Return to Flight Task Group

Plenary and Public Meeting

June 27, 2005
Washington, D.C.

Public Meeting Agenda

June 27, 2005

Holiday Inn Capitol Conference Center, Washington D.C.

- **1300 – 1305** **Administrative Remarks:**
  Mr. Vincent Watkins – Executive Secretary
- **1305 – 1310** **Introductory Remarks:**
  Mr. Richard Covey – Co-Chair
- **1310 – 1410** **Technical Panel Fact-Finding Status**
  Mr. Joseph Cuzzupoli – Lead
- **1410 – 1450** **Operations Panel Fact-Finding Status**
  Col. James Adamson – Lead
- **1450 – 1515** **Integrated Vehicle Assessment Sub-Panel Fact-Finding Status**
  Ms. Christine Fox – Lead
- **1515 – 1530** **Action Item Summary and Closing Remarks**
  Mr. Richard Covey – Co-Chair

Introductory Remarks

Mr. Richard Covey, Co-Chair

Management Panel Fact-Finding Status

Dr. Dan Crippen, Lead

Management Panel
CAIB Recommendations

6.3-2 NASA/NIMA MOA
Closed December 16, 2004

6.2-1 Scheduling and Resources
Closed June 8, 2005

6.3-1 MMT Improvements
Closed June 8, 2005

9.1-1 Detailed Plan for Organization Change
Closed June 8, 2005
7.5-1 Independent Technical Authority

7.5-2 S&MA Organization

7.5-3 Shuttle Integration Office Reorganization

Technical Panel
Fact-Finding Status

Mr. Joe Cuzzupoli, Lead

Technical Panel
CAIB Recommendations

3.2-1 External Tank (ET) Debris Shedding

3.3-1 Reinforced Carbon Carbon (RCC) Structural Integrity
Closed February 17, 2005

3.3-2 Orbiter Hardening

4.2-1 Solid Rocket Booster Bolt Catchers
Closed December 16, 2004

4.2-3 Two Person Closeout
Closed December 16, 2004

6.4-1 Thermal Protection System (TPS) Inspection and Repair

Technical Panel

3.3-2 – Orbiter Hardening

Mr. Sy Rubenstein

Mr. Ben Cosgrove

3.3-2 – Orbiter Hardening

CAIB Recommendation

- Initiate a program designed to increase the Orbiter's ability to sustain minor debris damage by measures such as improved impact-resistant Reinforced Carbon-Carbon and acreage tiles. This program should determine the actual impact resistance of current materials and the effect of likely debris strikes.

3.3-2 – Orbiter Hardening

RTF TG Interpretation

- Develop a detailed plan for an Orbiter hardening program including the testing and modeling to determine the impact resistance of the thermal protection system. For the first Orbiter returning to flight, the actual impact resistance of installed material and the effect of likely debris strikes should be known. Implement hardware changes as defined in the hardening program.

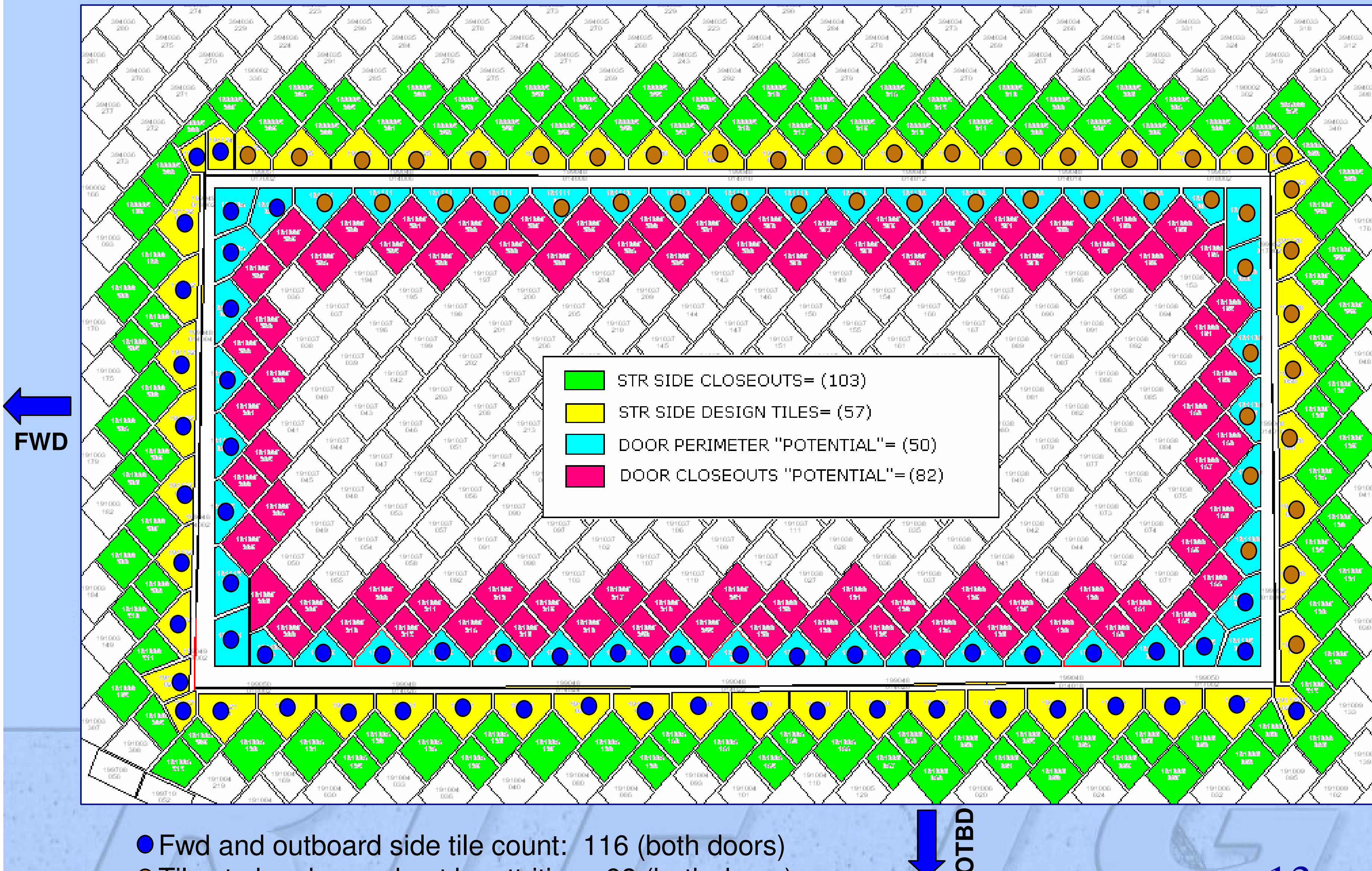
3.3-2 – Orbiter Hardening Project Overview

Family	Redesign Proposal	Phase	Status
WLESS	"Sneak Flow" Front Spar Protection (RCC #5 – 13)	I	Installed/final cert approval pending
	"Sneak Flow" Front Spar Protection (RCC #1 – 4, 4 - 22)	II	Final cert approval pending
	Lower Access Panel Redesign/BRI 18 Tile Implementation	III	BRI-18 tile continues to be in qual & cert
	Insulator Redesign	III	On hold for higher priority arc-jet testing
	Robust RCC	III	Schedule and cost of implementing this option is not in sych with Agency's vision to retire Shuttle in 2010
Landing Gear and ET Door Thermal Barriers	Main Landing Gear Door Corner Void	I	Installed/final cert approval pending
	Main Landing Gear Door Perimeter Tile Material Change	II	In Final Design phase
	Nose Landing Gear Door Thermal Barrier Material Change	III	In Assessment/lower priority to RTF
	External Tank Door Thermal Barrier Redesign	III	In Assessment/lower priority to RTF
Vehicle Carrier Panels – Bonded Stud Elimination	Forward RCS Carrier Panel Redesign – Bonded Stud Elimination	I	Installed/ final cert approval pending
Side Windows	Thicken Windows #1 and #6	I	Windows installed on OV-103 and OV-104/final cert approval pending
Tougher Lower Surface Tiles	Tougher Periphery (BRI 18) Tiles around MLGD, NLGD, ETD, Window Frames, Elevon Leading Edge and Wing Trailing Edge.	III	Qual & Cert in work. BRI 18 tile has been authorized for installation on all three Orbiters
	Tougher Acreage (BRI 8) Tiles and Ballistics SIP on Lower Surface.	III	Qual & Cert in work
Instrumentation	TPS Instrumentation	III	On-hold until post RTF
Elevon Cove	Elevon Leading Edge Carrier Panel Redesign	III	In Assessment/lower priority to RTF
Tougher Upper Surface Tiles	Tougher Upper Surface Tiles.	III	Development complete/ authorization pending for qual & cert
Vertical Tail	Vertical Tail AFSI High Emittance Coating	III	This option will be eliminated since it only increases the Orbiter's capability in the event of an abort during ascent. Trajectory can be designed to minimize vertical tail temperature.

3.3-2 – Orbiter Hardening Project Summary

- Phase II Projects
  - Sneak flow front spar protection (RCC #1 – 4, 14 - 22)
    - Same certification approach as RCC #5 – 13 under Phase I
    - Certification is compete less final approval by NASA
    - Forward work
      - Complete modification on all three Orbiters
        - OV-103 and OV-104: 4 panels/flt and during OMM
        - OV-105: prior to vehicle first flight.
  - MLGD perimeter tile material change out
    - Decision was made by SSP to not implement MLGD redundant thermal barrier modification due associated high risk with requiring significant MLGD mechanism rework post implementation of this modification
    - Boeing Rigidized Insulation (BRI-18) will replace the current FRCI-12 tiles around the MLGD perimeter
    - BRI-18 tile is 3X more impact resistance than the current FRCI-12 tiles
    - BRI-18 tiles have been authorized by SSP to be installed on all three Orbiters
    - OV-105 will be the first vehicle to receive BRI-18 tiles beginning in Summer of 2005

3.3-2 – MLGD T/B Redesign With Tiles



- Fwd and outboard side tile count: 116 (both doors)
- Tiles to be changed out by attrition: 98 (both doors)

3.3-2 – Determination of Impact and Damage Tolerance

- Windows shown good for predicted debris environment by test
  - Testing showed that the 99.9% damage inflicted by the predicted debris environment was less than the window allowable with a 95% confidence
- Tile impact tolerance determined empirically by test
  - Cert rigor equations for impact tolerance and damage depth calculation developed that enveloped 99% of the test data for foam on tile (Boeing)
  - Cert rigor equations for damage depth calculation developed from a physics-based model that enveloped 95% of the test data for ice on tile (SwRI)
  - Also developed different damage depth equations that enveloped 99% and 50% of the foam and ice test data for use in the end-to-end probabilistic risk assessment
- Tile damage maps developed from a series of linked models from cavity definition through aeroheating, 3D thermal, RTV bondline temperature, tile stress and structural stress determination
  - Foam damage map produced for full certification rigor
  - Foam damage map produced for "50%" allowable for use in probabilistic risk assessment only
  - Ice damage map not produced
- RCC impact tolerance determined by physics-based DYNA model and verified by testing
  - Foam and ice thresholds developed with full certification rigor
  - "Mean" and 1 sigma values developed for use in probabilistic risk assessment

3.3-2 – Impact Test Summary

Orbiter Impact Testing Summary			
as of 6/05			
	Planned	**Completed**	
Window testing subtotal	524	524	100%
Tile testing subtotal	868	868	100%
RCC testing subtotal	232	232	100%
Total Testing	**1624**	**1624**	**100%**

