Orbiter Assessment of STS-107 ET Bipod Insulation Ramp Impact

P. Parker

D. Chao

I. Norman

M. Dunham

January 23, 2003

Order of Analysis

- **Orbiter assessment of ascent debris damage includes**
  - **Evaluation of potential for debris to damage tile and RCC**
    - **Program "Crater" is official evaluation tool**
      - Available test data for SOFI on tile was reviewed
      - No SOFI on RCC test data available
    - **Even for worst case, SIP and densified tile layer will remain when SOFI is impactor**
  - **Thermal analysis of areas with damaged tiles**
    - **Thermal analysis will predict potential tile erosion and temperatures on structure**
  - **Structural assessment based on thermal environment defined above**
    - **Basis is previous Micrometeriod and Orbital Debris (M/OD) study performed in 1996**

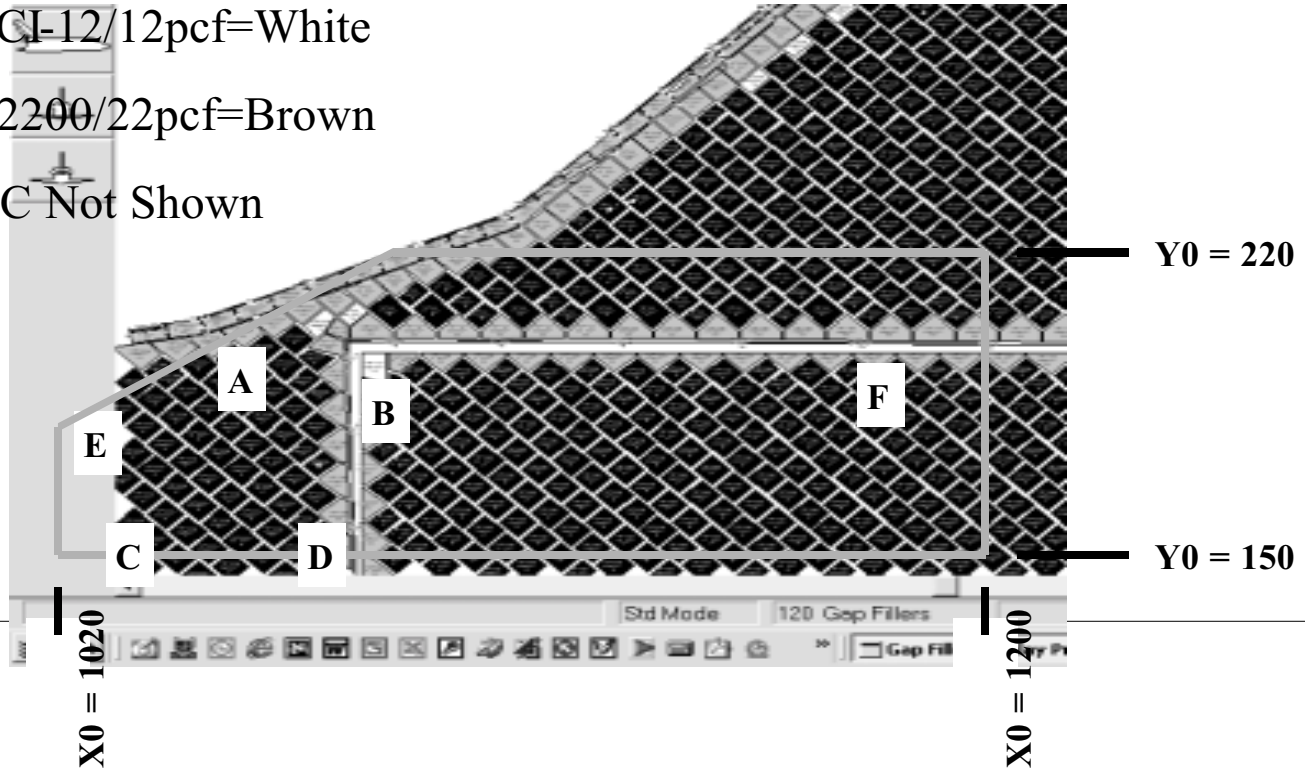
System Integration Inputs Were Matched Against Orbiter Tile/RCC to Determine Critical Locations

