STS-121
Flight Readiness Review

External Tank Project (ET-119)

June 16, 2006

Agenda

Presenter: M. Quiggle, LM-ET/ 3000
Date: June 16, 2006

	Topic	Status
1.0	ET-119/STS-121 Processing / Certification Overview	To be presented
2.0	Resolution of Anomalies from Previous Flight	To be presented
3.0	Configuration Inspection	No issues
4.0	Changes Since Previous Flight	
	4.1 Requirements	To be presented
	4.2 Configuration	To be presented
	4.3 Process	No issues
	4.4 Planned Work	No issues
	4.5 OMRSD	No issues
	4.6 LCC	No issues
5.0	Senior Management Review Nonconformance Items	No issues
6.0	Technical Assessments	No issues
7.0	STS-121 Readiness Assessment	To be presented
8.0	Special Topics	To be presented
	8.1 STS-121 Possible Outcomes	
	8.2 STS-300 LON Readiness Assessment	

1.0 ET-119/STS-121 Processing / Certification Overview

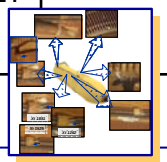
Presenter: M. Quiggle, LM-ET/ 3000
Date: June 16, 2006

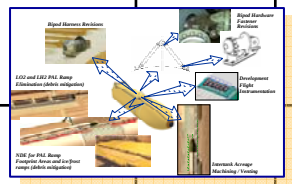
2002 | 2003 | 2004 | 2005 | 2006: Jan | Feb | Mar | Apr | May | Jun | Jul | Aug

DD250, 5/28/02
Ship to KSC
Return to MAF
RTF 1 Mods
Ship to KSC
Ship to MAF
RTF 2 Mods
Ship to KSC
ECOs & GO2 Valve R&R
ET/SRB Mate
12 ET/Orb Mate
19 SSV Roll to Pad
1 19
ET-119 ~ 4 yrs old at Launch
STS-121 Launch Window

ET-119 History & STS-121 Launch Processing Milestones

STS-114





ET-119 and STS-121 Highlights

- Implemented corrective actions for STS-114 IFAs
  - Bipod wire harness adhesive fill
  - LH2 PAL ramp (and LO2 PAL ramp) elimination
- ECO sensors subjected to Nanofocus X-ray installed
  - Sensors exhibit geometric features that provide 'best' geometric contact
  - Increases confidence in sensor reliability
- Bipod heater control system operational
  - – Fixed set points utilized on STS-114/ET-121
  - – Demonstrated during ET-120 tanking test
- New facility valve for LH2 pre-pressurization system
- First use of refurbished Firing Room 4 for launch

14 LM/Mich Ops Pre-Mate
17 ET Project Pre-Mate
21 SSP ET/SRB Mate
9 ET Project PFRR
12 MP01 PFRR
13 LMSSC PFRR
16 SSP FRR
29 L-2 Day

CoFR Milestone Reviews

CDR
CDR Preboard 18
DCR Kick-off 23
DVR 30-31
DCR On-Site 1-3
DCR Preboard 5
DCR Board 7

Verification / Certification Reviews

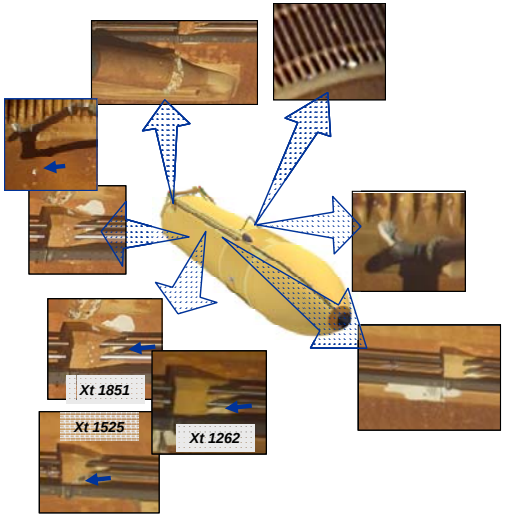
Misc Tech Reviews / Assessments

LM IAT Rev
PAL Elimination TIM
Debris Summit
LMSSC CE/MS Rev
Debris TIM
IFR TIM
Foam Debris Model Peer Rev
23 LM IAT Rev

2.0 Resolution of Anomalies from Previous Flight

- Six (6) External Tank In-Flight Anomalies (IFAs) documented
  - Fault Tree Investigation complete
  - Root cause testing complete
  - Most probable cause of IFAs identified

- IFA Investigation Teams (MSFC/NASA IFA Team and SSP HQ Tiger Team) identified recommendations for ET Project consideration
  - 83 total recommendations received
    - All mandatory items implemented
  - Items with potential scope impact forwarded to ET Project Configuration Control Board (CCB) for assessment

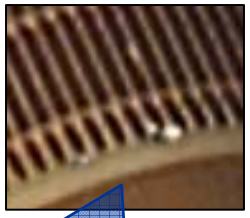


STS-114 IFA Fault Tree			
Team	**Open**	**Closed**	**Total**
T-01, Flange	0	28	28
T-02, Bipod	0	20	20
T-03, PAL Ramp	0	30	30
T-04, Ice/Frost	0	20	20
T-05, Acreage	0	14	14
T-06, Thrust Strut	0	69	69
Total	**0**	**181**	**181**

2.0 Resolution of Anomalies from Previous Flight – Root Cause Determination

Thrust Strut Flange TPS Closeout (STS-114-T-06)

- ***Most Probable Cause Scenario(s):*** Secondary impact or multiple subsurface voids resulting in observed foam loss

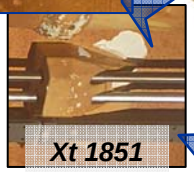


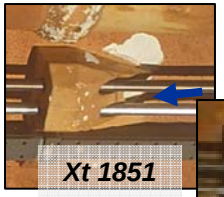
Intertank/LH2 Tank Flange, 2 locations (STS-114-T-01)

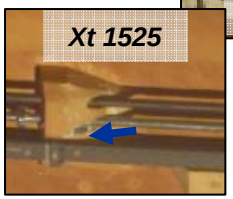
- **Most Probable Cause Scenario:** Foam loss caused by voids in the close-out manual spray foam subjected to ascent thermal and pressure environments

LH2 Tank Acreage, 2 locations (STS-114-T-05)

- ***Xt 1160 Most Probable Cause Scenario:*** Work induced damage or delta pressure void in adjacent repair
- ***Xt 1851 Most Probable Cause Scenario:*** Cryopumping divot event due to voids, cracks and/or delaminations







Bipod Fitting Closeout (STS-114-T-02)

- ***Most Probable Cause Scenario:*** Divot caused by cryoingestion through and into cable

LH2 PAL Ramp (STS-114-T-03)

LH2 Ice/Frost Ramps (IFRs), 3 locations (STS-114-T-04)

- ***Xt 1262 and 1841 Most Probable Cause Scenario:*** Divoting due to an internal process-induced void and delta pressure
- ***Xt 1525 Most Probable Cause Scenario:*** Impact during ascent due to TPS, ice or other Shuttle element debris

- ***Most Probable Cause Scenario (combination of the following)***
  - Cryopumping of outside air through leak path connecting to atmosphere
  - Defects(s) and or damage to initiate failure or driving force to peel foam from tank

