  - **TPS confidence testing of three (3) TPS configurations demonstrated that the Conathane was much stronger than the foam**

Conathane TPS Tie-Coat Adhesive Acceptability (SMR 04-001)

- ***Rationale for Acceptance***
  - **Test data indicated no change in material characteristics**
  - **Material tensile strength exceeds application requirement (600 psi vs 40 psi)**
  - **This Conathane lot used for all TPS applications redesigned, reapplied and tested for RTF**
    - **Testing included Wind tunnel, Hot Gas, Cryogenic Exposure, Cryogenic Cycling, and Thermal / Vac**
- ***Disposition: Use As Is, Revise STM***
  - **LM review, 2/20/04**
  - **MSFC review, 3/18/04**
  - **Conathane STM Revisions (released in May 2004)**
    - **Tensile testing requirement revised to 600 psi minimum (no MEK added) and 400psi minimum (MEK added)**
    - **Tensile test required for each lot**
    - **Viscosity test temp requirement revised from (25±2°C) to (27±1°C)**

- ***Certification / CoFR Assessment***

System Safety

System Safety Assessment
No change in risk

Certification Impacts

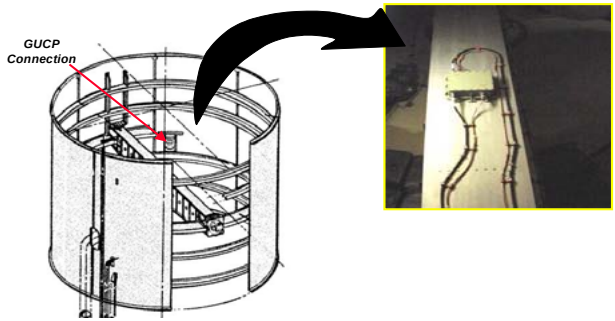
FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
No impact	No impact	No impact	No impact	None

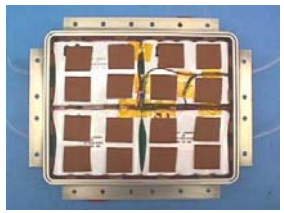
CoFR Assessments

SSP DCR	EAR	ET/SRB Mate	LM Corp PFR	Project PFR	MP01 FRR	FRR
N	N	N	Y	Y	Y	Y

Camera System Battery Replacement (SMR-04-002)

- *Issue*
  - Non-standard repair required for replacement of camera system battery
    - Battery replacement, soldering, and potting not normally performed at MAF
- *Background*
  - ET Camera Packages would not accept battery charge during planned testing
    - Manufacturer suggests 3 – 4 year life on batteries without charge/ discharge cycles and batteries were over 4 years old

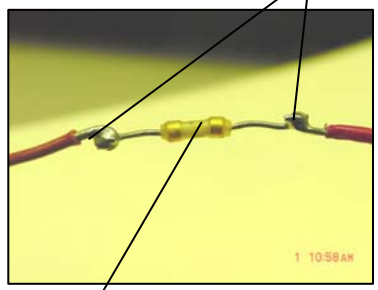


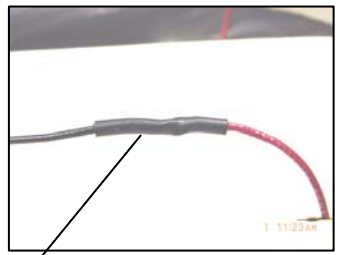


- *Discussion*
  - Battery screening, repair and testing approach presented and approved (approach more rigorous than original procurement)
    - Replace batteries with same manufacturer type
    - Used potting material (RTV) previously approved for use at MAF
      - Same physical properties (vibration and thermal response the same)
    - Use same soldering technique as original procurement

Camera System Battery Replacement (SMR-04-002)

- ***Rationale for Acceptance***
  - **Battery pack replacement performed by certified technicians**
  - **Acceptance testing (charge/discharge, thermal cycling, and vibration) screens out workmanship defects in the battery packs**
  - **Inspection of solder splices verifies workmanship**
  - **Functional testing of the completed flight units verifies operational capability**
    - **Bench top and post-installation testing at MAF**
    - **KSC functional testing**
  - **Battery affects camera system only**
    - **Crit 3 function, not a launch commit constraint**
- ***Disposition: Use As Repaired, Crit 3 Hardware***
  - **LM review, 6/22/04**
  - **MSFC review, 6/29/04**
- ***Certification / CoFR Assessment***





System Safety

System Safety Assessment
No change in risk

Certification Impacts

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
No impact	No impact	No impact	No impact	None

CoFR Assessments

SSP DCR	EAR	ET/SRB Mate	LM Corp PFR	Project PFR	MP01 FRR	FRR
N	N	N	Y	Y	Y	Y

Agenda

Presenter	M. Quiggle/LM-ET	
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Certification Status

Certification Item	*Status*
ALERTs	All cleared
Limited Life Hardware	All items within required life through scheduled launch date +90 days
Personnel Training / Certification	Employee Certification to support launch • Loading / launch support console personnel trained • Ice/Debris Inspection Team members certified for “walk-down” • ET Mission Management Team personnel certified
ICD	All Approved – No issues
OMRSD	All Approved – No issues

LCC	CR S082701 released 6/28/05 - Revises NSTS 08303, Ice/Debris Inspection Criteria
	• Revisions affecting ET are expanded “no ice” zone and documentation of acceptable ice conditions for LO2 feedline bellows, brackets and bipod closeout
	  • ET day of launch probability for July through September unaffected
	  • Probability for October through June launch reduced (lowest probability is February at 65%)

Certification Status

Certification Item	*Status*
Level II Certification Baseline	ET-121 design assessed against Level II requirement through NSTS 07700, Vol. X, Rev M. Change 315 (dtd 6/13/05)
Load / Environment Updates	Additional Assessments Completed • Generic (Istres TAL Certification and PE Certification LH2 Tank Barrel, 2 BP based on IH-108 test) • Mission Specific Analysis (STS-114/ET-121 Bipod TPS closeout)
FMEA/CIL	FMEA/CIL Assessment Complete – The following CILs pending PRCBD approval • Vol. V – Thermal Protection Systems (47 CILs), PRCBD S040221T • Vol. III – Electrical, LO2 feedline bellows heater (1 CIL), CR S040221U
Hazard Analysis	Hazard Analysis Assessment Complete - The following HAR pending PRCBD • E.01, Electrical Fires due to Electrical Malfunctions in the Presence of an Oxidizer and Flammable Materials • E.04, Malfunction of Electrical Heaters on the ET • E.06, ET RTF Instrumentation – Accelerometers and RTDs • P.05, GUCA Separation Malfunctions • T.02, Loss of ET TPS • T.04, ET Ice Debris

Certification Status
Hazard Analysis Report Risk / Cause Matrix

Presenter

Date June 29, 2005

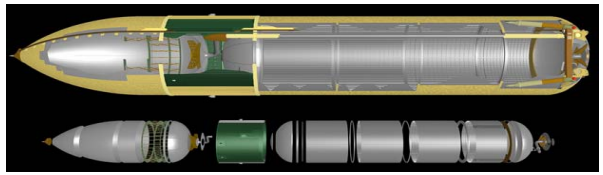
LIKELIHOOD	Marg.	Crit.	Cat.
Probable			
Infrequent			5
Remote			12
Improbable	1		90

Severity

Classification

- *Unacceptable Risk*
- *Accepted Risk*
- *Controlled Risk*

ET Hazard Reports



Hazard Report #		CONTROLLED				ACCEPTED RISK						
		Remote-Marginal	Improbable-Marginal	Improbable-Critical	Improbable-Catastrophic	Probable-Marginal	Infrequent-Marginal	Remote-Critical	Remote-Catastrophic	Probable-Critical	Infrequent-Critical	Infrequent Catastrophic
ACCEPTED RISK HAZARD REPORTS (5)												
E.03	Lightning	0	0	0	0	0	0	0	4	0	0	0
S.09	Hydrogen Venting in Flight	0	0	0	1	0	0	0	2	0	0	0
S.10	Partially Open GO2/GH2 Vent/Relief Valve Indicated Closed	0	0	0	1	0	0	0	1	0	0	0
T.02	Loss of ET Thermal Protection System	0	0	0	8	0	0	0	4	0	0	4
T.04	ET Ice Debris	0	0	0	0	0	0	0	1	0	0	1
CONTROLLED RISK HAZARD REPORTS (24)												
E.01	Elect. Fires Due to Elect. Malfunction in Presence of Oxidizer & Flammable Materials	0	0	0	12	0	0	0	0	0	0	0
E.04	Failure of ET Heaters	0	0	0	5	0	0	0	0	0	0	0
E.05	ET Imaging System Malfunctions	0	1	0	11	0	0	0	0	0	0	0
E.06	ET Return-to-Flight Instrumentation System Failures	0	0	0	6	0	0	0	0	0	0	0
P.01	LH2 / LO2 Tank Overpressure	0	0	0	1	0	0	0	0	0	0	0
P.02	Mechanical/Thermal Shock in the LO2 Tank	0	0	0	4	0	0	0	0	0	0	0
P.03	Binding Of Mechanical Joints	0	0	0	3	0	0	0	0	0	0	0
P.04	Purge Malfunction	0	0	0	3	0	0	0	0	0	0	0
P.05	GUCA Separation Malfunction	0	0	0	7	0	0	0	0	0	0	0
P.06	Propellant Feed System Malfunctions	0	0	0	2	0	0	0	0	0	0	0
P.07	Orbiter / ET Recontact After Separation	0	0	0	2	0	0	0	0	0	0	0
P.09	ET Lands Outside of Footprint	0	0	0	1	0	0	0	0	0	0	0
P.10	Usage of Isopropryl Alcohol for ET Cleaning and Verification	0	0	0	1	0	0	0	0	0	0	0
S.01	Excess Stress in Intertank	0	0	0	2	0	0	0	0	0	0	0
S.02	Failure of Penetration Covers	0	0	0	3	0	0	0	0	0	0	0
S.03	LO2 Tank Buckling	0	0	0	3	0	0	0	0	0	0	0
S.04	LH2 Tank Buckling	0	0	0	3	0	0	0	0	0	0	0
S.05	LO2 and LH2 Tank Negative Differential Pressure	0	0	0	3	0	0	0	0	0	0	0
S.06	Hydrogen Leaks	0	0	0	1	0	0	0	0	0	0	0
S.07	Oxygen Leaks	0	0	0	1	0	0	0	0	0	0	0
S.08	Incipient Weld Leaks	0	0	0	1	0	0	0	0	0	0	0
S.11	ET Structural Systems Debris	0	0	0	3	0	0	0	0	0	0	0
T.01	TPS Flammability	0	0	0	1	0	0	0	0	0	0	0
T.03	Vacuum Bellows Failure	0	0	0	1	0	0	0	0	0	0	0
	Totals	0	1	0	90	0	0	0	12	0	0	5

Design Certification Status Waivers / Exceptions

- ***RTF PRCBD S061954A (05/26/03) and KSC-MK Letter (W. Hale 06/03/03) directed activity re-review of waivers***

  "Develop a plan for review of waivers, deviations and exceptions to program baseline requirements. Verify validity and acceptability. Report results to PRCB. (Return to Flight Constraint.)"

  - **ET Project responded to directive by assessing requirements and hardware and identifying actions required to eliminate waivers / exceptions**
  - **Action closed**
    - **Two waivers and 1 exception eliminated through hardware redesign or requirement revision**
    - **Five waivers and 1 exception retained**

- ***Two new NSTS 07700, Vol X waivers for RTF***
  - **Waiver #706, ESD Sensitive marking of parts, assemblies, and equipment (approved by S061990K)**
    - **Requirement waived for the ET Camera Units - ESD marking of ELVIS hardware not performed (ETs 120 and 121)**
  - **Waiver for ESD Sensitive marking of parts, assemblies, and equipment (approved by S0062637 06/24/05)**
    - **Requirement waived for ET RTF Instrumentation (relay assembly, accelerometers and signal conditioners) - ESD marking of IVIS hardware not performed (ET-119 and 121)**

- ***No Level III deviations***

Agenda

Presenter	M. Quiggle/LM-ET	
Date	June 29, 2005	Page 23

Item	***Presenter***
Overview / Introduction	*Sandy Coleman*
Configuration Change	***Mike Quiggle***
Senior Management Review Items	
Certification Status	
STS-114 / ET-121 Readiness Assessment	
STS-300 (LON) Readiness Assessment	
STS-114 / ET-121 Readiness Statement	
Appendices	

- *Class I Changes Reviewed through DCR Process*
- *STS-114/ET-120 Tanking Test Observations*
- *Waivers / Exceptions*
- *Accepted Risk Hazards*

STS-114/ET-121 Readiness Assessment

- ***CoFR Exceptions - Open Work Identified as Constraint to STS-114***

CoFR Para	*Open Document*	*Associated Documentation*	*ECD*
8.5.4.1 (f)	Six (6) ET Hazard Reports • E.04 Malfunction of Electrical Heaters on the ET • E.06 ET RTF Instrumentation	PRCBD S050411AL	Prior to L-2
	• E.01 Electrical Fires Due to Electrical Malfunctions in the Presence of an Oxidizer and flammable Material • P.05 GUCA Separation Malfunction	PRCBD S050411AN	
	• T.02 Loss of ET TPS • T.04 ET Ice Debris	PRCBD S050411AM	
8.5.4.1 (f)	Forty-eight (48) CILs • Vol. V – Thermal Protection Systems (47 CILs), • Vol. III – Electrical, LO2 feedline bellows heater (1 CIL)	PRCBD S040221T CR S040221U	Prior to L-2

STS-114/ET-121 Readiness Assessment

- ***CoFR Exceptions - Open Work Identified as Constraint to STS-114***

CoFR Para	*Open Document*	*Associated Documentation*	*ECD*
8.5.4.1 (f)	• Certification of Qualification, 132 Bellow Heater • Hardware Certification Sheet E052, Heater Installation	• Bellows Heater Qualification Test Report (809-9714) • Bellows DCR RID C004	Prior to L-2

Agenda

Presenter	M. Quiggle/LM-ET	
Date	June 29, 2005	Page 26

Item	Presenter
Overview / Introduction	Sandy Coleman
Configuration Change	**Mike Quiggle**
Senior Management Review Items	
Certification Status	
STS-114 / ET-121 Readiness Assessment	
STS-300 (LON) Readiness Assessment	
STS-114 / ET-121 Readiness Statement	
Appendices	

- Class I Changes Reviewed through DCR Process
- STS-114/ET-120 Tanking Test Observations
- Waivers / Exceptions
- Accepted Risk Hazards

STS-300/ET-120 LON Readiness Assessment

Presenter: M. Quiggle/LM-ET
Date: June 29, 2005

Item	Assessment Status	Open Work
Senior Management Review Items		
• Conathane TPS Tie-Coat Adhesive Acceptability (SMR 04-001)	Complete	None
• Camera System Battery Replacement (SMR-04-002)	Complete	None
• GO2 Vent Duct Breakthrough (SMR 04-003 Delta)	Complete	None
Changes		
• LO2 feedline flange Material Spec Revision (B02053B)	Complete	None
• Zinc chromate primer replacement (B02027)	Complete	None
• Delete LO2 low level pressure transducer test (B02076)	Complete	None
• Redesign thrust strut assembly (B02062)	Complete	None
• Eliminate foam ramp over bipod fittings (B02093A)	Complete	None
• Intertank / LH2 tank flange TPS closeout enhancement and partial LH2 PAL ramp re-spray (B02093A)	Complete	None
• Redesigned Longeron TPS closeout (B02093D)	Complete	None
• Expanded Intertank TPS vented TPS area (B02093A)	Complete	None
• Implement ET camera system (B02093A)	Complete	None
• Replace lubricated thru bolts on bipod struts (B02089)	Complete	None

STS-300/ET-120 LON Readiness Assessment

Presenter: M. Quiggle/LM-ET
Date: June 29, 2005

Item	Assessment Status	Open Work
Changes (cont'd)		
• Redesigned ET portion of ET/SRB bolt catcher (B02085)	Complete	None
• Redesign ET ground umbilical (B02091)	Complete	None
• LO2 feedline bellows drip lip (B02093A)	Complete	None
• Forward LO2 feedline bellows heater system (B02093D)	Complete	HCS, COQ, F/C, HAR
Level II Environments Updates		
• Mission Specific Environments for ET-120 (LON)	Preliminary assessment complete – No issues	None
• ECO Sensor Measurement Anomaly	Preliminary assessment complete – No issues	None for ET-120 flight
• Prepress Anomaly Resolution	Complete	None
• LO2 Feedline Foam Damage	Assessment in work	Disposition in work
• Crack / Ice /Frost on Bipod TPS Closeout	Preliminary assessment complete – No issues	Update to NSTS 08303 in work

Items requiring closure prior to STS-300 (LON) FRR

Agenda

Presenter	M. Quiggle/LM-ET	
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Item	***Presenter***
Overview / Introduction	*Sandy Coleman*
Configuration Change	***Mike Quiggle***
Senior Management Review Items	
Certification Status	
STS-114 / ET-121 Readiness Assessment	
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- *Class I Changes Reviewed through DCR Process*
- *STS-114/ET-120 Tanking Test Observations*
- *Waivers / Exceptions*
- *Accepted Risk Hazards*

STS-114/ET-121 Readiness Assessment

Presenter	M. Quiggle/LM-ET	
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The External Tank, ET-121, is ready for STS-114 launch pending completion/closure of open and planned work

Michael Quiggle, ET Project Chief Engineer
Lockheed Martin Space Systems Company

Neil Otte, Chief Engineer
Marshall Space Flight Center, External Tank

Ronald Wetmore, ET Project Manager
Lockheed Martin Space Systems Company

Sandra Coleman, Manager
Marshall Space Flight Center, External Tank

External Tank Project
MP01 FRR

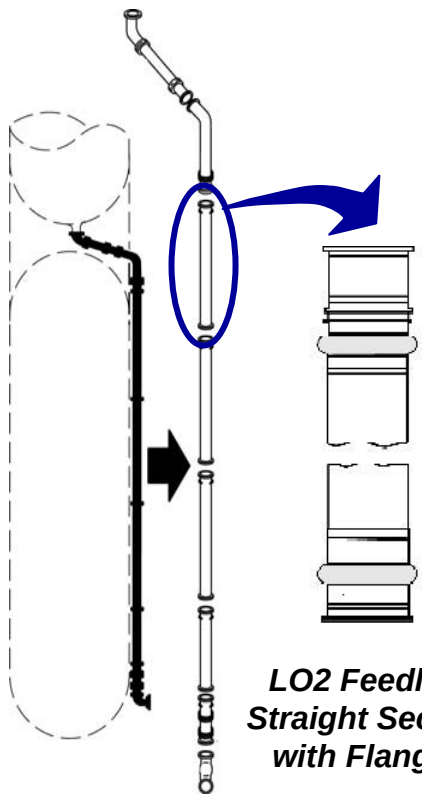
STS-114/ET-121

Appendix A
Class I Changes Reviewed through DCR

June 29, 2005

Revise LO2 Feedline Flange Material Spec Revision (B02053B)

- Change
  - Changed supplier of LO2 feedline flanges
    - Increased minimum mechanical property requirements
    - No change to configuration
- Reason for Change
  - Previous supplier disapproved
- Basis for Certification
  - Analysis
    - Higher minimum mechanical properties based on based on T851 (was T62)
  - Hardware hydrostatic proof test for acceptance
  - Certification reassessed for RTF – no change



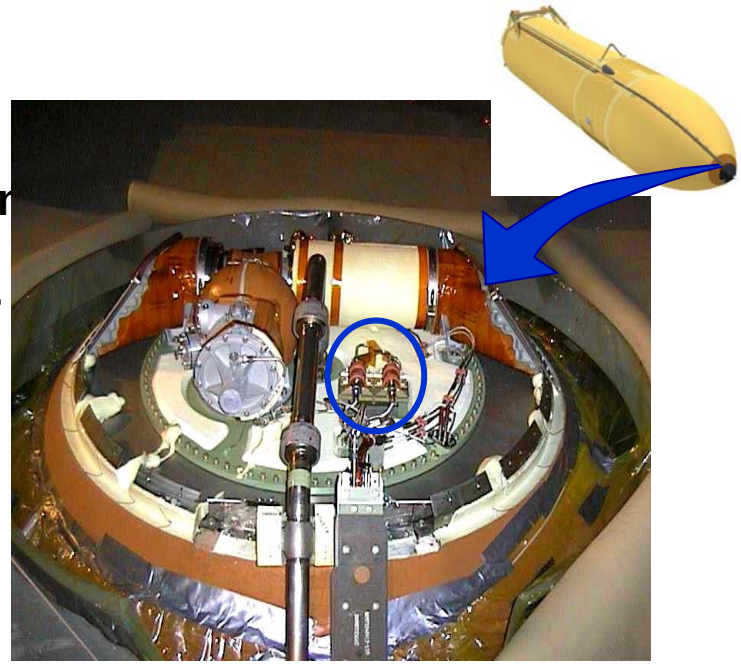
LO2 Feedline Straight Section with Flanges

Replace Zinc Chromate Primer (B02027)

- Change
  - Replaced zinc chromate primer with EPA compliant corrosion barriers
    - Anodize or epoxy (water-base) used in place of zinc chromate
    - No change to configuration
    - Intertank interior components, such as angle clips and roll ties
      - Primary Intertank structure (skin/stringer and thrust panels) was changed during SLWT program
    - Primer on the exterior surfaces, which have TPS applied, was not changed
- Reason for Change
  - Comply with EPA requirements
- Basis for Certification
  - Test
    - Anodize coating and epoxy satisfy Mil spec salt spray requirements
    - Coatings qualified for flight

Delete LO2 Low Level Pressure Transducer Channelization Test (B02076)

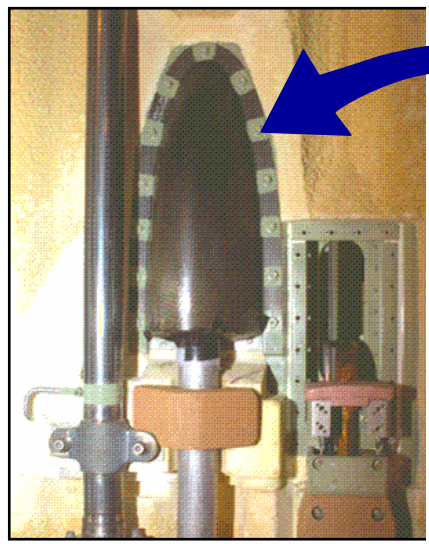
- Change
  - Deleted LO2 low level pressure transducer channelization test from MAF acceptance and checkout
- Reason for Change
  - Test not required for transducers with connectors
    - Test was initiated for earlier configuration with lead wires
  - Harness pre-installation test verifies proper wire channelization to connectors
- Basis for Certification
  - Post installation functional test verifies proper installation
  - Sensors are for ground use only



Low Range Ullage Pressure Transducers on LO2 Tank Cover Plate

Requalify GH2 Pressline Fairing Resin Catalyst (B02067)

- Change
  - New subtier GH2 Pressline Fairing resin catalyst supplier
    - Supplier discontinued production
- Description of Change
  - No structural configuration changes
  - No material type change
    - Replacement material (AS4/3501- 6) has well documented material property database
    - Large database of material property test data provided by NASA MSFC SRB (nosecone project)
    - Same material used for Intertank Access Door
      - Implemented and flown on STS-112/ET-115
- Basis for Certification
  - Design is certified by test and analysis
  - A-basis allowables generated by NASA SRB CNC
  - Aerothermal testing performed on flat graphite/ epoxy laminates to design heating environments
    - All articles passed with no ply loss
      - Minimum FS = 4.75 (FS req'd = 1.40)
        - Failure Mode: Stability



"Make" SLWT Intertank at MAF (B02040)

- Change
  - Intertank Skin/Stringer Panels and SRB Beam assembly moved to MAF for 6th buy build
- Description of Change
  - No structural configuration changes
  - Producibility design enhancement changes
    - Hi-sets changed to Hi-Loks Rivets on panel chords
    - Pilot holes added to detail parts
    - Dimensions and tolerances revised for MAF assembly processes and tooling
    - Net trimmed chords installed
  - Updated tooling, manufacturing, and handling requirements
    - Modified Facilities and prepared MPPs and N/C programs
- Basis for Certification
  - Inspection
    - Intertank engineering requirements and design FS are unchanged
  - Assembly performed by certified technicians

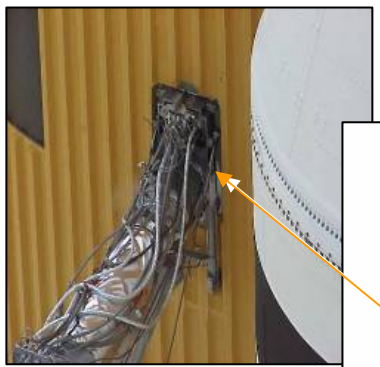
SRB CrossBeam

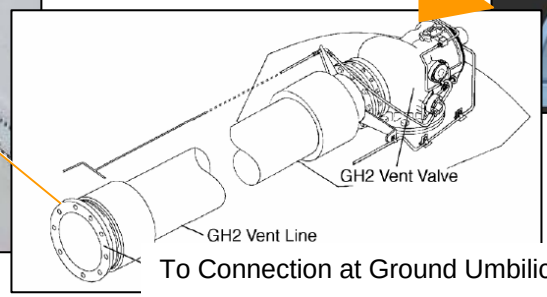
Intertank Half Section

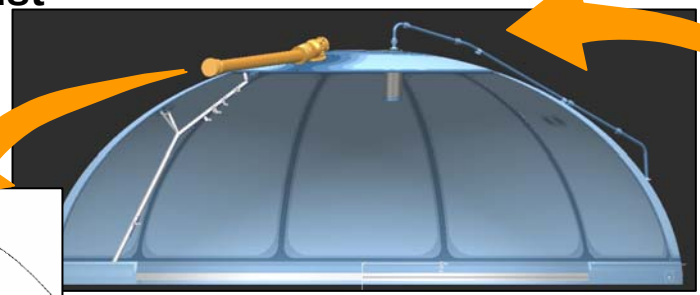
Intertank Complete

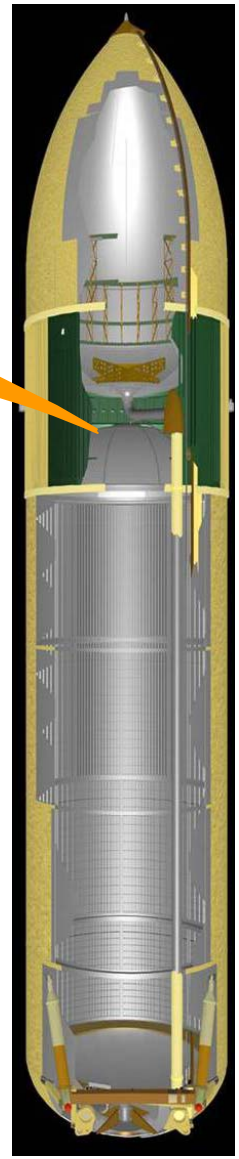
Change GH2 Vent Line Supplier (B02053B)

- Change
  - GH2 Vent Line supplier changed (prior supplier out of business)
- Description of Change
  - New supplier uses new tooling and enhanced process to form bellows
  - New hydrostatic forming process replaced operator dependent process
    - Process is more stable and robust









- Basis for Certification
  - Re-qualification and acceptance testing performed to verify hardware integrity
  - GH2 Vent Line engineering requirements and structural design FS are unchanged

Redesigned Bipod Fitting

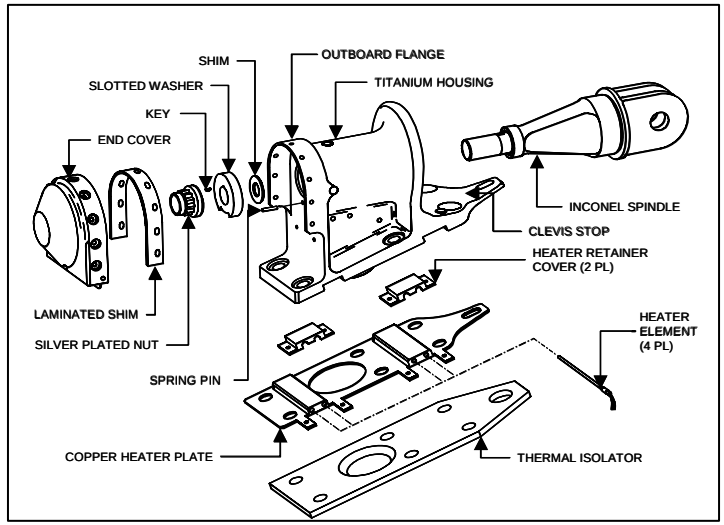
- Change
  - Redesigned the ET bipod fittings to eliminate the foam ramp over the fittings
- Reason for Change
  - Loss of STS-107/ET-93 left hand bipod ramp identified as most likely contributor to Columbia Accident
    - Dissection of flight hardware identified critical substrate geometry-induced voids existed in the STS-107 configuration foam ramp
      - Tests showed most likely cause of STS-107 foam loss attributed to large internal defects in bipod ramp closeout
        - Liquid Nitrogen (LN2) ingestion was also identified as an additional load environment that could contribute to large-scale foam loss