3.3-2 – Tile Impact and Damage Tolerance

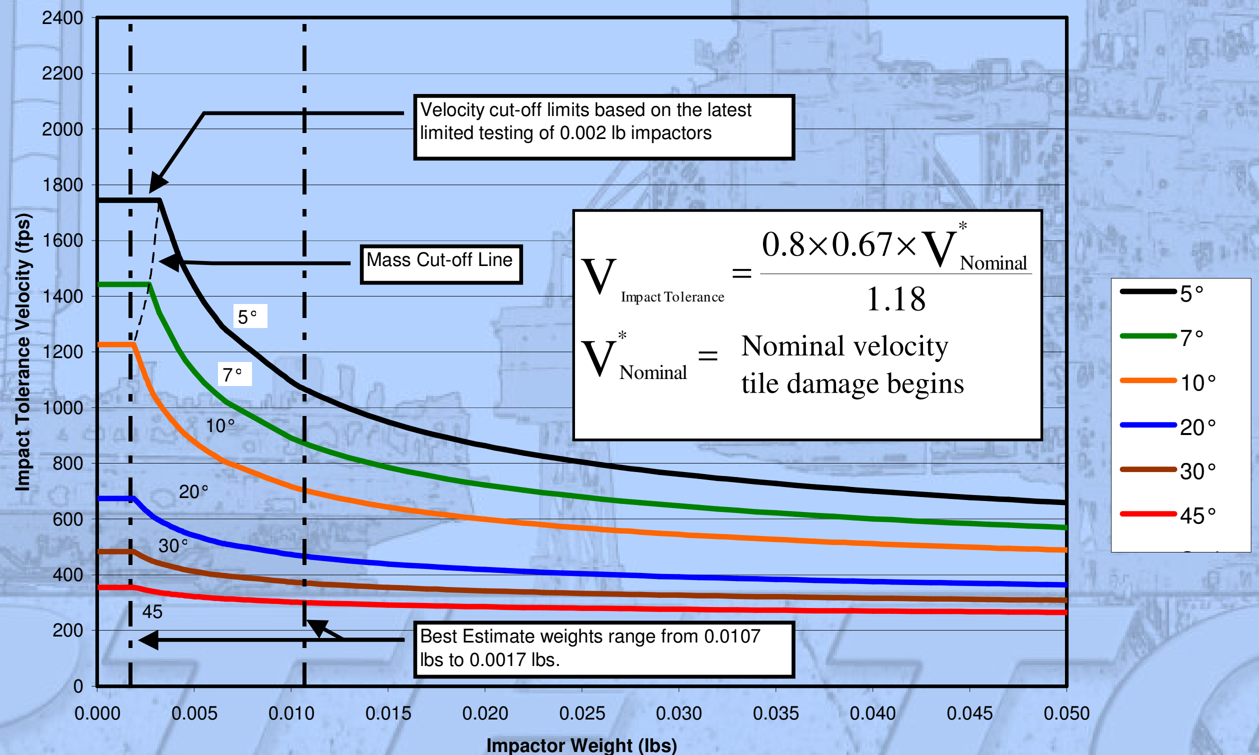
- Applicability of foam impact tolerance curves
  - Impact Tolerance curves are applicable for both acreage and special configuration tiles (MLGD, NLGD, Carrier Panels, ETD, etc.)
    - FRCI-12 and LI-2200 compressive strengths are 2 to 3 times larger than LI-900
    - Tests of MLGD and Carrier Panels showed greater damage tolerance for an equivalent impact on LI-900 tile
  - Impact Tolerance curves have been derived for BX-265, NCFI and PDL and are applicable for BX-250 foam as well
  - Angle Range: 5° to 60°
  - Velocity Range up to 2200 fps

RTF TG

3.3-2 – Cert Rigor Impact Tolerance Curves for Foam on Tile

- **Impact Tolerance Curves**
  - Appropriate factors are applied to nominal curve to establish Impact Tolerance curves
    - Test Scatter Factor = 0.8 (Bounds 95% of the test data points)
    - Aging Tile Factor = 0.67 (Difference between new and aged tile)
    - Factor of Safety = 1.4 on total energy (Equates to 1.18 on velocity)

Impact Tolerance Velocity Curves For BX-265, BX-250 and NCFI Foam



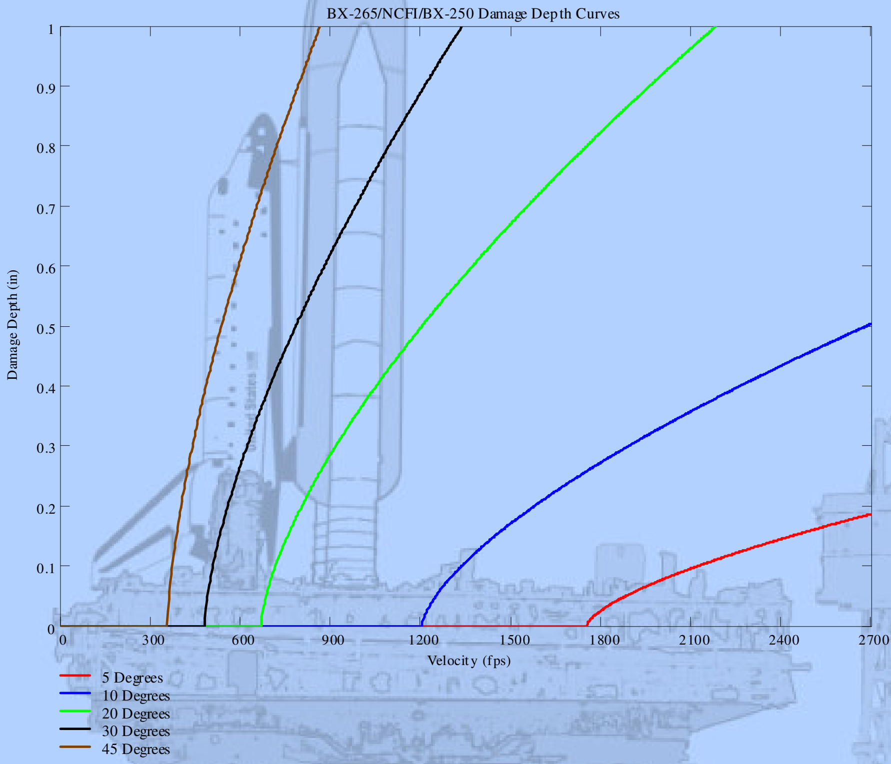
$$V_{\text{Impact Tolerance}} = \frac{0.8 \times 0.67 \times V^{*}_{\text{Nominal}}}{1.18}$$

V^{*}_{Nominal} = Nominal velocity tile damage begins

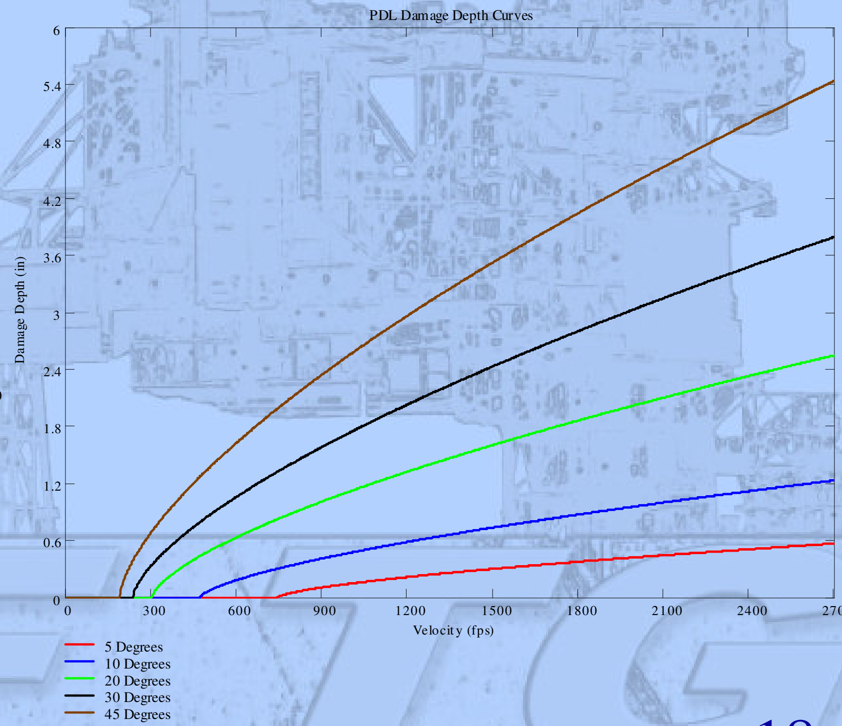
Note: Data based on NASA Closure Package

3.3-2 – Cert Rigor Damage Depth Curves for Foam on Tile

- 99 Percentile Damage Curves for BX-265, BX-250 and NCFI for 0.002 lb impactor

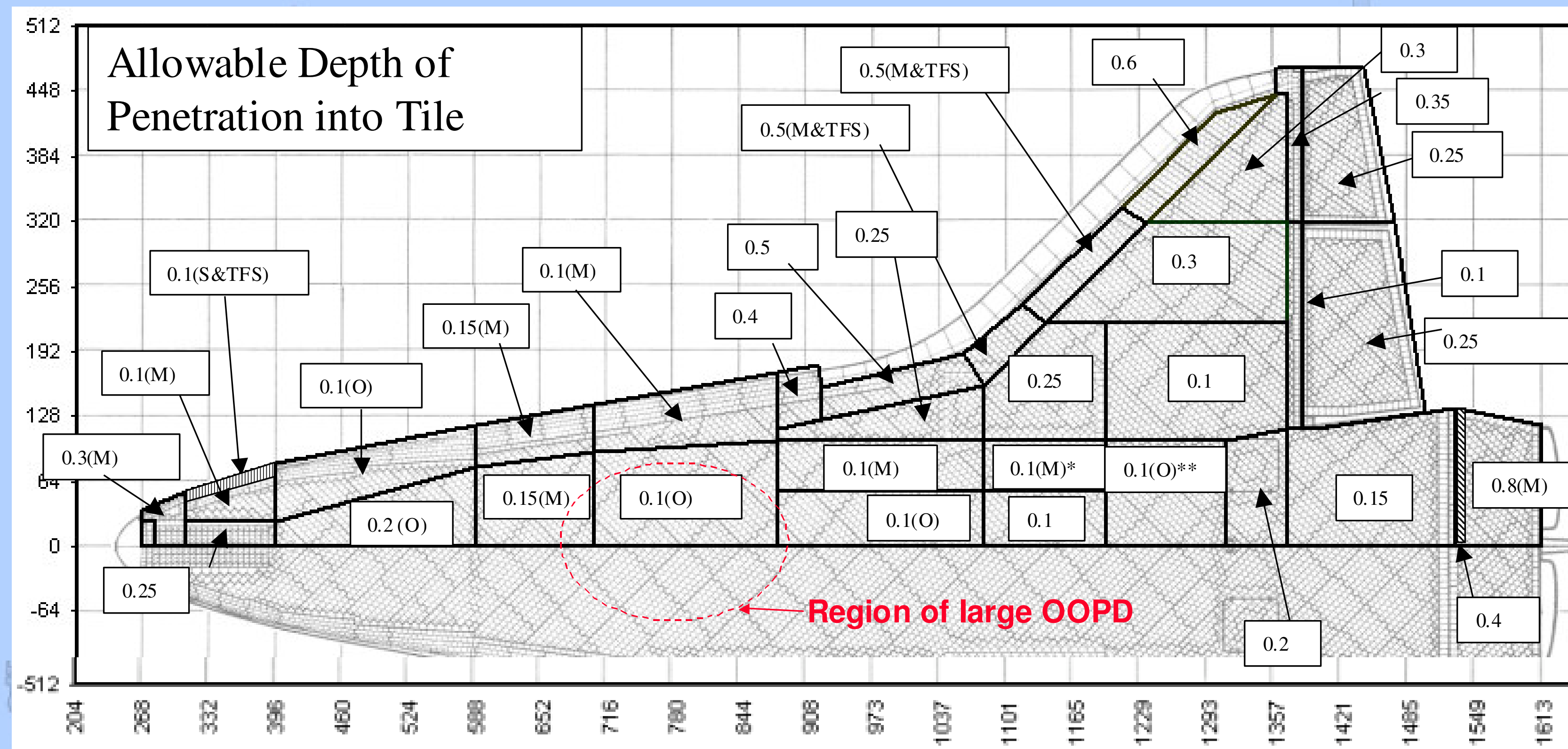


- 99 Percentile Damage Curves for PDL for 0.0073 lb impactor



Note: Data based on NASA Closure Package

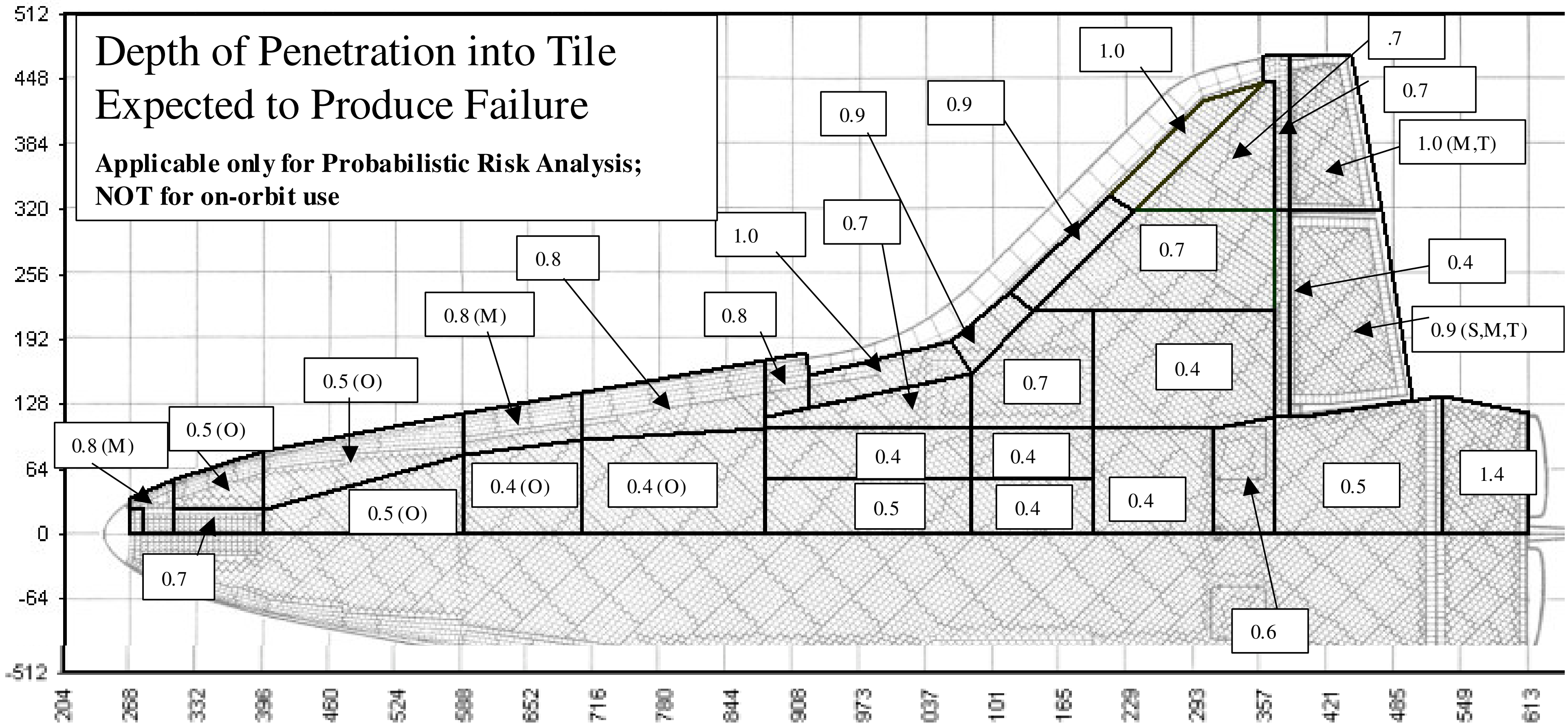
3.3-2 – "Cert Rigor" Damage Map



Primary failure mode is Tile Factor of Safety (TFS). Other modes are structural temperature (S), structural margin (M), and excessive OOPD (O)