2.0 Resolution of Anomalies from Previous Flight – Mitigations for STS-121

Thrust Strut Flange TPS Closeout

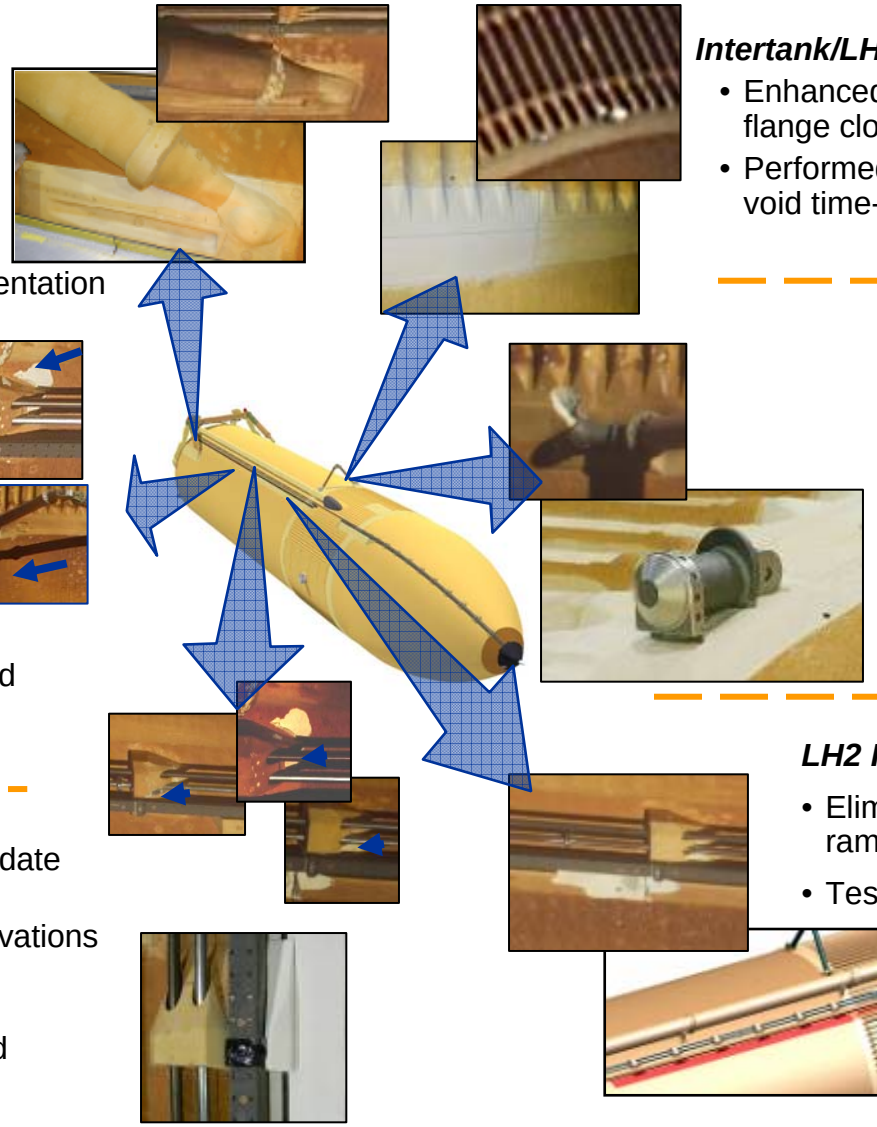
- Analysis indicates > expected or multiple voids required to result in STS-114 foam loss size / mass
- Dissected additional hardware to validate void distribution (used in PRA)
- Closeout redesign – future implementation (SSP assessment)

LH2 Tank Acreage

- Enhanced controls for tooling, documentation & personnel access
- Assessed effectiveness of damage detection, damage repair techniques and effects of crushed foam (used in PRA)
- Redesign to mitigate thermal induced delaminations under IFR for future implementation (SSP assessment)

LH2 Ice/Frost Ramps

- Assessed additional hardware to validate void distribution (used in PRA)
- Considered ET-120 dissection observations in design verification (wind tunnel, cryo/thermal vac tests)
- Redesign to mitigate thermal induced delaminations under IFR for future implementation (SSP assessment)



Intertank/LH2 Tank Flange

- Enhanced trim & inspection prior to flange closeout
- Performed thermal/vac tests for ΔP void time-to-divot (used in PRA)

Bipod Fitting Closeout

- Sealed/filled bipod wires to mitigate cryoingestion leak path
- Enhanced / validated harness bonding process to eliminate void volume under harnesses
- Test verified

LH2 PAL Ramp

- Eliminated LO2 and LH2 PAL ramps
- Test verified

2.0 Resolution of Anomalies from Previous Flight – Mitigations for STS-121

- PAL ramp and bipod closeout TPS loss mitigated through redesign
  - PAL ramp elimination design certified and application of TPS verified
    - Sufficient data provided by wind tunnel, CFD analysis and flight instrumentation to mitigate aero elastic concerns
  - Bipod harness seal/fill was test demonstrated to reduce cryo-ingestion leak path
    - Mitigation demonstrated through qualification test and process demonstration

- Thrust strut flange loss and ice/frost ramp loss at Xt 1525 most probably caused by external (secondary) impact, requiring no mitigation
  - Additional test data generated to validate void distribution

- Most probable cause for delta P divot events observed for Intertank flange closeout, LH2 acreage at Xt 1163 and ice/frost ramp body at Xt 1262, later than ASTT = 166 sec
  - Test-based analysis used to assess risk of delta-P voids, including additional data to verify time of release (input to Probabilistic Risk Assessment)
  - ET-120 LH2 ice/frost dissection data increased the population of the void data base
    - PRA performed based on ‘debris cloud’ including all failure mechanisms

2.0 Resolution of Anomalies from Previous Flight – Mitigations for STS-121

- Acreage loss at Xt 1851 most probable cause identified as cryopumping divoting due to subsurface delaminations observed under acreage foam ice/frost ramp body
  - Ice/frost ramp certification testing (due to PAL ramp elimination) used to demonstrate performance for TPS debris requirements - Complete
    - Wind Tunnel Tests demonstrated ascent critical environment using full scale ice/frost ramp (max design dynamic pressure)
    - Cryo/thermal vac tests used to demonstrate prelaunch/ascent critical environments (max environments)
  - Stress analysis provided understanding of TPS cracks / delaminations
  - Flat panel flaw tolerance thermal/vac test validated stress analysis

- Flight history assessment supports analysis that TPS debris is not expected to exceed values identified and used for input to the PRA

Root Cause of STS-114 In-Flight Anomalies Identified – IFAs closed through ET Project CCB

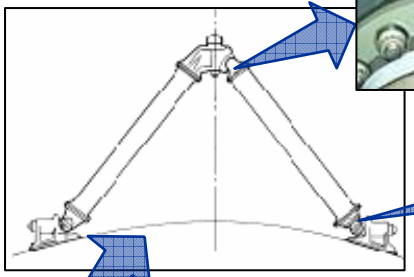
4.1 Requirements Changes Since Previous Flight

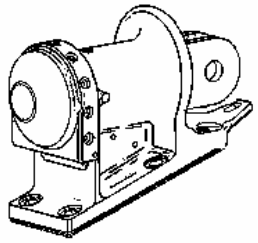
Change Description	SSP Requirement	ET Requirement (End Item Specification)
Launch Probability		
Extended 'no-ice' zone and PAL elimination impact	NSTS 07700, Vol. X, Book 1, Para 3.2.1.2.14.1 - Approved • Launch Holds due to ice formation shall not occur more than 11% of the time on an annual basis based on atmospheric conditions at the launch pad in the proximity of applicable launch vehicle • Exception for No-PAL ramp retrofit tanks (15%)	EIS Para 3.2.1.6.1 – Approved
ET Debris Requirements		
Potential Change - Extension of 'no-ice' zone from 100° to 110° of +Z	NSTS 08303 Ice/Debris Inspection Criteria Update • Levied by NSTS 16007, Launch Commit Criteria, ICE-01 • CR S063412 released for review 6/12	EIS Para 3.2.1.6.1, 3.2.1.1.17 and 3.2.1.6.4 – No expected impacts
Update TPS certification limitations	NSTS 60555, Verification Limitations for the External Tank Thermal Protection System • CR S062571A reviewed at PRCB 6/8/06, pending approval	EIS Para 3.2.1.1.17 and 3.2.1.6.6 • Pending CR approval • No issues
Update debris allowables to ensure consistent SSP and ET Project debris requirements	NSTS 60559, Expected Debris Generation and Impact Tolerance Requirements, Groundrules and Assumptions – Pending Approval • CR S063369 reviewed at SICB 06/06/06 – Approval deferred to PRCB	EIS Para 3.2.1.1.17 and 3.2.1.6.6 • Pending CR approval • No issues
Induced Environment Updates		
Thermal Environments Vehicle Loads, and Protuberance Airloads Used for Hardware Design	NSTS 07700, Vol. X, Book 2, Appendix 10.11 – Pending formal transmittal and incorporation into Appendix 10.11 • "CDR" environments transmitted to ET via SSP web site • CR S063281 reviewed at SICB 6/13/06 – Pending	EIS para 3.2.7.1 • Pending CR approval • No issues