STS-107 Configuration

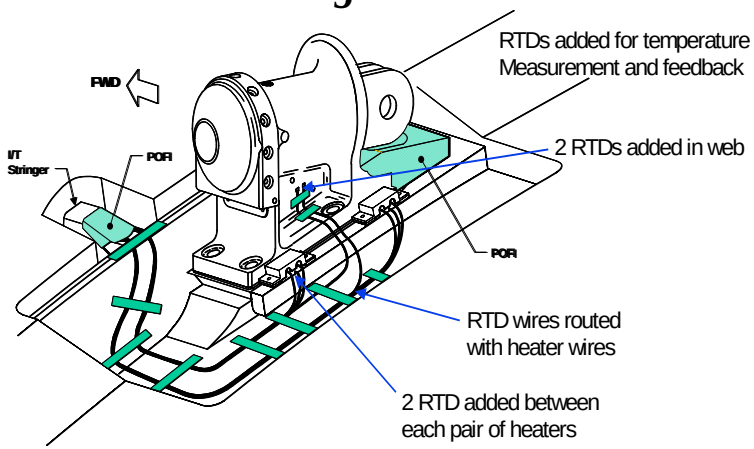
STS-114 Configuration

Redesigned Bipod Fitting

- Details of Change
  - Structure
    - Titanium fitting
      - Machined slots to accommodate heaters
      - Added drain holes
      - Deleted lockwire on fitting fasteners
    - End Cover
      - A286 end cover (no SLA required)
      - Reduced flange
      - Added high temperature nut plates
    - Isolator
      - Reduced thickness by 0.050”
      - Added copper plate for installation of heaters
  - Electrical
    - (4) 300-w heaters each bipod fitting
    - Two (2) Al 2219-T87 heater retainer covers
    - Four (4) Resistance Temperature Devices to each bipod (2 in web, 1 each center of heater slots)



Fitting Structure



ET to ground connector J3 increased from a 32 pin to 55 pin connector to account for addition of RTDs

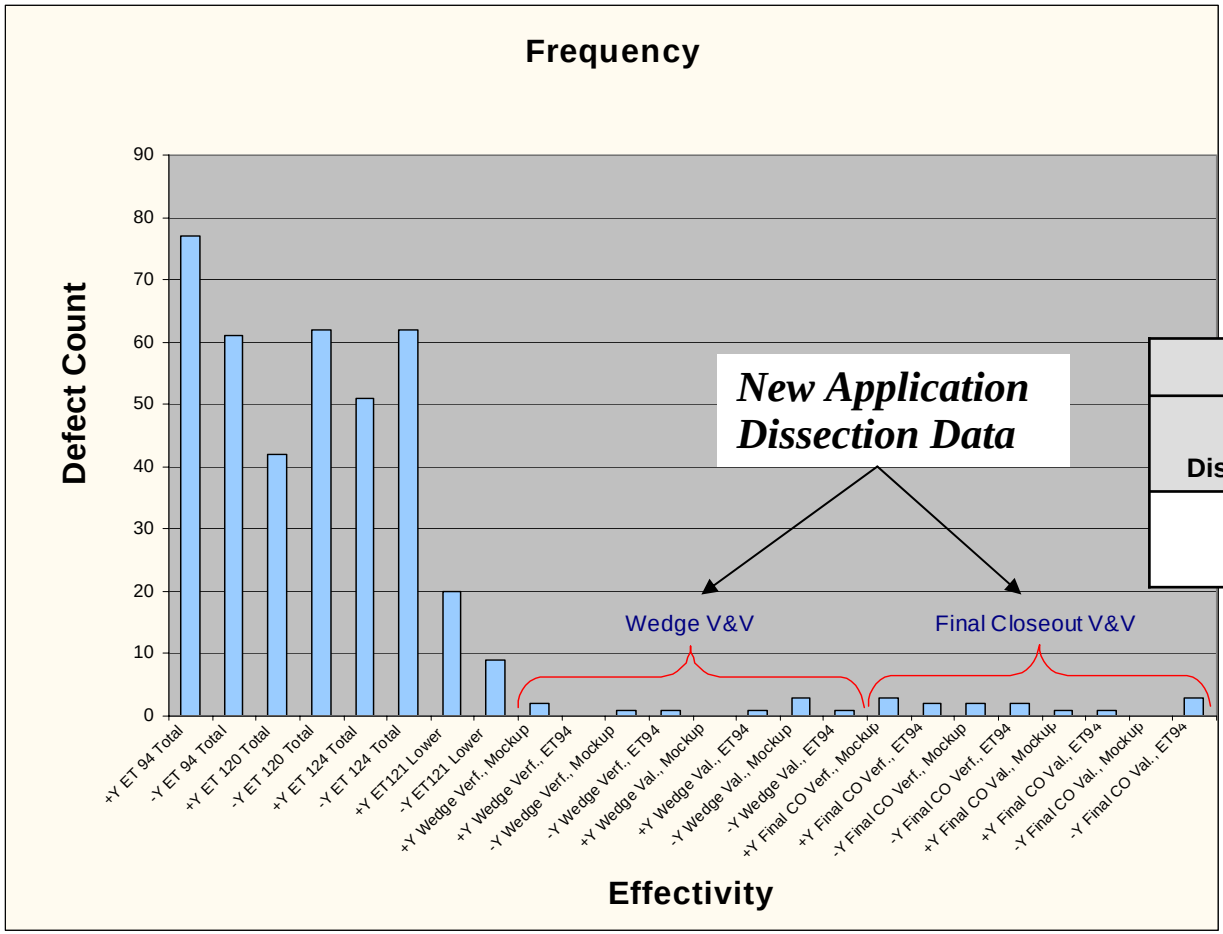
Redesigned Bipod Fitting

- Details of Change
  - TPS
    - Eliminated SOFI ramp over fitting
    - Redesigned closeout application process to reduce complexity
    - Modified closeout under spindle to create clearance for end fittings
    - Enhanced spray techniques and implemented additional process controls to reduce application variability

- *Process optimized to reduce frequency and size of voids*
- *Lead-in, lead-out high-fidelity 'witness' panels required for each production spray application*

Redesigned Bipod Fitting

- **Design Verification Summary – Process Yield Assessment**
  - **Bipod redesign has significantly reduced void count from previous design**

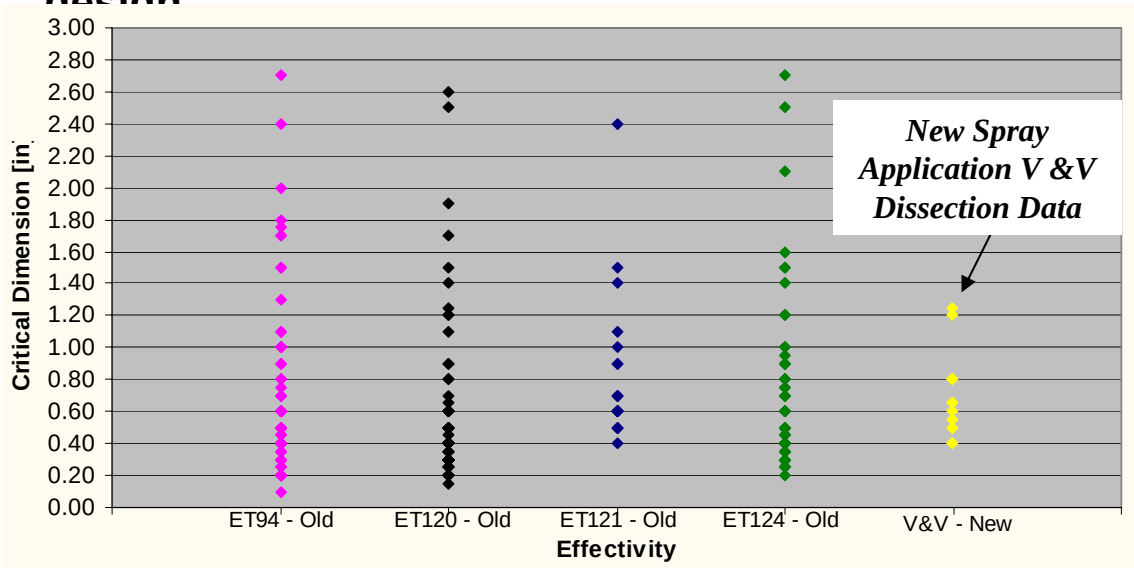


Bipod Closeout Dissection Locations

Dissection Data		
# of Dissections	# of Parts (V&V)	Foam dissected
8	*4 (2 ea)*	*24 linear ft.* *21600 cu. In.*

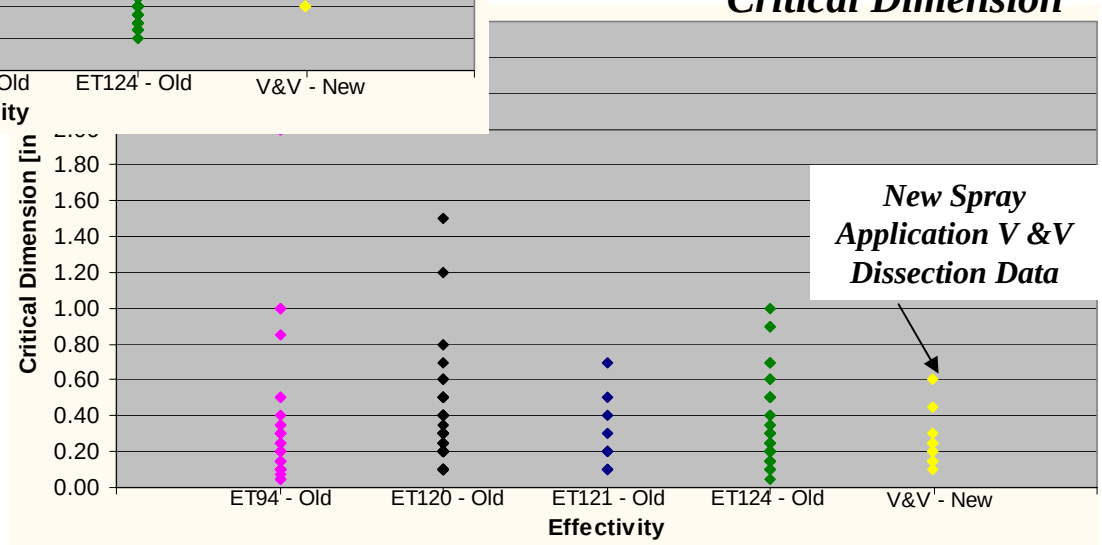
Redesigned Bipod Fitting

- **Design Verification Summary – Process Yield Assessment**
  - **Bipod redesign has significantly reduced void sizes and quantity from previous design**



Cylindrical Void Critical Dimension

Slot Void Critical Dimension

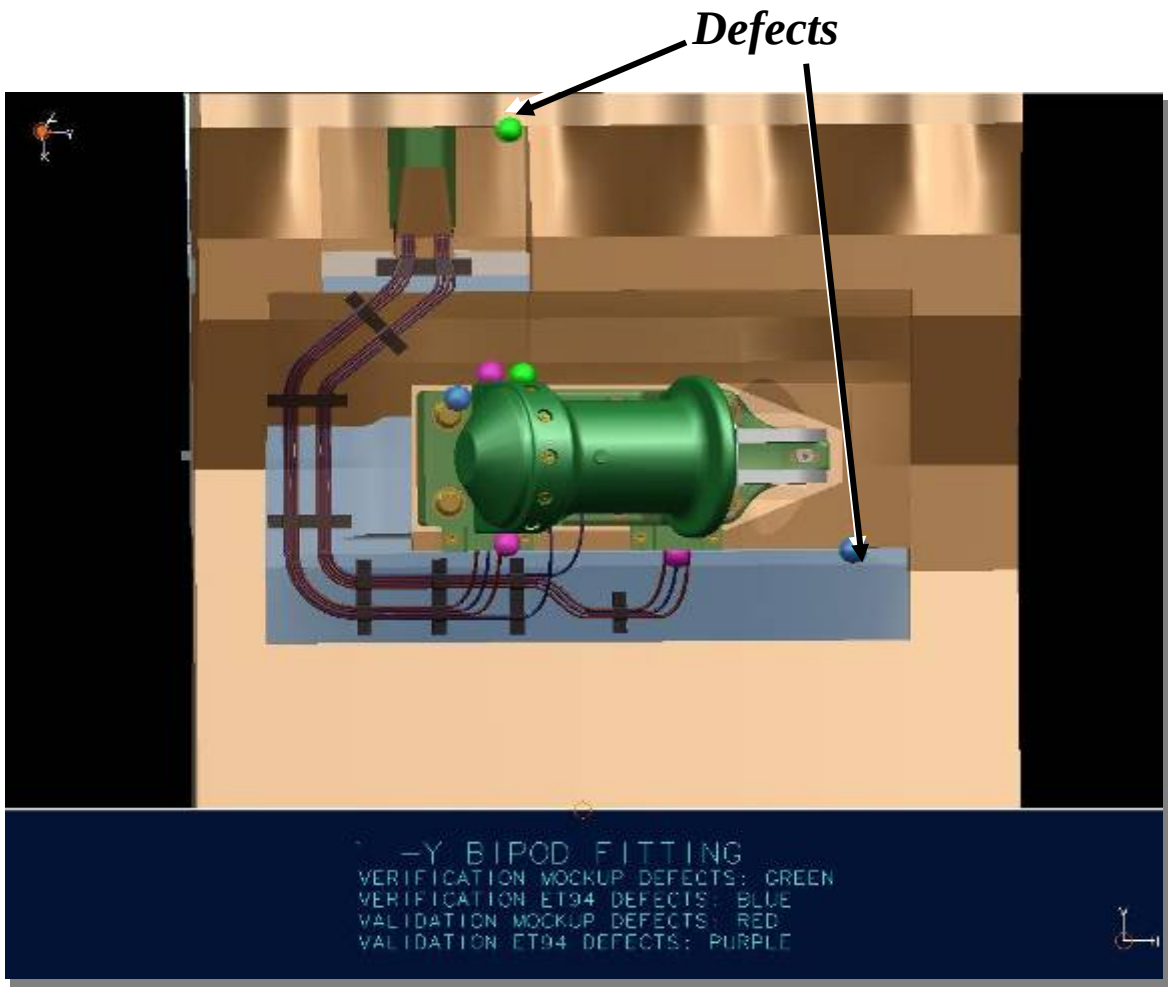


Redesigned Bipod Fitting

- Design Verification Summary – Process Yield Assessment
  - Hardware dissection void data assessed for susceptibility to cryoingestion / cryopumping loading
    - Voids are considered susceptible to cryoingestion if,
      - 1) Located within 0.5 inch to a cryogenic substrate and
        - 0.5 inch criteria based on thermal analysis prediction of depth where the temperature is below -320°F for flange / bipod thickness range
      - 2) Located adjacent to a known leak path to the Intertank
        - Critical for Bipod and Flange ONLY
    - Voids are considered susceptible to cryopumping * if,
      - 1) Located within 0.5 in (BX) / 1.0 in (PDL) to a cryogenic substrate and
        - 0.5 inch criteria based on thermal analysis prediction of depth where the temperature is below -320°F
      - 2) Viable leak path to OML
        - Viable leak path defined as an unimpeded crack from the OSL to the critical void
        - Subsurface conathane bondlines provide additional reinforcement to prevent crack growth to a critical void and further reduce probability
        - Cracks not expected by design (positive MS) but possible

Redesigned Bipod Fitting

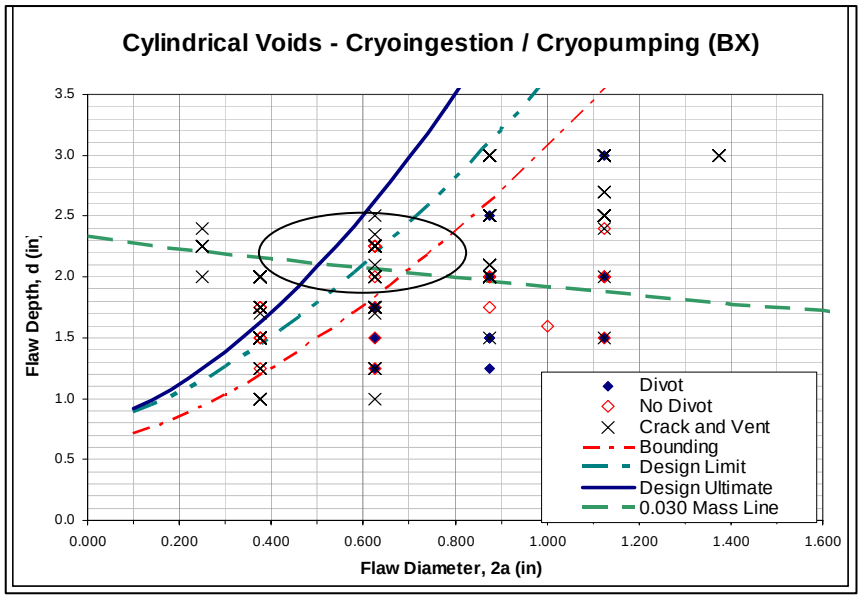
- Design Verification Summary – Process Yield - Results
  - Void locations from Bipod V&V dissections

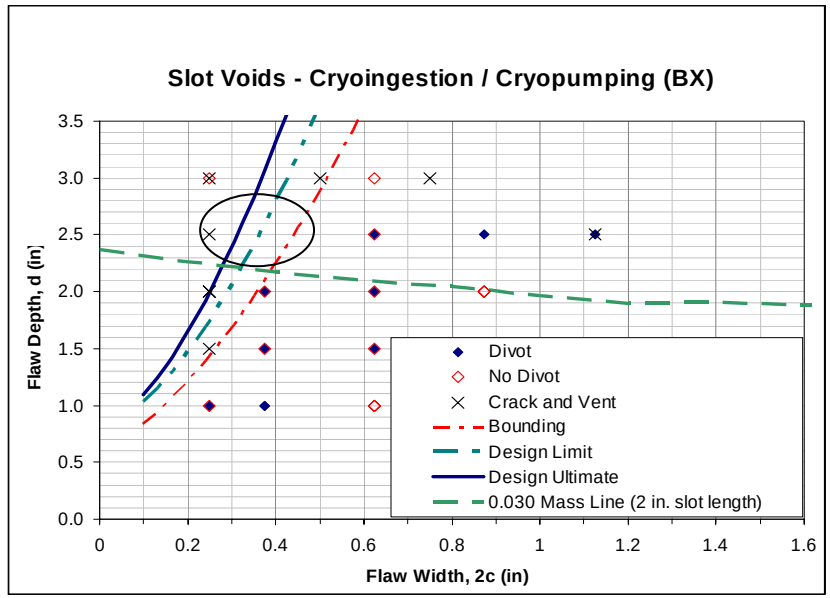


- ***All defects geometry based***
- ***No observed defects located in regions susceptible to either cryoingestion or cryopumping***

Redesigned Bipod Fitting

- Design Verification Summary – Cohesive Strength Margin Assessment
  - LH2 Flange and Bipod TPS Closeouts (BX)
    - LEFM used to define shape of bounding divot / no-divot curve
      - Linear shape function used for cryoingestion data





	CDS		
Defect Type	Bounding	Design Limit	Design Ult.
Cyl	0.69	0.59	0.50
Slot	0.39	0.32	0.28

Redesigned Bipod Fitting

- Design Verification Summary – Cohesive Strength Design Margin Assessment
  - Bipod TPS assessed for cryoingestion / cryopumping condition using largest observed or dissection criteria size limited defect sizes in susceptible locations
    - Susceptible locations defined as adjacent to known intertank structure leak paths and cryogenic substrate (< 0.5" from substrate is only region below -320°F during Prelaunch)
    - Assessment performed using ultimate defect acceptance criteria for BX
    - Defect size includes 1.40 uncertainty factor
  - No defects observed in locations susceptible to cryoingestion or cryopumping
  - Analysis shows acceptable margins for both non-cryopumping and cryopumping conditions

Allowable Defect Size (0.030 lbm)		*Observed Defects*			*TPS Debris MS (SF = 1.25)*	
Cylinder (D, in.)	*Slot (W, in.)*	*# of Defects*	*# of Defects/*	*Max (in.)*	*Cylinder*	*Slot*
1.90	*0.85*	23	1/ linear ft.	1.25	*0.09*	*0.35*
0.50	*0.28*			0.30	*0.19**	*0.00**

**Cryoingestion/Cryopumping Condition assumed minimum recordable defect to calculate MS (0.3 cylinder, 0.2 Slot). Divoting not expected*

BX-265				Estimated TPS Debris Mass (lbm)	
Application / Dwg. No.	Debris Table ID	Station/s	Debris Req. (lbs)	Limit (SF = 1.0)	Ult. (SF = 1.25)
Bipod	ET-COMP10-004-00-A	1123	0.030	0.0200	0.0250

Redesigned Bipod Fitting

- **Redesign Verification / Certification Framework**

Bipod Redesign Verification / Certification

- ***Bipod Structures***
  - ***HCS S508: Fwd ET/Orb Bipod Strut, Yoke, & Fitting***
- ***Propulsion ****
- ***Bipod Electrical***
  - ***COQ 129: Bipod Heater***
  - ***COQ 130: Bipod Temp Sensor***
- ***Bipod TPS***
  - ***Materials***
    - ***HCS T503: Ice/Frost Foam (PDL 1034)***
    - ***HCS T504: Closeout foams (BX-250, BX-265, SS1171)***
  - ***TPS Applications***
    - ***HCS T540: Fwd Bipod Closeout (Re-Design)***

Note: Re-certified LO2 feedline support components due to increased loads due to ramp elimination

- ***HCS S507: LO2 Feedline Support Base, Yoke and Strut Assemblies***
- ***HCS S520: Propellant Feedline Installation (LO2/LH2)***

* *Analysis completed and reviewed at PSIG showing Bipod Heaters have no effect on propellant quality*

Redesigned Bipod Fitting

- Certification Summary, Non-TPS
  - Tests
    - Electrical
      - Heater and temperature sensor component qualification and acceptance
      - Electrical wire bonding demonstrated adhesive strength capability for design environments
    - Structure
      - Fitting verification test performed with combined load and thermal environments
        - Verified no impact to rotational capability
        - Demonstrated 261% of DLL for critical design condition (strut tension)
      - Fitting-to-tank joint preload test demonstrated torque / preload performance to verify acceptable joint gapping design margin
      - LO2 feedline component structural test demonstrated > 140% of DLL for all components
        - Removal of bipod ramp resulted in higher design air loading for LO2 feedline and reactions for support structure
    - Thermal
      - System testing of flight-like hardware performed to demonstrate ice/frost prevention requirements and operational performance

Redesigned Bipod Fitting

- Certification Summary, Non-TPS
  - Analysis
    - Stress analysis shows adequate design FS for critical design condition (strut tension)
      - Min. FS = 1.51 (Req'd = 1.40)
      - Failure Mode: Tank Fitting Inboard Lug Ultimate
    - Venting and thermal analysis performed using Level II provided environments to generate requirement for input to stress analysis

Redesigned Bipod Fitting

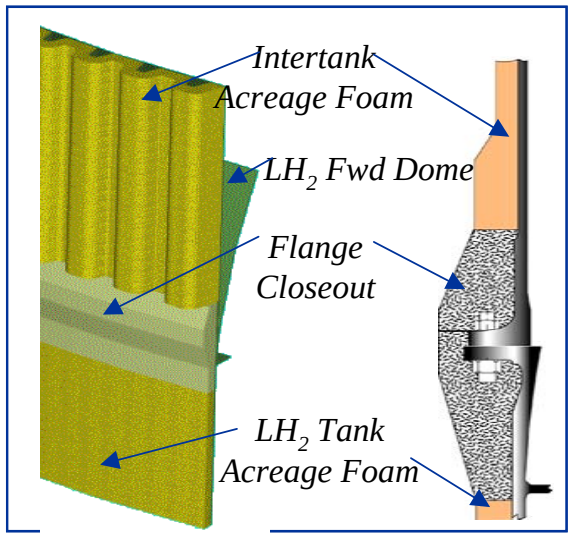
- Certification Summary, TPS
  - Demonstration
    - Manual spray process verified / validated on full-scale article
      - Pre-control used to establish process performance requirements
      - As-sprayed acceptance testing used to verify critical performance requirements
        - Tensile strength, dissections, and density tests performed and inspected on HFPTA and/or witness panels
  - Tests / Analyses
    - Thermal verification – System meets ice/frost prevention requirements
      - Heaters / temperature sensors configuration test verified with flight-like hardware
    - Structural verification
      - Application process verification / validation
        - Demonstrated through dissection / mechanical property test of flight-like hardware
      - Wind tunnel – Simulating multiple load environments, simulated debonded foam closeout and material capability of the foam in front of the bipod fitting (high temperature and shear test environments)
      - Delamination at web interface using predicted temperature gradients for ascent environment

Redesigned Bipod Fitting

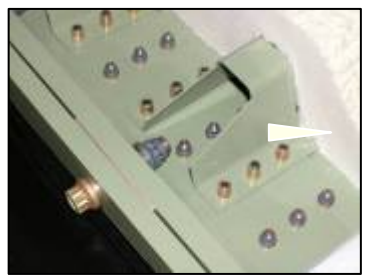
- Certification Summary, TPS
  - Tests / Analyses
    - Venting and thermal analysis performed using Level II provided environments to generate requirement for input to stress analysis
    - Stress analysis – Hardware meets FS requirements
      - Assessed for cryoingestion / cryopumping condition using largest observed
      - Test-based verification demonstrates FS > 1.25 for critical failure mode (Bondline Delamination)
        - Cryogenic wide panel testing demonstrates 214% design limit mechanical strain
      - Cohesive Strength
        - Positive margins with FS = 1.25 for cryoingestion condition using maximum observed defect size x 1.40
        - No defects found that would be susceptible to cryoingestion
          - Analysis uses dissection criteria limited value for defect size (0.30 in. dia.)
    - Systems test
      - Bipod heater and control systems
      - Demonstrated prelaunch cryogenic cycle load requirement (13 cryo cycles) with ascent load thermal / vacuum loading
- Certification Status

Intertank/LH2 Tank Flange Enhancement

- Change
  - Reduce / eliminate foam defects by enhancing closeout +/-112° from +Z axis (includes +Z stringer panels and both thrust panels)
- Reason for Change
  - Foam loss observed from Intertank/ LH2 tank flange closeout on 65% of flights with useable imagery
- Details of Change
  - Reversed Flange Bolts
    - Reduces potential for voids formation on upper flange
    - Provides operator a much less complex configuration for lower flange foam spray application
    - Higher profile nut end encapsulated in stringer end foam closeout
  - Reduced possible external LN2 leak paths in structure and fasteners
    - PDL TPS used as point fill material
    - Loctite used for LN2 barrier
  - Three-Step closeout applied using equipment and process recommendations and enhancements identified by the TPS Working Group and the Manual Spray Enhancement Team (MSET)



Intertank to LH2 Tank Flange

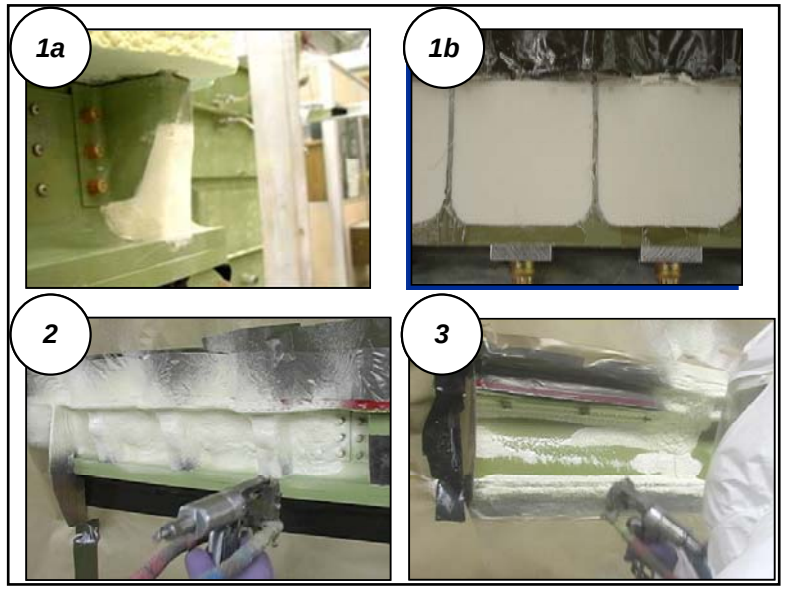


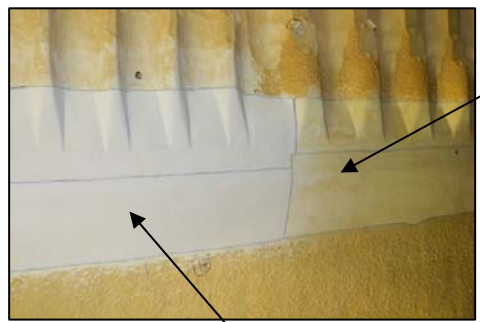
Bolt End on Lower Flange Provides Less Complex Application