LI-900/9pcf=Black

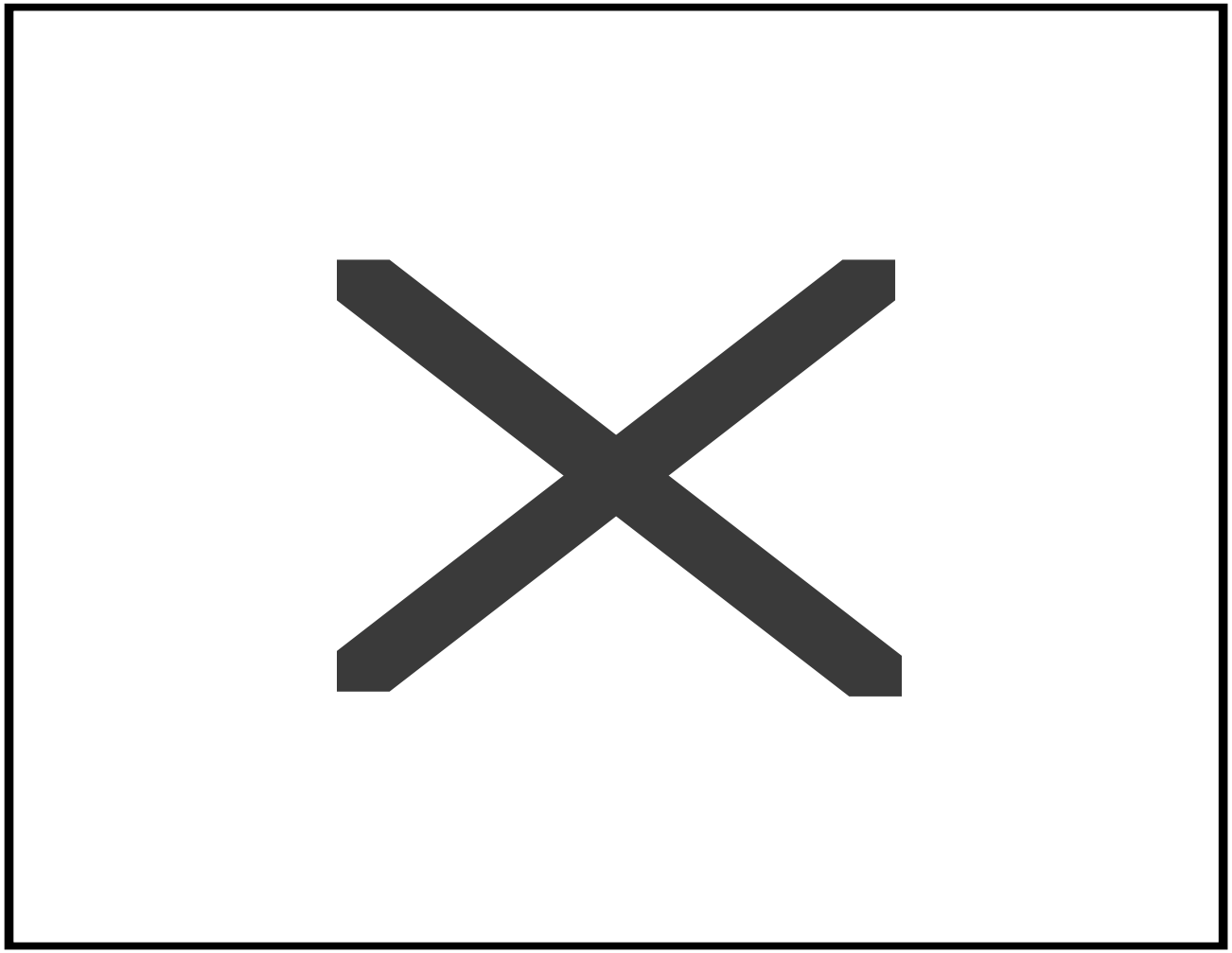
FRCI-12/12pcf=White

LI-2200/22pcf=Brown

RCC Not Shown



Tile Thickness



Damage Results From "Crater" Equations Show Significant Tile Damage

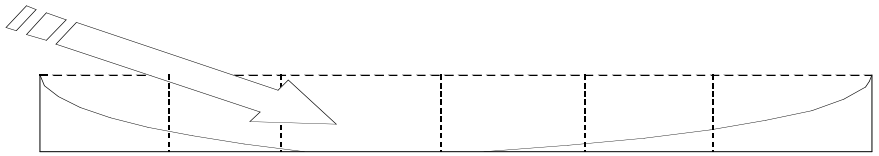
- **"Crater" indicates that multiple tiles would be taken down to densified layer**
  - **However, program was designed to be conservative due to large number of unknowns**
  - **Crater reports damage for test conditions that show no damage**

Tile Information		Location			Impactor		Calculated Damage		
Type	Thickness	Letter	X	Y	Angle	Velocity	Depth	Length	Width
9 lb	2.6 - 2.8	A	1060	190	13	720	4.7	25.8	7.2
22 lb	2.6 - 2.8	A	1060	190	13	720	3.2	25.8	7.2
9 lb	2.3 - 2.4	B	1090	180	6	700	2.8	31.9	7.2
9 lb	2.0 - 2.4	C	1036	150	8	680	3.3	29.8	7.2
22 lb	2.0 - 2.4	C	1036	150	8	680	2.3	28.6	7.2
9 lb	1.9 - 2.0	D	1075	150	8	710	3.4	32.2	7.2
12 lb	2.8 -3.1	E	1029	177	10	680	2.9	19.0	2.4
22 lb	2.8 -3.1	E	1029	177	10	680	2.6	19.0	2.4
9 lb	1.7	F	1184	182	6	730	2.8	32.8	2.4

Damage data and tile thickness are given in inches.