4.2 Configuration Changes Since Previous Flight

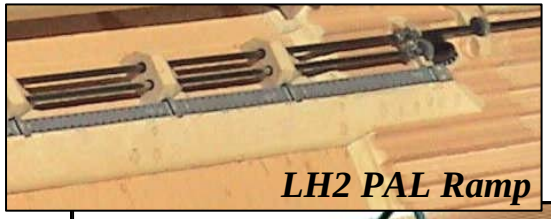
Bipod Harness Revisions

Bipod Hardware Revisions

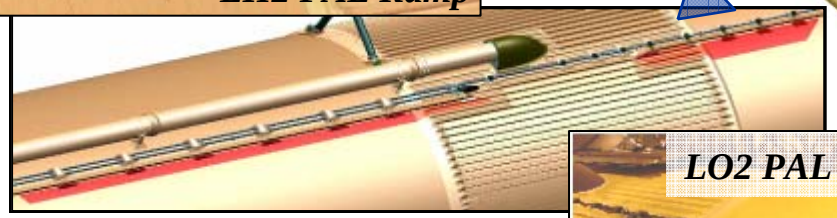




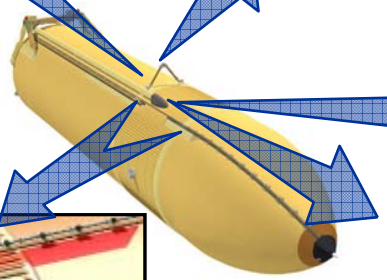
LO2 and LH2 PAL Ramp Elimination

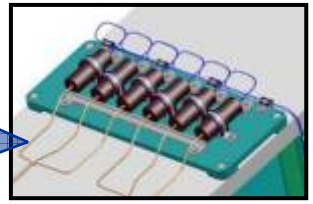


LH2 PAL Ramp



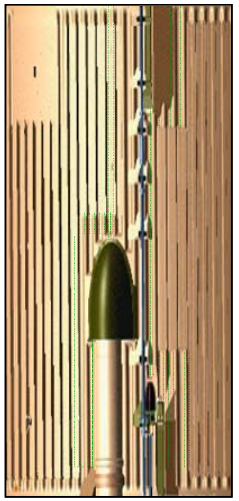
LO2 PAL Ramp





Development Flight Instrumentation

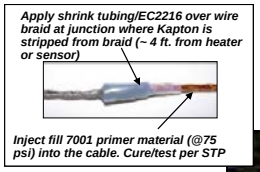
Intertank Acreage Machining / Venting



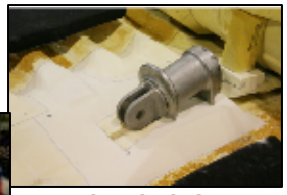
Design Reviewed through DCR Process
- - - Design Verification of Configuration Changes Complete

4.2 Configuration Changes Since Previous Flight

Change Description	Reason for Change	Basis for Certification	Verification Status
• Sealed/filled bipod wires • Enhanced / validated harness bonding process	• Debris mitigation (IFA corrective action) • Mitigate cryoingestion leak path and eliminate void volume	• Test • Demonstration	√
Revised bipod fitting to tank fastener length from 0.875” to 1.0” (6 places ea fitting)	• Ensure adequate breakaway torque	• Test • Analysis	√
Replaced bipod strut lubricated washer with non-lubricated washer and dry-lube nut and revised torque requirements (12 plcs ea strut)	• Preclude excessive bolt elongation and preload	• Test • Analysis	√

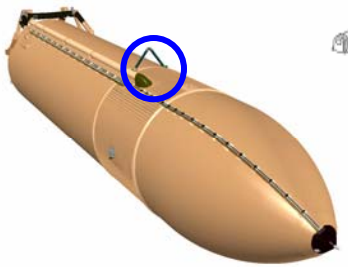


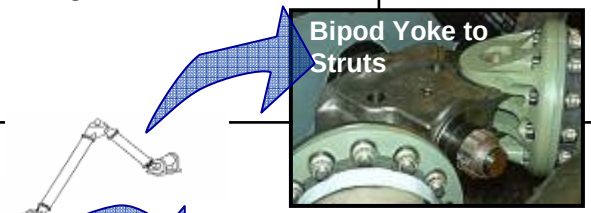
Wire Harness Sealing

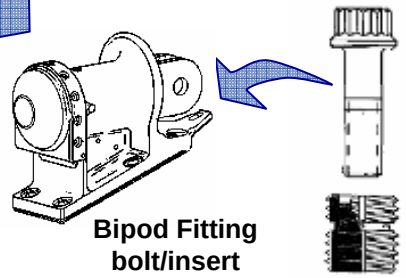


Wire Harness Bonding

Bipod Fitting Closeout (harnesses under closeout)



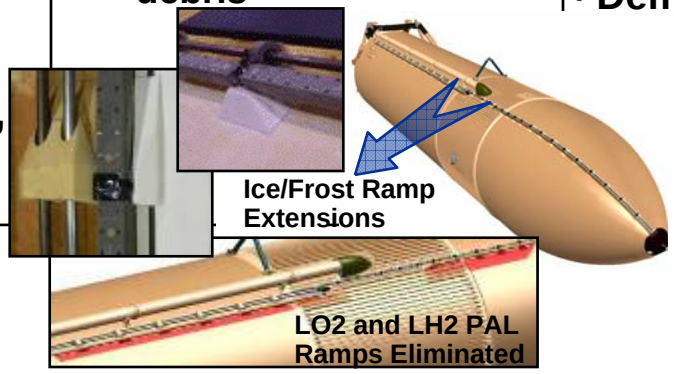


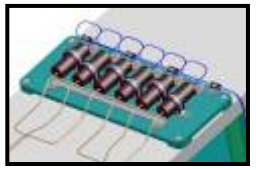


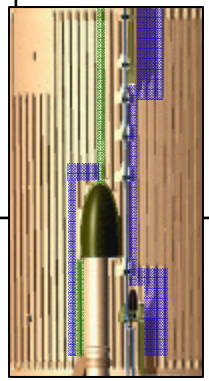
Bipod Fitting bolt/insert

4.2 Configuration Changes Since Previous Flight

Change Description	Reason for Change	Basis for Certification	Verification Status
Sanded / vented additional Intertank acreage TPS similar to other Intertank acreage	• Debris mitigation • Reduce TPS thickness / potential debris size	• Test • Analysis	√
Install development flight instrumentation (DFI) suite to obtain accelerometer data from accelerometers in LO2 cable tray (4) and LH2 cable tray (8)	• Obtain data for PAL elimination model validation	• Test • Analysis	√
Eliminated LO2 and LH2 PAL ramps • Re-sprayed foam over acreage / adhesive in removal footprint, as required • Modified ice/frost ramps, cable tray fairing, supports as required	• Debris mitigation (IFA corrective action) • Reduce potential TPS debris	• Inspection • Test • Analysis • Demonstration	√




Development Flight Instrumentation


Intertank acreage Sanded/vented areas

7.0 STS-121 Readiness Assessment

Presenter: M. Quiggle, LM-ET/ 3000
Date: June 16, 2006

Category	*Topics*	*STS-121/ET-119 Rationale/ Mitigation*	*Status*
Flight Anomalies from Previous Flight	• Bipod closeout loss (Redesign) • LH2 PAL ramp loss (Redesign) • Intertank flange loss (Reqmt update) • Ice/frost ramp losses (Reqmt update) • LH2 acreage loss (Reqmt update) • Thrust strut flange loss (Reqmt update)	Root cause identified – Required corrective actions implemented	G
Configuration Changes	• Bipod harness revisions • Bipod fitting bolt length • Bipod strut bolt revisions • Development Flight Instrumentation • Intertank acreage TPS venting / sanding • PAL ramp elimination	Design implemented, verified and certified – No issues	G
Requirements Changes	• TPS debris requirements • Induced environment updates	Received environments assessed – No issues	G
Limited Life Component Status	• Age and cycle sensitive hardware	All items within required life	G