Inject PDL in Gaps in Structure

Intertank/LH2 Tank Flange Enhancement

- Details of Change: Three-Step Application
  - Step 1
    - BX 265 foam is used in support of stringer cavity injections and thrust panel pocket closeouts
      - Injection molds are used to ensured that stringer is filled to the required height and voids have been minimized
      - Pockets are sprayed and trimmed in preparation for final closeout
  - Step 2
    - Apply BX 265 foam to the upper section of the flange closeout
      - Spray covers the stringer end caps and fills in the remaining metal substrate and machined to drawing requirements
  - Step 3
    - Apply BX 265 foam to the lower side of the flange



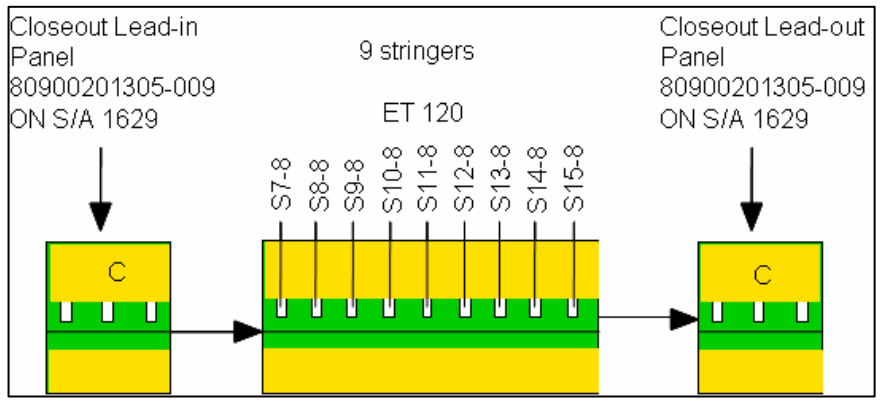


Existing flange closeout (outside of critical debris zone)

ET-120 Enhanced Flange Closeout, Trimmed / Machined

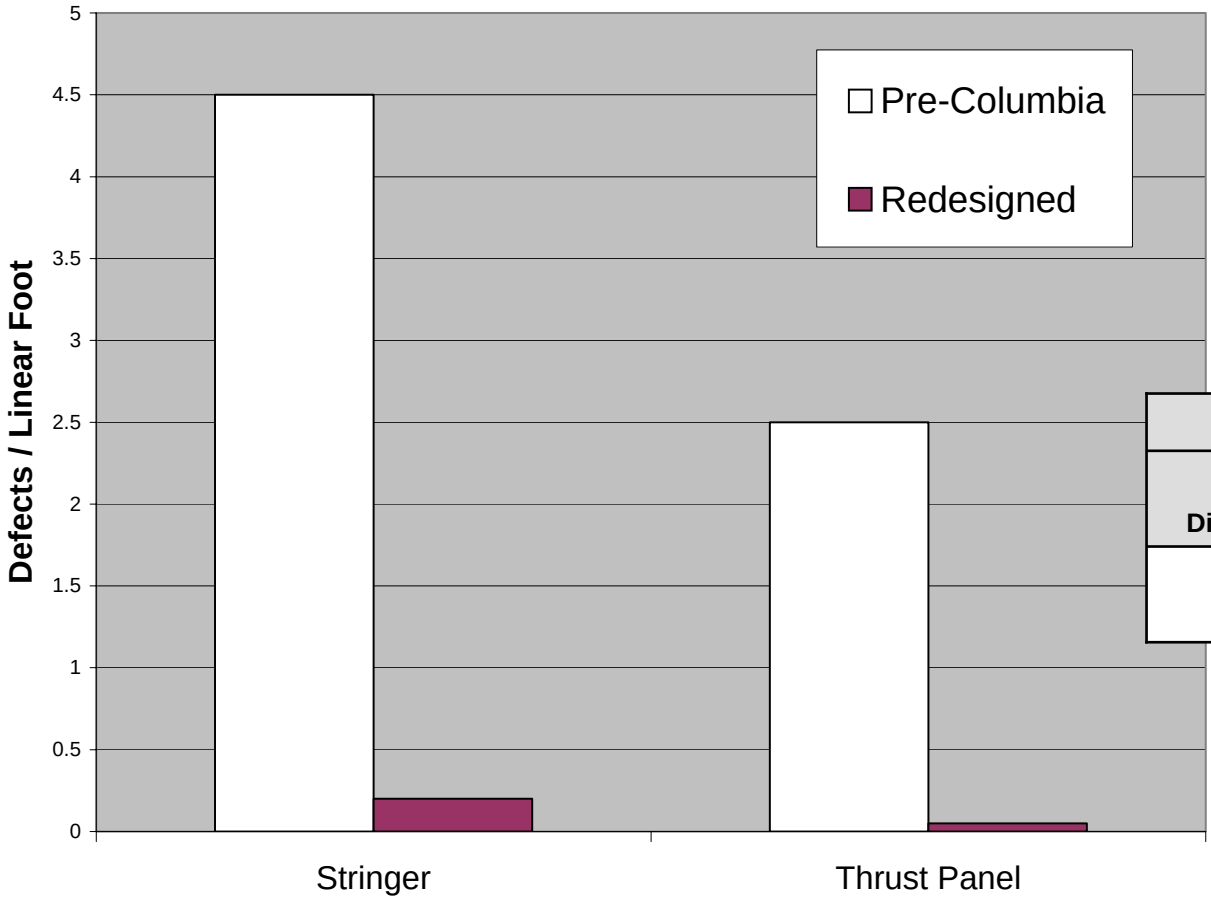
Intertank/LH2 Tank Flange Enhancement

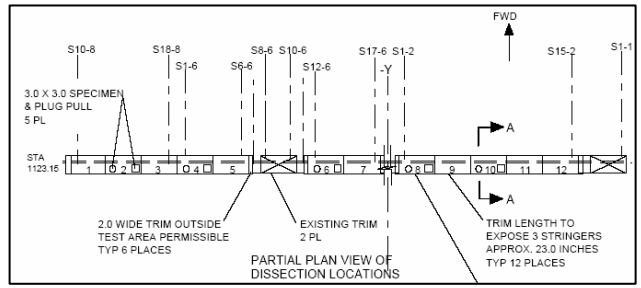
- Design Overview (cont'd)
  - Stringer panel injection and manual thrust panel pocket and final closeout sprays performed by certified technicians using verified and validated application technique
  - Process verified
    - Dissection / mechanical property test of high fidelity full-scale test articles process with production article and lead-in/lead-out flat panels
    - Review of spray video and critical processing parameters (proportioner data)
  - Process controlled in MPP
    - Equipment/critical processing parameters
      - Gun output pressure
      - Substrate / cell temperature
      - Spray technique
      - Spray overlap time
    - Continuous monitoring/ recording of critical parameters



Intertank/LH2 Tank Flange Enhancement

- **Design Verification Summary – Process Yield Assessment**
  - **Flange redesign has significantly reduced void count from previous design**



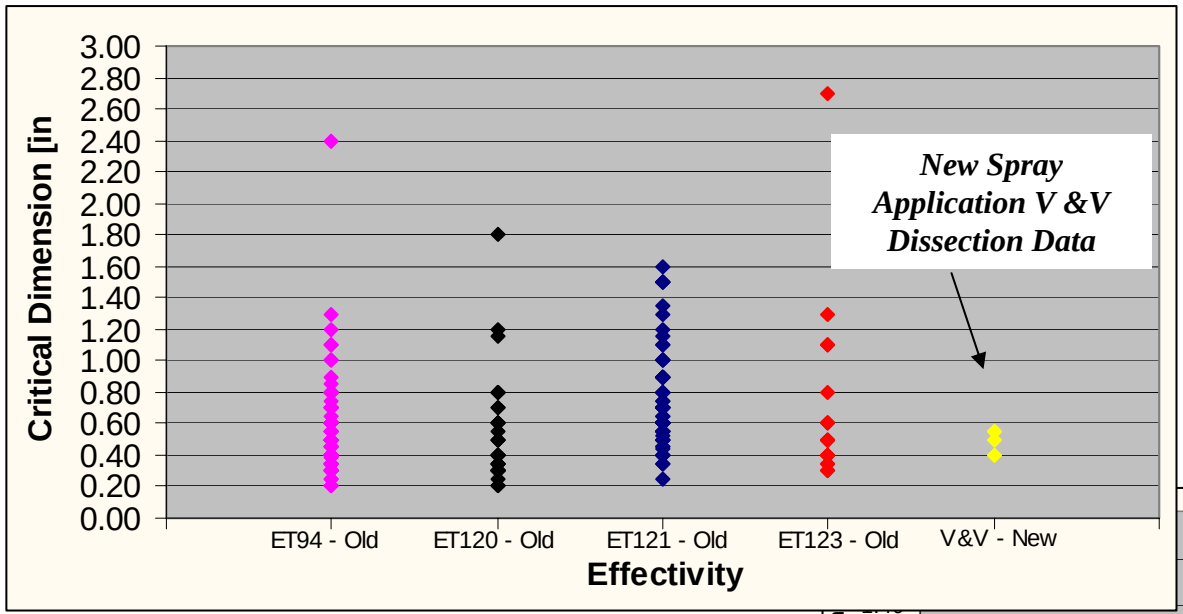


Flange Closeout Dissection Locations

Dissection Data		
# of Dissections	**# of Parts (V&V)**	**Foam dissected**
1	***6***	***80 linear ft. 24449 cu. in***

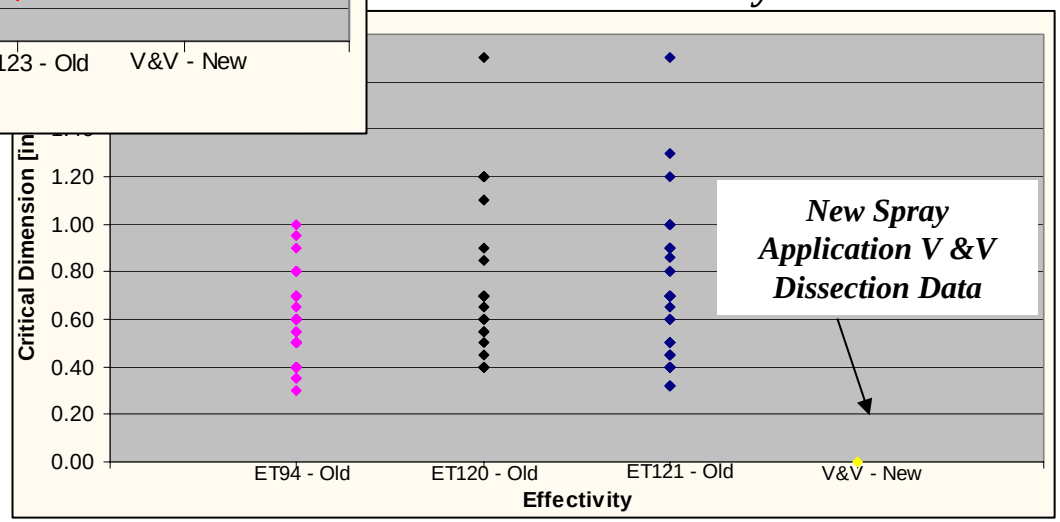
Intertank/LH2 Tank Flange Enhancement

- **Design Verification Summary – Process Yield Assessment**
  - **Flange redesign has significantly reduced void sizes from previous design**



Stringer Area Critical Dimension Cylindrical Voids

Thrust Panel Critical Dimension Cylindrical Voids

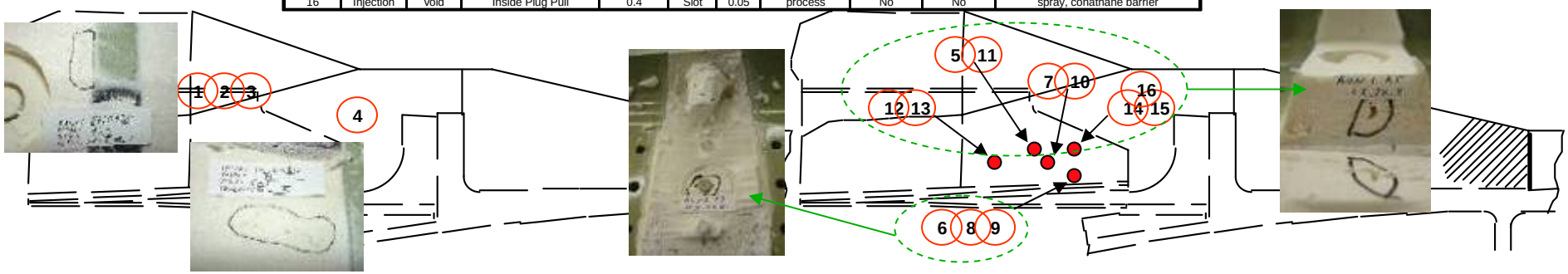


- Design Verification Summary – Process Yield Assessment
  - Hardware dissection void data assessed for susceptibility to cryoingestion / cryopumping loading
    - Voids are considered susceptible to cryoingestion if,
      - 1) Located adjacent to a known leak path to the Intertank
        - Critical for Bipod and Flange ONLY
      - 2) Located within 0.5 inch to a cryogenic substrate and,
        - 0.5 inch criteria based on thermal analysis prediction of depth where the temperature is below -320°F for flange / bipod thickness range
    - Voids are considered susceptible to cryopumping if,
      - 1) Located within 0.5 in. to a cryogenic substrate and
        - 0.5 inch criteria based on thermal analysis prediction of depth where the temperature is below -320°F
      - 2) Viable leak path to OML
        - Viable leak path defined as an unimpeded crack from the OSL to the critical void
        - Subsurface conathane bondlines provide additional reinforcement to prevent crack growth to a critical void and further reduce probability
        - Cracks not expected by design (positive MS) but possible

Intertank/LH2 Tank Flange Enhancement

- **Design Verification Summary – Process Yield Assessment**
  - **Defects assessed for susceptibility to cryoingestion / cryopumping**

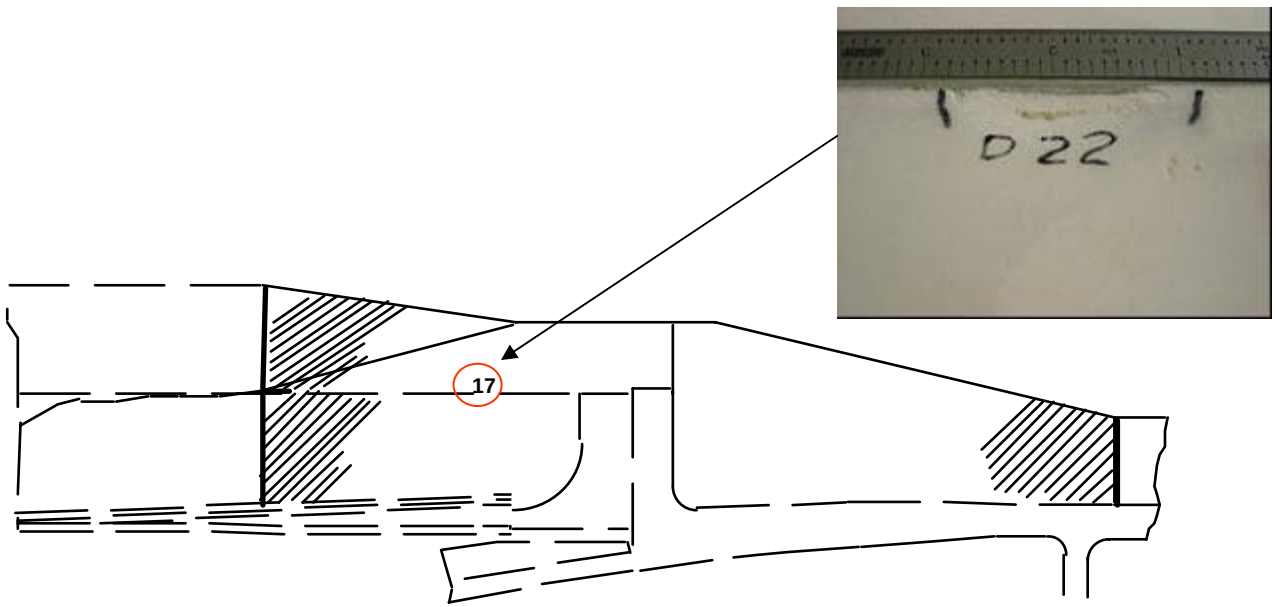
Defect Number	Part	Defect	Description	Dist. from Sub. [in]	Defect Type	Crit. Dim.	Process Segregation	Cryo-ingestion	Cryo-pumping	Rationale
1	Flange C/O	void	At top of left side of stringer	2.7	Cylinder	0.55	Geometry	No	No	Shallow depth
2	Flange C/O	void	At top of left side of stringer	2.7	Cylinder	0.50	Geometry	No	No	Shallow depth
3	Flange C/O	void	At top of right side of stringer	2.7	Slot	0.15	Geometry	No	No	Shallow depth
4	Flange C/O	void	left side in valley b/t stringer 3&4, 1" above flange, flush with top of flange	2.0	Slot	0.15	process	No	No	Shallow depth
5	Injection	void	Stringer side of plug pull, 0.6 " up from substrate	0.6	Cylinder	0.55	process	No	No	Above 0.5", under Final closeout spray, conathane barrier
6	Injection	void	On Substrate around hiset, under plug pull	0.0	Cylinder	0.40	Geometry	Yes	No	No Cryo-pumping, under Final closeout spray, conathane barrier
7	Injection	void	Stringer side of plug pull, 0.4 " up from substrate	0.4	Slot	0.30	process	No	No	Above substrate, under Final closeout spray, conathane barrier
8	Injection	void	top of hiset under p/p core	0.0	Slot	0.20	Geometry	Yes	No	No Cryo-pumping, under Final closeout spray, conathane barrier
9	Injection	void	fwd of hiset under p/p core	0.0	Slot	0.20	Geometry	Yes	No	No Cryo-pumping, under Final closeout spray, conathane barrier
10	Injection	void	3" from flange, 0.4" up from Substrate	0.4	Slot	0.20	process	No	No	Above substrate, under Final closeout spray, conathane barrier
11	Injection	void	Stringer side of plug pull, 0.6 " up from substrate	0.6	Slot	0.20	process	No	No	Above 0.5", under Final closeout spray, conathane barrier
12	Injection	void	Up inside Stringer	0.4	Slot	0.20	process	No	No	In stringer, Above substrate, under Final closeout spray, conathane barrier
13	Injection	void	Up inside Stringer	0.4	Slot	0.20	process	No	No	In stringer, Above substrate, under Final closeout spray, conathane barrier
14	Injection	void	Inside Plug Pull	0.3	Slot	0.10	process	No	No	Above substrate, under Final closeout spray, conathane barrier
15	Injection	void	Inside Plug Pull	0.5	Slot	0.10	process	No	No	Above substrate, under Final closeout spray, conathane barrier
16	Injection	void	Inside Plug Pull	0.4	Slot	0.05	process	No	No	Above substrate, under Final closeout spray, conathane barrier



Intertank/LH2 Tank Flange Enhancement

- **Design Verification Summary – Process Yield Assessment**
  - **Defects assessed for susceptibility to cryoingestion / cryopumping**

Defect Number	Part	Defect	Description	Dist. from Sub. [in]	Defect Type	Crit. Dim.	Process Segregation	Cryo-ingestion	Cryo-pumping	Rationale
17	Pocket	Rollover	Rollover along top of rib, would normally be machined out before next spray	2.0	Slot	0.10	Geometry	No	No	Above 0.5", under Final closeout spray, conathane barrier



Intertank/LH2 Tank Flange Enhancement

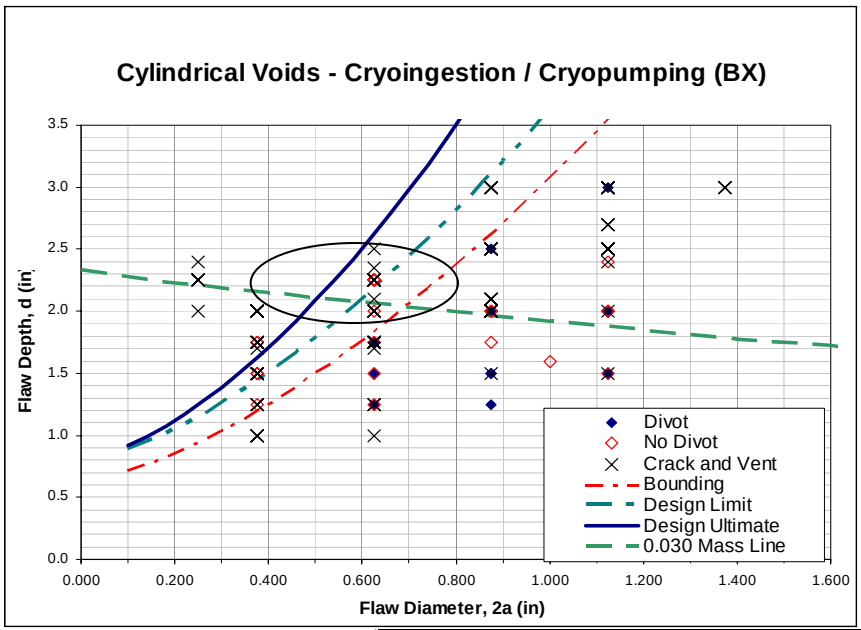
- Design Verification Summary – Cohesive Strength Margin Assessment
  - LH2 / Intertank flange TPS assessed for cryoingestion / cryopumping condition using largest observed or dissection criteria size limited defect sizes in susceptible locations
    - Susceptible locations defined as adjacent to known intertank structure leak paths and cryogenic substrate (< 0.5” from substrate is only region below -320°F during Prelaunch)
    - Assessment performed using ultimate defect acceptance criteria for BX
    - Defect size includes 1.40 uncertainty factor
  - Only one defect observed in locations susceptible to cryoingestion
    - 0.40 inch diameter cylindrical void @ 3.0 in depth
    - 0.20 inch width slot void assumed based on dissection technique

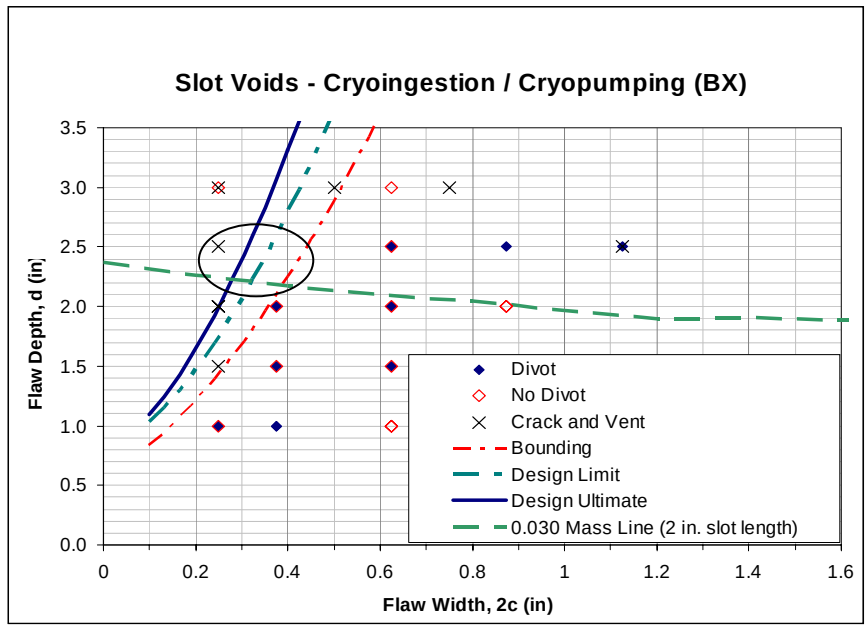
Allowable Defect Size (0.030 lbm)		Observed Defects			TPS Debris	
					MS (SF = 1.25)	
Cylinder (D, in.)	Slot (W, in.)	# of Defects	# of Defects/ linear ft. or cu. In.	Max (in.)	Cylinder	Slot
1.90	0.85	*12*	*0.2 / linear ft.*	*0.55*	1.47	0.84
0.50 *	0.28 *			*0.30*	0.19*	0.00*

*Cryoingestion**

Intertank/LH2 Tank Flange Enhancement

- Design Verification Summary – Cohesive Strength Margin Assessment
  - LH2 Flange Defect Acceptance Criteria – Cryoingestion / Cryopumping
    - LEFM used to define shape of bounding divot / no-divot curve
      - Linear shape function used for cryoingestion data

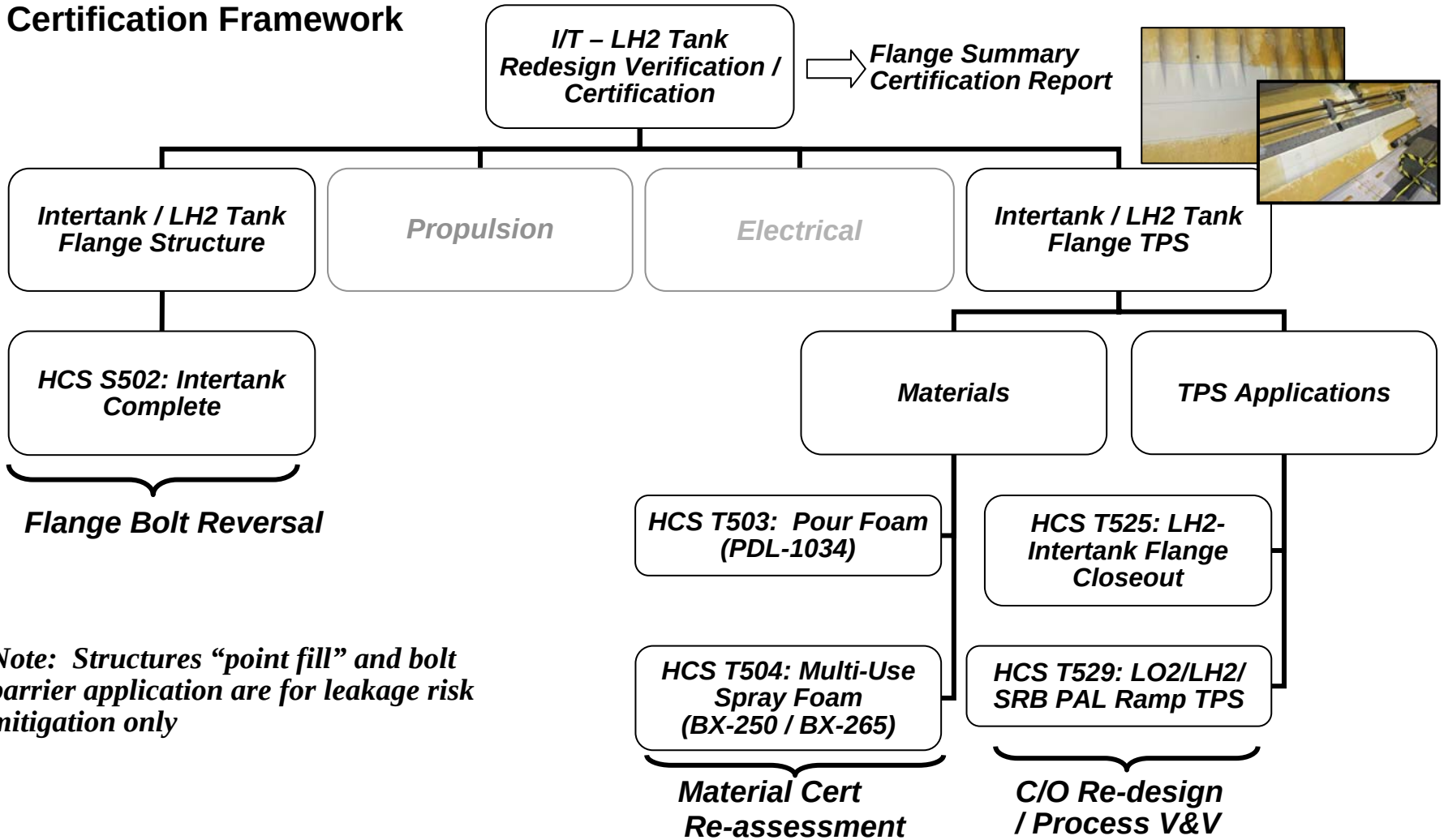




	CDS		
Defect Type	Bounding	Design Limit	Design Ult.
Cyl	0.69	0.59	0.50
Slot	0.39	0.32	0.28
Cyl (3.0 in depth)	-	-	0.65
Slot (3.0 in depth)	-	-	0.35