Note: Data based on Debris DVR (6/24/05)

3.3-2 – Final "Expected/Mean" Foam on Tile Damage Map



Primary failure mode is tile FS (blank or T). Other modes are structural out-of-plane deflections (O), structural temperature (S), and structural margin (M)

Note: Data based on Debris DVR (6/24/05)

3.3-2 – RCC Impact Tolerance Threshold Definitions with Associated Factors

Impact Threshold Capability Terms	Worst-on-Worst (Certification Rigor)		Supporting Tests & Analyses
	Foam	Ice	
DYNA Baseline Damage Threshold Kinetic Energy (.03lb Foam on Panels 10-12) (Ice on Panels 10-12)	1494	326	Flat Panel Tests Full-Scale Panel Tests DYNA Analyses using Minimum Degraded Material Properties
Adjustment for "A-Basis" Material Properties	1.22		Vought coupon data base RTF fleet coupon tests RTF high-strain rate tests
Velocity Adjustment for NDE Detectable Damage Threshold	0.75	0.80	3-Point Bend Tests Flat Panel Tests Full-Scale Panel Tests
Adjustment for End-of-Life Aged Material Properties	0% (Included in original baseline)		Vought coupon data base RTF fleet coupon tests RTF high-strain rate tests
Factor of Safety Applied to Kinetic Energy	1.4		Certification Rigor Requires 1.4 Lower Factor of Safety is Acceptable for PRA
Current Impact Tolerance Capability (ft-lb)	492	122	

Note: Data based on NASA Closure Package

3.3-2 – RCC Expected Failure Distribution for BX-265 Foam Debris

BX-265	Wing Panel Regions (ft-lb)								
	1 to 4	5 to 6	7	8 to 9	10 to 12	13 to 15	16 to 18	19 to 22	Nose Cap
Orbiter Certification Value	1125	642	642	500	492	539	598	1125	168
Mean Expected Failure (risk assessment)	2210	1373	1321	926	976	1040	1176	2210	345
Standard Deviation (risk assessment)	232	144	139	97	102	109	123	232	36

Note: Data based on Debris DVR (6/24/05)

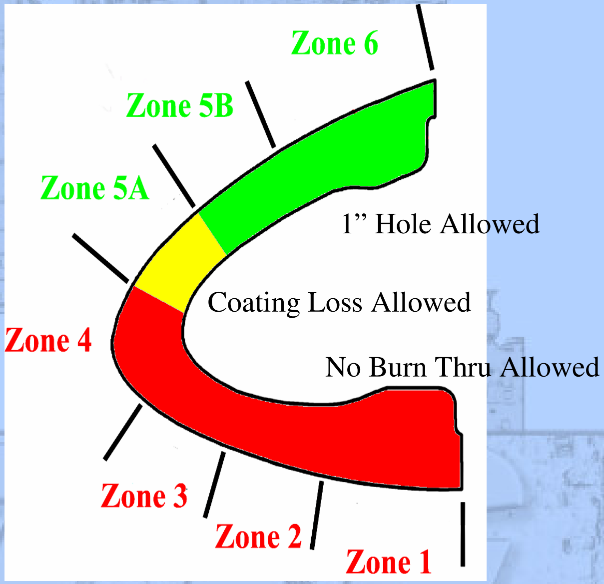
3.3-2 – RCC Expected Failure Distribution for PDL Foam Debris

PDL	Wing Panel Regions (ft-lb)								
	1 to 4	5 to 6	7	8 to 9	10 to 12	13 to 15	16 to 18	19 to 22	Nose Cap
Orbiter Certification Value	911	520	520	405	399	437	485	911	118
Mean Expected Failure (risk assessment)	1790	1112	1070	750	790	842	952	1790	249
Standard Deviation (risk assessment)	188	117	112	79	83	88	100	188	26

Note: Data based on Debris DVR (6/24/05)

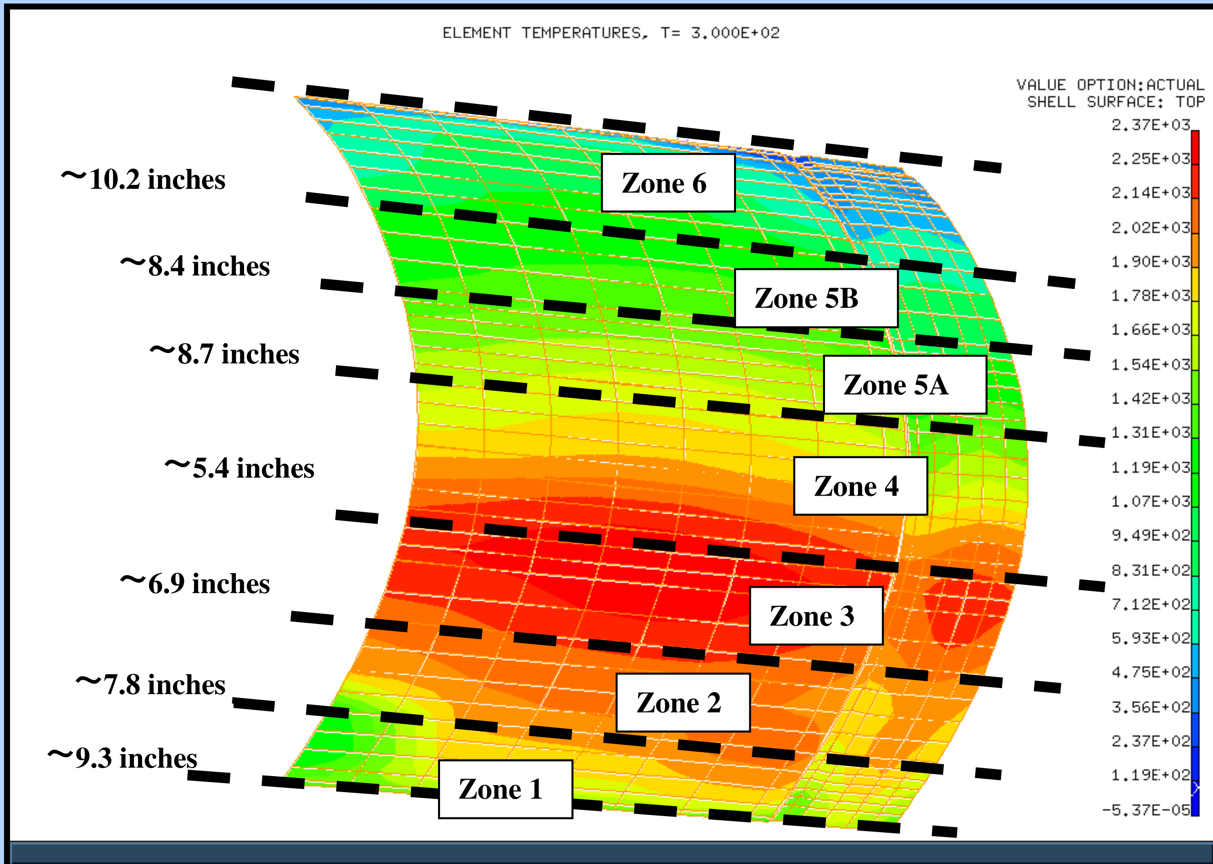
3.3-2 – WLE Inspection Criteria

- Assumptions
  - Delaminations are associated with all damage types
    - Delaminations can occur with or without coating loss
    - Delamination cannot be detected on-orbit
- Inspection Requirements for WLE
  - Coating damage that exposes more than 0.020 to 0.038" substrate with associated delaminations
    - WLE Panel, Zones 1 Thru 4, 0.020" x 2"
  - Coating damage exposing substrate, no hole allowed
    - WLE Panel Zones 5A
  - Coating damage to a 1" Hole Allowed
    - WLE Panel Zones 5B and 6
    - Boeing Evaluation In-Work for Zone 5B and 6



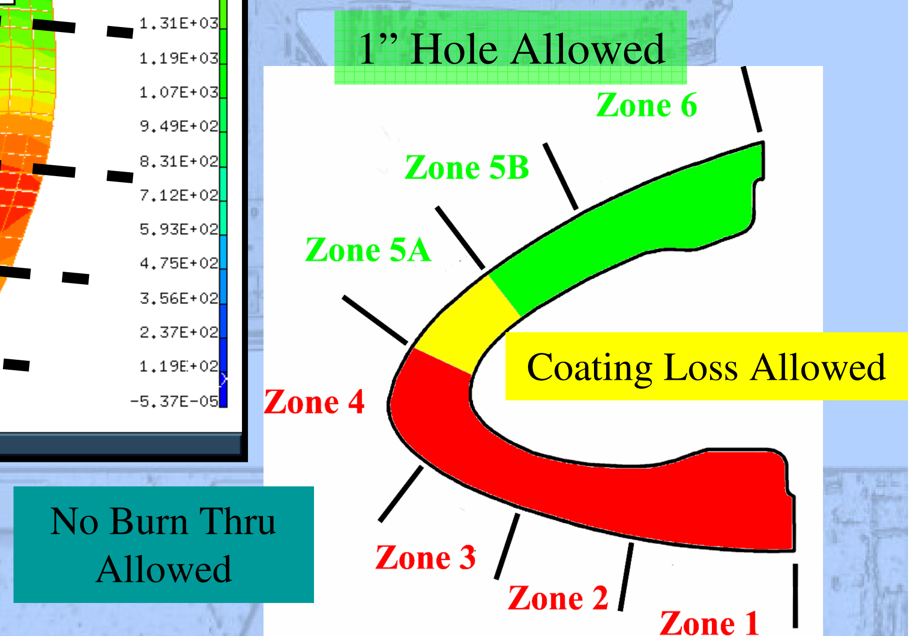
Note: Data based on NASA Closure Package

3.3-2 – WLE Panel Zones and Regions Allow for Two Critical Damage States



Critical Damage Criteria

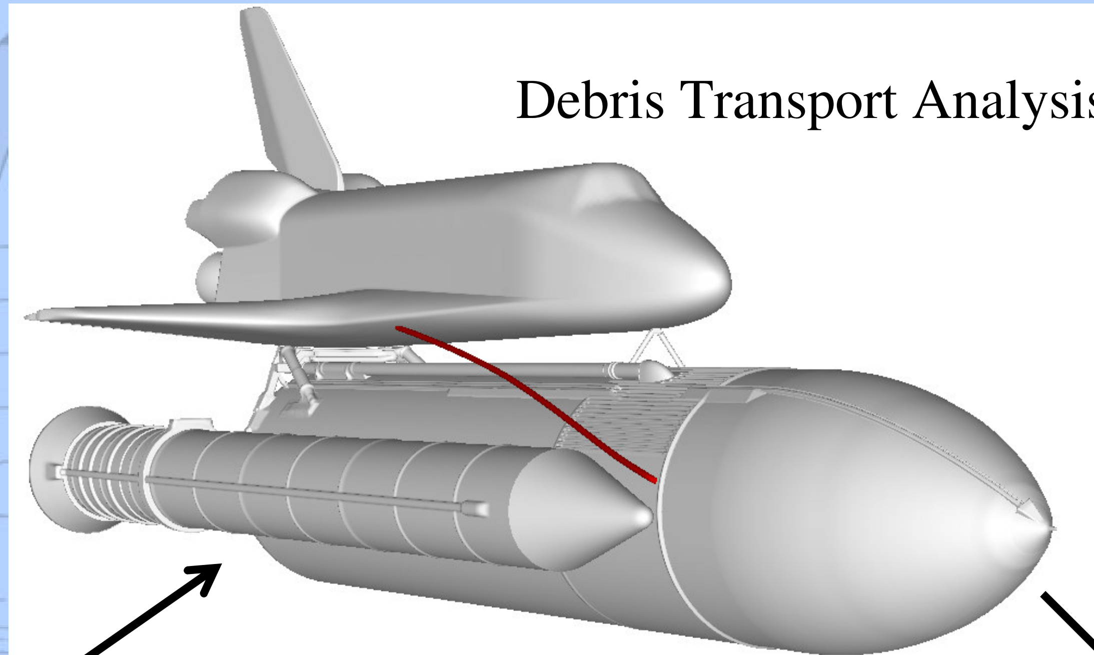
- Impact Threshold
  - Defined as on-set of NDE detectable damage
  - Zones 1 thru 5A
- Damage Threshold
  - Defined as Through Damage
  - Zones 5B thru 6