7.0 STS-121 Readiness Assessment

Presenter: M. Quiggle, LM-ET/ 3000
Date: June 16, 2006

Item	*Topics*	*STS-121/ET-119 Rationale/ Mitigation*	*Status*
Senior Management Review Items	• Conathane requalification • GO2 vent duct breakthrough • Ice/frost ramp application	Dispositioned – No issues • Use as is • Repaired • No defect	G
Launch Site Processing	• Out of position processing • PR/MRB Dispositions • Planned Work Changes • OMRSD Changes • LCC Changes • Software Changes • Facility Changes	• Complete - No issues • Dispositioned - No issues • Approved – No issues • Approved – No issues • Approved – No issues • Assessed – No issues (validation complete) • Assessed – Potential impact to LCC due to facility ground valve change	G
Acute Launch Emergency Reliability Tip (ALERT)	• Applicable items	No issues	G
Certification Status	• Design Certification Review RIDs	• Closed – No issues	G
	• Certificate(s) of Qualification (COQ)	• Complete – No issues	G
	• Hardware Certification Sheets (HCS)	• Complete – No issues (2 remaining open shown as CoFR Exception)	G
	• Exception / Waiver / Deviation Status	• All approved – No issues	G

7.0 STS-121 Readiness Assessment

Item	*Topics*	*STS-121/ET-119 Rationale/ Mitigation*	*Status*
Technical Assessments	• ECO sensor #2 resistance shift	• ECO sensors removed / replaced with sensors subjected to Nanofocus x-ray	G
	• Propulsion Line Hardware Safe Life Analysis	• Mission > 4	G
	• LO2 tank pressure decay	• GO2 vent valve removed / replaced	G
	• NESC concern for ET-119 Bipod fitting bolt insert locking feature	• Tests indicate that main contributors to loss of insert locking feature are high preload and minimum thread engagement • Bipod bolt thread increased by 0.125 in. to potentially preclude loss of insert locking feature • Reviewed at SERB – ET-119 cleared	G
	• Acceptability of thick TPS applications	• Tests and analysis demonstrated that TPS cracks do not lead to delaminations except for LH2 IFRs • Tests and analysis demonstrate LH2 IFRs performance for TPS debris requirements	G

	• MLP prepress ground valve cycle timing
	  • Potential LCC violation (and inadvertent scrub) due to new ground valve for LH2 prepressurization
		• Proposed resolution presented at 6/10 ICB
		  • No actions currently planned for STS-121
		• Pending final review by PRCB 6/15
			Y Pending SSP disposition

7.0 STS-121 Readiness Assessment Open Work

Presenter: M. Quiggle, LM-ET/ 3000
Date: June 16, 2006

Item	Open Item	STS-121/ET-119 Rationale/ Mitigation	Status

SSP Requirements	• Updates to Design Requirements pending
	  • NSTS 60555 update (S06271A)
	  • NSTS 60559 update (S063369)
	  • NSTS 60559 update (S063411)
	  • Induced environments updates (S063281)
		• ET-119 design assessed against changes
		• No issues
			Y
			Pending PRCB approval

Certification Status	• HCS S506, LH2 Cable Tray and Pressurization Line Support Installation • HCS S514, LH2 C/T Segments, Covers & Rubber Dams	• Design verification complete • Final signatures pending • No issues	Y CoFR Exception
FMEA/CIL	• Updates due to Vol. V, TPS due to Bipod revisions PAL elimination, environment updates and ET-120 dissection results (ice/frost ramps)	• CIL retention rationale updated and approved by Level III • CRs S040221V and S040221Y pending PRCB OSB approval • No issues	Y CoFR Exception

Hazard Analysis Reports	• Updates due bipod changes, PAL elimination, environment updates and ET-120 dissection results (ice/frost ramps)	• Hazards risk ranking approved by Level III
		  • CRs S050411AQ, S050411AT, S050411AU pending PRCB OSB approval
		  • No issues
		  • CR S0050411AV pending PRCB disposition / approval, ECD 6/15
			Y
			CoFR Exception

The External Tank, ET-119, is ready for STS-121 launch pending completion/closure of open and planned work

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

Kenneth Welzyn, Chief Engineer External Tank
Marshall Space Flight Center, NASA

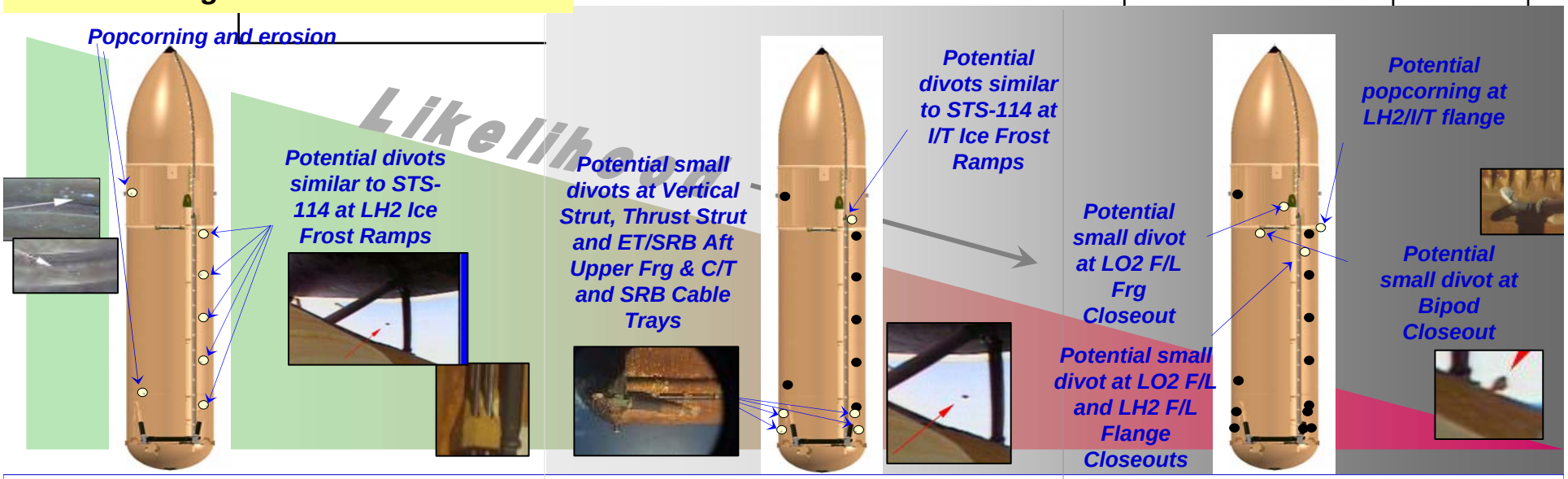
Wanda Sigur, ET Project Manager
Lockheed Martin Space Systems Company, Michoud

John Chapman, Manager External Tank
Marshall Space Flight Center, NASA

8.1 Special Topic – Possible Outcomes

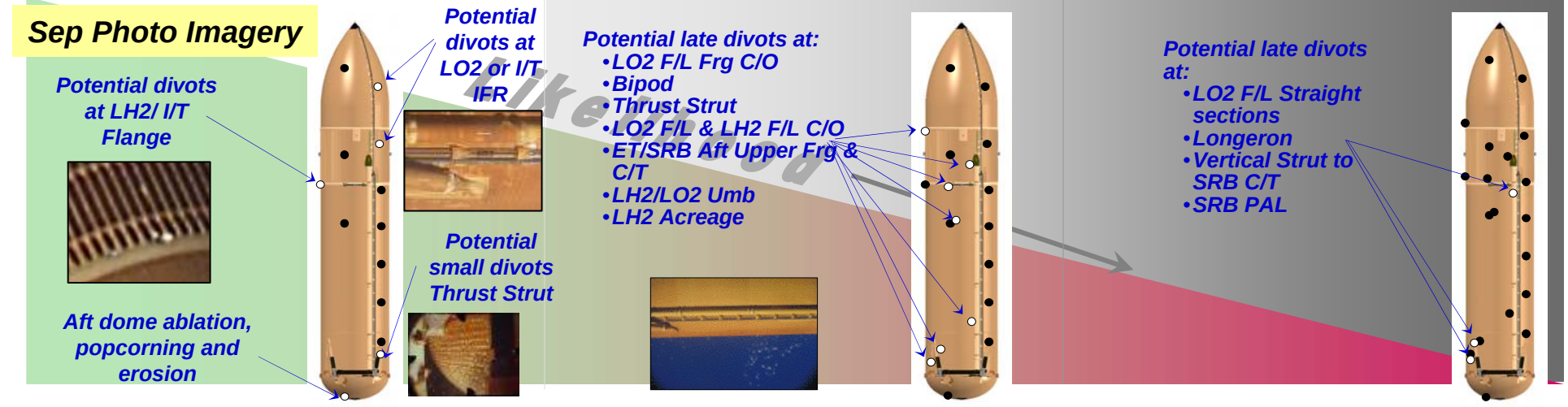
Presenter: W. Sigur, LM/ET-3000

Visible through ET and SRB Cameras



Most Probable (likely) imagery results + **Less likely imagery results** + **Unlikely, but possible imagery results**