Intertank/LH2 Tank Flange Enhancement and Partial LH2 PAL Ramp Replacement

- **Intertank / LH2 Tank Flange Closeout and Partial LH2 PAL Ramp Verification / Certification Framework**



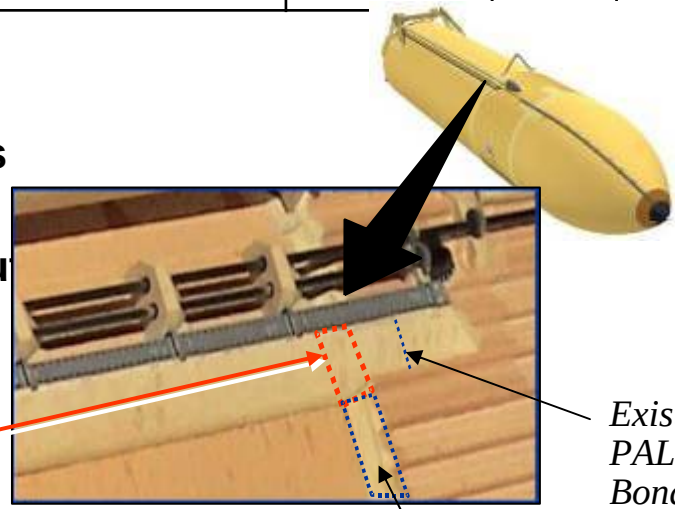
Note: Structures "point fill" and bolt barrier application are for leakage risk mitigation only

Intertank/LH2 Tank Flange Enhancement

- Certification Summary
  - Demonstration
    - Manual spray process verified / validated on full-scale article
      - Pre-control used to establish process performance requirements
      - As-sprayed acceptance testing used to verify critical performance requirements
        - Tensile strength, dissections, and density tests performed and inspected on HFPTA and/or witness panels
  - Tests / Analyses
    - Test-based verification demonstrates FS > 1.25 for critical failure modes
      - Bondline Delamination
        - Cryogenic wide panel testing demonstrates 214% design limit mechanical strain
      - Cohesive Strength
        - FS = 1.25 for cryoingestion condition using maximum observed defect size x 1.40
        - Analysis uses dissection criteria limited value for defect size (0.30 in dia.)
    - Systems test successfully demonstrated prelaunch cryogenic cycle load requirement (13 cryo cycles) with ascent load thermal / vacuum loading
      - Baseline testing completed with no divots
      - Testing also included engineered defects representative of largest observed during Process Verification / Validation x 1.40
        - 4 panels tested (2 stringer panel and 2 thrust panel) – no divots
        - Dissection of test article in progress

Partial LH2 PAL Ramp Respray

- Change
  - Replace forward 10 ft. of LH2 PAL ramp with enhanced, verified and validated TPS process
- Reason for Change
  - Required to access underlying flange closeou
    - Design unchanged
- Details of Change
  - Replaced PAL ramp section using process recommendations and enhancements identified by the TPS Working Group and the Manual Spray Enhancement Team (MSET)
    - Removed and replaced GO2 and GH2 pressline sections and top half of forward LH2 ice/frost ramp
    - PAL ramp bondline relocated
    - Outer mold line unchanged
  - Closed out plug pulls with verified and validated repair method



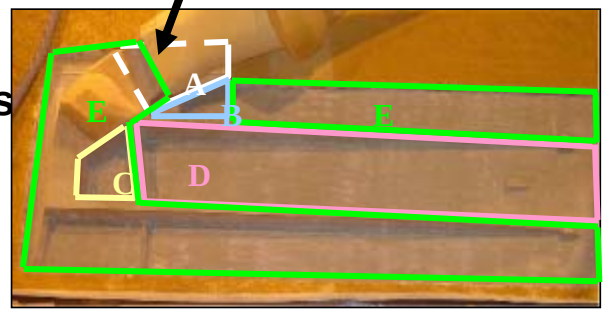
ET-120 LH2 PAL Ramp Fwd 10 ft. Re-spray

Partial LH2 PAL Ramp Respray

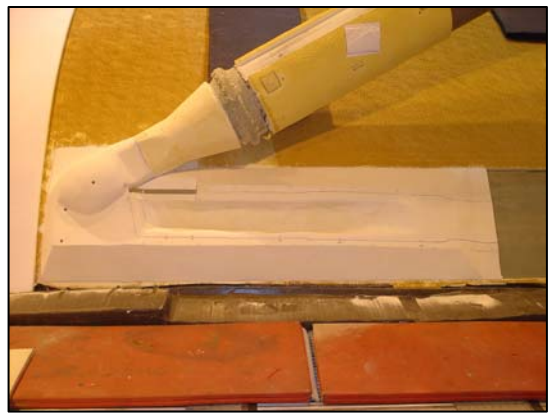
- Certification Summary
  - Demonstration
    - Manual spray process verified / validated on full-scale article
      - Pre-control used to establish process performance requirements
      - As-sprayed acceptance testing used to verify critical performance requirements
        - Tensile strength, dissections, and density tests performed and inspected on HFPTA and/or witness panels
  - Tests / Analyses
    - Test-based verification demonstrates FS > 1.25 for critical failure modes
      - Outer Fiber Cracking / Bondline Delamination
        - Cryogenic / Flexure testing demonstrates 125% design limit structural flexure induced loading
      - Cohesive Strength
        - Min. MS = 0.25 (SF req'd = 1.25) using maximum observed defect size x 1.40
        - Critical max. observed defect size is 0.40 in. slot width
  - Non-destructive inspection (using development techniques) of existing and replace PAL ramps showed no defects in excess of criteria dimension acceptance criteria
- Certification Status

Reapply TPS on Longeron

- Change
  - Removing/replacing longeron closeouts with enhanced,
    verified, and validated application process
- Reason for Change
  - Dissection of longeron closeout on the dissection test article (ET-94) showed geometry induced defects and areas of inadequate adhesive strength at substrate
  - RTF tank (ET-120) had smaller voids and similar areas of reduced strength at substrate
- Details of Change
  - Replacing longeron closeouts with enhanced design and application process
    - Multiple-step closeout employed to reduce application complexity
    - Adhesive impregnated scrim over “C” pocket
    - Near net spray in “D” pocket
  - Closed out plug pulls with verified and validated repair method



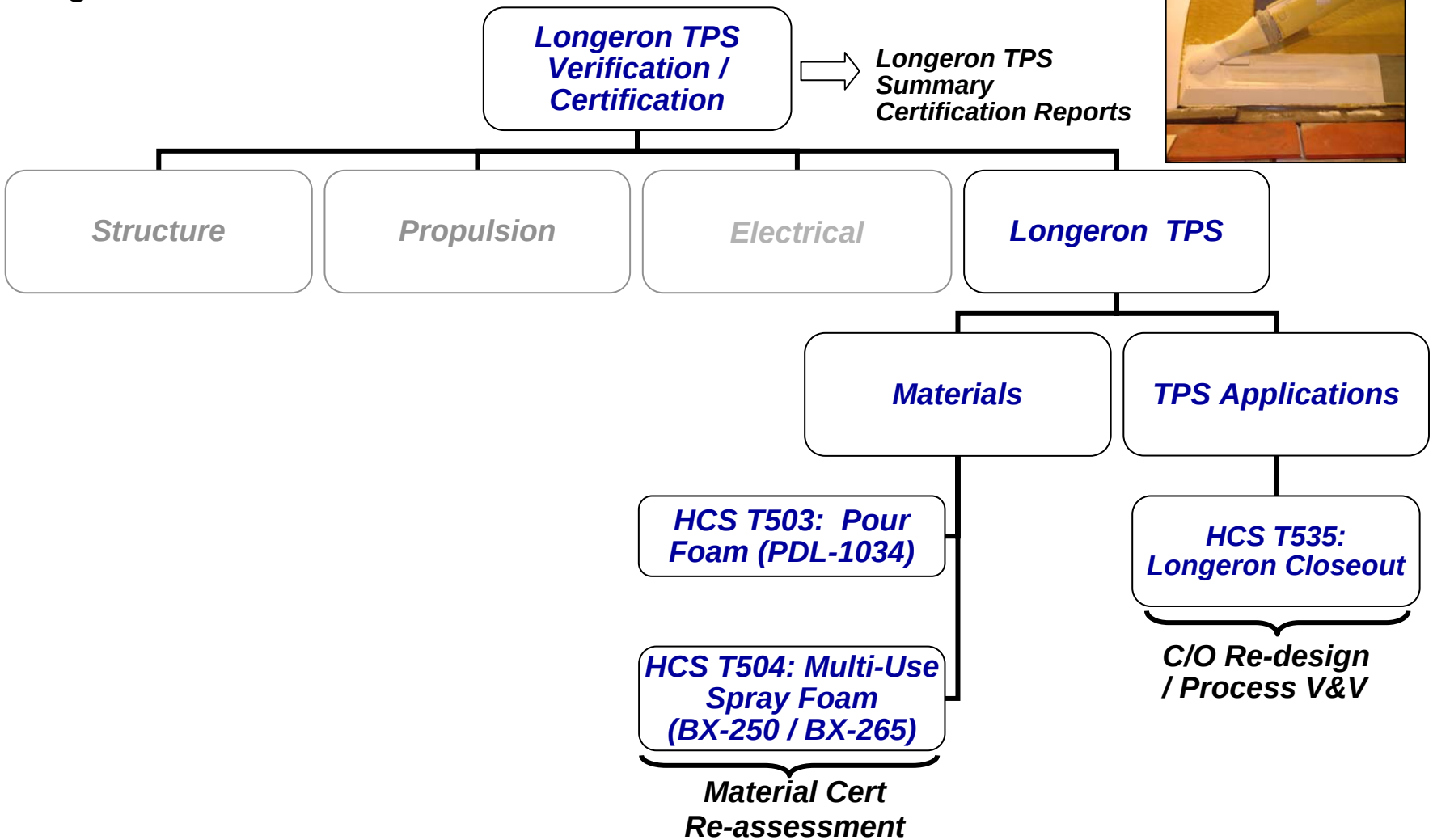
Multiple-Step Closeout



Redesigned Longeron Closeout

Reapply TPS on Longeron

- **Longeron Closeout Verification / Certification Framework**

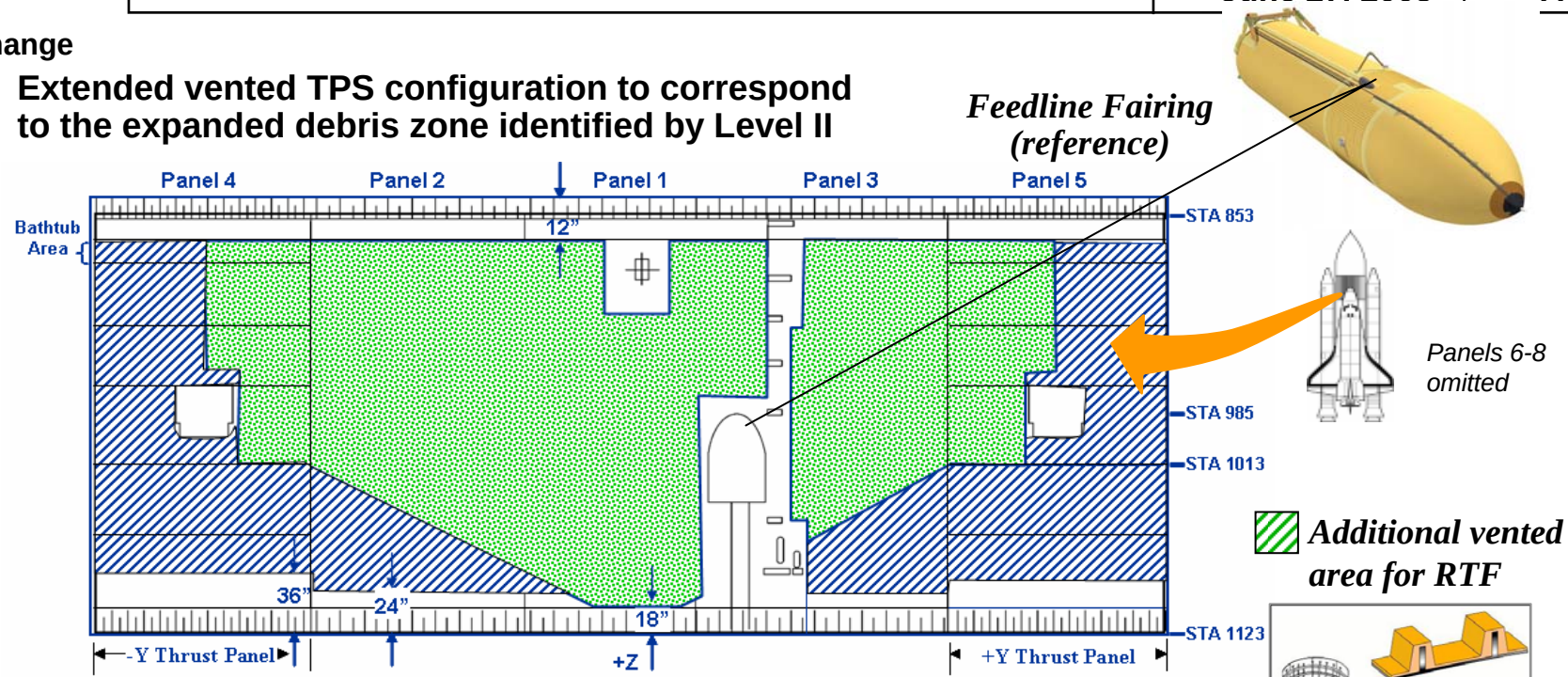


Reapply TPS on Longeron

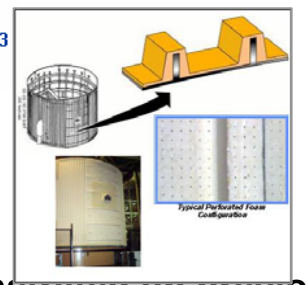
- Certification Summary
  - Demonstration
    - Manual spray / pour foam process verified / validated on full-scale article
      - Pre-control used to establish process performance requirements
      - As-sprayed acceptance testing used to verify critical performance requirements
        - Tensile strength, dissections, and density tests performed and inspected on HFPTA and/or witness panels
  - Tests / Analyses
    - Test-based verification demonstrates FS > 1.25 for critical failure modes
      - Bondline Delamination
        - Cryogenic / Flexure testing demonstrates 164% design limit substrate strain
      - Cohesive Strength
        - Min. MS = 0.59 (SF req'd = 1.25) using maximum observed defect size x 1.40
        - Critical max. observed defect size is 0.90 in. slot width
    - Stress analysis shows FS > 2.0 for embedded scrim cloth installation
      - Analysis shows adequate adhesive / cohesive material strength based on strain compatibility assuming rigid scrim cloth
- Certification Status
  - Complete

Increase Intertank Venting Area (B02093A)

- Change
  - Extended vented TPS configuration to correspond to the expanded debris zone identified by Level II



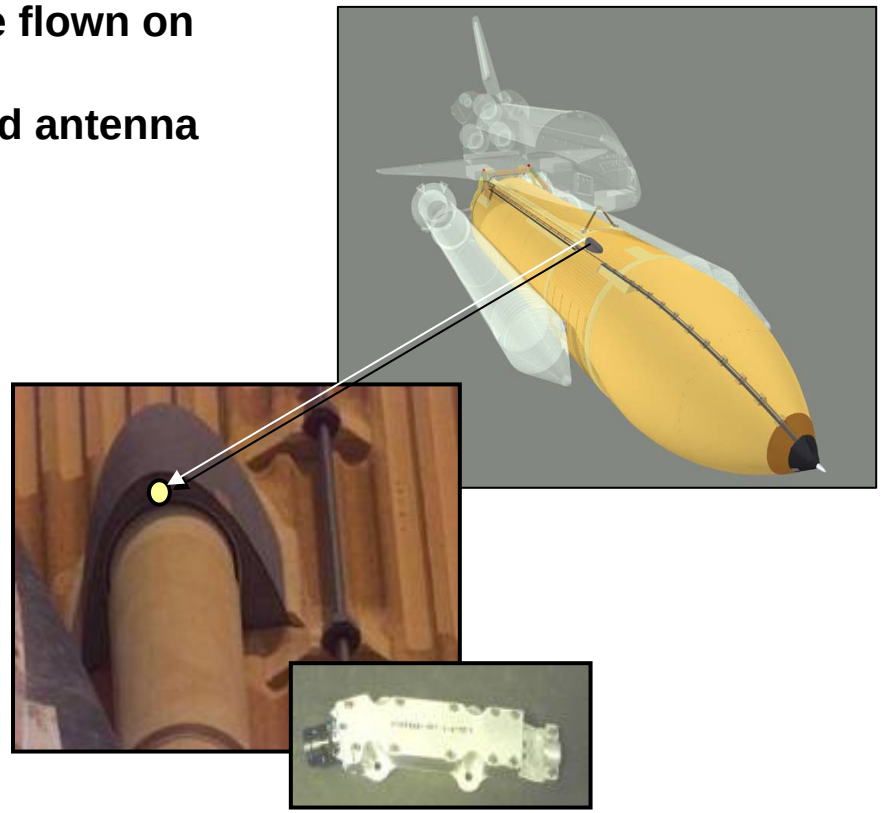
Note: Non-shaded areas near flanges remain not vented. Venting potentially results in ice/frost formation in vent holes



- Reason for Change
  - Level II expanded critical debris zone beyond area previously vented (perforated) area
- Certification Summary
  - Venting verified by thermal / vacuum testing and successfully flight demonstrated on previous STS missions
- Certification Status
  - Complete

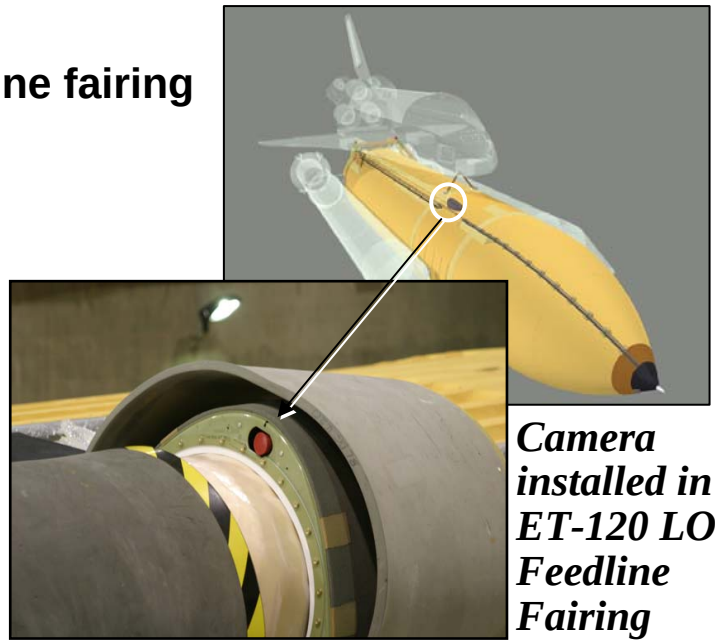
Camera in LO2 Feedline Fairing (B02093A)

- Change
  - Install camera in ET LO2 feedline fairing to enable in-flight assessment of ET TPS performance
    - Camera system similar to hardware flown on STS-112
      - Same design electronics box and antenna
      - Revised camera design and camera / antenna location
- Reason for Change
  - CAIB recommendation
    - Provide capability for in-flight assessment of TPS performance

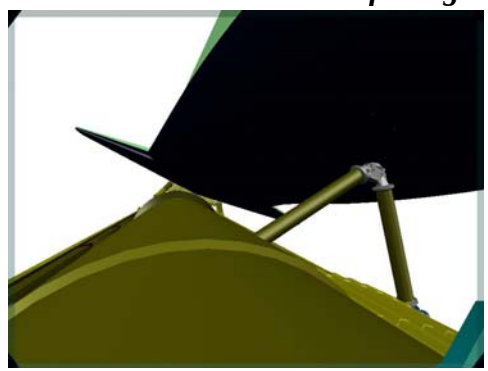


Camera in LO2 Feedline Fairing (B02093A)

- Details of Change
  - COTS camera installed in existing LO2 feedline fairing
    - No additional protuberances
  - Camera system functions independently of other flight elements
  - Electronics box components and cabling installed in Intertank to facilitate system operation
    - Battery monitoring and charging
    - System deactivation during flight
    - Transmission of RF video signal
    - Two S-band Antennas approximately +/-45 degrees about –Z
  - Fused Silica window protective cover over camera lens
  - Modified Intertank to accommodate the installation of the ET Camera System antennas
    - Following installation, TPS is applied to the area
  - Ground interfaces enable system maintenance and operation
  - Functional performance is Crit 3



Camera installed in ET-120 LO2 Feedline Fairing
(protective cover over fairing shown)

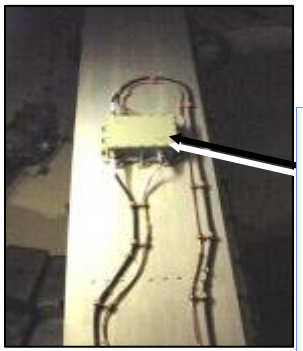


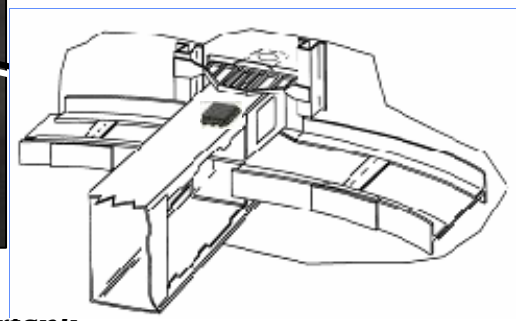
Potential Field of View

Camera in LO2 Feedline Fairing (B02093A)

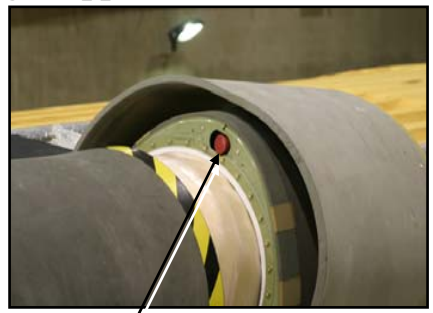
- **Details of Change**

System Weight approx 30 lbs.





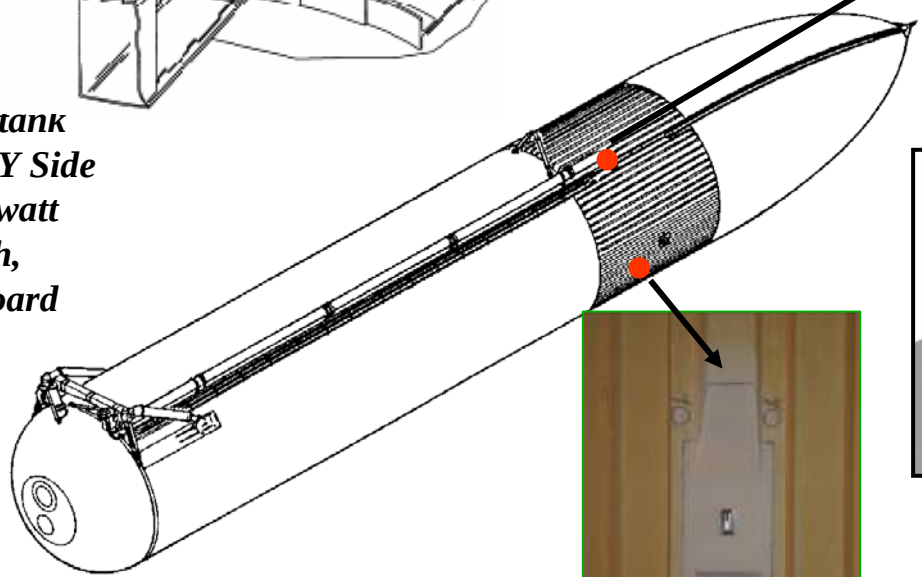
Camera inside housing

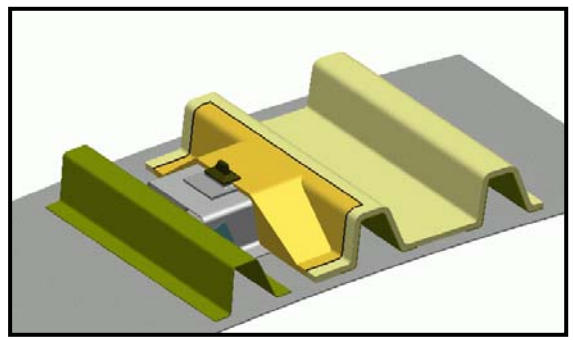


Camera inside LO2 Feedline Fairing

Electronics Box

- *Mounted Inside Intertank on SRB Crossbeam +Y Side*
- *Houses Batteries, 10 watt Transmitter, G-Switch, Power Splitter, PC Board*



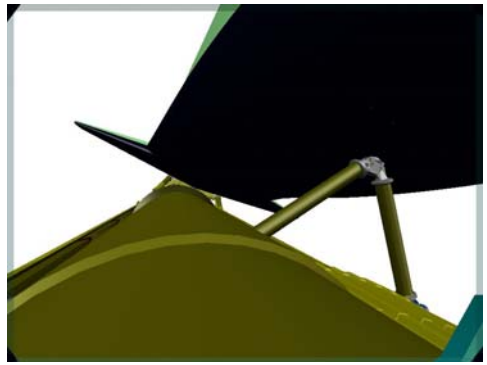


Two S-band Antennas (Approx. +/-45 degrees about -Z)

Electronics routed through GUCP for battery charging, on/off capability, and battery health monitoring

Antenna Installation/Closeout

Camera in LO2 Feedline Fairing (B02093A)



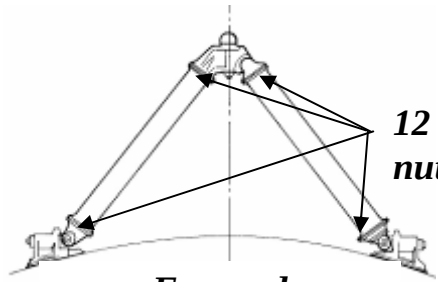
- Certification Summary, Non-TPS
  - Test
    - STS-112 hardware and system certification
      - Electronics box and antenna designs (thermal cycling, vibration and functional burn-in)
      - System subjected to EMI and RF tests
    - Components qualified and acceptance tested in excess of design environments
      - Camera
        - Vibration, thermal cycling, burn-in and Delta vibration
        - Explosive and operational (fogging) environment
      - Electronics box battery vibration, thermal cycling, functional
    - Operational tests verified performance for flight environments (RF, corona)
    - GUCP connector redesign verified per EMI and bonding requirements
      - Cable shielding and structure bonding uses standard practices/components
  - Analysis
    - Loads and thermal analysis performed using Level II provided environments to generate requirement for input to stress analysis
    - Stress analysis shows adequate design Factor of Safety
      - Min. FS = 2.03 (Req'd = 1.4)
      - Failure mode: Fairing bulkhead crippling

Camera in LO2 Feedline Fairing (B02093A)

- Certification Summary, TPS
  - Demonstration
    - LO2 Feedline Fairing TPS
      - Pour foam process verified / validated on full-scale article
        - Tensile strength, dissections, and density tests performed and inspected on HFPTA and/or witness panels
    - Antenna Closeout
      - Spray foam process verified / validated on full-scale article
        - Tensile strength, dissections, and density tests performed and inspected on HFPTA and/or witness panels
  - Tests / Analyses
    - Test-based verification demonstrates FS > 1.25 for critical failure modes
      - Cohesive Strength
        - Min. MS = 0.85(SF req'd = 1.25) using maximum observed defect size x 1.40 (LO2 feedline fairing TPS)
        - Critical max. observed defect size is 0.40 in. slot width
- Certification Status
  - Complete

Bipod Strut Hardware (B02093D)