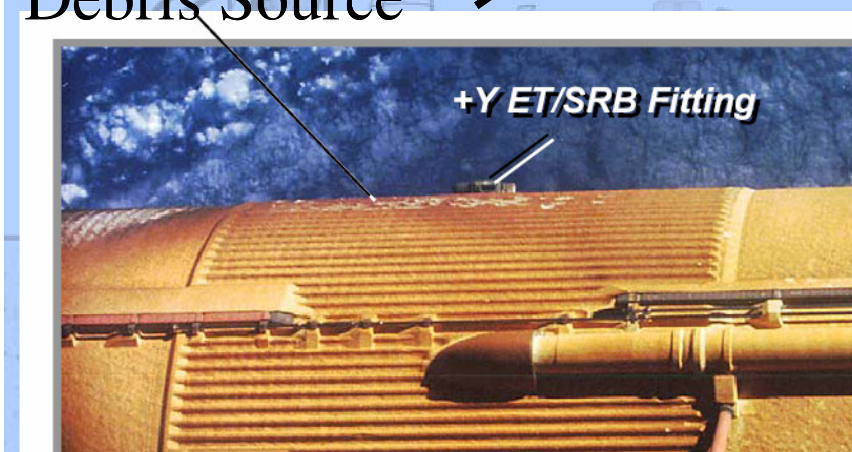
Note: Data based on NASA Closure Package

3.3-2 – Debris Assessment Process

Debris Transport Analysis

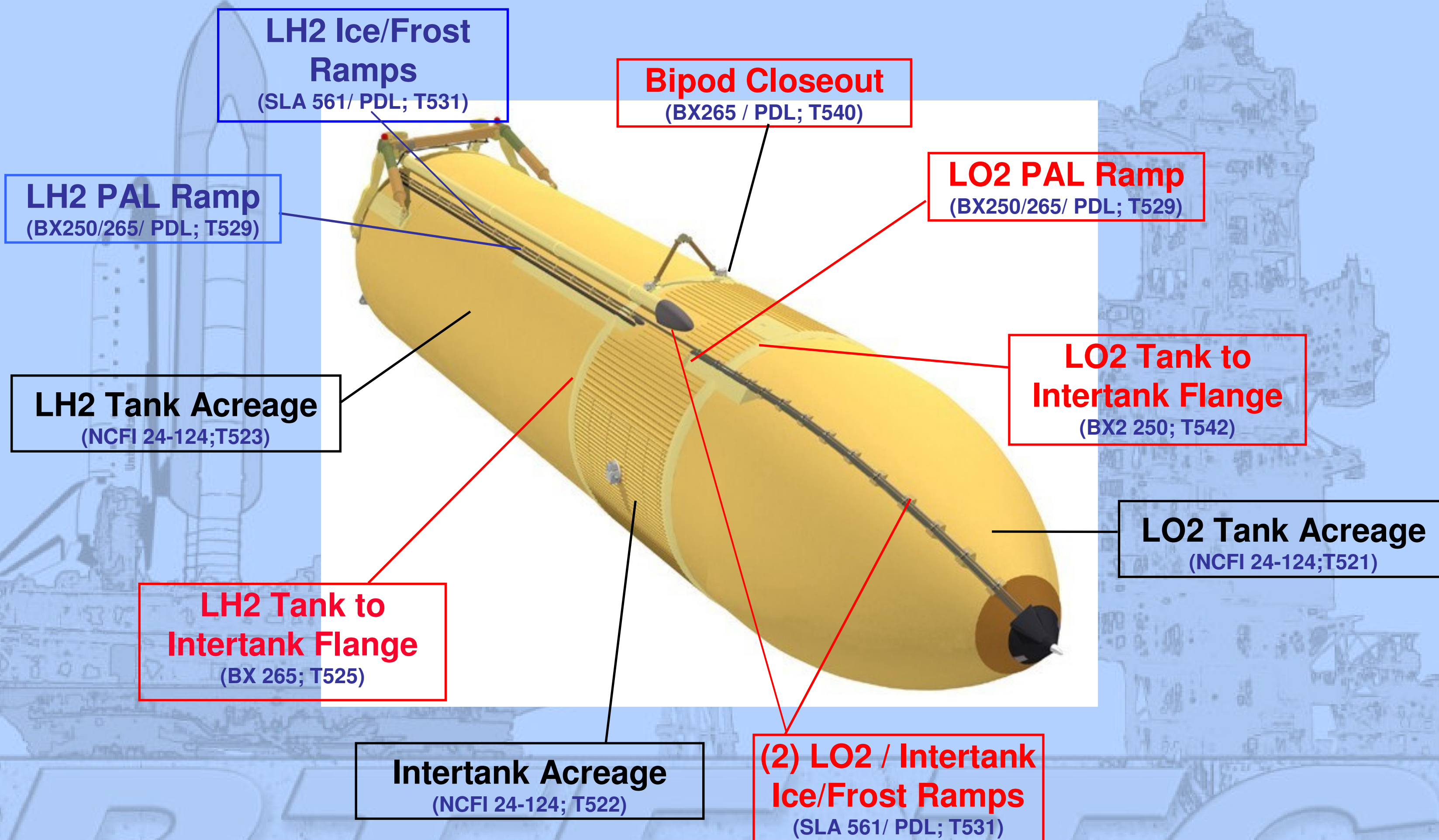


Debris Source



Damage Assessment

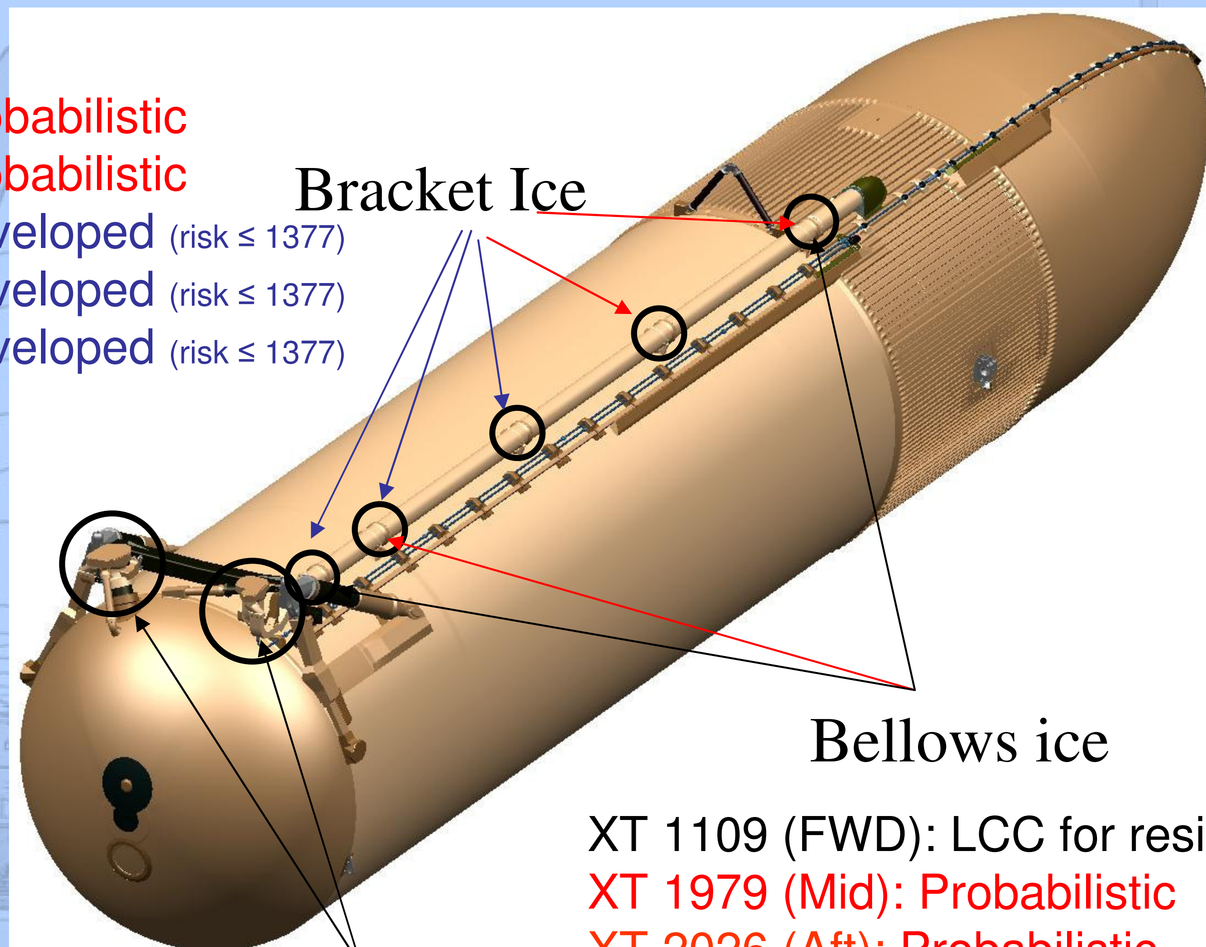
3.3-2 – Specific Foam Debris Assessments



Monte Carlo
Worst on Worst
Enveloping

3.3-2 – Specific Ice Assessments

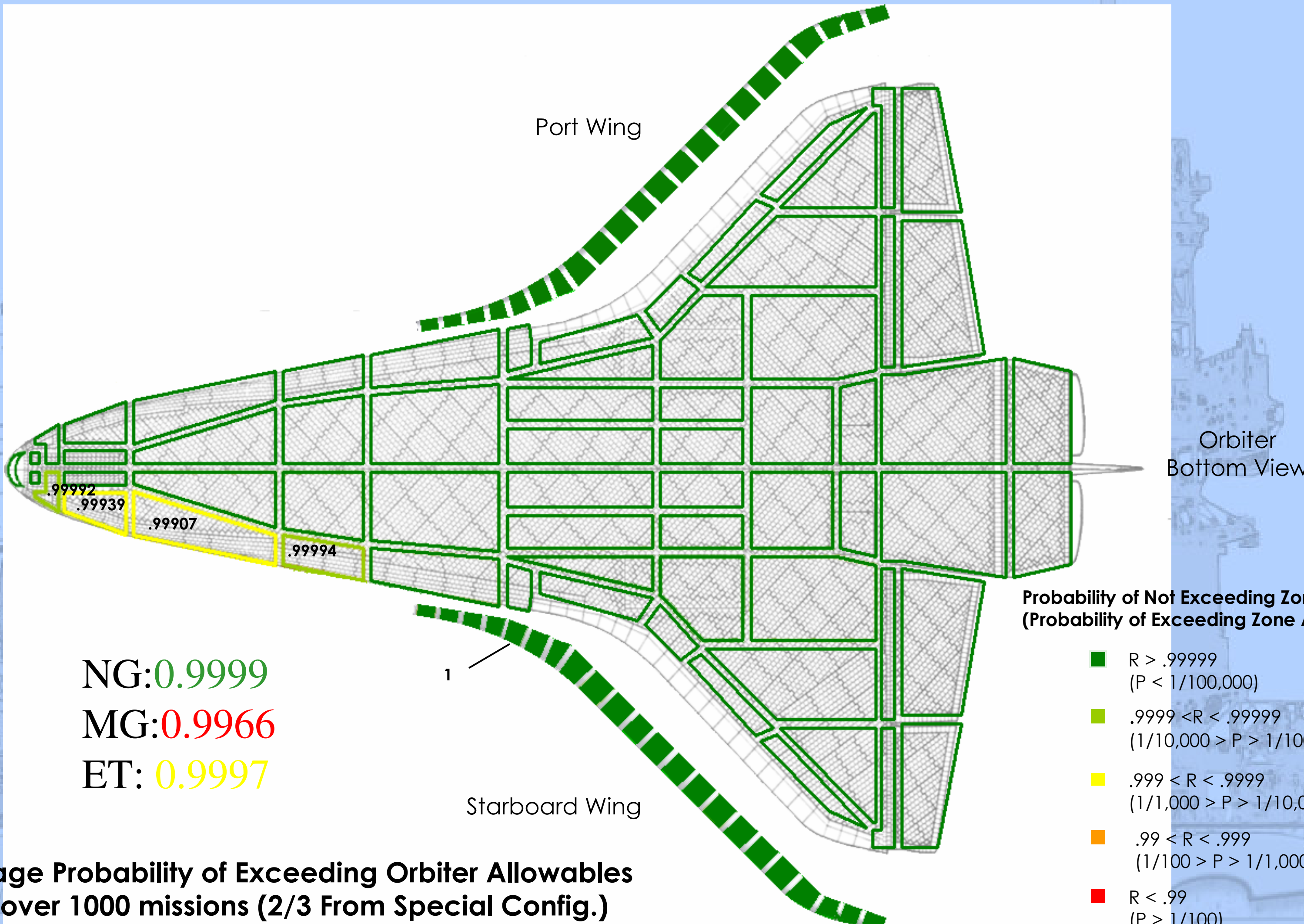
XT 1129: Probabilistic
XT 1377: Probabilistic
XT 1623: Enveloped (risk ≤ 1377)
XT 1871: Enveloped (risk ≤ 1377)
XT 1923: Enveloped (risk ≤ 1377)