Sep Photo Imagery



8.1 Special Topic – Possible Outcomes Specific Possible Foam Losses for ET 119/STS-121	Presenter W. Sigur, LM/ET-3000	
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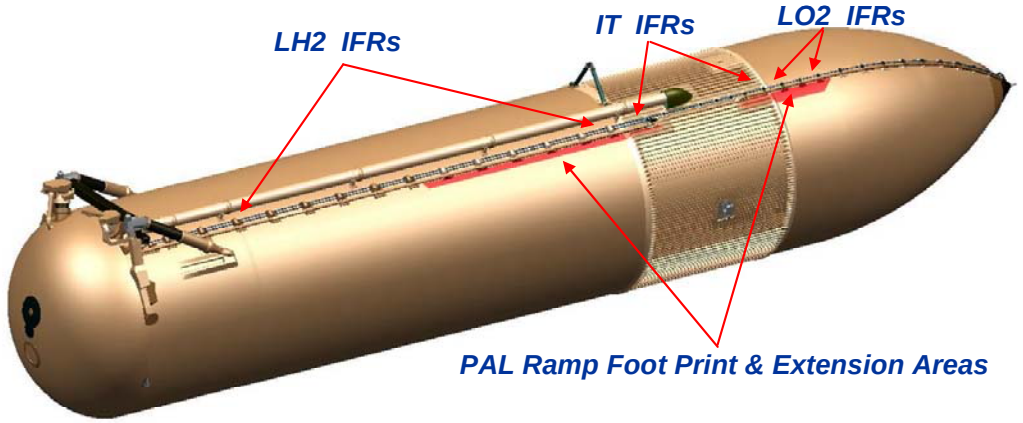
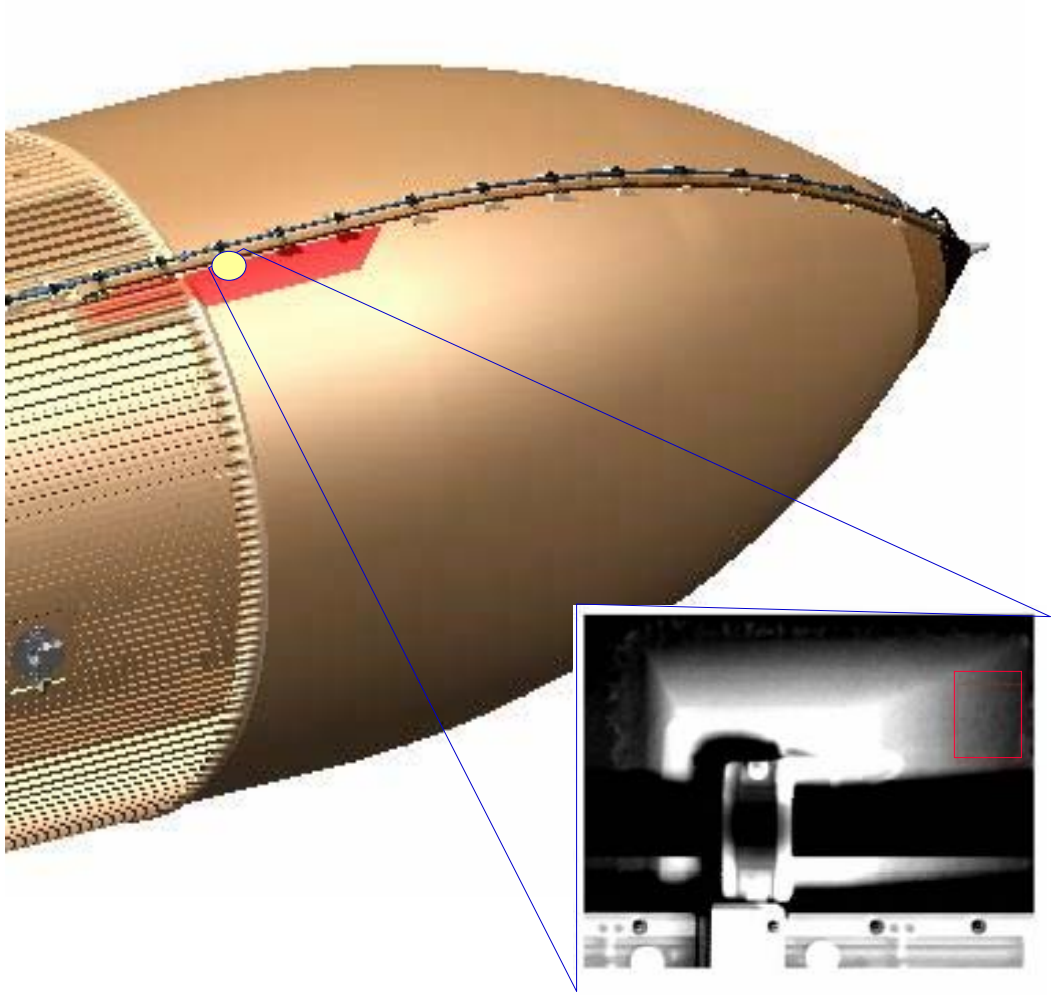
- ET119 NDE Inspections
  - TPS NDE was performed on ET119 based on accessibility of NDE tooling
    - Ice Frost Ramp inspections completed via BSX (backscatter) & THz (terahertz)
    - Surrounding acreage inspected via Shearography
      - LO2 Stations: 760, 794, 828
      - Intertank Stations: 861, 897, 922, 949
      - LH2 Stations: 1151 through 1851
      - BX Extensions (all stations)
    - LO2 & LH2 PAL Ramp footprint inspections completed via Shearography
- Worst case assessment
  - Force a divot, and
  - Create largest mass



8.1 Special Topic – Possible Outcomes
Possible Foam Losses for ET 119/STS-121 Based on NDE



Station 828: Small cluster of porosity in extension spray.

Area of cluster = 1.25" dia

Mass = 0.017 lbm

NSTS 60559: 0.026 = Risk Assessment Mass

Notes: Geometric defect, tied to bracket also observed at STA 794. (No divot expected due to depth)
"Unexpected divot" max mass = 0.011 lbm

8.1 Special Topic – Possible Outcomes
Possible Foam Losses for ET 119/STS-121 Based on NDE

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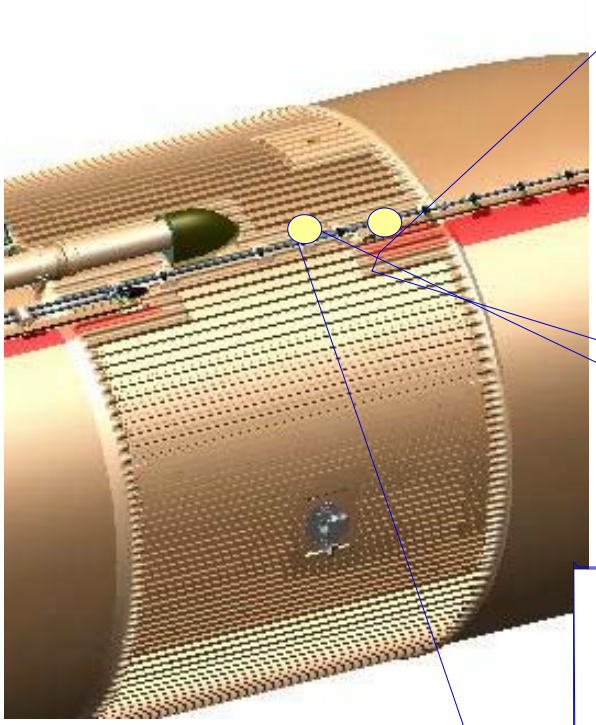
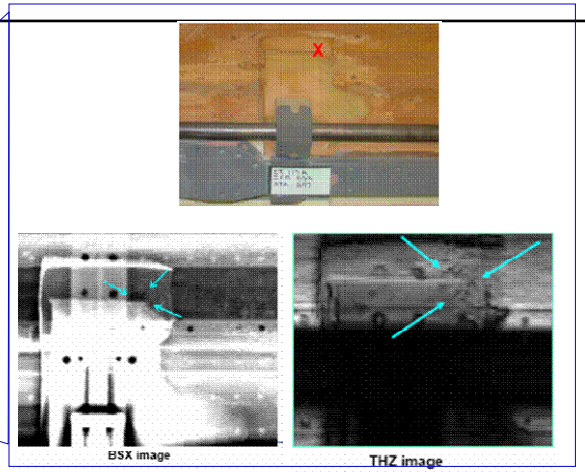