- Change
  - Replaced lubricated thru-bolts on forward bipod struts with non-lubricated bolts and lubricated washers
- Reason for Change
  - Addressed Columbia investigation concern with locking feature
- Details of Change
  - Replaced shop lubricated thru-bolts on bipod strut to yoke fitting interface and bipod strut to end fitting with non-lubricated bolts and lubricated washers
  - Revised pack and ship kits and offsite installation and assembly drawings
  - FMEA/CIL Vol. IV, ASI - Revised FMEA and CIL to reflect use of non-lubricated thru-bolts
- Certification Summary
  - Torque tension test of fasteners using load cells used to generate revised installation torques
  - Stress analysis shows increased margin for joint separation with new installation (~15% increase to min. preload)
- Certification Status
  - Complete

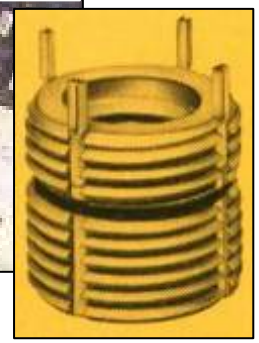


Forward ET/Orbiter Bipod

Redesign ET/SRB Bolt Catcher (B02085)

- Change
  - Redesigned inserts on ET side of ET/SRB bolt catcher
- Reason for Change
  - USA change to bolt catcher design required larger / stronger inserts on ET side of interface
- Details of Change
  - Designed ‘extra heavy duty’ 34L11-9L18 inserts to replace ‘heavy duty’ 34L2-6L12 inserts on the ET fitting
    - Was 3/8” A-286
    - Now: 9/16” A-286
  - Revised off site installation and assembly drawing to reflect new part number

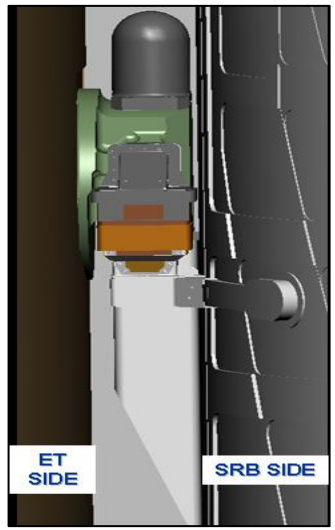
ET/SRB Bolt Catcher



ET/SRB Bolt Catcher Insert

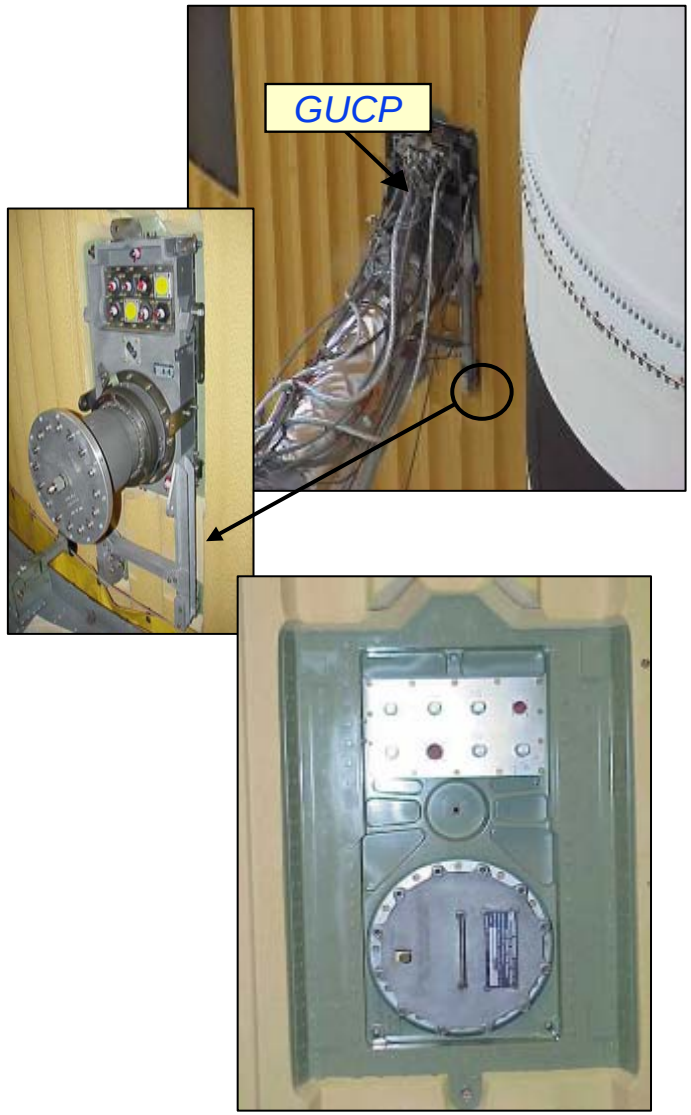
Redesign ET/SRB Bolt Catcher (B02085)

- Certification Summary
  - Redesigned inserts verified by Test and Analysis
    - Test demonstrated insert capability above required strength at maximum design temperature
    - Venting analysis shows compartment meets requirements
    - Stress analysis shows adequate design FS
      - Min. FS = 2.37 (Req'd = 1.4)
      - Failure mode: Thread shear out
- Certification Status
  - Complete



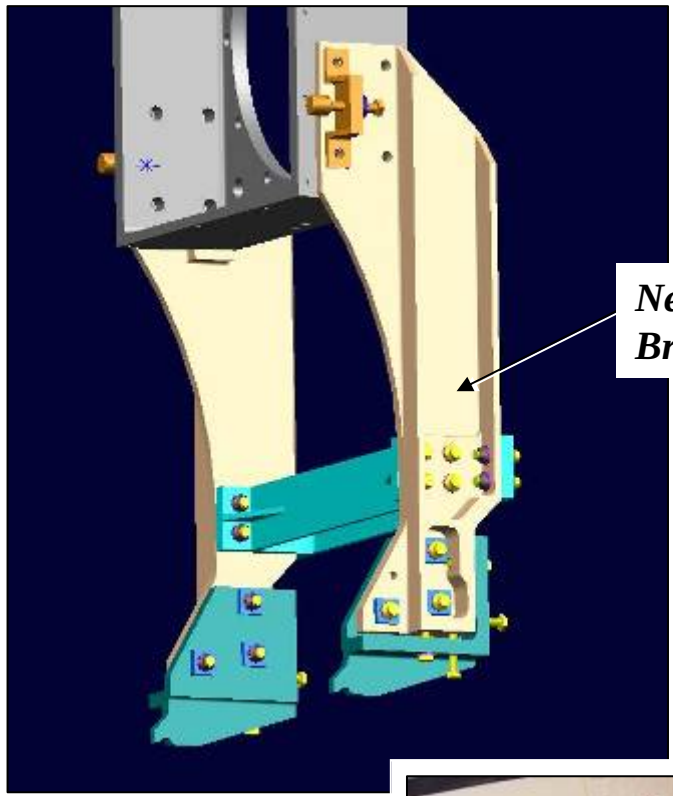
Redesign ET Ground Umbilical (B02091)

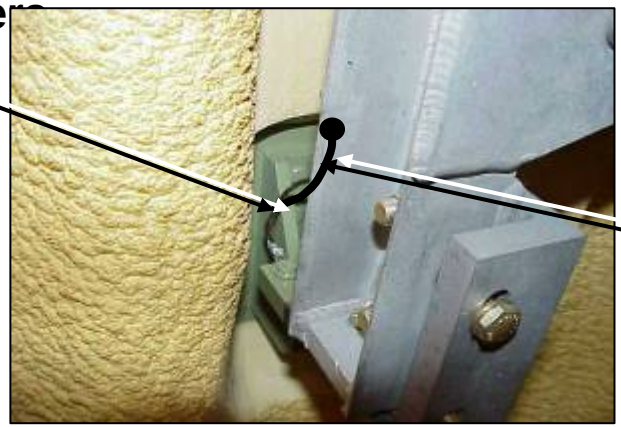
- Change
  - Redesigned ground umbilical leg
- Reason for Change
  - Eliminate Waiver for GUCP leg Factor of Safety requirement
    - FS < 2.0 for previous GUCP leg design
  - Modify ET and ground interface to accommodate new 55 pin connectors required for bipod fitting heater and temperature sensor measurements
  - Enhance electrical bonding on GUCA leg assembly
  - Enhance GUCP bellows guard design to prevent contamination



Redesign ET Ground Umbilical (B02091)

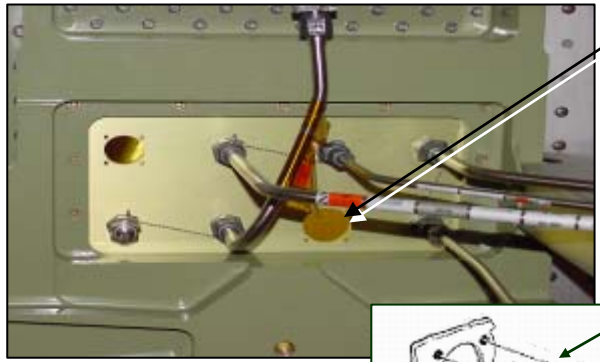
- Details of Change
  - One piece machined design using (Al 2219-T87)
    - Prior GUCP leg configuration consisted of eight separate pieces welded together (Al 2219-T87)
  - Four through bolts and bushings to achieve added strength at leg to body attachment
    - Replaced inserts with bushings and through bolts
  - Two additional lightning ground jumpers





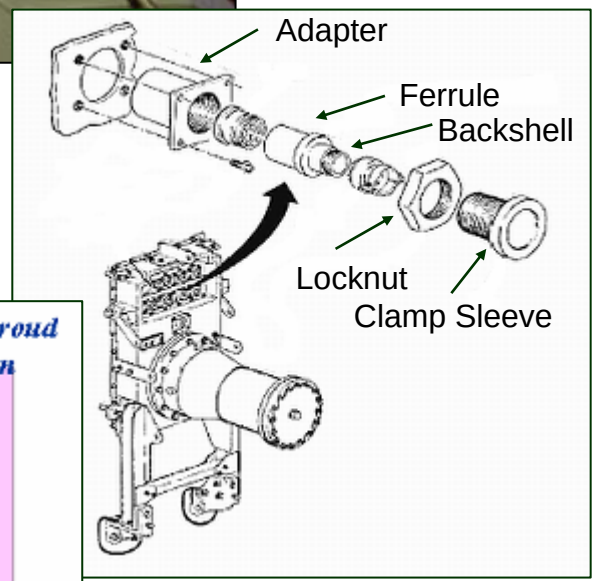
Redesign ET Ground Umbilical (B02091)

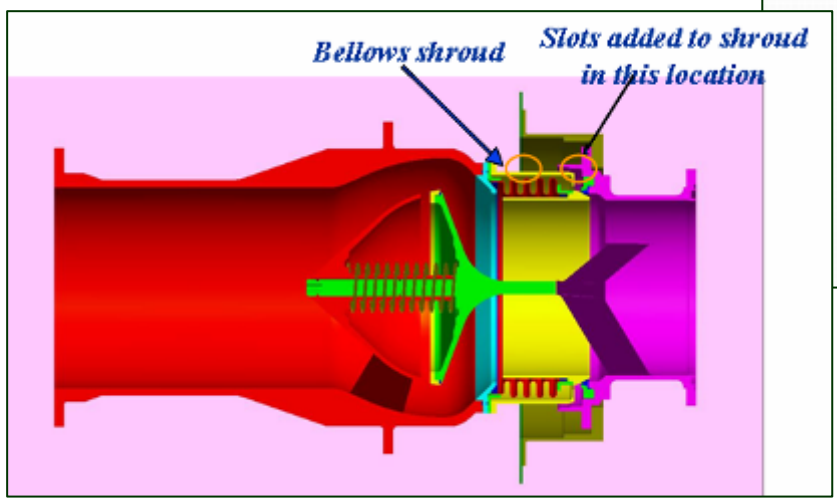
- Details of Change
  - Modified ET Carrier Assembly and Ground interface to accommodate new 55 pin connectors needed for bipod fitting heater and temperature sensor measurements
    - Connectors changed from 32 to 55 pin (Shell size 18 to 22)
    - Remains a NASA 40M connector
  - Changed vent hole location in GUCP bellows guard to prevent contamination from entering the guard thru vent holes during launch



New 55-pin connector requires larger hole in ET Carrier Assembly

ETCA





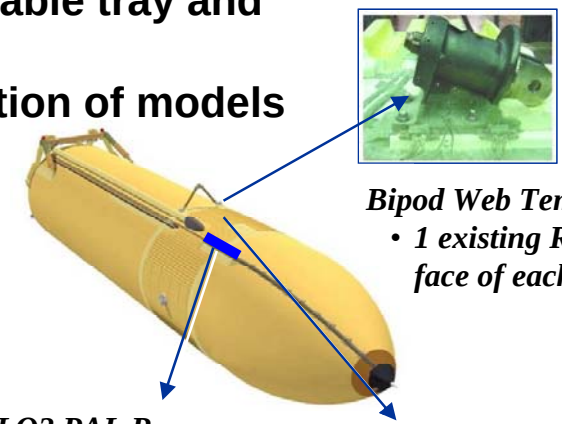
Redesign ET Ground Umbilical (B02091)

- Certification Summary
  - Analysis
    - Loads and thermal analysis performed using Level II provided environments to generate requirement for input to stress analysis
    - Stress – Hardware meets FS requirements (SW-E-002)
      - Min. FS = 3.12 (Req'd = 3.0)
      - Failure mode: Ultimate bending

- Certification Status
  - Complete

Return to Flight Instrumentation (B02096A)

- Change
  - Install instrumentation system hardware in LO2 cable tray and Intertank on ET-121 and ET-119
    - Measurements requested by Level II for validation of models
    - Accelerometers in LO2 cable tray to support removal of LO2 PAL ramp
- Background
  - Configuration requirements defined at the June 17, 2004 PRCB
  - Program approved implementation using COTS hardware
- Details of Change
  - Impacts to hardware elements/operations
    - ET/SRB electrical interface updated
    - SRB Enhanced Data Acquisition System (EDAS) units required
    - Bipod web temperature circuit
      - COTS relay to enable switching over to EDAS shortly after lift-off
  - External Tank Instrumentation
    - 13 Measurements routed to LH and RH SRBs
    - GUCP Interface is deadfaced at T-1 minute 52 sec

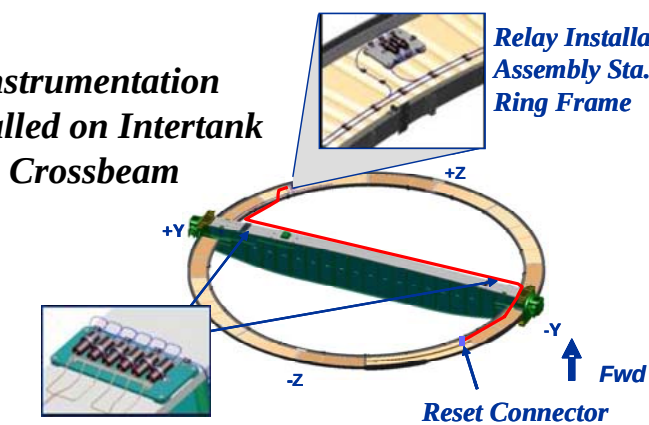


Bipod Web Temperatures
- *1 existing RTD on aft face of each fitting web*

LO2 PAL Ramp Instruments
- *4 Accelerometers Total (5 Data Channels)*

Intertank Measurements
- *3 Accelerometers (6 Data Channels)*

Instrumentation Installed on Intertank Crossbeam



Relay Installation Assembly Sta. 985 Ring Frame

Signal Conditioner Assemblies on SRB Beam

Reset Connector for Relays

Return to Flight Instrumentation (B02096A)

- Details of Change (continued)
  - Interface with SRBs EDAS
    - Modified RSS Cross Strap interface cables
      - Two-pin separation maintained between instrumentation and RSS functions
    - SRB EDAS units
      - Provide power and data recording (liftoff thru SRB separation)
      - System turns on by EDAS G-switch activation after liftoff
      - Data retrieved from SRBs following launch
  - Two Relay assemblies used to switch signals from each Bipod web temp sensor from ground to flight recording
- Certification Summary
  - Testing and analysis demonstrate system performance meets requirements
    - Analysis complete
      - FS = 4.74, Failure Mode: Bond adhesion (FS required = 1.4)
    - EMI emissions, interface and qualification testing complete
  - Certification reviewed and approved at RTF DCR
- Certification Documentation Status
  - COQ 131 pending approval
  - Waiver for ESD part marking presented/accepted at PRCB 06/16/05, pending PRCBD
  - Exception to ET/SRB interface deadfacing (CR in work)
    - SRB project responsibility (power provided by SRB)
- CoFR / Certification Assessment

SSP DCR	EAR	MAR	NASA Pre-FRR	FRR	ITAR
Y	N	Y	N	N	Y

System Safety Assessment
Increase in risk - Causes classified as Controlled

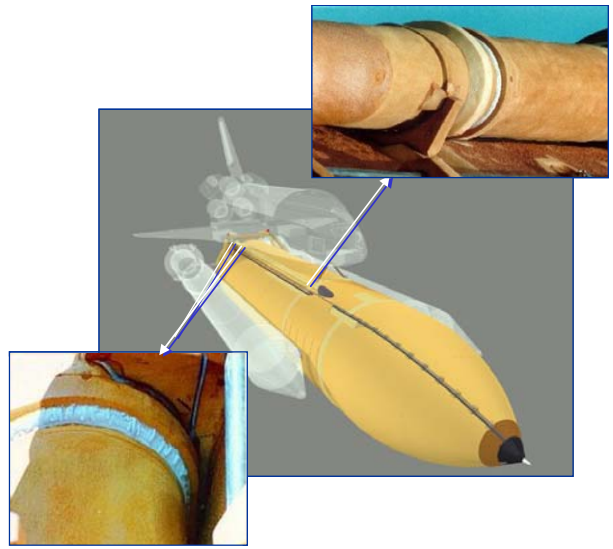
FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
FMEA Impact	Impact	131	No impact	ESD Marking

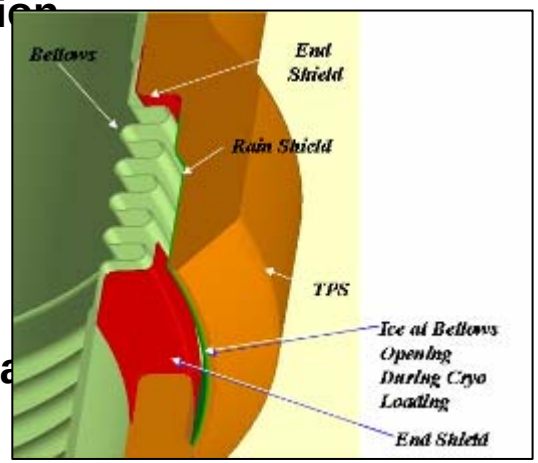
Return to Flight Instrumentation (B02096A)

- Discussion of Relay Certification
  - COTS Relays are used to switch bipod web sensor measurement
    - Power to “set” the relay is provided by the EDAS approximately 3 seconds after T-0
    - Once relay is set, it is not required to switch back during flight
      - Only planned use of reset of relay is during functional checkout
    - Relays are in the bipod ground temperature circuit for measurements on LCC ET-14
  - Demonstrated reliability of existing relay assemblies is lower than expected during ascent vibration testing
    - Failure analysis identified workmanship concerns and a deficiency in the design
  - Acceptance Rationale
    - Acceptance and qualification failures do not affect safety of flight
    - Failure modes experienced in testing would not affect ground system operations
      - No single failure of COTS hardware can cause violation of LCC (ET-14)
      - Most failures have occurred after vibration exposure
      - Teledyne relays within the assemblies have not shown problems with inadvertent switching under vibration
    - Increased performance risk of COTS relays is acceptable
      - System is not required for flight function (Criticality 3)
      - Effect of failures not likely to impact flight performance of the relays
        - Majority of the failures experienced after exposure to vibration
        - Flight function of relays occurs just after liftoff
        - No failures after vibration resulted in the loss of flight function
  - Approved at PRCB

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Change
  - Add TPS drip to lip to LO2 Feedline Bellows (3 locations) closeout to divert condensate from bellows cavity opening
  - Install heater system at fwd bellows location
- Background
  - Previous configuration bellows rainshield TPS configuration channeled condensate to bellows opening
- Reason for Change
  - Ice / frost formation is inherent to the ET design
    - Previously accepted in LCC and NSTS 08303, Inspection Criteria
  - ET Project identified LO2 feedline bellows ice as a potential debris source to the SSP
    - TPS drip lip was implemented for RTF to reduce ice formation mass
  - ET RTF design baseline revised following the SSP Delta DVR to mitigate unacceptable risk of residual ice at forwa feedline bellows location (Station 1106)

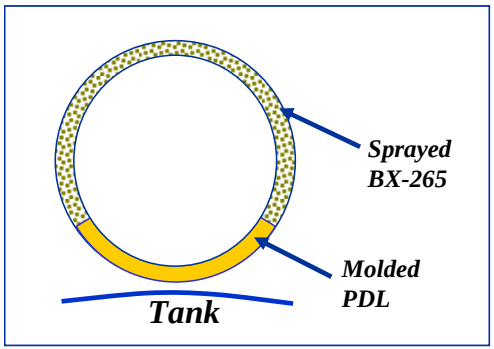




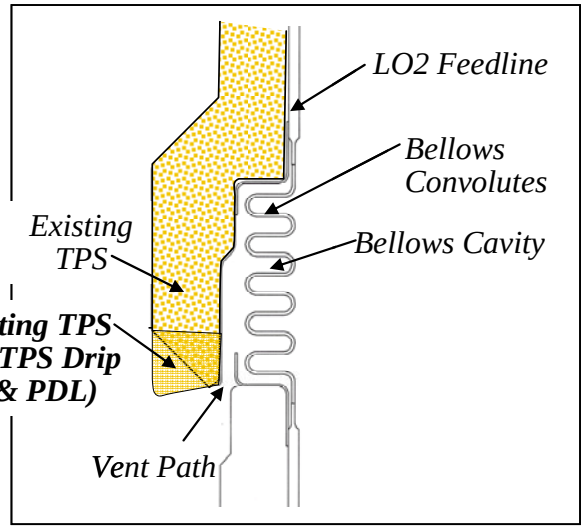
Previous Configuration Flight Bellows

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Details of Change – TPS Drip Lip
  - Two-step closeout selected for Sta 1106 and 1979
    - BX-265 spray and molded PDL for area near tank



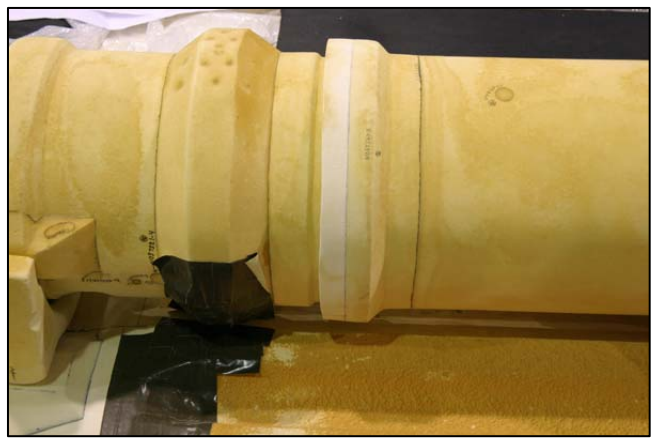
Two-Step Closeout



TPS Drip Lip Design

  - 360° PDL molded drip lip required due to sprayer access issue at Sta 2026
    - Spray gun too close to part with limited clearance between bellows and aft hardware for spray mold

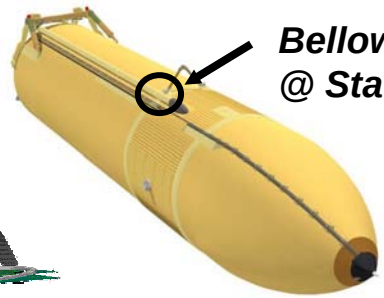
Bellows Drip Lip PDL Mold

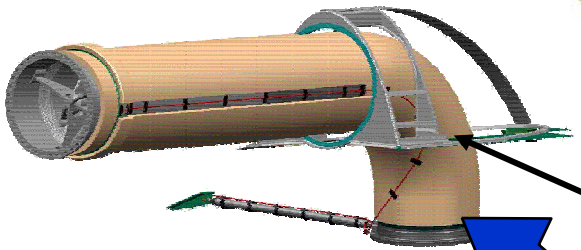


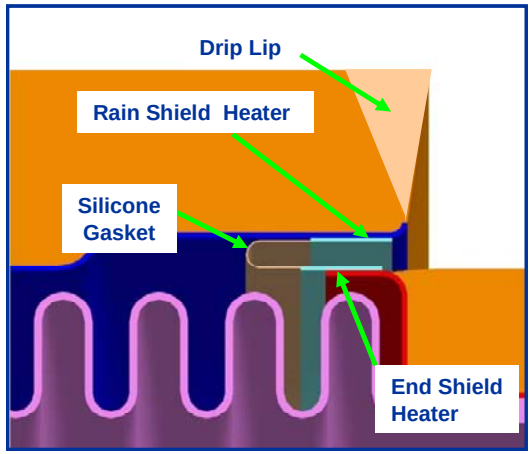
TPS Drip Lip on ET-120 at Sta 1106

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

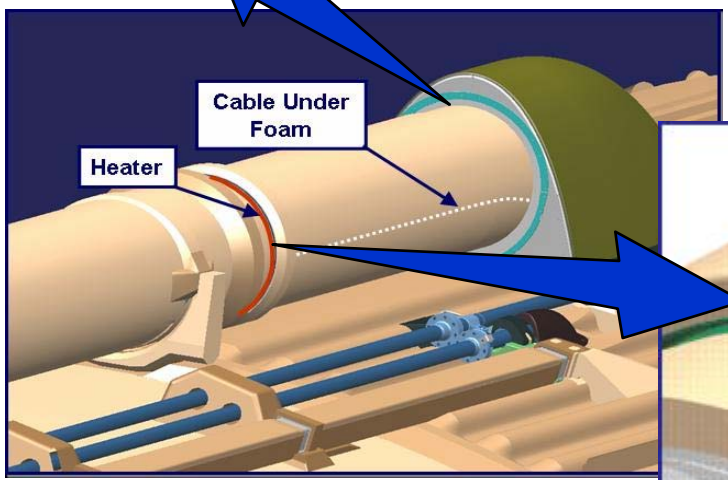
- **Details of Change - Heater on Forward LO2 Feedline Bellows**



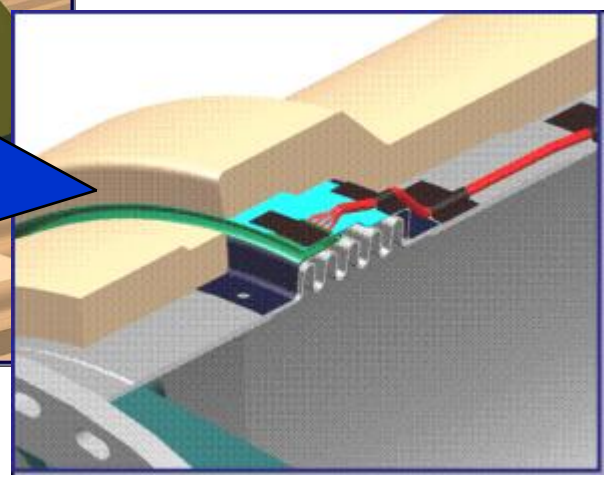




Heater adhesively bonded to bellows rain shield and end shield



Heater wire routed under foam to LO2 feedline fairing penetration to Intertank



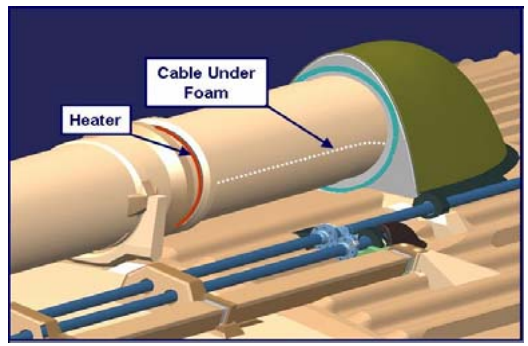
Heater installed in bellows cavity

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Details of Change
  - Overview
    - Strip heater with 30/70 power split to rain shield and end shield sides of heater
      - Heater (both sides) contains redundant circuits
    - Heater is adhesively bonded to rain shield and end shield and wires adhesively bonded to the LO2 feedline substrate
  - Heater System
    - Copper resistive heater element
      - Resistance 48.4 +/-5% Ohms
      - Rated for 400 watts 120 vac
    - Kapton on heater used as adhesive bonding surface
    - Silicone rubber gasket used to join heater elements
    - Two twisted shielded 2-conductors
    - Heater horizontal (MAF) and vertical (KSC) installation verified and validated (V&V
  - TPS rework required
    - TPS closeout over wires bonded to feedline substrate
      - Required removal of 3 inch area along existing drip lip and LO2 feedline surface
      - Closeout with BX-265 foam on feedline and PDL foam at LO2 Fairing feedline interface
    - TPS horizontal (MAF) and vertical (KSC) closeout V&V
      - Pre-control limits established
      - Zero defects observed during validations