XT 1109 (FWD): LCC for residual ice
XT 1979 (Mid): Probabilistic
XT 2026 (Aft): Probabilistic

Umbilical Ice
Design, Flight History

3.3-2 – Ice / Frost Ramp Impact Summary (Nominal)



NG:0.9999
MG:0.9966
ET: 0.9997

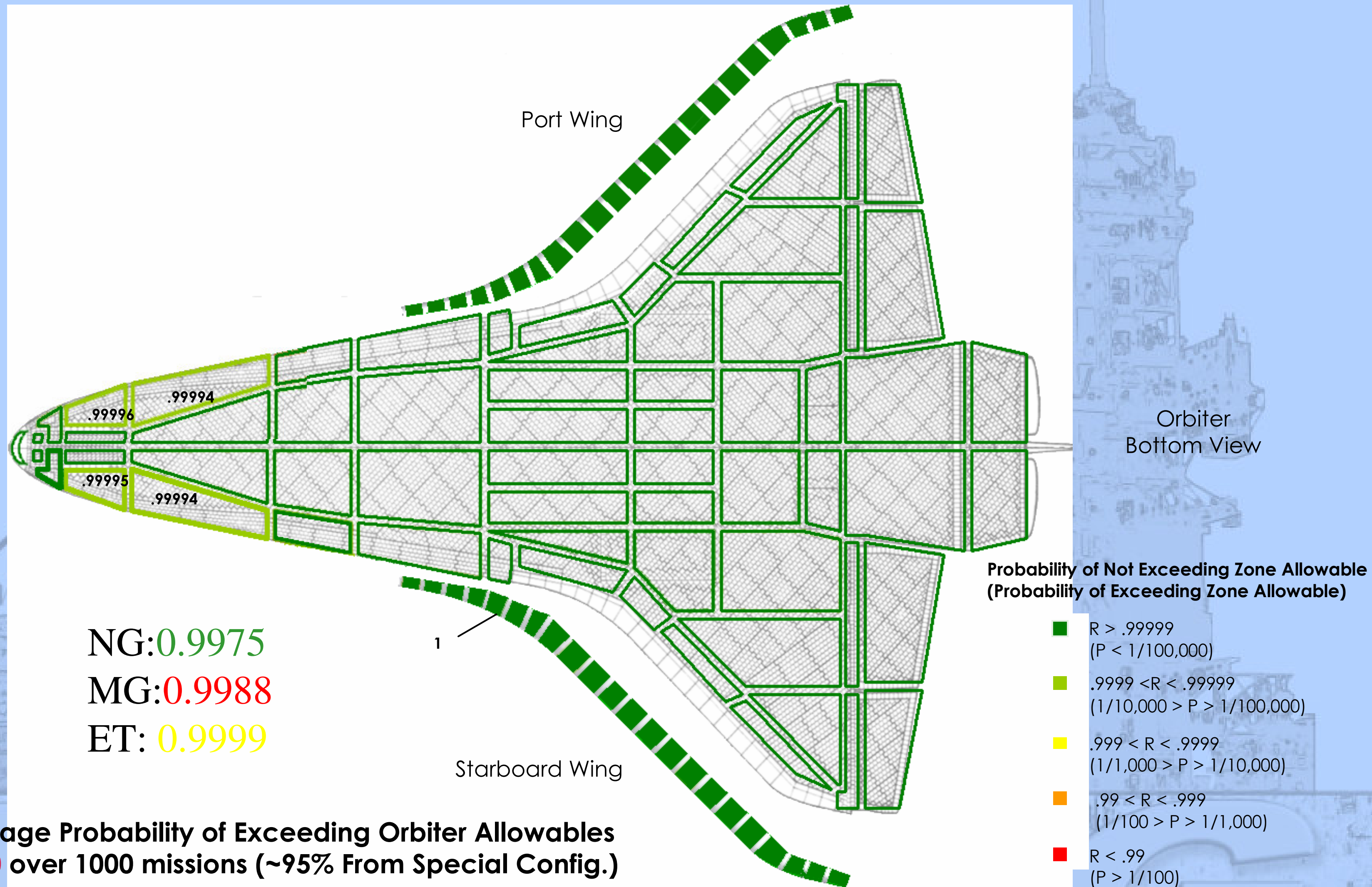
Probability of Not Exceeding Zone Allowable (Probability of Exceeding Zone Allowable)

- R > .99999 (P < 1/100,000)
- .9999 <R < .99999 (1/10,000 > P > 1/100,000)
- .999 < R < .9999 (1/1,000 > P > 1/10,000)
- .99 < R < .999 (1/100 > P > 1/1,000)
- R < .99 (P > 1/100)

Average Probability of Exceeding Orbiter Allowables is 6.2 over 1000 missions (2/3 From Special Config.)

Note: Data based on Pre Debris DVR (6/16/05)

3.3-2 – LOX Flange Damage Summary (Nominal)



NG:0.9975

MG:0.9988

ET: 0.9999

Average Probability of Exceeding Orbiter Allowables is 4.0 over 1000 missions (~95% From Special Config.)

Note: Data based on Pre Debris DVR (6/16/05)

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3.3-2 – Foam Probability of Exceeding Capability

Nominal Foam on RCC Results

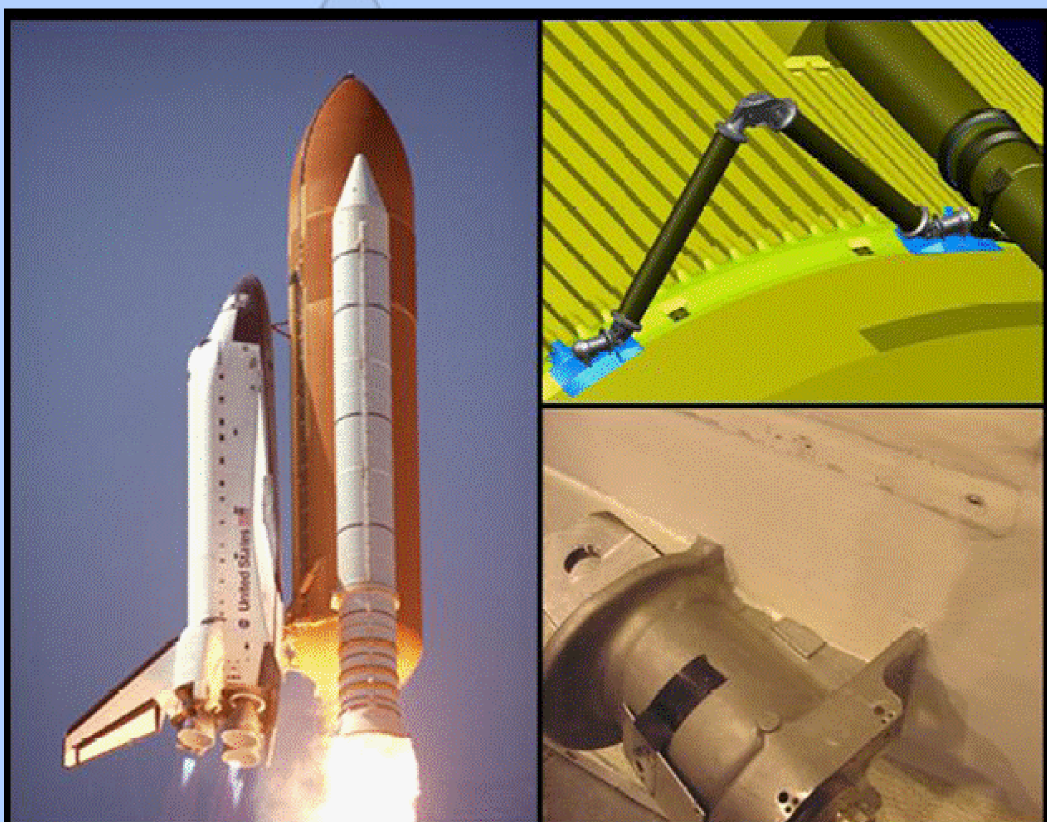
Case	I/F Nom	LOX PAL Nom	LOX Flange Nom	LH2 Flange Nom	LH2 Flange Cryo. Nom
RCC	<1/10,000	<1/10,000	<1/10,000	<1/10,000	<1/10,000

Nominal Foam on Tile Results

Case	I/F Nom	LOX PAL Nom	LOX Flange Nom	LH2 Flange Nom	LH2 Flange Cryo. Nom
Tile	1/420	1/10,000	1/3,300	1/10,000	1/10,000

Note: Data based on Debris DVR (6/24/05)

3.3-2 – Bipod TPS Closeout



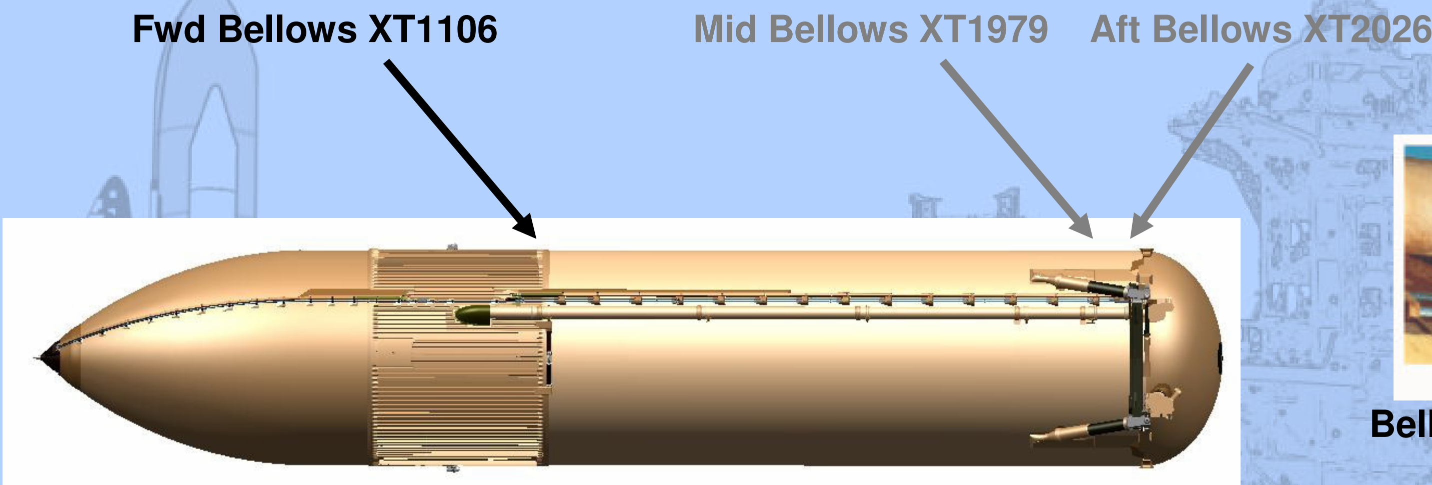
- Bipod Ramp was eliminated
- New Foam closeout around bipod has potential for some voids
- Risk associated with these voids was assessed

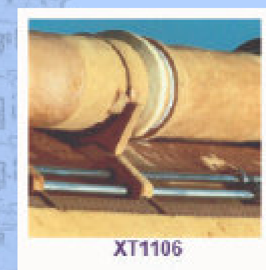
3.3-2 – Bipod Foam Closeout

- Aerospace statistical model shows high reliability < 1/10,000
- ET project created a bipod divot Monte Carlo process
  - Divot mass distribution will be transported with Aerospace process
  - Comparison will be made to ensure Aerospace statistical model is conservative