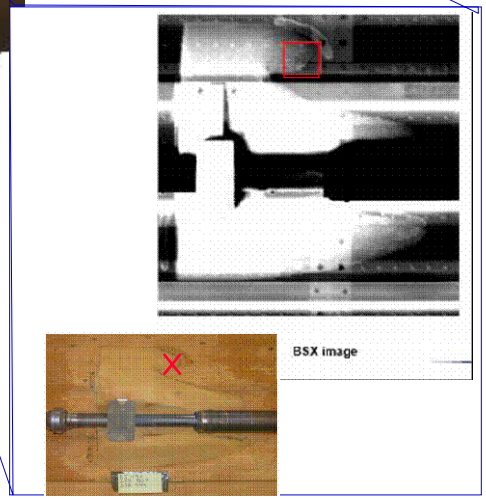


Station 897: Small cluster of porosity in pour

Area of cluster = 0.5” dia

Mass = 0.004 lbm

NSTS 60559: 0.018 = Risk Assessment Mass



Station 949: Small cluster of porosity

Area of cluster = 0.5” dia

Mass = 0.004

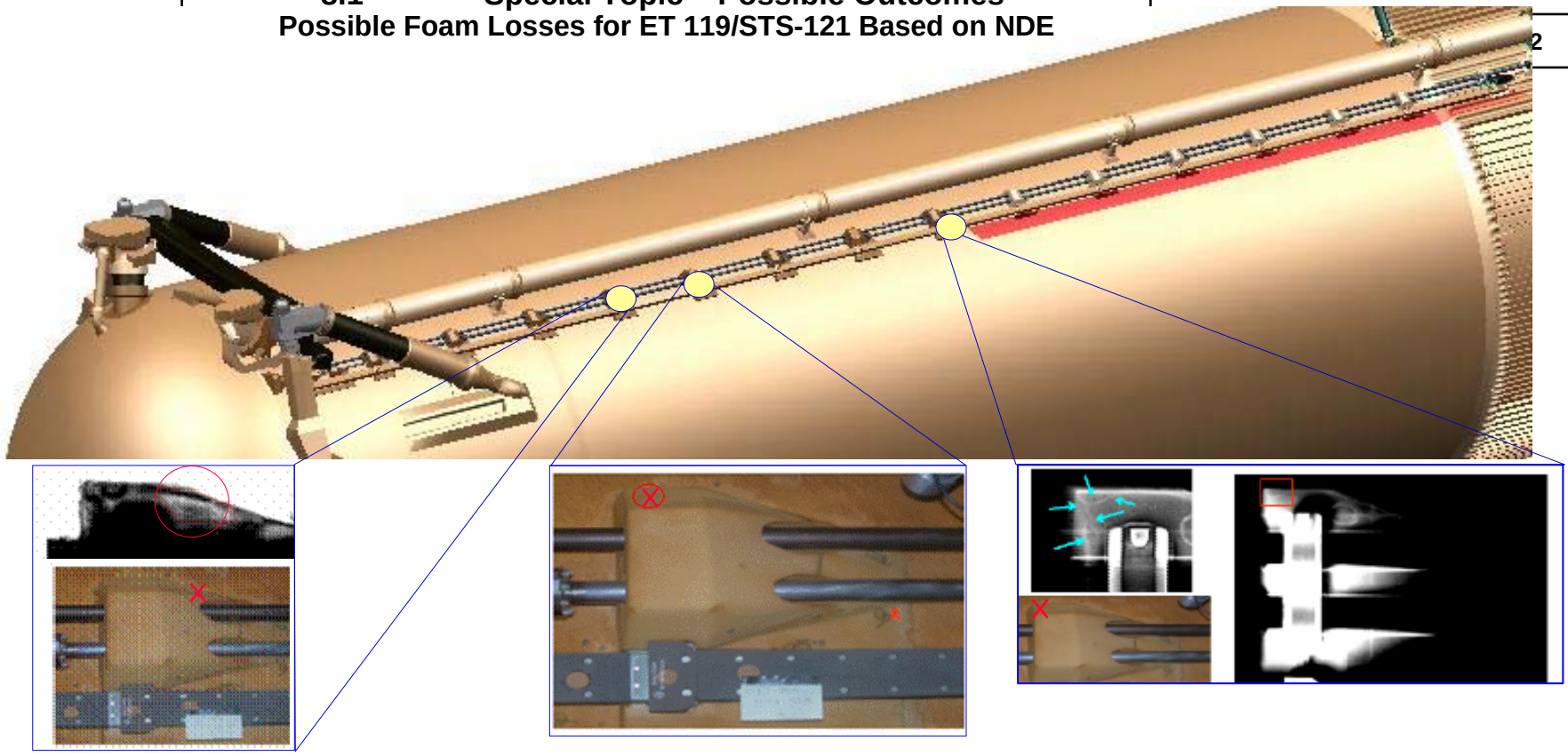
NSTS 60559: 0.018 = Risk Assessment Mass

Note: Geometric defects, tied to bracket observed at STA 897, 922, 949, 980 and 1049. (no divot due to depth)

“Unexpected divot” max mass = 0.018 lbm

8.1 Special Topic – Possible Outcomes
Possible Foam Losses for ET 119/STS-121 Based on NDE

Presenter W. Sigur, LM/ET-3000



Station 1787: Small cluster of porosity in PDL flow lines

Area of cluster = 0.5" dia

Mass = 0.011 lbm

NSTS 60559: 0.084 = Risk Assessment Mass

Station 1722: Two void locations

Area = 0.3" dia and 0.4" dia

Mass = 0.003; 0.003 lbm, resp

NSTS 60559: 0.084 lbm = Risk Assessment Mass

Station 1528: Flow lines with a void

Area = 1.0" dia

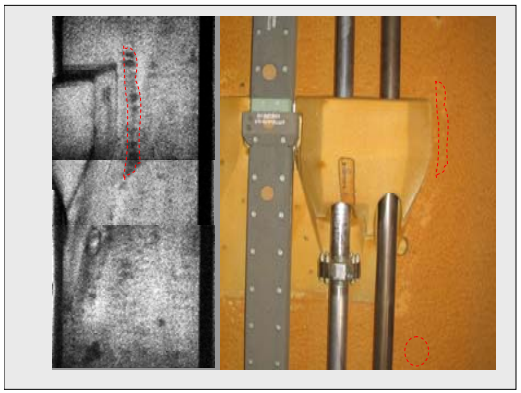
Mass = 0.008lbm

NSTS 60559: 0.084 lbm= Risk Assessment Mass

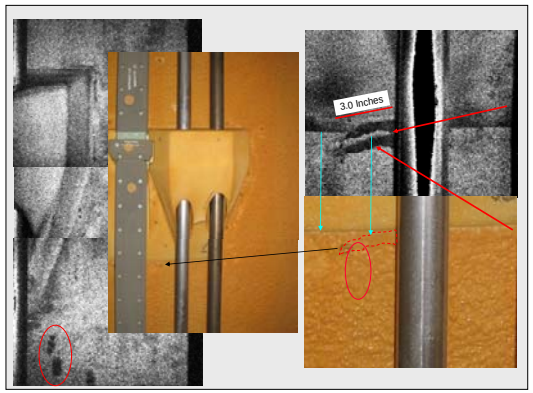
Note: Geometric defects, tied to bracket observed at STA 1399, 1528, and 1851. (no divot due to depth)
"Unexpected divot" max mass = 0.011 lbm