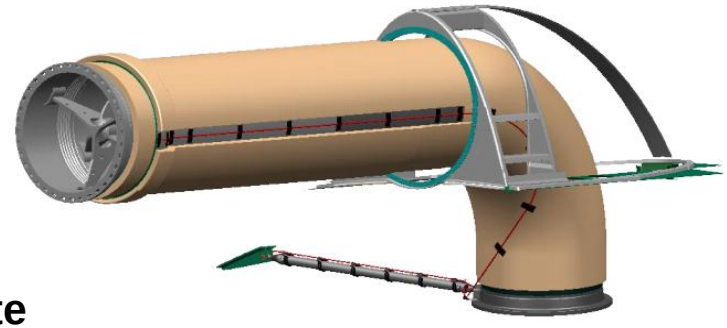
Heater Elements Joined with Silicone Rubber Gasket

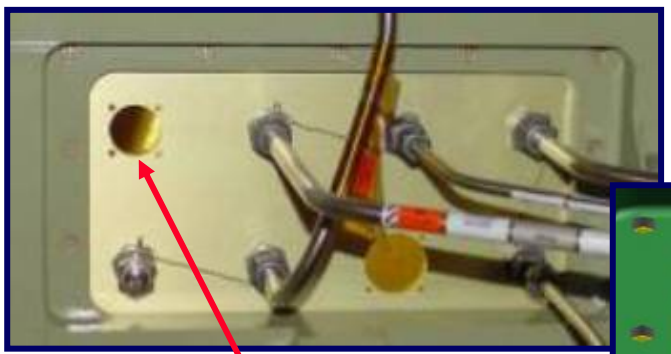
TPS Closeout



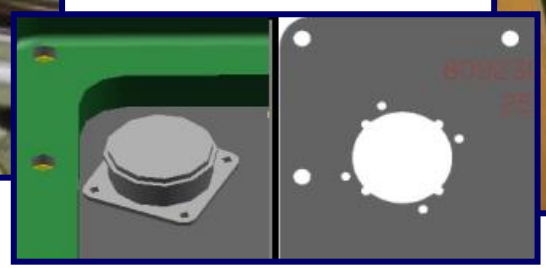
Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Details of Change - Interfaces
  - Heater wire is routed into the Intertank and to the ET/Ground Umbilical Interface
  - Interface changes documented in the ICD
    - Additional bellows heater circuits added to J02 connector
      - Connector enlarged
        - Same connector specification
        - More contacts
  - Ground system and interface validation complete
    - ET participated in design review

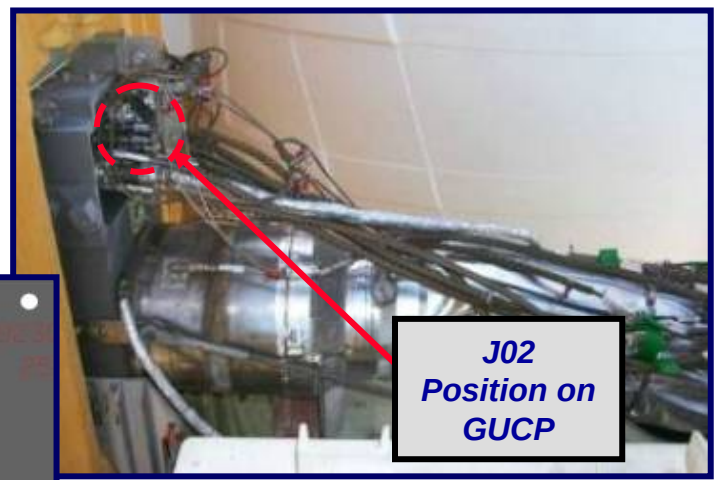




Heater Connector (J02) Location



Reworked Connector Location (ET-121, 120 Only)



J02 Position on GUCP

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Details of Change – System Checkout and Operation Requirements
  - System Checkout
    - ET Standalone: Isolation resistance , continuity
    - Integrated
      - Set Voltages on power supply (Controlled by ICD)
      - Monitor current draw through LPS
      - Check redundant heater and power supply thru LPS
  - Operation
    - Heater primary circuits are activated after initiation of fast fill
      - Activation controlled by LO2 head pressure measurement (52 psig)
      - Heater operates at set voltage approx. 115 vac (no active control required)
    - Current and voltages are monitored
      - Secondary heater circuit activated in the event of primary circuit failure
    - Heaters turned off T-8 min and 50 sec
    - Heater operation required through LO2 drain in the event of a launch scrub
  - Launch Commit Criteria
    - Monitor heater voltage and current to verify heater operations
      - ET Project submitted LCN to delete this LCC due to the new OMRS requirement to turn heater off at T-8 min and 50 sec
    - Verify Deadface GUCA connector at T-40 sec

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- **Details of Change – Level III Documentation Impacts**

Document	Change	Status (√ = Approved)
MUA	*0365A – Silicone Adhesive/ Sealant RTV 162 and DC 3145, Revision to AML, Table 3.2 Plastics, Adhesives, and Elastomers of MMC-ET-SE16 (A-1)* *0429 – Bond-on Strip Heater, Anti-Icing, Addition to LUL, Table 3.7 Electro/Mechanical Components of MMC-ET-SE16 (A-1)*	√ √
SE10 – ET Project External Tank/STE Wiring List	*Added requirements for new cabling associated with Bellows Heater System*	√
MMC-ET-CM01, Contract EIS	*Bellows heater weight and certification documentation impacts*	√
MMC-ET-TM01, ET Verification Plan	*Appendix for ET bellows heater verification plan*	√
MMC-ET-TM06, COQ	• *132, Created new to document certification of heater* • *038, Revised to reflect J-2 connector change* • *100, Revised to reflect J-2 connector change*	*ECD 7/1/05*
MMC-ET-TM08, HCS	• *E052, Created new to document certification of heater installation* • *T528, Revised to reflect TPS configuration*	*ECD 7/1/05*
MMC-ET-SE02, Mass Prop. Status	• *Revised to reflect weight impact (+8 lbs)*	√

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- **Details of Change – Level II Documentation Impact**

Item	Change	Status		
		Document	ET	SSP
ICD	*Revise to add design requirement for the bellows heater systems ET/Ground Umbilical Interface*	*2-2A001, Rec, Stor & C/O, TC-2083* *2-0A001, Platform & VAB, TC-2082* *2-0A002, Pad & Platform, TC-2081*	√ √ √	√ √ √
OMRSD	• *Requirement for Heater Checkout* • *Requirements for Heater activation/ deactivation and scrub/detanking*	*File IV, MT16759* *File II, MS16758*	√ √	√ √
LCC	• *Requirement for monitoring heater voltage and current* • *Requirement to verify heater deadfaced at T-40 sec*	*LCN 1167* *LCN 1173*	√ √	√ √
FMEA/ CIL	• *Added one crit 1 failure mode for debond of heater* • *Added 4 crit 3 FMEAs for heater and harness failures* • *Added TPS closeout to CIL*	*Vol. III - Electrical, Bellows Heater* *Vol. V - TPS*	√ √	** *
HAR	• *Reference heater design and installation & connection at GUCP* • *Add causes / controls / verification for heater* • *Add control / verification for heater TPS closeout* • *Reflect reduction in risk for ice formation / debris*	• *E.01, Electrical Fires* • *E.04, Malfunction of Electrical Heaters on ET* • *P.05, GUCA Separation Malfunction* • *T.02, Loss of ET TPS Debris* • *T.04, ET Ice Debris*	√ √ √ √ √	**

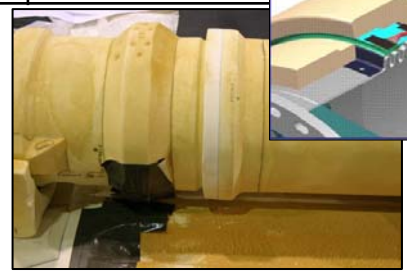
* *Pending SSP approval*

** *Pending closure of identified open work and SSP approval*

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

Presenter M. Quiggle, LM-ET

Date June 27, 2

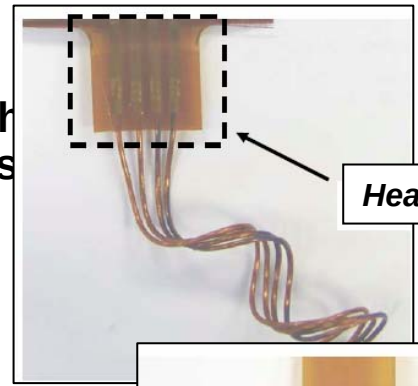


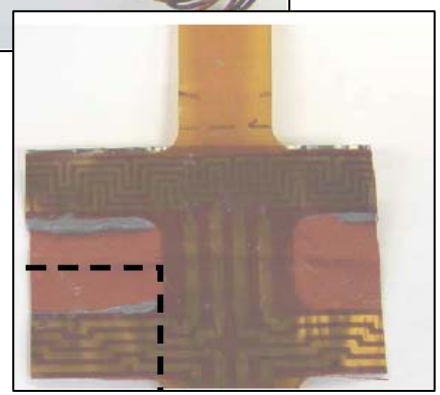
- Certification Summary, Heater TPS Closeout
  - Tests / Analyses
    - Test-based verification demonstrates FS > 1.25 for critical failure modes
      - Bondline Delamination
        - Cryogenic / Flexure testing demonstrates > 200% design limit substrate strain
      - Cohesive Strength
        - Critical divoting not expected using max observed defect x 1.40
    - TPS bond line temperature meets requirement (200° F)

  - Demonstration
    - Manual spray / pour foam process verified / validated on full-scale article
      - Pre-control used to establish process performance requirements
      - As-sprayed acceptance testing verified critical performance requirements
        - Tensile strength, dissections, and density tests
      - Defects observed during processing of ET-121 (pre-rework) assessed against critical defect acceptance criteria and pre-control limits
        - No issues

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Certification Summary – Heater System
  - Heater component qualification - Complete
    - Burn-in
    - Insulation resistance
    - Humidity
    - DC resistance
    - DWV
    - Power conditioning at operating voltage
  - Heater installation structural verification
    - Analysis - Complete
      - Thermal analysis using max design condition with heater installed provided as input to stress analys
      - Stress analysis of heater bond adhesion using conservative design environment assuming 5 psi
        - Min FS = 2.82
        - FS required = 2.0
    - Test (heater materials)
      - Heater and wire tab thermal exposure to ascent and abort temperatures - Complete
        - Ascent: Heater tabs to 600°F and heater to 550°F for duration of 10 minutes
        - Abort: Heater tabs and heater exposed to ascent temperatures for 7 minutes prior to 4 minutes exposure to 900°F for heater tab and 800°F for heater





Heater Test Article

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

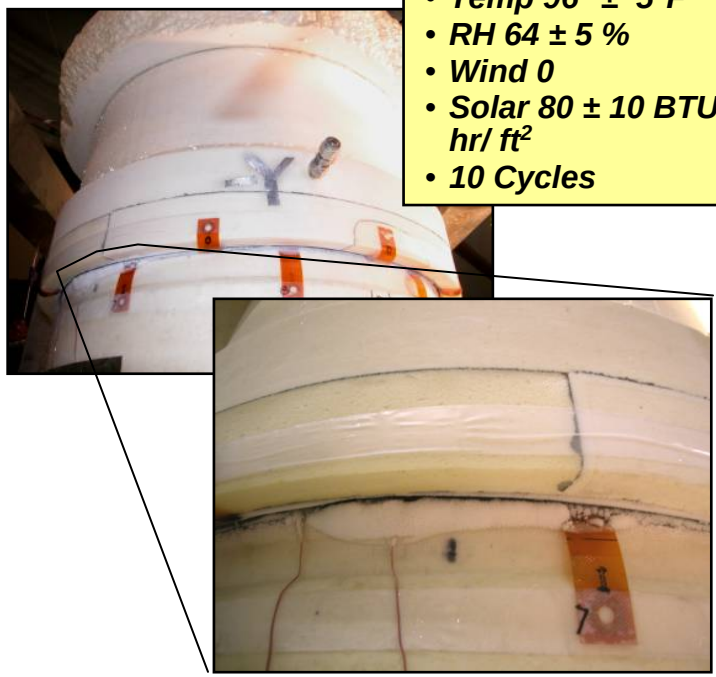
- Certification Summary – Heater System
  - Heater installation/structural verification – Test (cont'd)
    - Venting test - Complete
      - No appreciable ΔP measured (0.02 psig)
      - No damage to heater or installation
      - Installation subjected to post test ambient pull test – No issues
    - Acoustic test – ECD 6/22/05
      - Objectives
        - Functionality of the heater after exposure to on-pad abort environments
        - Structural integrity of the heater assembly (including the heater bond) after exposure to on-pad abort and ascent environments
          - Pull test to be performed after testing
        - No debris after exposure to the induced environments
      - On-pad board case successfully completed - Ascent case in process

  - Heater installation materials testing
    - Environmental conditions exposure – In-work (test article exposure will precede flight article exposure by 30 days)
      - Inspection/electrical test will verify heater and installation integrity

Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Certification Summary – Heater System
  - Heater system verification (cont'd)
    - System thermal / mechanical test – Complete (13 cycles with varying environmental conditions and power settings)
      - Ice formation observed < than 0.013 lb guideline at end of prelaunch cycle
        - Ice guideline provided at CDR in April 2005
      - TPS bondline (200°F) and heater temperature (392°F) within limits
      - Bellows articulation profiles unaffected by heater installation during prelaunch and ascent

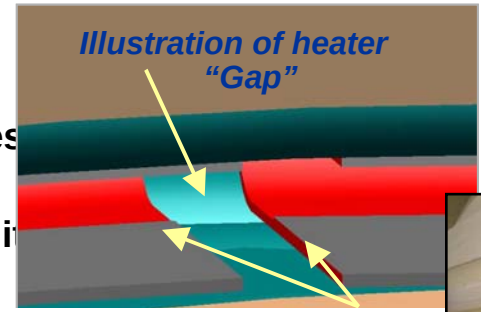
- *Temp 96° ± 5°F*
- *RH 64 ± 5 %*
- *Wind 0*
- *Solar 80 ± 10 BTU/ hr/ ft^2*
- *10 Cycles*

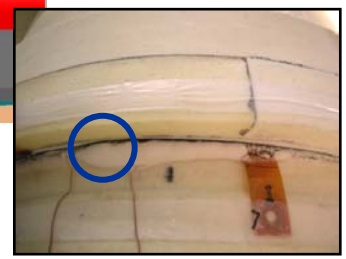


Thermal/Mechanical Test
Condition at End of Pre-Launch Cycle
(5 min after heater off)

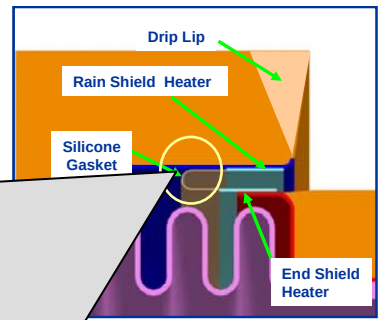
Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

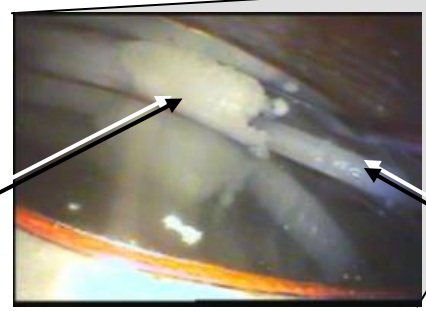
- System thermal/mechanical test observations
  - Observations during test
    - Localized ice/frost at "gap" between heater ends
    - Potential condition inherent with installation proces
    - "Gap" location ~7 – 8 o'clock inboard
    - Ice characteristics varied with environmental condi
    - Mass calculations ranged from 0.002 – 0.013 lb
      - Conservative calculation based on 57 lb/ft3 ice with constant max recorded height
      - Ice mass provided SE& I to develop prelaunch ice assessment criteria





  - Internal Ice Observations (Development Test)
    - Frost/Ice typically formed on sides of heater membrane and did not bridge across apex
    - Frost/Ice typically accumulated on convolute side more than rain shield side
    - Assessed against ice debris guidelines provided for CDR ice debris requirement (0.013 lbm)
      - Description: Cross-sectional area ~ 0.0256 in2 based on comparison to a 0.08 inch dia. nylon cord
      - Analysis: Using 57 lbm/ft3 density, a 15.4" long piece would be required to violate ice debris guidelines
    - Ice/densified frost inside heater not a critical debris concern





Redesigned LO2 Feedline Bellows TPS and Install Heater System at Fwd Bellows (B02093D)

- Certification Summary – Heater System Verification (cont'd)
  - Propellant quality verification
    - Propulsion analysis considered anti-geyser effects and propellant load impacts
      - Analysis shows engine start ICD requirements are met
      - 13 lb LO2 load decrease predicted
      - Anti-geyser requirements met for nominal operations and stop flow/revert
        - Heater deactivation required for loss of engine bleed
- Certification Documentation Status
  - Pending verification test completion and approval of certification documentation, ECD 7/1/05
    - COQ 132, LO2 Feedline Bellows Heater
    - TPS Closeouts
      - HCS T528, LO2 Feedline, Bellows and Flange Closeout
      - HCS E052, LO2 Feedline Bellows Heater Installation
    - Interfaces
      - COQ 038G, Ground Umbilical Carrier Assembly (GUCA)
      - COQ 100D, ET Carrier Assembly (ETCA)
- C

SSP DCR	EAR	MAR	NASA Pre-FRR	FRR	ITAR
N	N	Y	Y	Y	Y

System Safety Assessment
Increase in risk - Causes classified as Controlled

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
F/C Impact	Impact	132 038G 100D	E052 T528	None

External Tank Project
MP01 FRR

STS-114/ET-121

Appendix B
STS-114/ET-120 Tanking Test Observations

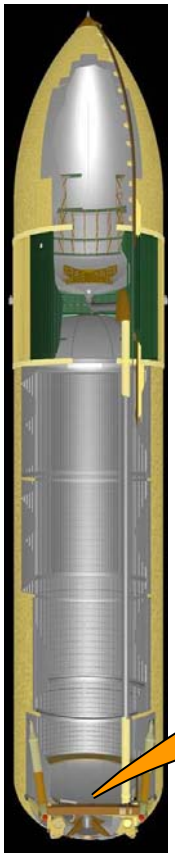
June 29, 2005

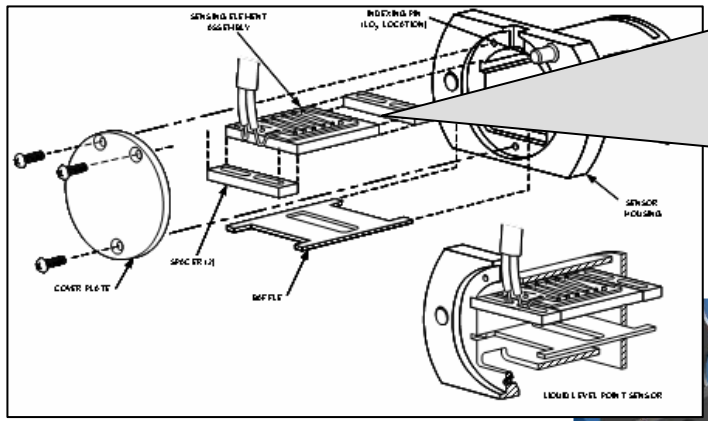
Erratic ECO Sensor #3 and #4 Measurements During Load and Drain (IPR 114V-0314)

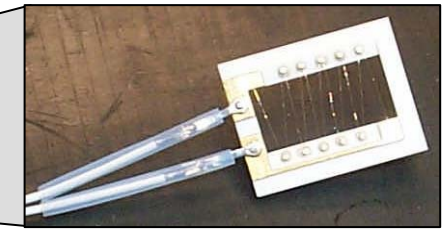
- **Observation**
  - **Toggling of ECO sensors #3 and #4 measurements during load and drain of STS-114 Tanking Test #1 (04/14/05)**
    - **LH2 ECO #4 (302A17) failed OMRSD S00FF0.204 “Wet” to “Dry" sensor test**
    - **Subsequent trouble shooting and rerun of test showed no anomalies**
    - **LH2 ECO # 4 indicated “Wet” after LH2 passed that tank level during drain**
      - **Sensor indicated “Wet” 8 minutes after liquid receded and then indicated “Dry”**
    - **All LH2 ECOs monitored after drain complete**
      - **LH2 ECO #3 (302A16) indicated “Wet” during this phase for approximately 1.5 hr**
- **Concern**
  - **Failure of LH2 ECO sensor system to initiate proper shutdown of SSMEs**

Erratic ECO Sensor #3 and #4 Measurements During Load and Drain (IPR 114V-0314)

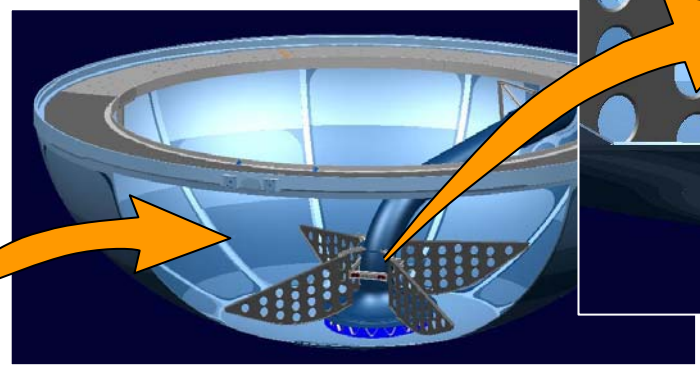
- **Background – LH2 ECO Sensor Locations**

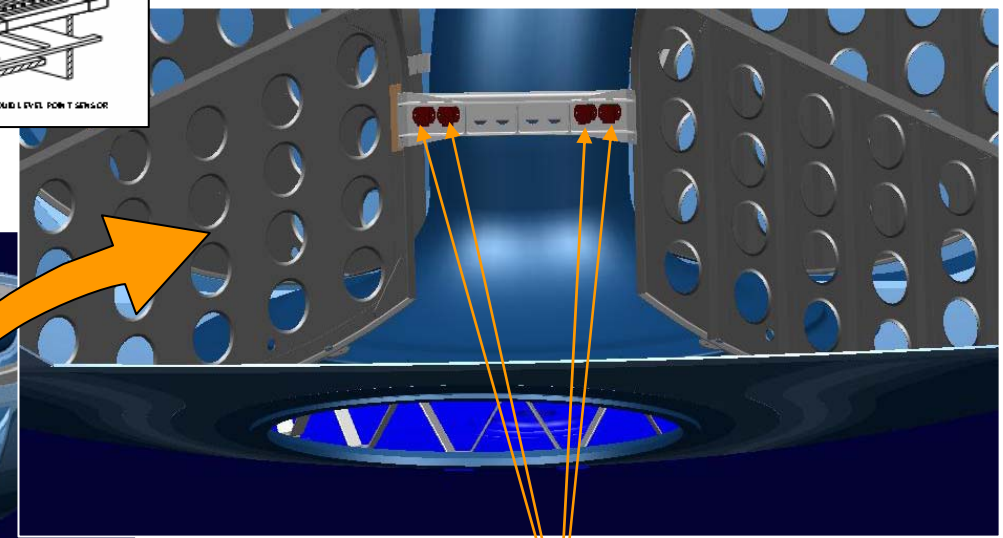






Sensing Element





Depletion Sensors Mounted on Shock Mount

All LO2 & LH2 and ECO sensors are similar design

- *LO2 has oxygen compatible cabling*

ECO sensors installed on shock mount at bottom of LH2 tank

Erratic ECO Sensor #3 and #4 Measurements During Load and Drain (IPR 114V-0314)

- Actions Taken to Identify Cause of Anomaly – Reviewed ET-120 Checkout History
  - Original Delivery of vehicle
    - Sensor/Feedthru connector ATP – passed
    - Harness buildup, 1500 vdc, 500 vdc, 50 vdc IR, DC Continuity – passed
    - Level sensor installation, 50 vdc, DC Continuity – passed
    - Cable connection to feedthru and umbilical (J23), 50 vdc IR, DC Continuity – passed
    - Confidence and "All Systems Check", 50 vdc, DC Continuity – passed
  - Post Delivery KSC Checkout
    - 50 vdc DC Continuity – passed
  - RTF Activity (2004-2005)
    - MAF Confidence and "All systems Check" 50 vdc, DC Continuity – passed
    - Post Delivery KSC Checkout
      - 50 vdc DC Continuity – passed
    - Post Tanking Test # 1 Trouble Shooting – passed
      - Inspections, pin retention tests, socket force gage measurements (J23)
      - Measurement Circuit (Breakout box used)
        - Continuity, isolation resistance, megger check on harnesses / connectors
    - Tanking Test # 2 – passed
    - ET-120 Remate Checkout, 50 vdc DC Continuity and functional check to be repeated

Standalone ET Hardware has been tested many times
- - - No anomalies occurred during any checkouts

Erratic ECO Sensor #3 and #4 Measurements During Load and Drain (IPR 114V-0314)

- Actions Taken to Identify Cause of Anomaly – Tanking Test #2
  - SSP identified subsequent tanking test to investigate cause of anomaly
    - Instrumentation added prior to Tanking Test #2 to isolate anomaly to Orbiter side of the or the ET side of the production break
      - Two (2) current measurements
        - Excitation – Identify a short or open from Orbiter electronics
        - Return – Identify a short or open on last cable run and ET
      - Three (3) voltage measurements to determine voltages at various points in circuit
  - Tanking Test #2 Results
    - External measurements read proper current and voltage
      - Current: Wet Sensor reads 185 ma / Dry Sensor reads 50 to 80 ma
      - Voltages: Wet Sensor reads 1 to 3 volts / Dry Sensor reads 9 to 14 volts
    - Automated OMRSD test - All sensor responded as required
    - Tanking Test #2 planned trouble shooting steps
      - Measurements verified proper current and voltages when sensors were commanded
    - Drain and boil-off
      - External measurements verified proper current and voltages and function based on liquid level state

Erratic ECO Sensor #3 and #4 Measurements During Load and Drain (IPR 114V-0314)

- Basis for Acceptance of ET-120 and ET-121 hardware
  - Design qualified
  - ET acceptance testing met all requirements
    - Original Acceptance Test prior to DD250
    - RTF Acceptance Retest prior to delivery
  - DC&R activity identified no anomalies in the cable tray
  - First time use of hardware and no subsequent access after initial installation
  - All non conformances on hardware associated with this measurement reviewed for proper disposition and resolution – No issues
  - ET-120 hardware verified to meet all pre-tanking test and checkout requirements
  - ET-120/STS-114 trouble shooting and tanking test #2 instrumentation of ET hardware verified proper function
    - Tanking test thermal cycling provides additional confidence in ET hardware
  - ET hardware meets engineering and interface requirements
    - ET-121 hardware verified to meet checkout requirements
  - Change planned to perform additional check of ECOs at T-20 min for STS-114 & subs
- ET-120 acceptance rationale presented at SSP ICB and PRCB
  - "No defect" rationale provided by ET Project accepted through MP01
  - Proposed IPR disposition includes ET hardware as most probable cause
    - ET Project non-concurs with proposed disposition based on presented rationale
- CoFR / Certification Assessment

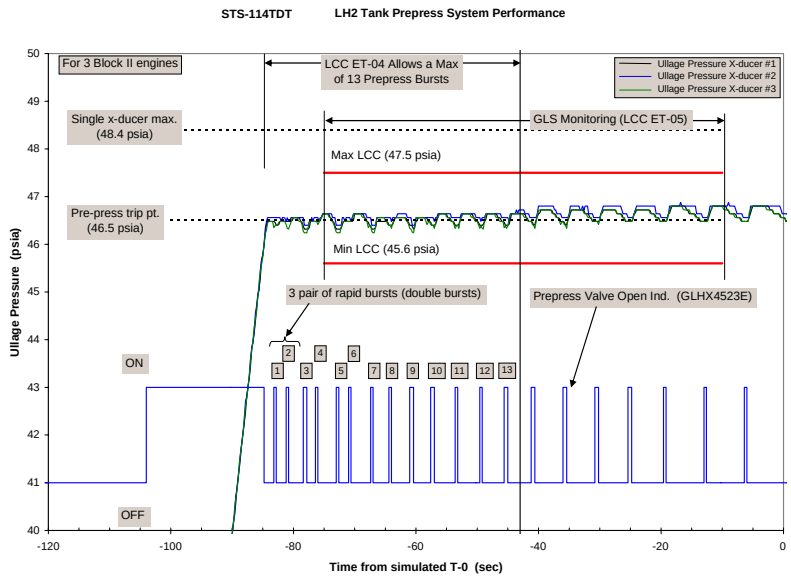
SSP DCR	EAR	MAR	NASA Pre-FRR	FRR	ITAR
N	N	N	Y	N	Y