Debris Size = 20" x 16" x 6"

(Density = 2.4 lb/ft^3)



Review of Test Data Indicates Conservatism for Tile Penetration

- **The existing SOFI on tile test data used to create Crater was reviewed along with STS-87 Southwest Research data**
  - **Crater overpredicted penetration of tile coating significantly**
    - **Initial penetration to described by normal velocity**
      - Varies with volume/mass of projectile (e.g., 200ft/sec for 3cu. In)
    - **Significant energy is required for the softer SOFI particle to penetrate the relatively hard tile coating**
      - Test results do show that it is possible at sufficient mass and velocity
    - **Conversely, once tile is penetrated SOFI can cause significant damage**
      - Minor variations in total energy (above penetration level) can cause significant tile damage
  - **Flight condition is significantly outside of test database**
    - **Volume of ramp is 1920cu in vs 3 cu in for test**

(Potentially) Similar STS-50 Impact Demonstrates that Damage is Possible

- Damage to aft lower tile (0.5"d x 9"L x 4" W) on wing was found after STS-50 landing; wheel well camera also observed missing ET bipod ramp insulation similar in size
- Small variation in energy input could substantially increase damage
- Incidence angle for STS-107 is predicted higher than STS-50

Volume = 1920in3

L (in)	d (in)	V (ft/sec)	Angle	Vadj (in/sec)	Flt Damage	damage (depth)	Normal Energy	
20	6	**700**	**3.2**	69	**0.50**	0.53	100%	STS-50 (estimated conditions)
20	6	770	3.2	116		0.75	121%	STS-50 plus 10% velocity
20	6	700	5.2	361		1.60	264%	STS-50 plus 2 deg incidence angle
20	6	600	3.2	2		0.05	73%	STS-50 "threshold"
20	6	720	10	1100		3.37	1024%	STS-107
20	6	788	10	1243		3.66	1228%	STS-107 + 10% energy
20	6	914	10	1505		4.16	1650%	STS-107 + 50% energy
20	6	720	10	700		2.49	551%	STS-107 with V* = 800

V*	C	density (SOFI)	density (tile)	Strength (tile)				219912
400	0.0195	0.0014	0.0052	53				

Volume	V* (in/sec)		Ratio	power	V* (ft/sec)	
0.11	6500		1.0	3.5	542	test
0.33	4500		0.8		375	test
1.00	3200		0.8		267	test
3.00	2500		1.0		208	test
1920	400		1.0		33	flight

Volume vs V* (velocity to penetrate tile coating)

RCC Predicted Damage at Incidence Angles Greater than 15 Degrees Based on Ice Database

Impactor		Damage
Angle	Velocity (fps)	Depth (in.)
5	720	0.11
10	720	0.18
15	720	0.23
20	720	0.28
25	720	0.33

Debris Size = 20” x 10” x 6”