8.1 Special Topic – Possible Outcomes
Possible Foam Losses for ET 119/STS-121 Based on NDE

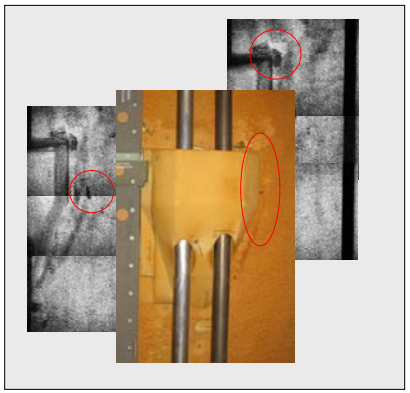
- NDE using shearography identified potential risk for crushed foam losses
  - Crushed foam indications noted at stations 1151, 1205, 1528, 1593, 1722 and 1787
  - Visual inspections also performed in area to assess risk
    - Visual methods validated by test
  - Typical scans noted



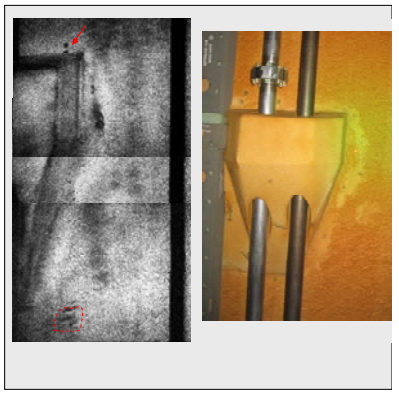
STA 1787



STA 1722



STA 1593



STA 1528

8.2 Special Topic
LON Readiness Assessment

- ET-118 designated for LON requirements

- Assessment of ET-118 to support STS-114 LON
  - No significant issues identified
  - Closure/mitigation plans in place to support required LON processing and CoFR milestones

STS-121
Flight Readiness Review

External Tank Project (ET-119)

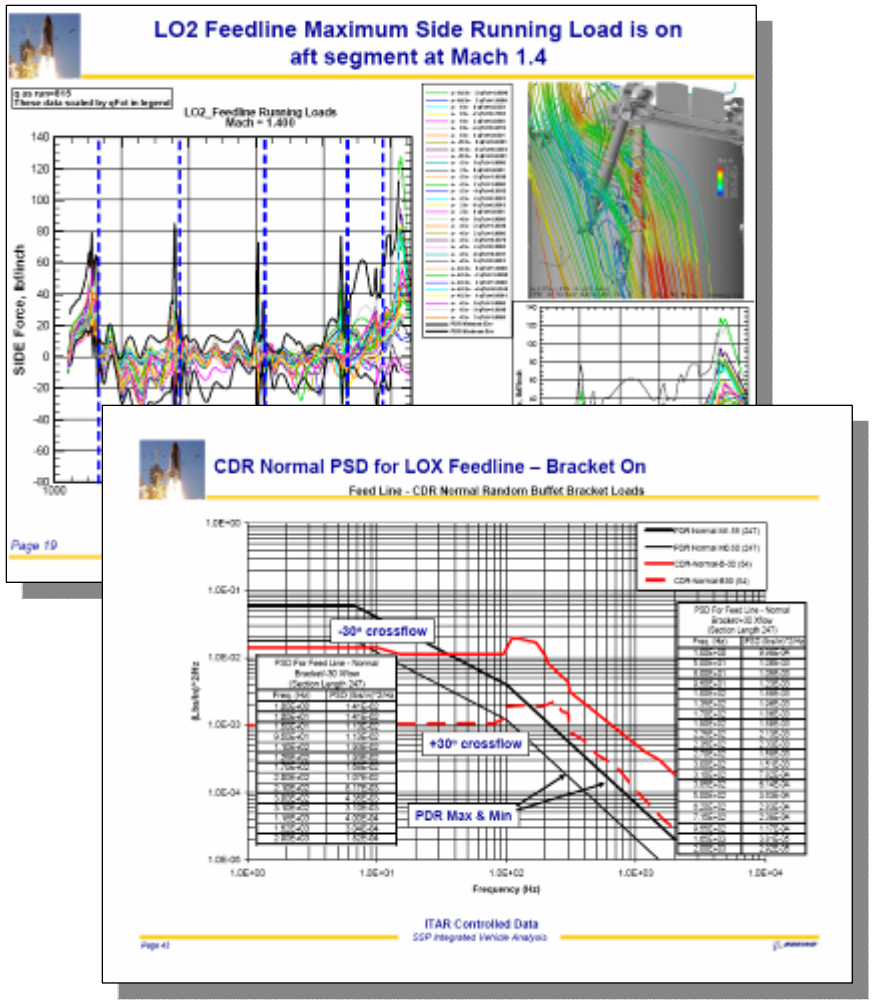
Back-Ups

June 16, 2006

Induced Environment Update Assessment

Presenter M. Quiggle, LM-ET/ 3000

- Environment Impacts
  - New environments received from SE&I and assessed for impacts to structure
    - Updates to existing thermal and steady airloads environments
    - New unsteady airloads environment
  - Environment updates result from
    - PAL ramp elimination
    - New methodology used by SE&I
    - to generate environments
      - Resulting environments
      - cover entire tank
  - Environments provided for the
  - following protuberances
    - LO2 and LH2 cable trays
    - GO2 and GH2 presslines
    - LO2 feedline
    - Aft protuberance hardware with increases over existing Loads Data Book

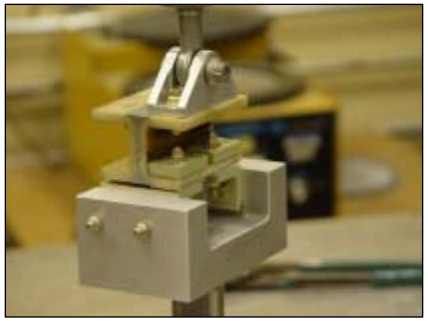


Induced Environment Update Assessment	Presenter: M. Quiggle, LM-ET/ 3000	
	Date: June 16, 2006	Page: BU-3

- Verification of the revised requirements were performed by Analysis and Test
  - Analysis resulted showed adequate structural factor of safety for affected hardware
  - No additional testing required for factor of safety demonstration
  - Additional testing was required for safe life demonstration
    - Glass epoxy support brackets for LH2 and LO2 presslines and cable trays

Induced Environment Update Assessment

- Design Verification for Updated Environments
  - Analysis - Adequate structural factor of safety for affected hardware
    - No additional testing required for factor of safety demonstration
    - Additional testing was required for safe life demonstration
      - Glass epoxy support brackets for LH2 and LO2 presslines and cable trays
  - Tests, Complete
    - LO2 tank cable tray support bracket bolt and fillet weld testing performed to provide additional confidence in analytical results
      - Tests complete and demonstrated capability > 200% DLL
    - LO2 and LH2 cable tray support glass epoxy simulated service
      - Two test articles each subjected to 4 mission cycles
        - "Barely visible' damage induced into test articles
      - Both test articles incurred no permanent deformations or flaws
        - The 'barely visible' damage had no noticeable changes
      - Test-demonstrated capability >200% DLL following mission life testing



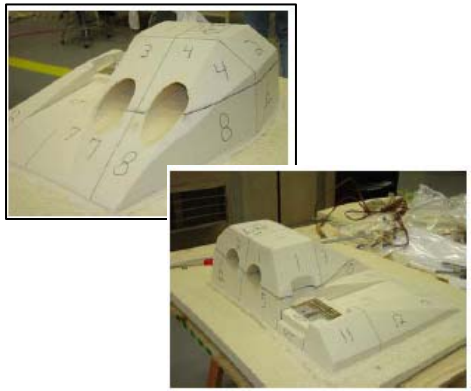
LO2 Cable Tray Support Simulated Service Test

LH2 Ice/Frost Ramp Flight Rationale

Presenter: M. Quiggle, LM-ET/ 3000
Date: June 16, 2006

- Issue
  - Concern for risk of LH2 ice/frost ramp process defects and thermally-induced cracks / delaminations resulting in unacceptable debris