System Safety Assessment
No change in risk

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
No impact	No Impact	No Impact	No Impact	None

Increased Number of LH2 Prepressurization Cycles

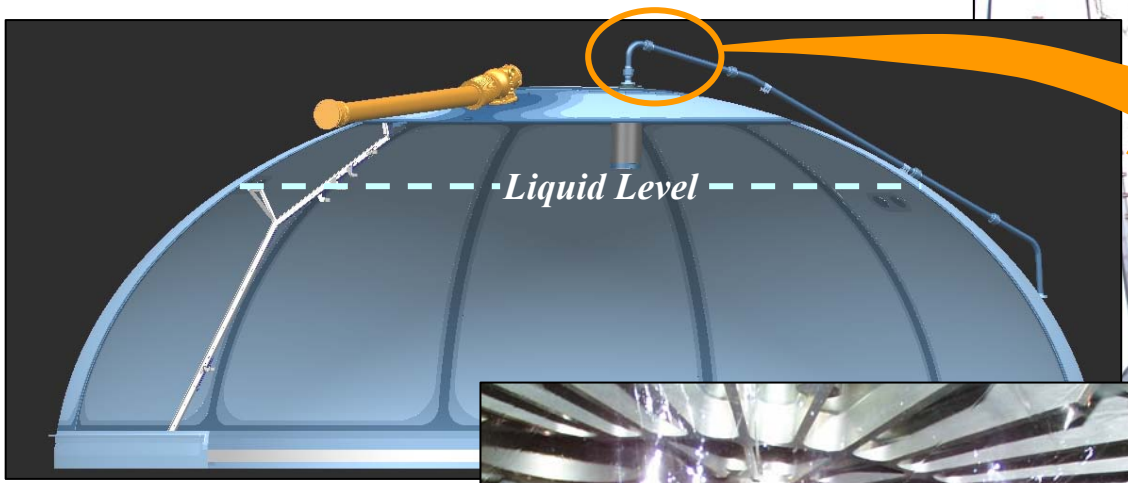
- **Observation**
  - **Unexpected "high" number of prepress cycles required to maintain tank ullage pressure within the control band (identified during the post-test data review)**
    - **LCC Requirement ET-04:**
      - **Maximum of 13 prepress cycles during prepressurization**
        - **A. Start counting command cycles after initial pressurization**
        - **B. Stop counting command cycles at T-43 seconds**
    - **STS-114 tanking test performance: 13 cycles (still within requirements)**
    - **Typical # of command cycles for SLWT/Pad B/MLP 1: 8 to 9**

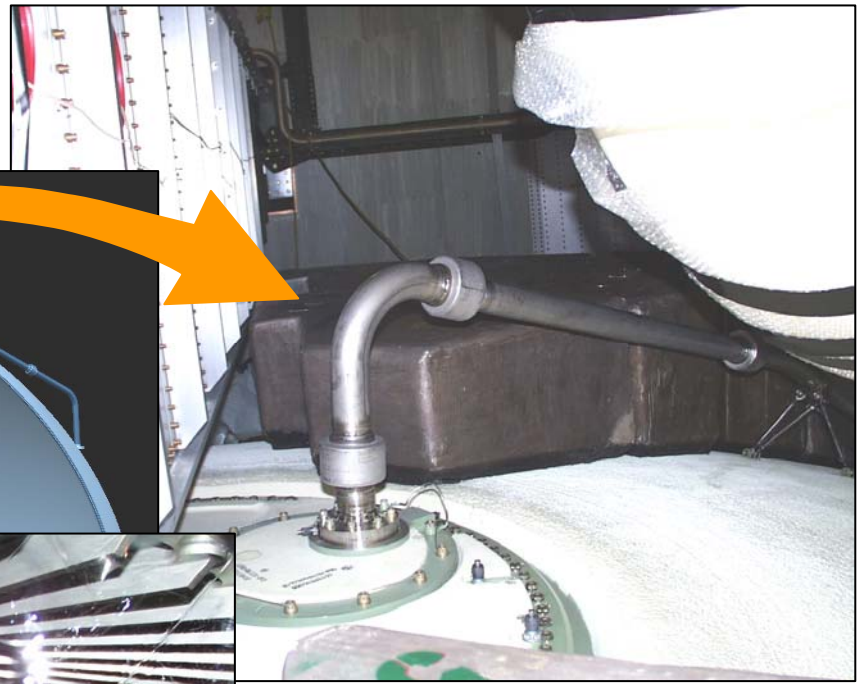


- **Concern**
  - **Ability to maintain flight pressure within ICD requirements**
    - **Consequences of exceeding the cycle count limit**
      - **Possible failure to maintain LH2 tank structural safety margin**
      - **Early engine shutdown because of loss of Net Positive Suction Pressure (NPSP)**
      - **Possible adverse structural heating/loss of Intertank structural integrity due to vent valve leakage which could ignite and burn the TPS as it exits the vent line**

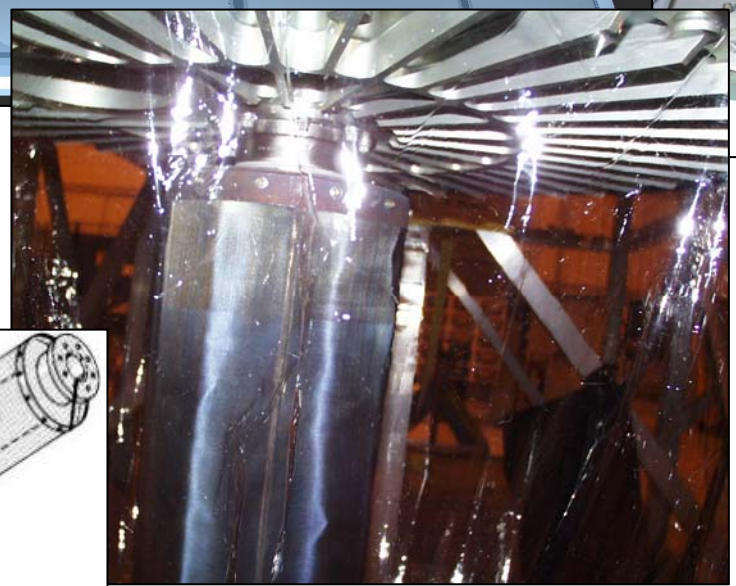
Increased Number of LH2 Prepressurization Cycles

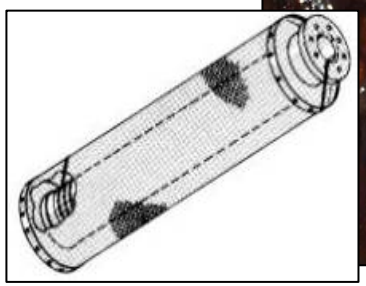
- **Background – Hardware Orientation**





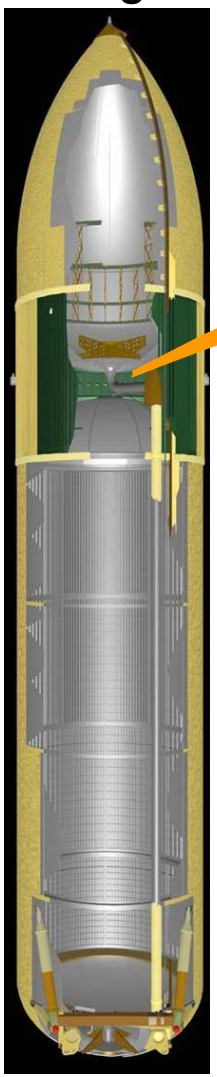
GH2 Pressline to Diffuser Cover Plate

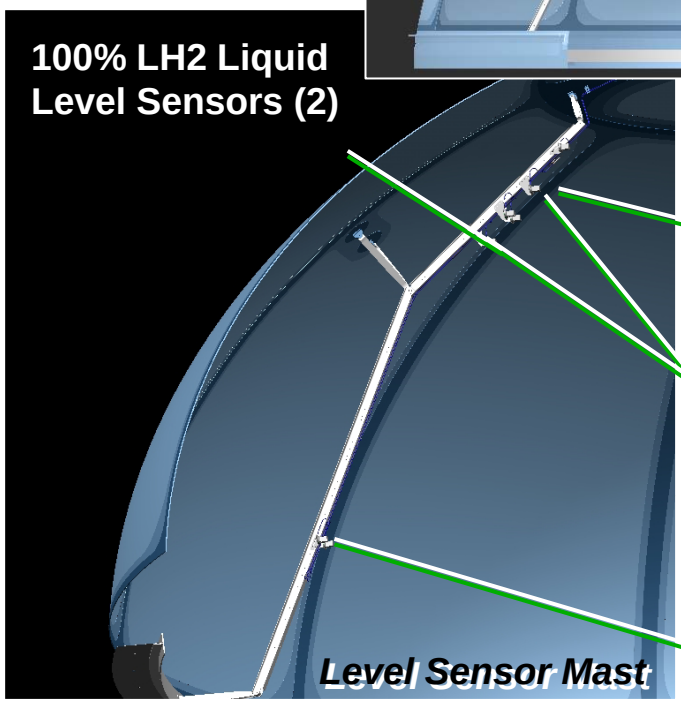




Diffuser to Cover Plate (GO2 Diffuser Shown)

- **Background – Hardware Orientation**





100% LH2 Liquid Level Sensors (2)

Overfill Sensor and Ullage Temp Sensor

LH2 Fwd Dome to LH2 Tank Barrel Ring Frame

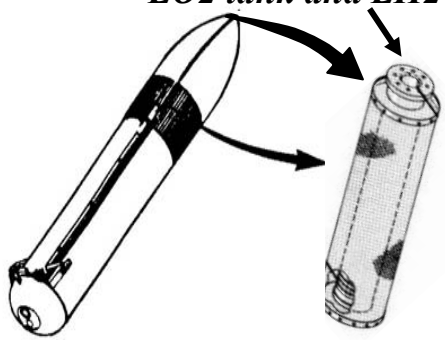
100% (+) and 100% (-) LH2 Liquid Level Sensors

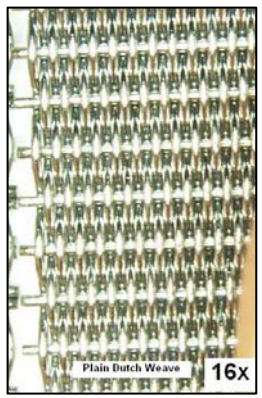
98% LH2 Liquid Level Sensors (2)

Increased Number of LH2 Prepressurization Cycles

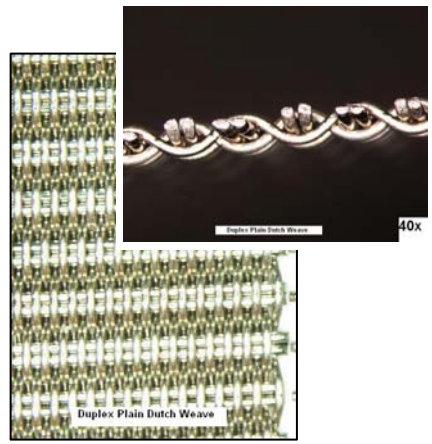
- **Background**
  - Out of configuration screen material for diffusers installed on RTF tanks
    - ET-121: GO2 and GH2 diffuser
    - ET-120: GH2 diffuser
    - ET-119: GH2 diffuser
  - Screen material not per engineering requirements (discovered at subtier supplier)
    - Plain dutch weave wire specified
    - Duplex dutch weave wire used
  - Nonconforming hardware assessed prior to STS-114/ET-120 tanking test
    - Concerns were potential for flow reduction and loads (structure) on the screen
  - Analysis performed for GH2 diffuser with duplex dutch weave screen
    - Delta pressure change from 0.35 psig to 0.68 psig
    - Pressure increase a result of higher wire density in the 'warp' direction
      - 'Shute' fiber density is unchanged
    - Structural Factor of Safety assessment
      - Factor of Safety >100 for increased delta pressure loading
        - A316L S/S ultimate strength at max operating temp (115°F) is 66.0 ksi
        - Hoop stress is 560 psi @ 0.68 psid

Diffuser located internal to LO2 tank and LH2 tank





Plain Dutch Weave



Duplex Plain Dutch Weave

Increased Number of LH2 Prepressurization Cycles

- Actions Taken to Identify Cause of Anomaly
  - Fault Tree investigation identified potential contributors that could result in the anomaly
    - Actions assigned to determine applicability of concern
      - ET RTF tank heat leak
      - GH2 vent valve performance
      - Out of configuration GH2 diffuser
        - ET Project recommended R&R of diffusers
  - Reviewed RTF changes to assess tank heat leak
    - Changes increased the ET heat leak by ~ 0.6%
      - Total LH2 Tank heat leak ranges from 393K to 748K BTU/hr
  - Reviewed vent valve pedigree (build, acceptance and post installation acceptance)
    - Supplier : Cryogenic leak test (ATP) at supplier in spec
    - MAF
      - Functional - Valve actuation and vent mode response @ambient temp
      - Leakage (external only) - valve to tank and valve to connections / lines
    - KSC - Leakage
      - Valve cycled at pressure to seal the valve after depressurization
      - Tank pressure verified twice weekly to verify no leakage
    - No anomalies noted for ET-120 hardware
  - SSP baselined subsequent tanking test to investigate cause of anomaly
    - Instrumentation installed to monitor GH2 vent valve performance
    - Bipod heater operations tailored to investigate effects of heat leak

Increased Number of LH2 Prepressurization Cycles

- **Actions Taken to Identify Cause of Anomaly**
  - **Tanking test #2 Results**
    - **No vent valve leakage that would result in the anomaly signature**
    - **Prepress performance essentially same for both heater on / heater off operations**
  - **Performed tests and analysis to assess the effect of the discrepant diffuser screen**
    - **Diffuser testing showed a significant difference in the exit flow velocity profile between the two types of screens which will potentially alter the transient response of the the ullage**

Observation	*Implication*
ΔP across the duplex screen was low (< 1 psi)	*Duplex screen did not cause a reduction in pressurant flow*
• *Negative ΔP across the top and bottom of the plain screen* • *Negative pressure at the bottom of the diffuser inside plain screen* • *Nitrogen temperature increase between the diffuser inlet and the plain screen entrance* • *Tufts stuck to the top and bottom of the plain screen*	*Indicates reverse flow for the plain screen and contributes to higher velocities and more mixing*
Temperature sensor same distance away from the diffuser as the ullage temperature sensor was influenced more by the plain screen	*Indicates higher velocities and would result in more mixing for the plain screen*
Higher exit velocities (anemometer data, video) for the plain screen	*More mixing*

Increased Number of LH2 Prepressurization Cycles

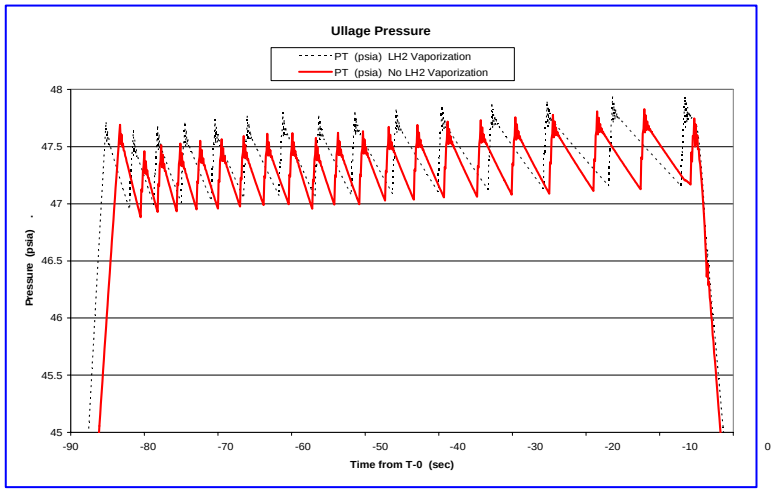
- Actions Taken to Identify Cause of Anomaly (Continued)
  - Modeled the potential effects of the duplex diffuser screen using two programs
    - Single Node Pressurization program (ET use and derived from Titan)
      - Treats the ullage space as a single, uniform volume
    - Multi-Node Pressurization program (converted for ET from early SSP)
      - Divides the ullage space into a series of nodes
      - Computes mixing and heat transfer between the nodes
    - Both codes perform mass and energy balances during prepress and include heat transfer between the ullage gas, the tank structure, and the liquid surface
  - Analysis results using data obtained from test
    - Higher exit velocities from the plain weave screen result in more mixing between the warm Helium gas entering the ullage and the cold Hydrogen gas already in the ullage
      - Result is less stratification and more heat transfer to the liquid surface
        - More vaporization of Hydrogen from the surface
        - Vaporized Hydrogen contributes to the pressurization of the tank
      - Exiting velocity with the duplex screen is significantly lower
        - Less mixing, more stratification, less heat transfer with the liquid surface and therefore less vaporization of Hydrogen from the surface
        - More heat transfer with the cold walls and upper structure
      - Less Hydrogen is added to the ullage due to reduced vaporization
        - Increased heat transfer between the Helium and the walls and structure
        - More Helium is required to maintain tank pressure and thus results in more prepress cycles (0.5 second bursts of Helium)

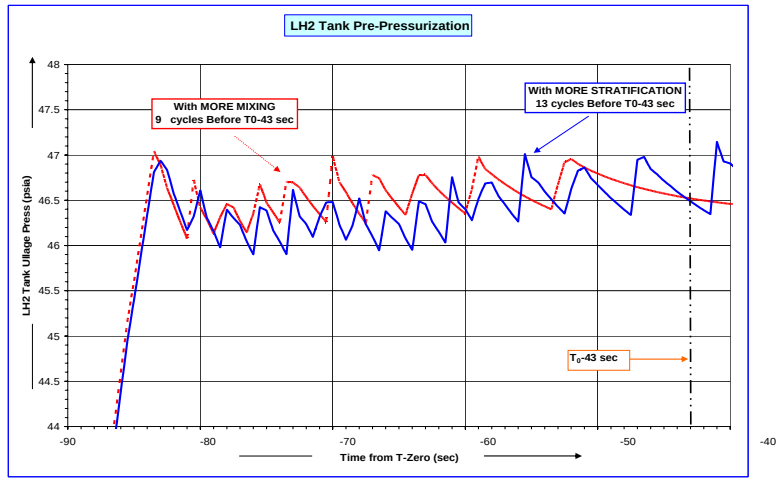
Increased Number of LH2 Prepressurization Cycles

Single Node Program

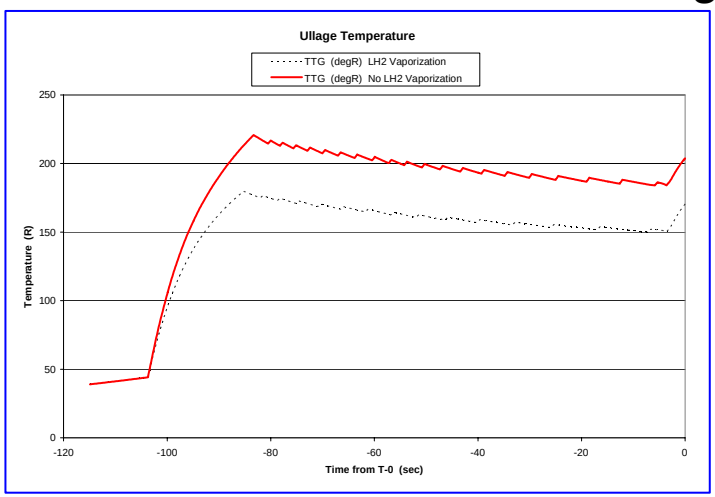
Multi-Node Program

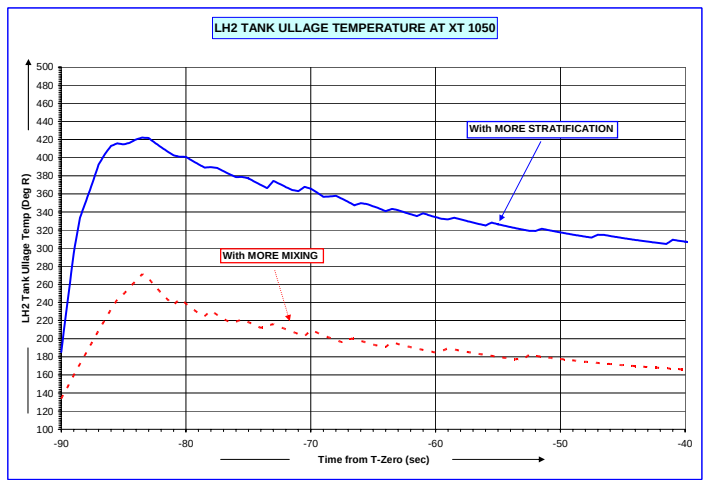
Ullage Pressure





Ullage Temperature





Increased Number of LH2 Prepressurization Cycles

- Actions Taken to Identify Cause of Anomaly
  - Analysis results using data obtained from test
    - Higher exit velocities from the plain weave screen result in more mixing between the warm Helium gas entering the ullage and the cold Hydrogen gas already in the ullage
      - Result is less stratification and more heat transfer to the liquid surface
        - More vaporization of Hydrogen from the surface
        - Vaporized Hydrogen contributes to the pressurization of the tank
      - Exiting velocity with the duplex screen is significantly lower
        - Less mixing, more stratification, less heat transfer with the liquid surface and therefore less vaporization of Hydrogen from the surface
        - More heat transfer with the cold walls and upper structure
      - Less Hydrogen is added to the ullage due to reduced vaporization
        - Increased heat transfer between the Helium and the walls and structure
        - More Helium is required to maintain tank pressure and thus results in more prepress cycles (0.5 second bursts of Helium)

Increased Number of LH2 Prepressurization Cycles

- **Analysis Summary**
  - Slower initial pressure rise rate, higher prepress cycle count, and higher ullage temperature observed in the STS-114 tanking tests have been reproduced with both models
  - Results provide confidence that the duplex diffuser screen is the cause of the STS-114 tanking test prepress performance
- **Basis for Acceptance of ET-120 and ET-121 hardware**
  - All out of configuration diffusers have been or will be replaced
    - Analysis indicates cause of prepressurization anomaly will be eliminated with plain weave diffuser screen
  - LCC changed from 13 max prepress cycles to 11 max for STS-114 only
    - 11 cycles based on historical max and flight pressure predictions within the ullage pressure ICD for 11 cycles
    - Ensures that the removal of discrepant hardware has returned the prepress performance to within our experience base (in-family) for STS-114
- **CoFR / Certification Assessment**

Milestone Reviews

SSP DCR	EAR	MAR	NASA Pre-FRR	FRR	ITAR
N	N	N	Y	N	Y

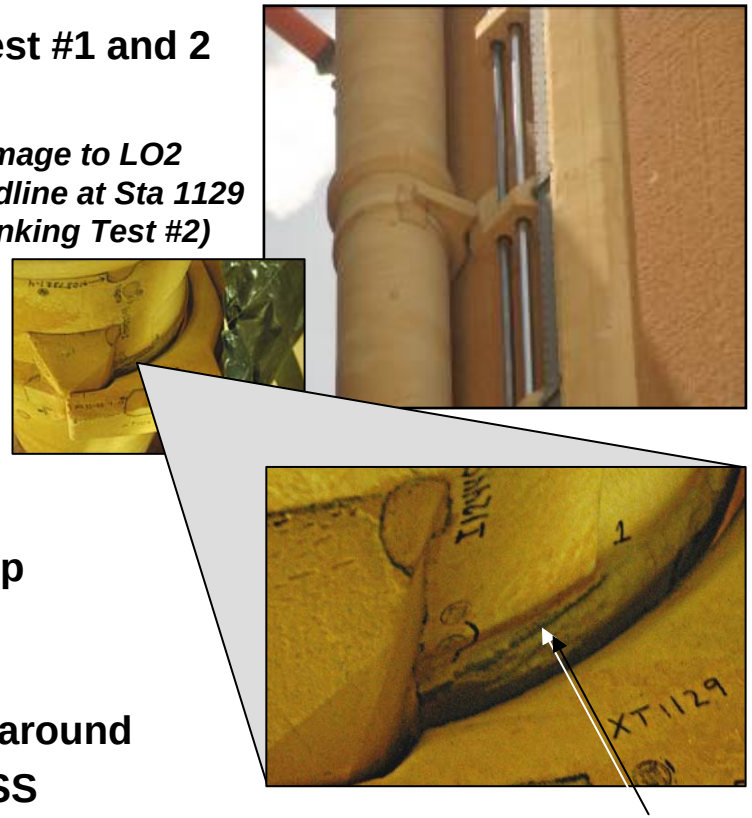
System Safety Assessment
No change in risk

Certification Documentation Impacts

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
No impact	Y	No impact	--	None

LO2 Feedline Bracket TPS Damage

- **Observation**
  - **Damage to LO2 feedline TPS following tanking test #1 and 2**
- **Concern**
  - **Potential for TPS or ice debris**
- **Background**
  - **Ice forms on LO2 feedline support brackets during prelaunch**
    - **Amount of ice is dependent upon environmental conditions and condensation**
    - **Damage to the feedline occurs when line articulates during drain when the ET warms-up**
    - **Less articulation occurs at aft locations (Sta 1871 and 1973)**
  - **Damage previously observed during scrub / turnaround**
    - **Hands-on inspection performed only when RSS (rotational service structure) is in place (typically when turnaround > 24 hrs)**



Damage to LO2 feedline at Sta 1129 (Tanking Test #2)

Damaged TPS with Exposed Primer

LO2 Feedline Bracket TPS Damage

- **Actions Taken**
  - **Documented damage dimensions and deltas between tankings**

Location	Tanking Test #1 Feedline Damage (on-pad inspection)	Tanking Test #2 Feedline Damage (post roll-back inspection)
Xt 1129	*No damage reported*	*7.5" L x 1.2" W x 0.3"D (exposed primer)*
Xt 1377	*11" L x 0.38" W (estimated to be one crack)*	• *6.0" L x 0.125" W x 0.125"D* • *3.0" L x 0.125" W x 0.125" D* • *0.5" L x 0.25" W x 0.125" D* • *1.5" L x 0.25" W x 0.125" D (exposed primer)*
Xt 1623	*4" L*	*12.0" L x 0.25 – 0.4" W x 0.125" D (primarily hairline crack with small excursion to 0.4" W)*
Xt 1871	*No damage noted*	*No damage noted*
Xt 1973	*No Access*	*No damage noted*

  - **Assessing damage against requirements (thermal, structural, propulsion and debris)**
    - **Preliminary assessment indicates no impact to ET structure or propellant**
    - **No concern for TPS debris**
      - **Hot gas testing of crushed foam shows liberation <0.0002 allowable (popcorning)**
      - **Loose material removed**
    - **Potential minimal increase of ice in damaged areas**
      - **Assessing condition as compared to existing LO2 feedline bracket ice**
  - **Assessing repair options (if required)**
- **CoFR / Certification Assessment**

Milestone Reviews

SSP DCR	EAR	MAR	NASA Pre-FRR	FRR	ITAR
N	N	N	Y	N	Y

System Safety Assessment
No change in risk

Certification Documentation Impacts

FMEA/CIL	Hazards	COQ	HCS	Waiver/ Deviation
No impact	No impact	--	No impact	None

Crack/Frost in Bipod TPS Closeout

- **Observation**
  - KSC observed two frost balls (approx 1.0”) on the - Y Bipod BX 265 TPS closeout following bipod heater reactivation after a planned 90 minute out
    - Cracks not visible due to frost formation
  - Similar conditions observed during ET Bipod closeout validation tests
- **Status**
  - KSC generated Problem Report to perform hands on inspection following ET return to VAB
    - KSC inspection complete - No cracks detected
  - NSTS 08303 update in-work to document occurrence as an acceptable condition
- **Rationale**
  - Cracks are caused by thermally-induced TPS stress levels as a result of coefficient of thermal expansion differences between the aluminum substrate and the TPS
  - Thermal / vacuum test was performed using 13 cryogenic cycles followed by 1 ascent thermal / vacuum cycle
    - During these tests, a minimum of 1 – 2 cracks developed during each detanking or ‘warm-up’ period. Over 14 cracks, varying in size from ¼” to 2” long, were observed
    - No divots were observed during the ascent cycle portion of the test
  - A second thermal / vacuum test panel was cryogenically cycled once to minimize crack formation prior to the ascent cycle
    - Two cracks were observed during the detanking period
    - No divots were observed during the ascent cycle portion of the test
  - The successful test demonstration of the bipod closeout TPS, cracks are considered to be ‘expected’ following a tanking /detanking cycle
    - Testing has verified that the presence of cracks in the bipod TPS will not result in divot formation and are acceptable for flight