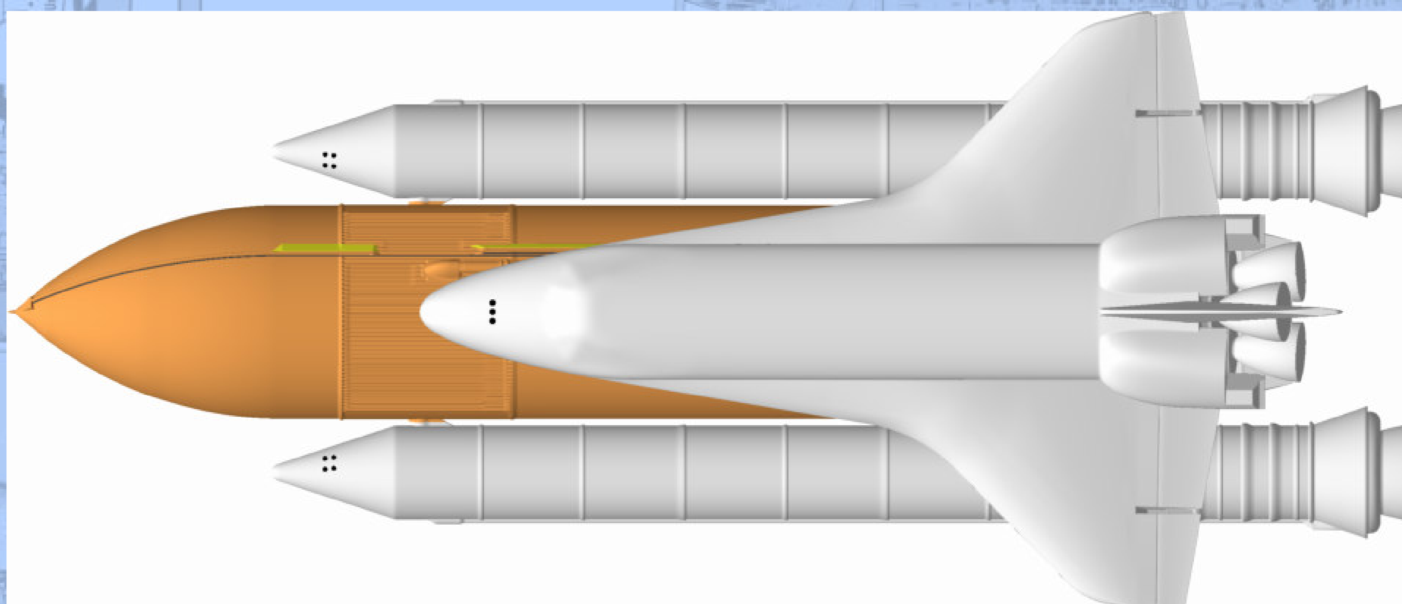
Note: Data based on Debris DVR (6/24/05)

3.3-2 – Bellows Ice on Tile Input Distributions for Probabilistic Analysis





Bellows Example

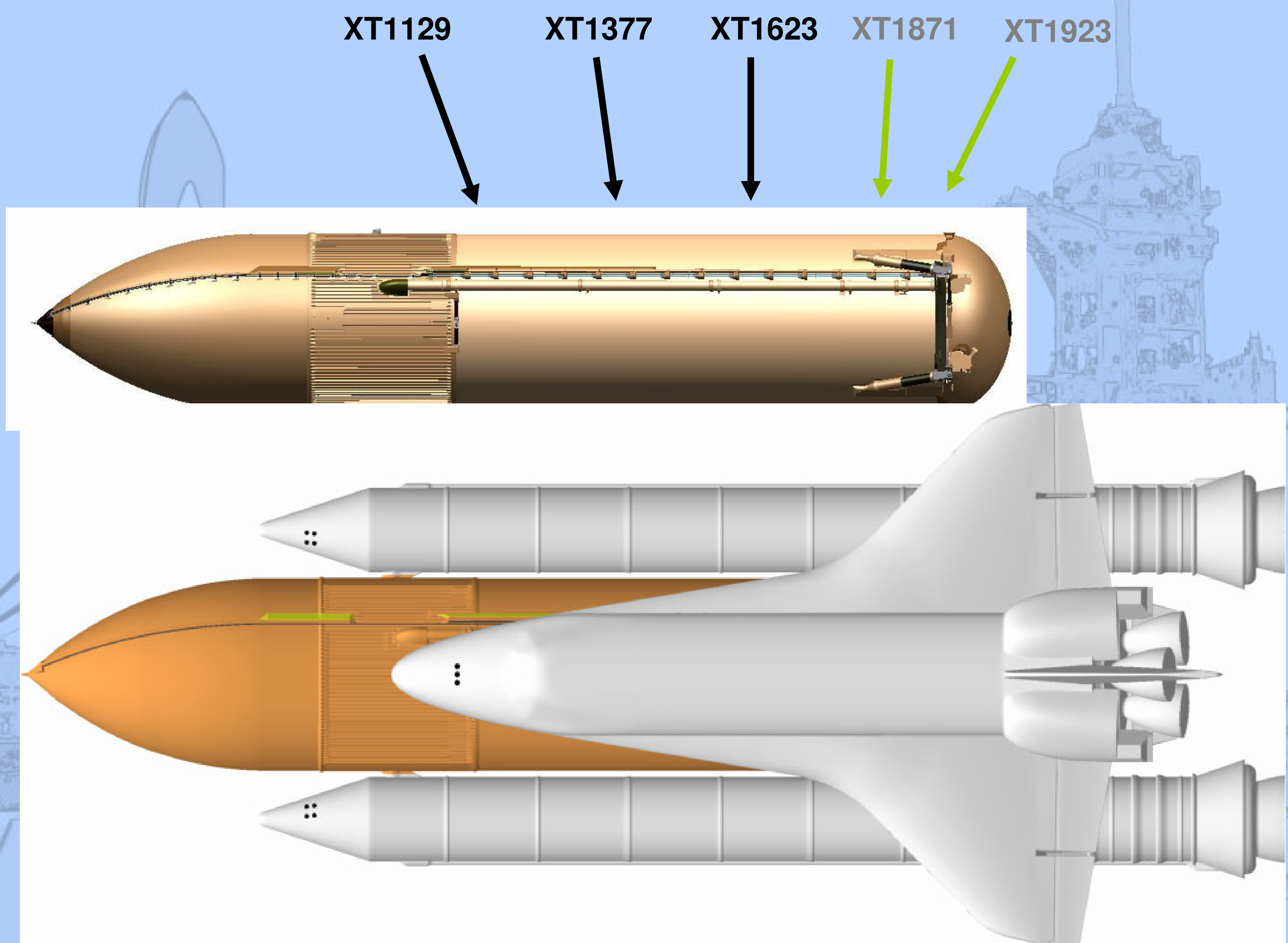


3.3-2 – Bellows Heater Qualification Test

- Build-up occurred only on the end of the convolute side of the bellows cavity (~7-8 o'clock position)
- Build-up did not bridge over to the rain shield
  - Eliminating articulation as a key means of liberation
- "Worst-on-Worst" deterministic transport analysis was completed to determine allowable
  - C/E = 1.0 with 0.0030 lbm (approx. 3.1 x 0.375 x 0.1 inches)
  - NSTS 08303 will be updated to ensure mass/volume during pre-launch will not exceed this

Note: Data based on Debris DVR (6/24/05)

3.3-2 – Bracket Ice on Tile



3.3-2 – Ice Results Summary
Mean Probability of Exceeding Capability

- Using an Exponential Mass Distribution and Lift-off Uniform Rate of Release Distribution

Ice on RCC Results

Case	XT 1129 Bracket	XT 1377 Bracket
RCC	<1/100,000	<1/1,000,000

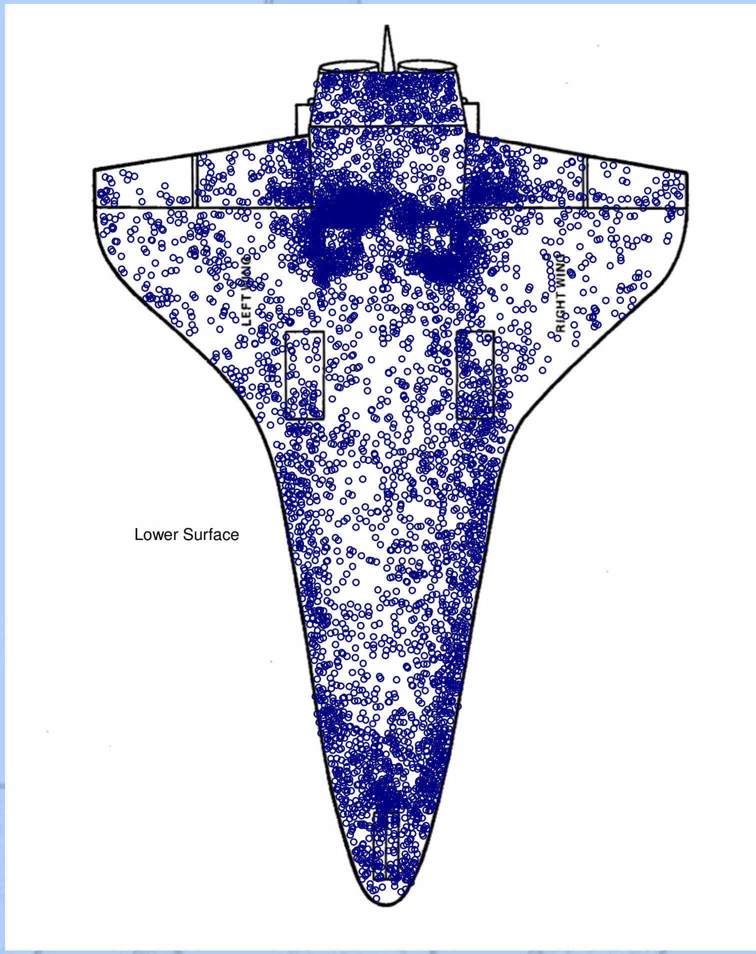
Ice on Tile Results (High Mass)

Case	XT 1129 Bracket	XT 1377 Bracket	XT 1979 Bellows	XT 2026 Bellows
Tile	1/1000	1/180	1/100	1/1000

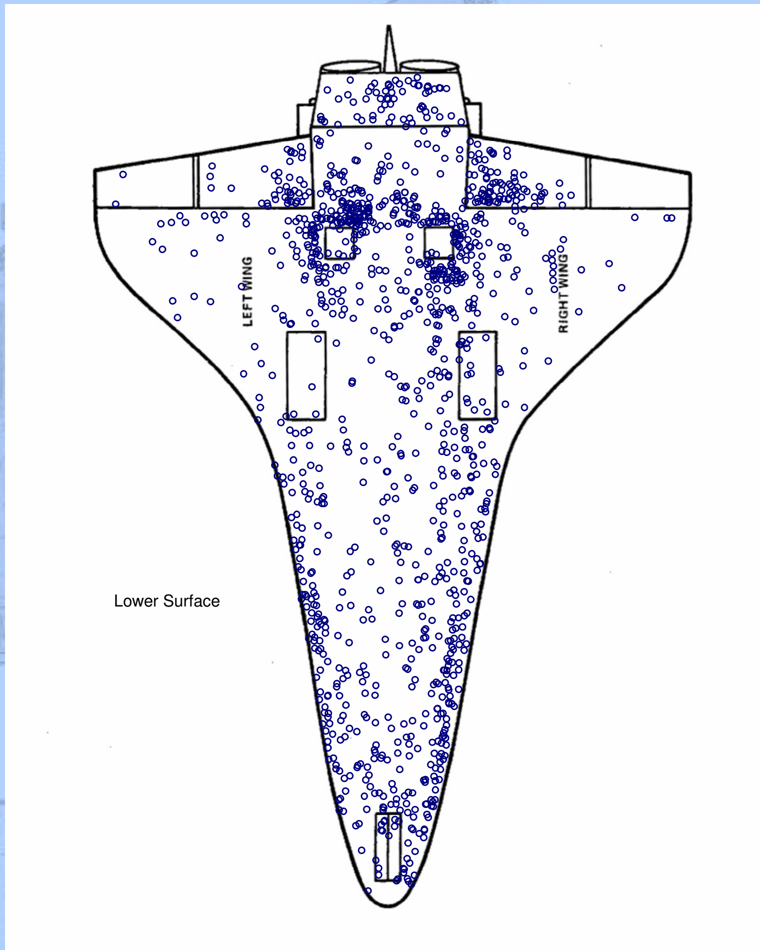
Note: Data based on Debris DVR (6/24/05)

3.3-2 – Impacts Recorded On Orbiter Surface

Lower Surface Impacts
STS-6 to STS-110



Lower Surface Impacts >= 1 inch
STS-6 to STS-110



3.3-2 – Umbilical Ice Observations

- Umbilicals are capable of having very large ice formations based on flight history
  - NOTE: Large ice observed in flight history includes multiple tanking cycles and rain during tanking
- Analysis sizes are based on enveloping ice formations (based on flight history) and are not representative of typical formations
- Large sizes exceed the bounds (upper size, lower velocity) of the tile damage model
  - Extrapolation not possible since model is based on impact test data
  - Many particles only experience low velocities
- Ice Debris from all sources analyzed have transport mechanism to tile aft of XT2058
  - No transport mechanism to RCC panels or Windows
- Evaluation of the Orbiter umbilical data indicates impact conditions as follows:
  - Max Velocity = 300 ft/sec with most impacts less than 200 ft/sec
  - Max Impact Angle = 60 degrees with most impacts less than 15 degrees
- Orbiter wind tunnel test data (1981) demonstrated that umbilical baggie separated between Mach =0.25 and 0.35
  - Corroborated by flight observations of baggie loss before/during roll maneuver
- Update launch commit criteria to monitor umbilical area ice formation

Note: Data based on Debris DVR (6/24/05)

3.3-2 – Orbiter Hardening

Summary

- 4 RTF Hardware Changes Certified and Installed
- Phase 2 Hardware Program Updated
- Impact TPS Test Program Completed
- TPS Certification and Statistical Allowables Completed
- Inspection Criteria Updated
- Damage Assessment Models Developed
- Historical Data Base Re Examined
  - Damage Measurement Process Updated for Future Flights
- Extensive Effort To Develop Techniques to Assess Likely Debris Effects
  - Foam Impact Assessments Well Understood
  - Ice Impact Assessments Still Being Refined
  - Ice Formation Inspection Requirements Updated
  - Statistical Assessment Made to Support Hazard Analysis
- Independent Verification Of Models In Process by NESC

3.3-2 – Orbiter Hardening

Panel Assessment

- The Hardware Program Defined and Supports RTF
- The TPS Impact Resistance Supported by Significant Test and Analysis
  - Independent Peer Reviews
- Likely Effects of Debris are Very Complicated
  - Orbiter Provided Damage Models
  - ET Provided Updated Expected Debris Information
  - Ice Formation and Liberation Estimates based on Tests
  - Statistical Estimates are a guide for Assessments
  - Independent Peer Review In Process
  - There is still a possibility of Critical Damage
- NASA has conducted an extensive program to improve their understanding of the impact resistance of TPS and the likely effects of damage . The major additions to this knowledge base will come as a result of vehicle flight test.