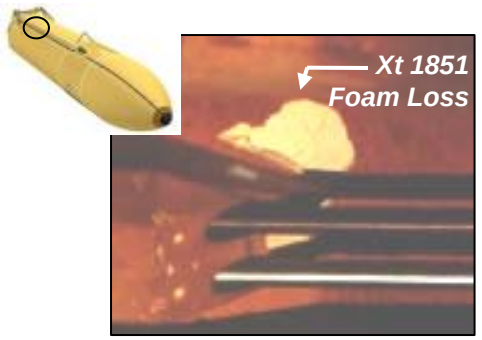
- Background
  - STS-114 Foam Loss Events Root Cause Investigation Summary
    - PAL ramp and bipod closeout TPS loss mitigated through redesign
    - Thrust strut flange loss and ice/frost ramp loss (Xt 1525) most probably caused by external (secondary) impact
    - Delta P divot events observed for Intertank flange closeout, LH2 acreage (Xt 1163) and ice/frost ramp body (Xt 1262 and Xt 1841) assessed through SSP PRA
      - Ice/frost ramp (IFR) losses > max expected performance based on pre STS-114 process assessment for void characterization
        - Dissection of mock-ups and ET-120 IFRs confirmed larger than expected voids in IFR body
      - Revised process assessment data used to update probabilistic risk assessment assumptions



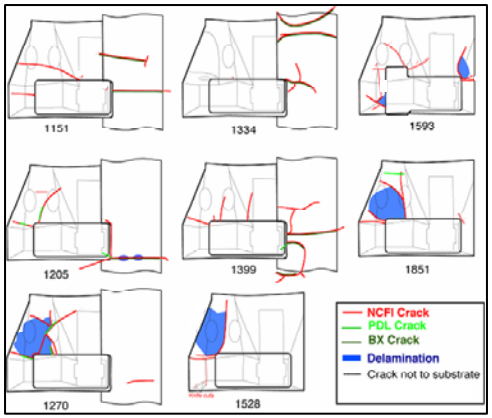
Debris Source	Failure Modes	Model Input	RCC Risk	Tile Risk	Special Tile Risk
LH2 IFR & Adjacent Acreage	Void DP	ET Debris Table	1/10,000	1/110	1/250
	Cryo-Pumping	MSFC Flt History	1/7,000	1/5,000	n/c
	Thermal Cracks	MSFC Flt History	1/1,000	1/75-1/125	n/c
	Airloads	MSFC Flt History	No risk	1/750	n/c

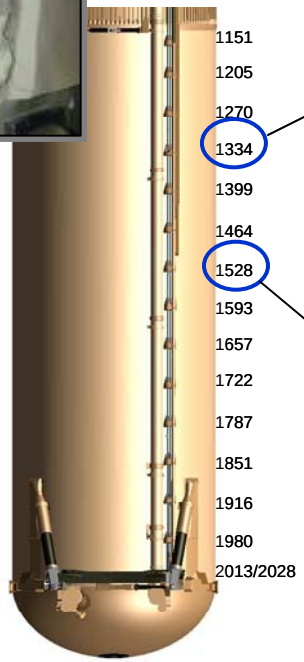
LH2 Ice/Frost Ramp Flight Rationale

- Background (cont.)
  - STS-114 Foam Loss Events Root Cause Investigation Summary
    - Acreage loss at Xt 1851 most probable cause identified as cryopumping divoting due to subsurface delaminations
      - Observed under acreage foam LH2 ice/frost ramp body on ET-120 'typical' IFR configurations (after 2 cryo / pressurization cycles)
    - Delaminations not observed under Xt 1334 IFR
      - Different configuration than typical LH2 IFR configurations
    - Damage mostly in NCFI within IFR footprint; although some PDL damage (IFR body)

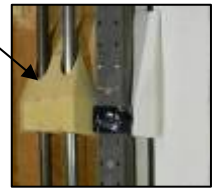


Delamination observed under LH2 IFR





Xt 1334 IFR config

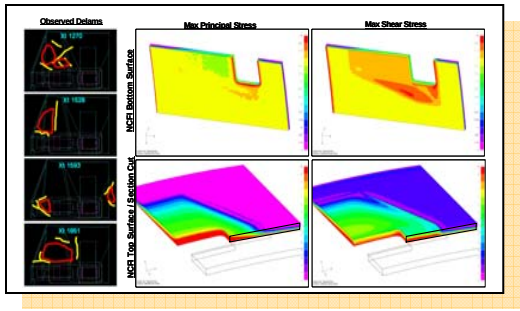


Typical IFR config, Xt 1528 shown

LH2 Ice/Frost Ramp Flight Rationale

Presenter M. Quiggle, LM-ET/ 3000

- TPS Cracking (Delamination) Root Cause Assessment
  - Component test and analysis shows that cracks and delaminations correspond to high thermally-induced loading and stress risers resulting from dissimilar TPS stiffness and geometric stress risers at cryogenic temperatures
    - Part by part assessment showed cracks at these locations
      - LH2 ice/frost ramps
      - Bipod
      - Intertank / LH2 tank flange
      - Intertank acreage valleys
      - Vertical struts
  - Delaminations only observed at LH2 ice/ frost ramp locations
  - All TPS applications were assessed to determine susceptibility to TPS crack-induced failures during ASTT (< 166 sec MET)
    - Tests and analysis demonstrated that TPS cracks do not lead to delaminations except for LH2 ice/frost ramps
      - Crack / delams can contribute to cryopumping, delta pressure, or aeroshear debris
    - Subsurface delaminations are possible for large, thick TPS applications at cryogenic temperature and exposed to high substrate mechanical strains
      - Acreage TPS susceptible but not considered a 'high risk'
        - Previous testing performed and demonstrates adequate capability (SF = 1.25)



Dissection / Analysis Correlation

Test And Analysis Show Subsurface Delaminations Not Expected Except At LH2 IFR Locations

LH2 Ice/Frost Ramp Flight Rationale

Presenter M. Quiggle, LM-ET/ 3000

- STS-121/ET-119 Flight Rationale
  - Foam loss due to multiple environments assessed
    - Aeroshear (Debris not expected)
      - AEDC wind tunnel testing demonstrated that cracks without visible off-set a crack face are acceptable (i.e. no debris)
    - Cryopumping (Debris expected)
      - Cryopumping-driven divoting during ASTT (<166 sec) possible for areas highlighted (incl. bipod, flange, LO2 feedline closeout and LH2 acreage and IFRs)
        - Delams only observed / expected at LH2 IFR locations
      - Low probability of critical debris at critical time based on DTA assessment (1/5,000)
    - Delta Pressure (Debris not expected)
      - Thermodynamics/fracture based analysis and testing performed for LH2 IFR TPS shows delta pressure loading not sufficient to cause delam crack growth during ASTT (1/75 assuming loss at critical time)
      - Cryo/Thermal Vac tests performed to characterize debris potential and failure mechanisms subjected to cryo cycling and simulated launch conditions
        - No observed debris liberated

Area susceptible to cryopumping divoting during ASTT (<166s)

Thermal Vac Test Article Configuration

LH2 Ice/Frost Ramp Flight Rationale

- STS-121/ET-119 Flight Rationale Summary (TPS Cracks / Delaminations)
  - Ice/frost ramp certification testing (due to PAL ramp elimination) used to demonstrate performance for TPS debris requirements - Complete
    - Wind Tunnel Tests used demonstrated ascent critical environment using full scale ice/frost ramp (max design dynamic pressure)
    - Cryo/thermal vac tests used to demonstrate prelaunch/ascent critical environments
      - Full scale ice/frost ramp (max environments)
      - Test articles subjected to cryo and ascent thermal/vacuum profiles
  - Stress analysis provides understanding of TPS cracks / delaminations
  - Flat panel flaw tolerance thermal/vac test validate stress analysis
    - Panels include engineered flaws
    - Subjected to cryo and ascent thermal/vac profiles
  - ET-120 LH2 ice/frost dissection data increase the population of the void data base
    - PRA performed based on ‘debris cloud’ including all failure mechanisms
  - Limitations associated with design verification (with crack / delaminations) recognized/documented by SSP
  - TPS inspected during Prelaunch to determine that identified cracks meet acceptance criteria in the Launch Commit Criteria, ICE-01 (i.e. no off-sets at crack face)
    - Acceptance criteria based on tests, analysis and demonstration
  - Flight history assessment supports analysis that TPS debris is not expected to exceed values identified and used for input to the PRA