External Tank Project
MP01 FRR

STS-114/ET-121

Appendix C
Waivers / Exceptions / Deviations

June 29, 2005

External Tank Waivers / Exceptions

- NSTS 07700, Vol. X, Book 1, Waiver #707
  - ET soldering of electrical connections design in LO2 low range ullage pressure transducers does not meet JSC 08800
    - Redesign required to eliminate waiver
    - Retention rationale for existing transducers
      - No flight function - Redundant Crit 3 prelaunch measurement
      - Good service record, no failures in life of program
      - Hardware currently procured through ET-181
      - SSP will deplete currently procured hardware and retain waiver
  - Approval: PRCBD S040732VR1 dtd 4/20/05
    - Deleted waiver and issued new waiver with limited effectivity (ET-117 – 181)

Low Range Ullage Pressure Transducers on LO2 Tank Cover Plate

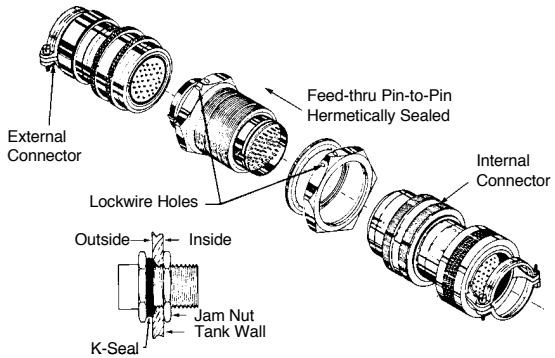
External Tank Waivers / Exceptions

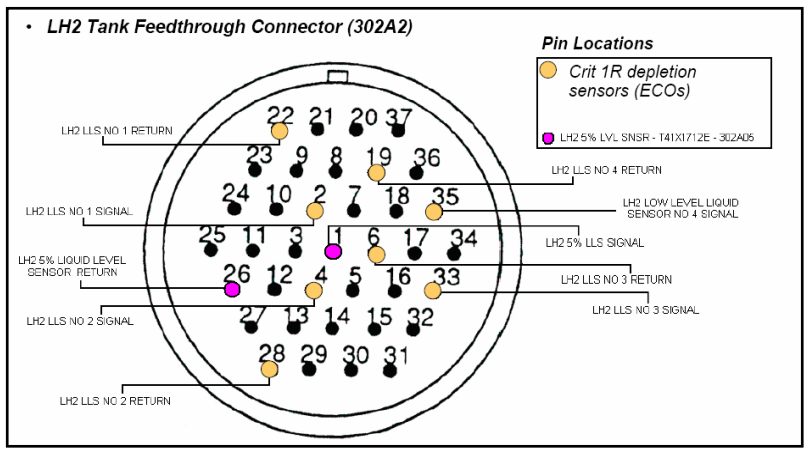
- NSTS 07700, Vol. X, Book 1, Waivers #708 and #709
  - ET circuit boards in LO2 low range ullage pressure transducers design does not meet design requirements specified in MSFC-STD-154 and design does not meet mounting requirements specified in MSFC-STD-136
    - Redesign required to eliminate waiver
    - Retention rationale for existing transducers
      - No flight function - Redundant Crit 3 prelaunch measurement
      - Good service record, no failures in life of program
      - Hardware currently procured through ET-181
      - SSP will deplete currently procured hardware and retain waiver
  - Approval: PRCBD S040732VR1 dtd 4/20/05
    - Deleted waiver and issued new waiver with limited effectivity (ET-117 – 181)

Low Range Ullage Pressure Transducers on LO2 Tank Cover Plate

External Tank Waivers / Exceptions

- **NSTS 07700, Vol. X, Book 1, Waiver #683**
  - **ET does not meet wiring separation requirement for redundant systems / elements in several locations: ET/Orb interface connections, ET/GUCA disconnect, LO2 and LH2 tank feed through connector, intertank disconnect panel**
    - **Elimination of waiver would require additional penetrations which adds failure mode for leakage**
    - **Retention rationale for existing design**
      - **Adequate qualification and acceptance tests and operational checkout of harnesses**
      - **Connector configuration provides pin isolation between Crit 1R components (LH2 depletion sensors)**
      - **Good service record**
  - **Approval: PRCBD S061451 dtd 8/8/00**
    - **SSP concurred with rationale to retain existing design and waiver**

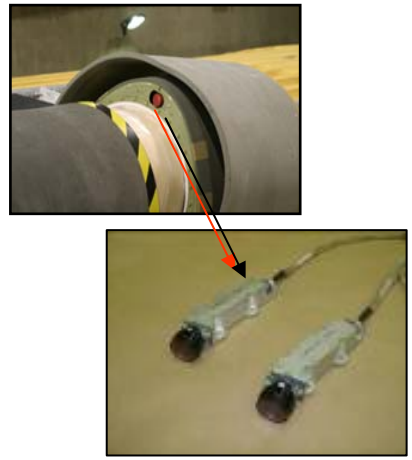




External Tank Waivers / Exceptions

- NSTS 07700, Vol. X, Book 1, Waiver 706
  - ET Camera does not meet design and construction standards from Section 3.6.25 Electrostatic Discharge (ESD) Protection
  - Per the requirement, all ESD sensitive parts should be marked with a precauti

CAUTION
Contains parts and assemblies susceptible to damage by Electrostatic Discharge (ESD).



  - Item discovered during the ELVIS DCR
    - ESD Marking has not been done to all ELVIS components
  - Rationale
    - Camera hardware was handled either ESDS and/or by previous flight hardware procedures at the build-up centers
    - Ground Operation procedures document handling of the ELVIS Camera hardware as ESDS
    - Testing post-installation has verified that the camera is functional prior to launch
    - Adding labels at this point in the flows is unproductive and hardware could be damaged trying to add labels “after the fact”
    - Labeling will begin with the third flight set
  - Approval: PRCBD S061990K dtd 4/12/05
    - Requirement is waived for ET-120 and ET-121 camera units

External Tank Waivers / Exceptions

- NSTS 07700, Vol. X, Book 1, Waiver TBD
  - ET instrumentation does not meet design and construction standards from Section 3.6.25 Electrostatic Discharge (ESD) Protection and Section 3.6.25.3 Handling Procedures
  - Per the requirement, all ESD sensitive parts should be marked with a precautionary statement

> CAUTION
> Contains parts and assemblies susceptible to damage by Electrostatic Discharge (ESD).

  - Rationale
    - IVIS hardware not identified as ESD sensitive by suppliers
    - Accelerometer supplier has ESD data, but testing not performed to levels specified in
    - NSTS 07700 ESD requirements
    - Relay and Signal conditioner supplier indicated no ESD concerns for the components
    - Test data is not available
    - IVIS hardware was handled during acceptance testing without benefit of ESDS handling
    - procedures
    - Post-installation testing has (or will) verify that the hardware is functional prior to launch
    - Adding labels at this point in the flows is unproductive and hardware could be damaged trying to add labels “after the fact”
    - Handling procedures cannot be implemented on these vehicles at this stage

  - Status: Rationale presented and approved at PRCB, 6/16/05
    - Pending PRCBD

External Tank Waivers / Exceptions

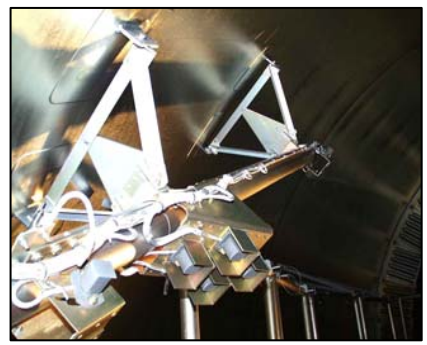
- NSTS 07700, Vol. X, Book 1, Exception
  - Exempt ET instrumentation from the NSTS 08080-1 Standard 69 deadfacing requirement
    - Existing notes do not identify each umbilical interface separately
    - Deadfacing of electrical connectors for ground and in-flight separations asses and approved by SICB
  - Rationale
    - No combustible environment during SRB separation (> 120K ft)
    - No connector damage concern due to electrical arcing
      - Connectors not re-used
      - Functions are required to support proper separation sequence
      - All functions deadfaces approximately 4 seconds after separation except for SRB power buses A and B
      - MEC outputs and SRB power buses have short circuit protection
      - Sockets on ET side of interface
  - Status: Pending approval

Note: This exception is included for completeness – SRB responsibility

External Tank Waivers / Exceptions

- NSTS 07700-10-MVP-01 Shuttle Master Verification Plan – Vol. I Waiver #13, General Approach and Guidelines
  - ET LO2 low range ullage pressure transducers and liquid level sensors do not meet environmental acceptance test requirements and liquid level sensors are not subjected to environments identified in SP-T-0023
    - Redesign required to eliminate waiver
    - Retention rationale for existing transducers
      - No flight function
      - Good service record, no failures in life of program
      - Hardware currently procured through ET-181
    - Retention rationale for existing level sensors
      - Adequate qualification and acceptance tests and operational checkout of sensors
      - Good service record, no failures in life of program
    - SSP issuing directive to delete existing waiver and issue new waiver with limited effectivity (ET-117 – 181)

Low Range Ullage Pressure Transducers on LO2 Tank Cover Plate



Liquid Level Sensors

External Tank Waivers / Exceptions

- SW-E-0002, Ground Support Equipment General Design Requirements
  - Exception, GSE General Design Requirements, Book 1 (Existing GSE)
    - For LM designed ET GSE, MMC specification 809-8000 Design Specification, Support Equipment - External Tank, shall be used to satisfy the intent of SW-E-0002
    - Retaining exception for existing GSE, approved by PRCB 08/11/04

External Tank Project
MP01 FRR

STS-114/ET-121

Appendix D
ET Hazards with Infrequent / Catastrophic Cause

June 29, 2005

Certification Status
Hazard Analysis Report Risk / Cause Matrix

Presenter: M. Quiggle, LM-ET
Date: June 29, 2005

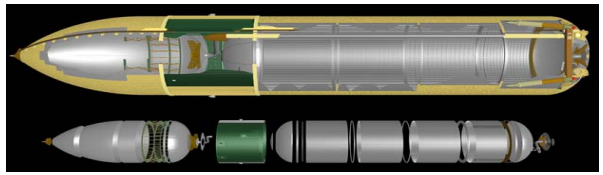
LIKELIHOOD	Marg.	Crit.	Cat.
Probable			
Infrequent			5
Remote			12
Improbable	1		90

Severity

Classification

- *Unacceptable Risk*
- *Accepted Risk*
- *Controlled Risk*

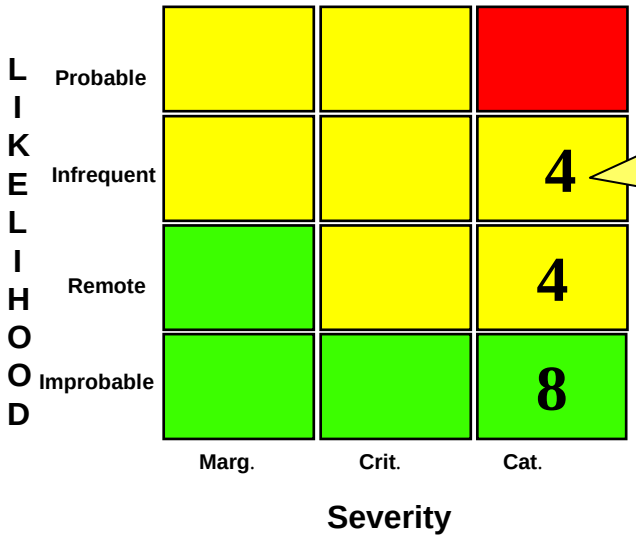
ET Hazard Reports



Hazard Report #		CONTROLLED				ACCEPTED RISK						
		Remote-Marginal	Improbable-Marginal	Improbable-Critical	Improbable-Catastrophic	Probable-Marginal	Infrequent-Marginal	Remote-Critical	Remote-Catastrophic	Probable-Critical	Infrequent-Critical	Infrequent Catastrophic
ACCEPTED RISK HAZARD REPORTS (5)												
E.03	Lightning	0	0	0	0	0	0	0	4	0	0	0
S.09	Hydrogen Venting in Flight	0	0	0	1	0	0	0	2	0	0	0
S.10	Partially Open GO2/GH2 Vent/Relief Valve Indicated Closed	0	0	0	1	0	0	0	1	0	0	0
T.02	Loss of ET Thermal Protection System	0	0	0	8	0	0	0	4	0	0	4
T.04	ET Ice Debris	0	0	0	0	0	0	0	1	0	0	1
CONTROLLED RISK HAZARD REPORTS (24)												
E.01	Elect. Fires Due to Elect. Malfunction in Presence of Oxidizer & Flammable Materials	0	0	0	12	0	0	0	0	0	0	0
E.04	Failure of ET Heaters	0	0	0	5	0	0	0	0	0	0	0
E.05	ET Imaging System Malfunctions	0	1	0	11	0	0	0	0	0	0	0
E.06	ET Return-to-Flight Instrumentation System Failures	0	0	0	6	0	0	0	0	0	0	0
P.01	LH2 / LO2 Tank Overpressure	0	0	0	1	0	0	0	0	0	0	0
P.02	Mechanical/Thermal Shock in the LO2 Tank	0	0	0	4	0	0	0	0	0	0	0
P.03	Binding Of Mechanical Joints	0	0	0	3	0	0	0	0	0	0	0
P.04	Purge Malfunction	0	0	0	3	0	0	0	0	0	0	0
P.05	GUCA Separation Malfunction	0	0	0	7	0	0	0	0	0	0	0
P.06	Propellant Feed System Malfunctions	0	0	0	2	0	0	0	0	0	0	0
P.07	Orbiter / ET Recontact After Separation	0	0	0	2	0	0	0	0	0	0	0
P.09	ET Lands Outside of Footprint	0	0	0	1	0	0	0	0	0	0	0
P.10	Usage of Isopropryl Alcohol for ET Cleaning and Verification	0	0	0	1	0	0	0	0	0	0	0
S.01	Excess Stress in Intertank	0	0	0	2	0	0	0	0	0	0	0
S.02	Failure of Penetration Covers	0	0	0	3	0	0	0	0	0	0	0
S.03	LO2 Tank Buckling	0	0	0	3	0	0	0	0	0	0	0
S.04	LH2 Tank Buckling	0	0	0	3	0	0	0	0	0	0	0
S.05	LO2 and LH2 Tank Negative Differential Pressure	0	0	0	3	0	0	0	0	0	0	0
S.06	Hydrogen Leaks	0	0	0	1	0	0	0	0	0	0	0
S.07	Oxygen Leaks	0	0	0	1	0	0	0	0	0	0	0
S.08	Incipient Weld Leaks	0	0	0	1	0	0	0	0	0	0	0
S.11	ET Structural Systems Debris	0	0	0	3	0	0	0	0	0	0	0
T.01	TPS Flammability	0	0	0	1	0	0	0	0	0	0	0
T.03	Vacuum Bellows Failure	0	0	0	1	0	0	0	0	0	0	0
	Totals	0	1	0	90	0	0	0	12	0	0	5

Accepted Risk HAR with "Catastrophic" Failure Causes

- **T.02, Loss of ET Thermal Protection System**

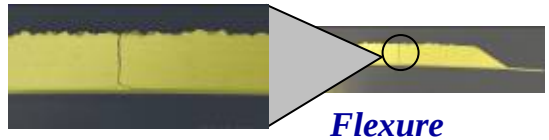


"Infrequent / Catastrophic" Failure Causes

- ***Manual foam (sprayed) application process deficiencies for non-redesigned ET locations***
- ***Manual foam (poured) application process deficiencies***
- ***Divoting due to internal voids for ET non-redesigned applications***
- ***External TPS Impact***

T.02, Loss of ET Thermal Protection System Acceptance Rationale

- Design Verification
  - Cryogenic panel tests (cryoflex, combined environments) testing performed to demonstrate critical load environments (mechanical strain >125% DLL, TPS temperature) for bondline delamination failure mode for all applications except LH2 tank aft dome (>110%)
  - Configuration specific tests performed for PAL ramp applications to demonstrate >125% of DLL flexure for the outer fiber cracking failure mode
  - Wind tunnel performance testing performed to demonstrate design capability for design certification aero and aero thermal load environments
  - Flat panel and system level thermal / vacuum testing performed to verify critical load environments for cohesive strength failure mode (divoting) (Delta P, TPS temperature) - *New for RTF*



Flexure

PAL Ramp Capability

Cryoflex

System (Flange) Thermal/Vac

- Personnel training / certification
  - Personnel performing TPS spray operations were certified TPS technicians or were allowed to apply TPS through On-the-Job Training (OJT)
    - Applications identified as suspect during Personnel Certification Investigation were assessed and dispositioned (Remove/replace of UAI)
      - UAI dispositions based on no flight hardware impact, acceptance testing, or certified QC witness/inspection
    - All personnel certification issues cleared for ET-121

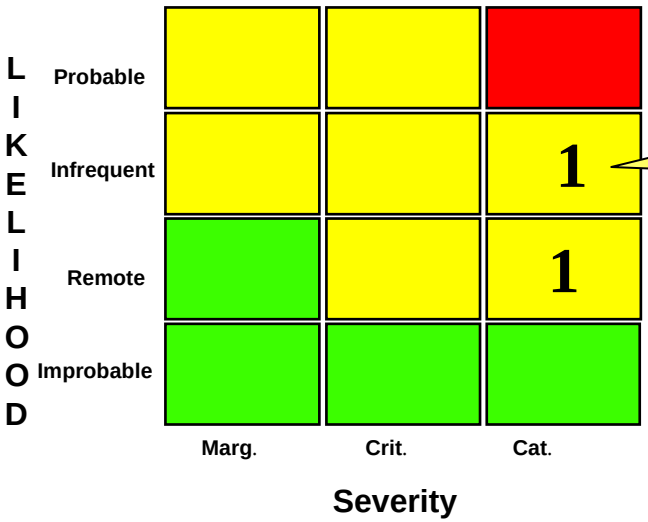
T.02, Loss of ET Thermal Protection System Acceptance Rationale

Hardware		Expected Debris using Max heating rates (< .0002 lbm)		Debris Req.	Best Est of Max Possible Mass (Ult. SF= 1.25)	Design MS (Ult SF = 1.25)
		Popcorning	Ablation			
1.	LO2 Tank Acreage	√	√	0.023	0.003	0. 79
2.	LO2 Ice/Frost Ramps		√	0.023	0.017	0.14
3.	LO2 PAL Ramp		√	0.023	0.013	0.25
4.	LO2-I/T Flange		√	0.026	0.026	0.00
5.	Intertank Acreage	√	√	0.030	0.004	0.61
6.	Bipod		√	0.030	0.025	0.09 *
7.	I/T Ice Frost Ramps		√	0.030	0.017	0.04
8.	LH2-I/T Flange		√	0.030	0.010	0.84 *
9.	LH2 Tank Acreage	√	√	0.030 – 0.075	0.004	1.14
10.	LH2 PAL Ramp		√	0.030	0.023	0.19
11.	LH2 Ice/Frost Ramps		√	0.030 – 0.075	0.008	0.84 *
12.	LO2 Feedline Flange		√	0.030	0.011	0.96
13.	Longeron		√	0.075	0.035	0.59
14.	Thrust Strut		√	0.072	0.005	2.04
15	Aft I/F Hardware		√	0.075	0.037	0.21
16.	LH2 Aft Dome Acreage	√	√	N/A	0.004	NA

** SF for cryoingestion environment shown*

Accepted Risk HAR with "Catastrophic" Failure Causes

- **T.04, ET Ice Debris**



"Infrequent Catastrophic" Failure Cause

- ***As-designed uninsulated ET surfaces exposed to cryogenic temperatures***

T.04, ET Ice Debris Acceptance Rationale

Location	Rationale
LO2 feedline bellows	Redesigned TPS drip lip to reduce the formation of ice across the liquid oxygen (LO2) feedline bellows cavities. Fwd bellows retrofitted with heater
LO2 feedline brackets	Inspections of TPS surfaces on day of launch that determine whether unacceptable ice formations exist as defined in NSTS 08303, *Ice/Debris Inspection Criteria*.
GH2/GO2 pressurization lines	Heated with an anti-icing purge up to prepressurization to prevent ice formation
ET GO2 vent louvers	Gaseous oxygen (GO2) vent arm is purged in the areas of the, and collects GO2 and LO2 tank purge gas until it is retracted at approximately T-120 seconds • Cameras located in the GO2 vent seals are focused on both GO2 exhaust vent louvers from approximately T-11 hours to T-120 seconds • After the vent arm is retracted, the Operational Television (OTV) system monitors the GO2 vent louvers for ice formation
Hardware aft of Sta 2058	It has been shown by debris transport analysis that ice formation on components at Sta. XT-2058 and aft do not pose a debris hazard to the SSV. All of these locations are addressed in the Expected Debris Table.

STS-114 Flight Readiness Review

External Tank (ET-121)

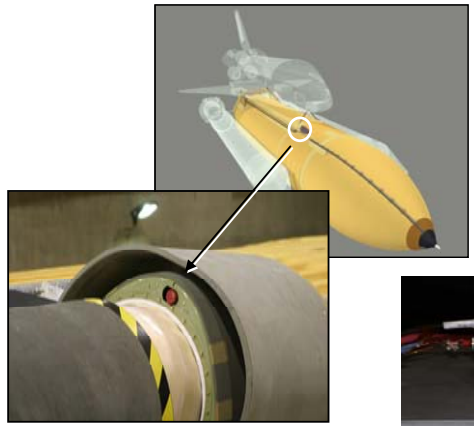
June 29-30, 2005

Back-Ups

Special Topic
STS-114 ET Camera System Battery Discharge

Presenter	M. Quiggle/LM-ET	
Date	June 29, 2005	Page BU-2

- *Issue:*
  - STS-114/ET-121 camera system failed to activate during pad testing
- *Concern*
  - Failure of system to operate during launch
- *Background*
  - System Overview
    - Camera installed in LO2 feedline fairing
    - Batteries installed on crossbeam in Intertank
    - Crit 3 function, not a launch commit constraint
  - System History
    - Batteries were previously replaced (SMR 04-002)
      - ET camera packages would not accept battery charge during previous planned testing
    - Battery screening, repair and testing approach reviewed and approved by system experts (approach more rigorous than original procurement)
    - New batteries were extensively tested before and after installation
      - System function verified after each of the six full battery charge / discharge cycles
      - System function verified after one partial charge when t he transmitter was turned on for a few minutes during system test after bellows heater mods in the KSC VAB



Camera installed in LO2 Feedline Fairing

Battery Installed on Crossbeam

Special Topic STS-114 ET Camera System Battery Discharge	Presenter M. Quiggle/LM-ET	
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- ***Status***
  - **Performed trouble shooting to identify cause of anomaly**
    - **Initial trouble shooting indicated proper GSE activation voltages to box on FSS**
      - **Battery Charge Unit (BCU) connected and battery voltage recorded (20.6 VDC, 29 VDC required)**
    - **Camera batteries successfully charged during two subsequent trouble shooting events**
      - **Camera system is functioning properly - Video reception similar to signal received during ET-120 tanking test**
  - **Developed Fault Tree to identify most probable cause of anomaly**
    - **Fault Tree analysis in progress**

Design Certification Status NSTS 08303 Document

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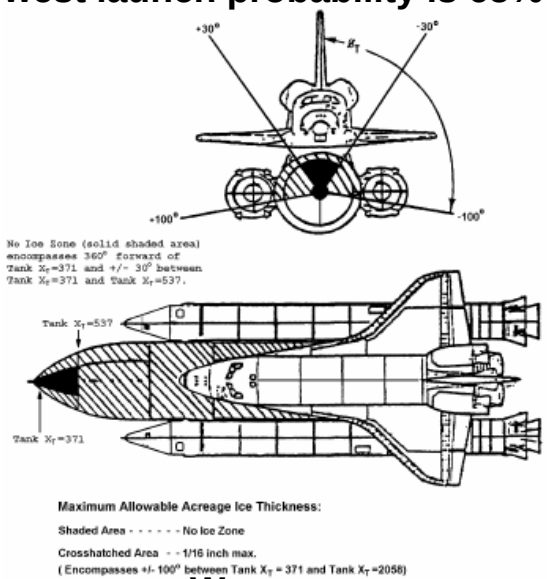
- ***Update NSTS 08303, Ice/Debris Inspection Criteria***
  - **Objective: NSTS 08303, Ice/Debris Inspection Criteria document is the operational control that assures DOL ice conditions meet the criteria established by the SSP as "acceptable risk"**
    - **Proposed revisions include expanded "No-ice zone" (draft document to be available 7/7)**
    - **ET reassessed proposal against "95% Launch Probability" requirement for July launch**
      - **ET TPS is sufficient to protect for "no ice" and meet 95% launch probability for launch in July – September**
    - **For launch beyond September (October - June), mission specific assessment or requirement revision required**
      - **Lowest launch probability is 65% in February**



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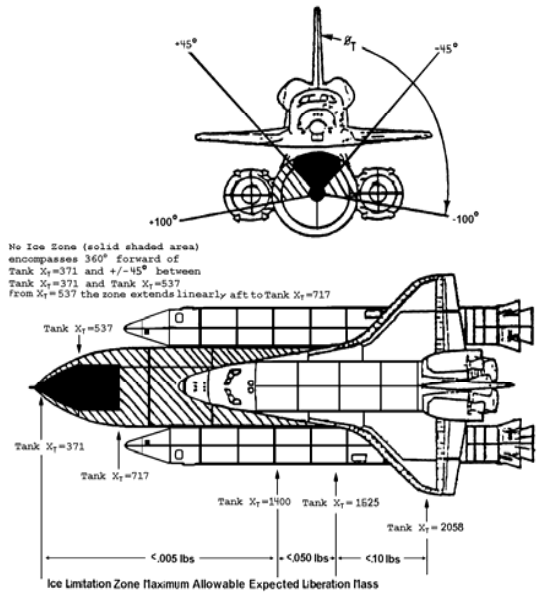

Proposed

Design Certification Status NSTS 08303 Document

Presenter	M. Quiggle/LM-ET	
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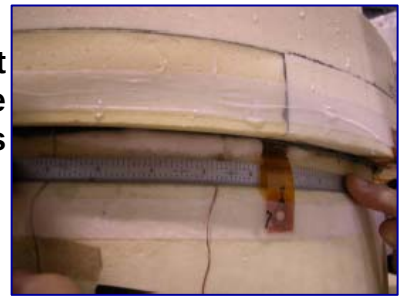
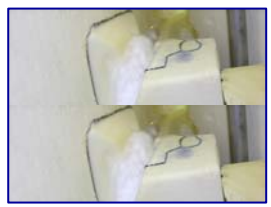
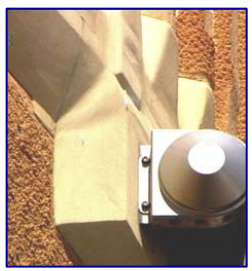
- *Update NSTS 08303, Ice/Debris Inspection Criteria*
  - Document is being updated for conditions observed on the LO2 feedline bellows with heater configuration, the LO2 feedline brackets as characterized in test and the bipod TPS crack and ice/frost observed during test
    - Residual ice conditions assessed through DVR process - determined to be an "acceptable risk'
    - LO2 feedline bellows
      - Ice/Frost conditions at fwd bellows will be inspected during Final Inspection Team walk-down and through OTV monitoring until heaters are deactivated
        - Monitoring after heater deactivation not required – No unacceptable increase in ice mass
        - Inspection will verify that gap ice formation does not exceed 0.013 lbs
    - LO2 Feedline Bracket locations
      - Final Inspection Team walk-down and OTV monitoring will ensure that conditions do not exceed conditions observed during ice characterization and liberation testing
    - Bipod closeout TPS crack and ice/frost
      - Final Inspection Team walk-down and OTV monitoring will ensure that conditions do not exceed conditions observed during test

Acceptable Ice/Frost at Fwd LO2 Feedline Bellows



Acceptable Feedline Bracket Ice/Frost



Acceptable Bipod Closeout Crack/Frost