3.3-2 – Orbiter Hardening

RTF TG Recommendation

- The Technical Panel believes that with the completion of the open work the SSP has demonstrated that they have met the intent of the CAIB recommendation.

- Accept NASA Implementation of CAIB 3.3-2

Technical Panel

3.2-1 – External Tank (ET) Debris Shedding

Mr. Richard Kohrs

3.2-1 – External Tank (ET) Debris Shedding

CAIB Recommendation

Initiate an aggressive program to eliminate all External Tank Thermal Protection System debris shedding at the source with particular emphasis on the region where the bipod struts attach to the External Tank.

3.2-1 – External Tank (ET) Debris Shedding

RTF TG Interpretation

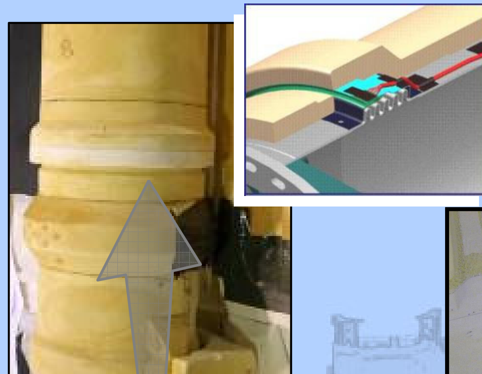
Eliminate all sources of critical debris including eliminating the bi-pod strut foam and determine the void size that correlates with a debris size that is acceptable, based on the transport and energy analysis.

3.2-1 – External Tank Return to Flight Summary

- New TPS debris requirements have been established for Return to Flight
- External Tank TPS hardware designs verified to RTF TPS debris requirements
  - Design verification modified for RTF to include assessment of internal defects
  - Hardware that did not meet RTF TPS debris requirements using the RTF design verification approach were redesigned
  - Requirements verification methodology and hardware designs reviewed at Preliminary Design Reviews/Critical Design Reviews and Project / Program Design Certification Reviews
- Limitations to the TPS verification approach were identified during the design certification process and accepted by the Space Shuttle Program Requirements Control Board (PRCBD S062571, dated 05/06/05)
  - Limitations are primarily associated with the ability to certify non-redesigned TPS applications to current TPS debris requirements
  - Limitations to TPS verification have been identified and are documented in Space Shuttle Program documentation
- SSP Delta DVR (Apr 27) identified residual ice at forward LO2 bellows location as critical debris
  - ET RTF design rebaselined to include heater system at forward bellows to eliminate ice

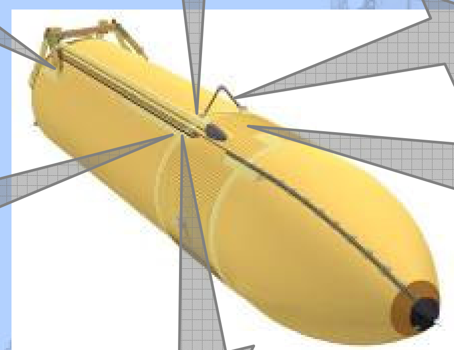
3.2-1 – ET Design Changes for Debris Reduction

Remove / Replace Longeron Closeouts



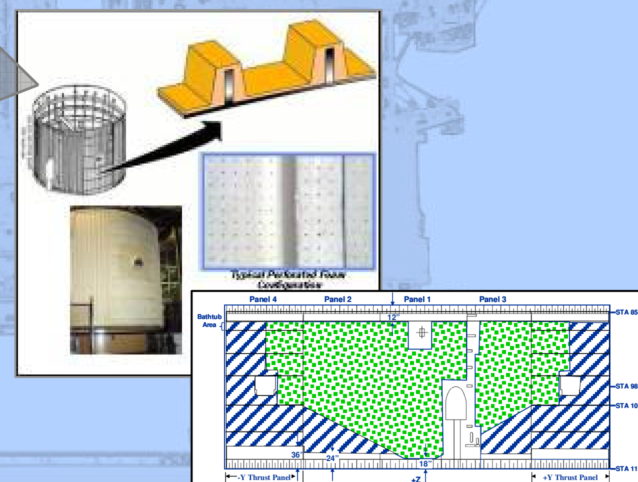
Ice Mitigation - LO2 Feedline Bellows TPS Drip Lip (3 locations) and Heater System (fwd location)

Redesigned Bipod Fitting



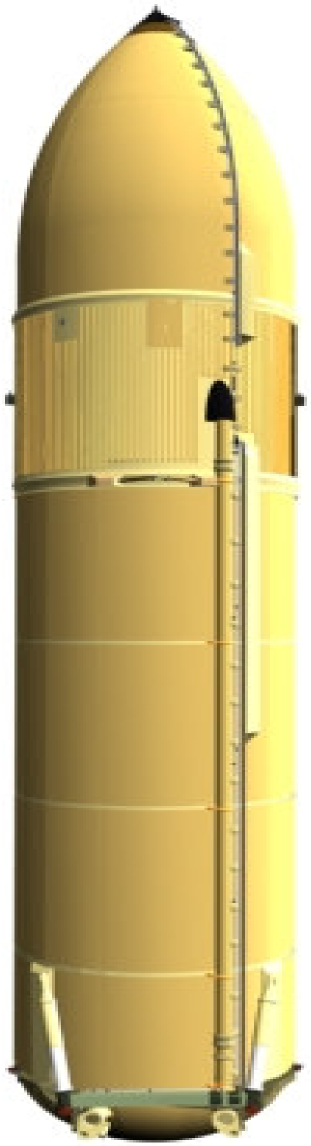
Intertank / LH2 Tank Flange Closeout Enhancement

Partial LH2 PAL Ramp Replacement (required to access underlying flange)



Increase Area of Vented Intertank TPS

3.2-1 ET TPS Debris Certification Verification Results

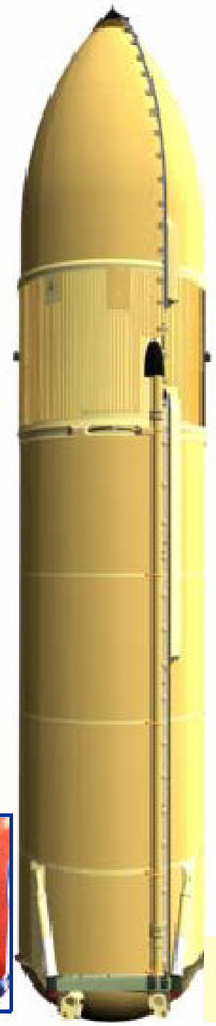


Hardware	Expected Debris using Max heating rates (< .0002 lbm)		Debris Req.	Best Est of Max Possible Mass (Ult. SF= 1.25)	Design MS (Ult SF = 1.25)
	Popcorning	Ablation			
1. LO2 Tank Acreage	√	√	0.023	0.003	0.79
2. LO2 Ice/Frost Ramps		√	0.023	0.017	0.14
3. LO2 PAL Ramp		√	0.023	0.013	0.25
4. LO2-I/T 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*

3.2-1 – ET Ice Debris Sources

Hardware	Observed Flight Performance Mass (lbm) Inherent by Design and/or Environments: Frost /Frost Balls	Ice	Max Possible Liberation (lbm)
LO2 Tank Acreage	√	√	0.000066
Bondline ice full length of tank (due to thermal shorts), e.g. LO2/LH2 Ice Frost Ramps, PAL Ramps, etc.	√	√	< 0.0002
Ice frost balls due to cracking or thermal shorts full length of Tank, e.g. Longerons, Ice Frost Ramps, etc.	√	√	0.0159
LH2 Tank Acreage	√	√	0.000066
* LO2 Feedline Bellows with TPS drip lip – (3) locations	√	√	0.0696 * (estimated max is a 8" linear piece)
* LO2 Feedline Support Brackets (5) Locations – Each bracket has numerous ice/frost formation areas	√	√	0.0670 * (estimated max is located at gap between bracket and feedline)
Aft I/F Hardware, e.g. aft transportation fitting, LH2 feedline bellows, SRB Fittings, etc.	√	√	0.257 (estimated max is located at lower SRB fitting)



* *On-going liberation test may provide additional insight into max possible predictions*

Indicates full length of Tank

3.2-1 – ET Ice Debris Sources

- **STS-114 External Tank has a heater system**

Baseline

Drip Lip
(~40% reduction for worst case environment)

Heater
(Thermal Mechanical Test Article)

3.2-1 – External Tank (ET) Debris Shedding

Panel Assessment

- **FOR FOAM**
  - **ET demonstrated that they met the SSP foam debris requirements at the DCR**
  - **The SSP determined that the requirements exceeded the Orbiter capability**
  - **ET then provided best estimate of expected debris based on test data, dissection data, and flight history**
  - **SSP program developed statistical analysis of risk based on the best estimate of debris from ET project and debris capability of Orbiter from the Orbiter project**

- **FOR ICE**
  - **ET added drip lip to bellows and through testing showed 40% reduction in ice buildup**
  - **SSP program analysis showed this as unacceptable risk**
  - **ET replaced with new tank with heaters on forward bellows**
    - **Eliminates critical ice debris**
  - **Other ice buildup locations have been reviewed**
  - **A statistical analysis was performed to evaluate the risk of critical damage due to residual ice from other locations**

3.2-1 – External Tank (ET) Debris Shedding

Panel Assessment

- The ET project implemented an aggressive program to eliminate critical foam debris and met the SSP requirements
- The certified tank debris allowables exceed the capability of the Orbiter (Not in all cases)
- The best estimate of debris allowables are significantly lower than the certified values
- The SSP has evaluated the ET foam and ice through statistical analysis using ET best estimate of expected debris and Orbiter capability
- The Program has developed NSTS 60559 Expected Debris Generation and Impact Tolerance Requirements, Ground rules and Assumptions in which they have fully documented the debris generation certification levels and the debris excepted risk levels
- Although the program has performed an extensive effort to reduce debris for Return to Flight, there still is the potential for foam and ice to cause damage to Orbiter that exceeds safe entry limits, however this potential has been significantly reduced

3.2-1 – External Tank (ET) Debris Shedding

RTF TG Recommendation

– The Technical Panel believes the ET and SSP have demonstrated that they have initiated an aggressive program to eliminate ET debris and, within the exceptions and limitations as documented in NSTS-60559, have met the intent of the CAIB recommendation

– Accept NASA Implementation of CAIB 3.2-1

Observation

– The SSP should continue their program to eliminate critical debris by aggressively working off the limitations documented in NSTS-60559.

Operations Panel
Fact-Finding Status

Col. James Adamson, Lead

Operations Panel
CAIB Recommendations

3.4-1 Ground-Based Imagery
Closed June 8, 2005

3.4-2 High-Resolution Imagery of External Tank (ET)
Closed December 16, 2004

3.4-3 High-Resolution Imagery of Orbiter
Closed June 8, 2005

4.2-5 KSC Foreign Object Debris (FOD)
Closed December 16, 2004

6.4-1 Thermal Protection System (TPS) Inspection and Repair

10.3-1 Digitize Close Out Imagery
Closed December 16, 2004

SSP-3 Contingency Shuttle Crew Support (CSCS)
Closed June 8, 2005

Operations Panel

R6.4-1 TPS Inspection and Repair

Dr. Kathryn Clark

Dr. Charles Daniel

Dr. Kathryn Thornton

6.4-1 – TPS On-Orbit Inspection and Repair

CAIB Recommendation

For missions to the International Space Station, develop a practicable capability to inspect and effect emergency repairs to the widest possible range of damage to the Thermal Protection System, including both tile and Reinforced Carbon-Carbon, taking advantage of the additional capabilities when near to or docked at the International Space Station.

For non-Station mission, develop a comprehensive autonomous (independent of Station) inspection and repair capability to cover the widest possible range of damage scenarios.

Accomplish an on-orbit TPS inspection, using appropriate assets and capabilities, early in all missions.

The ultimate objective should be a fully autonomous capability for all missions to address the possibility that an ISS mission fails to achieve the correct orbit, fails to dock successfully, or is damaged during or after undocking.

6.4-1 – TPS On-Orbit Inspection and Repair

<u>RTF TG Interpretation</u>

- CAIB Recommendation 6.4-1 consists of four separate provisions. Although the entire recommendation is labeled Return to Flight, the second and fourth provisions do not apply to STS-114. These provisions are not being considered by NASA or the Task Group.
  - If a non-ISS mission, such as HST Service Mission 4, is added to the flight manifest, the ASAP should review this recommendation.

- NASA must define any damage to tile and RCC that poses an unacceptable hazard to the Orbiter and crew during entry, and be able to detect the location and extent of such damage.

- Each of the repair options in the suite of options that constitutes the repair capability must have completed formal design reviews, ground verification testing, procedure development and an integrated Design Certification Review such that NASA could implement it in an emergency situation with confidence that it would behave as expected

6.4-1 – TPS On-Orbit Inspection and Repair

NASA Implementation: Inspection

- Developed an extensive suite of sensors to ascertain condition of TPS
  - On-orbit inspection of WLE & nose-cap via OBSS
  - On-orbit inspection of tile from ISS
  - Focused inspections with higher resolution as required
  - Imagery inspection capability covered under CAIB Recommendation 3.4-3
    - RTF TG assessment complete 6/8/05
- Sensors are uncertified for critical detection limits, but have been successful in necessary detection under laboratory conditions
- Wing Leading Edge Sensors provide impact detection to provide additional evidence of possible damage

6.4-1 – TPS On-Orbit Inspection and Repair

NASA Implementation: Integrated Assessment

- Developed an extensive plan to integrate data for logical presentation to MMT
  - NSTS 60549 STS-114 Operations Integration Plan (OIP) for Thermal Protection System (TPS)
  - NSTS 60549 OIP Damage Assessment Annex
- The decision to land the orbiter with an untested repair will require a difficult decision based on models, experimental runs in the arc jet facility, and flight history of the thermal environment during the landing.
- Decision process demonstrated in numerous integrated component and MMT simulations

6.4-1 – TPS On-Orbit Inspection and Repair

NASA Implementation: Tile Repair

- Critical damage threshold for tile has been defined as 1” around main landing gear or ET umbilical doors and 3” in major dimension for acreage tile

- Emittance Wash
  - Intended for shallow damage anywhere on black tile on the orbiter
    - Restore emissivity to increase heat rejection
  - Repair DTO planned on STS-114

- CIPA Repair & STA-54
  - Intended for damage up to 10” x 20” anywhere on tile
  - Requires triple containment
  - Repair DTO on STS-121

- Tile Overlay
  - Intended for damage up to 10” x 20”
  - Mechanical repair, removing the variability issues

6.4-1 – TPS On-Orbit Inspection and Repair

NASA Implementation: RCC Repair

- Critical damage threshold for RCC has been defined as cracks 0.020” x 2” long and 0.020” deep
- Crack Repair: Non-Oxide Adhesive experimental (NOAX) sealant
  - Intended for cracks up to 0.0625” x 9” and small areas of coating loss (1” OML, 2” IML)
  - Have completed Preliminary and Interim Design Reviews
  - Repair DTO planned for STS-114
- Plug Repair
  - Intended for holes up to 4” diameter (over 62% coverage)
  - Have completed Preliminary and Interim Design Reviews
  - Repair DTO planned (IVA) for STS-114

6.4-1 – TPS On-Orbit Inspection and Repair

<u>NASA Implementation</u>

- The ability to assess the condition of the TPS depends on
  - Success in gathering high quality imagery during launch and ascent (CAIB 3.4-1 and 3.4-2),
  - Down-linking high quality imagery of the TPS while on orbit (CAIB 3.4-3)
  - Access to data from other national assets (CAIB 6.3-2)
  - Preflight photography to compare with newly acquired flight imagery (CAIB 10.3-1)
  - Successful integration all of these data and the people with the expertise to provide the decision makers with appropriate information to make critical decisions regarding the capability of the shuttle to land safely (OIP, OIP Annex and CAIB 6.3-1).

- Inspection/imagery capability as assessed for 3.4-1, -2 and -3 are not constraints to launch except OBSS and the Pad camera power control system

6.4-1 – TPS On-Orbit Inspection and Repair

Panel Assessment: Inspection

- Primary methods to be used for on-orbit inspection of TPS, the OBSS sensor suite and the R-bar Pitch Maneuver (RPM) have been assessed as part of the Task Group's evaluation of Recommendation 3.4-3 (closed June 8, 2005)

- The wing-leading edge sensor system provides impact detection and is assessed within the context of Recommendation 3.3-2

6.4-1 – TPS On-Orbit Inspection and Repair

Panel Assessment: Repair

- Given the NASA'S stated limitations in meeting ET critical debris liberation (3.2-1) and orbiter ability to sustain critical debris damage (3.3-2), the inspection and repair capabilities must be further placed in context.
- In terms of risk mitigation, detection is quite different from being able to adequately respond to the detected damage.
- NASA will carry on STS-114 five experimental options to effect emergency repairs to the TPS
  - NASA is continuing to pursue capabilities to repair larger damage for future flights.
- Experimental repair options manifest on STS-114 show promise for future flights but are contingency measures rather than practicable repair capabilities at this time

6.4-1 – TPS On-Orbit Inspection and Repair

Panel Assessment: Repair

- NASA has demonstrated a concerted effort in attacking the difficult problem of developing operational techniques for the orbital repair of both RCC and Tiles

- Even though all TPS repair techniques being considered are only for contingency use and cover a limited range of potential damage, NASA should go through a rigorous design and certification process for the duration of the Shuttle program
  - To date, none of the tile and RCC repair techniques have gone through this process.

- Tile and RCC repair techniques are not considered sufficiently mature to be a practicable repair capability for STS-114.

6.4-1 – TPS On-Orbit Inspection and Repair

Observations

- The recommendation of the CAIB with respect to repair as written presented an extreme technical challenge to NASA given the physical characteristics of the Orbiter TPS.
- While there is a gap between possible debris liberation and the ability of the orbiter to withstand impact and repair damage, the proximate cause of the loss of STS-107 is no longer possible

6.4-1 – TPS On-Orbit Inspection and Repair

Recommendation

- Inspection has been addressed in Recommendation 3.4-3 and meets the intent of Recommendation 6.4-1
- Based on the majority opinion interpretation of the intent of 6.4-1; that any repair technique must be vetted through the design and ground verification processes prior to being considered a 'capability' and the failure of any of the current repair techniques to meet this standard – NASA has not met the intent of the CAIB Recommendation 6.4-1 with respect to TPS repair.

Integrated Vehicle Assessment Sub-Panel Update

Ms. Christine Fox, Lead

Integrated Vehicle Assessment Sub-Panel

Charter

- Purpose: Assess NASA's process to obtain and integrate external damage data to directly support decision-making

- Effort cut across many CAIB recommendations

- Members of the Management, Technical, and Operations Panels all participated

Integrated Vehicle Assessment Sub-Panel

Activities

- Significant revision to Orbiter Damage Assessment Process Annex to the Operations Integration Plan
  - Published 2/28/05 to support MMT #12
  - Refined after MMT #12
- Operations Integration Plan developers have significantly increased training and broadened participation
  - Designed and implemented a series of component and mini-integration sims
  - Significant contributions to the design and implementation of MMT #13
- Operations Integration Plan developers conducted “fact-finding” trips to explore data integration and independent assessment issues

Integrated Vehicle Assessment Sub-Panel

Significant Achievement

- Published NSTS-60540, *STS-114 Operations Integration Plan for Thermal Protection System Assessment* and its Annex, *Orbiter Damage Assessment Process*
  - Baselined on April 12, 2005
  - Program level recognition that the OIP has been created, vetted, and approved as "work in progress"

Integrated Vehicle Assessment Sub-Panel

Observations

- Orbiter Damage Assessment Process Annex important source of information to support decision-making
  - Documents sources of data necessary to support complex decisions
  - Includes risk vs. risk assessment matrices
  - A significant part of closure criterion for Recommendation 6.4-1, Inspection and Repair

- Senior NASA management continues to accept and support the Operations Integration Plan/Damage Assessment Annex

- Known values for critical damage assessment and critical debris size are key to the OIP/Damage Assessment Annex
  - Required to assess sensor capabilities, data analysis timelines, and information quality

Integrated Vehicle Assessment Sub-Panel

Summary

- The Task Group commends the OIP and Damage Assessment developers for designing, documenting, and training to a data integration and assessment process to support STS-114
- In the view of this sub-panel and the Task Force, OIP should continue to develop after STS-114
  - Information and understanding gained from STS-114 will be invaluable for future mission data integration
  - NASA should continue to resource and support the OIP development team
- Because of its importance, the RTF TG suggests IVASP development and training efforts as a candidate for ASAP follow-on
  - OIP integrates all available information on the health of the TPS to support decision-making
- OIP should serve as a model for other NASA information assessment processes required to support complex decision-making

RTF TG Transition to Aerospace Safety Advisory Panel Items

Mr. Dick Covey – Co-Chair

RTF TG Transition to ASAP Items

IVASP

- **Monitor the continued development of the OIP and its Annex, as well as how the documents are used for decision-making within the MMT and other groups**
- **Monitor how NASA implements other information assessment processes across other elements of the Agency.**

R3.2-1

- **Monitor the results of analyses conducted after the STS-114 launch and determine its applicability to the ETs scheduled for future missions**
- **Track the development of the proposed ET Certification Limitations document**
- **Monitor labor-intensive processes enacted for RTF and ensure familiarity does not breed contempt or laxness.**

RTF TG Transition to ASAP Items

R3.3-1

- **Monitor NASA's progress toward finishing the documentation, and also ensure that meaningful nondestructive inspections continue for all future flight of the Space Shuttle until the vehicle is retired.**

R3.3-2

- **Monitor the progress of each of these items, with particular attention on model verification and configuration management.**

R3.4-1

- **Continue to assess the availability of adequate imagery assets to ensure there are three useful views of the Space Shuttle available for all future launches.**

RTF TG Transition to ASAP Items

R3.4-2

- **Asses the implementation of the ET attach ring and SRB forward skirt cameras, along with the SRB solid-state recorders, planned for STS-115 and subsequent flights.**

R3.4-3

- **Continue to assess what constitutes "adequate resolution" as the Orbiter critical damage size evolves.**
- **Monitor NASA's continued analysis to ensure the OBSS-Orbiter structural margins during ascent and landing are adequate as the system continues to evolve (and, likely, gets heavier).**

R4.2-1

- **None.**

RTF TG Transition to ASAP Items

R4.2-3

- **Conduct periodic monitoring to ensure the process is still being followed, particularly as the program winds-down.**

R4.2-5

- **Evaluate the on-going Foreign Object Debris (FOD) program at the Kennedy Space Center and other NASA installations to ensure its continued effectiveness and compliance with accepted industry standards.**

R6.2-1

- **Monitor the NASA budget submission and approval and workforce metrics to ensure sufficient resources are available to meet the mission manifest.**

RTF TG Transition to ASAP Items

R6.3-1

- Observe selected MMT simulations, with particular attention to team performance and NASA's integrative capabilities.

R6.3-2

- None.

R6.4-1

- Closely monitor work in the inspection and repair area. With the suspension of CSCS and rescue missions after the first few flights, the issue of a certified and operational inspection and repair capability must be addressed.
- Ensure inspection and repair remains a high priority within the Space Shuttle Program.

RTF TG Transition to ASAP Items

R9.1-1

- **Review the progress toward completing the establishment of the ITA and its warrant holders.**
- **Monitor the process by which NASA grants waivers to technical requirements to ensure it meets the intent of the CAIB recommendations, as well as assessing the progress toward establishing a truly effective Systems Engineering and Integration Office.**

R10.3-1

- **Evaluate the digital imagery database and closeout photography procedures at the Kennedy Space Center and other NASA installations to ensure its continued effectiveness.**

RTF TG Transition to ASAP Items

SSP-3

- **Conduct an independent evaluation of the desirability of maintaining a CSCS capability for flights after STS-121.**
- **If the capability does continue into the future, ensure that it does not become a "crutch" for the Space Shuttle Program and lead to a tendency toward negative changes to the flight rules and operations.**

Other Observations

- **Make periodic visits to engineers and manufacturing areas, including contractor sites**
- **As the Space Shuttle Program phases down, monitor to ensure that critical skills and capabilities are not being lost**
- **Monitor to ensure NASA does an intensive examination of debris after each flight to better understand the debris environment**

RTF TG Transition to ASAP Items

Other Observations

- **Continue monitor the progress toward developing nondestructive inspection techniques**
- **Continue to monitor high-speed hardware (turbo-pumps, APUs, etc.)**
- **Consider development of protective hardware of RCC panels**
- **Establish a system to ensure that with the first instance of a design shortfall, such as ET debris or RSRM hot gas blow-by, the Program must undertake a study of design options to correct the problem. Where determined feasible, this should be phased in at the earliest flight available**
- **Attend, as much as possible, NASA SRB static firing testing and other major ground testing events.**

Action Item Summary and Closing Remarks

Mr. Dick Covey – Co-Chair