Density = 2.4 lb/ft^3

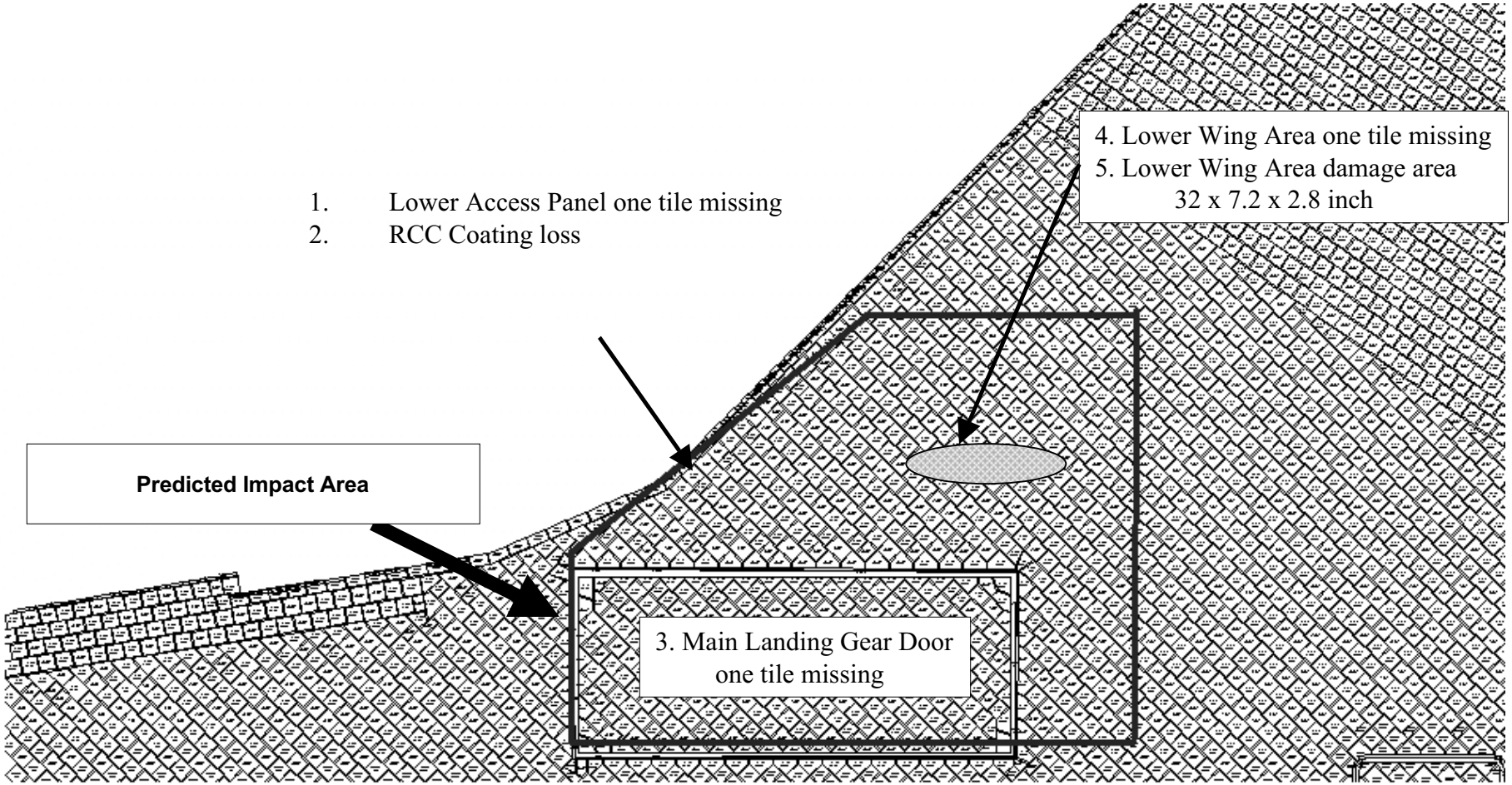
45° angle of wing was taken into account

Nominal panel thickness is 0.233 in.

RCC is clearly capable of withstanding impacts of at least 15 degrees; relative softness of SOFI (compared to ice) would indicate greater capability

- Maximum reported angle of 21 degrees is not an problem
  - Looking at using Window ice and RTV data as an analog

Thermal Analysis Assessment of Debris Impacted Lower Surface in STS-107 Mission Locations

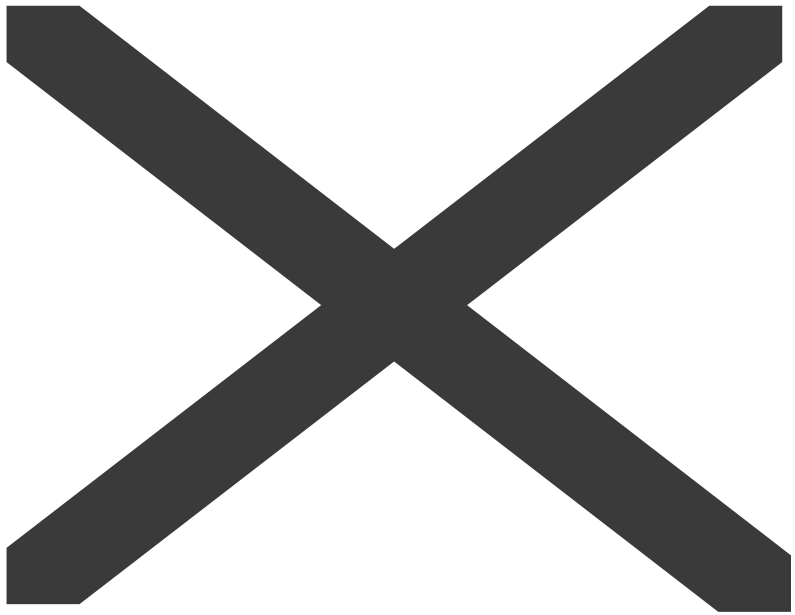


Impacted Lower Surface Location Thermal Predictions

Case	Location	Assumptions	Results
1	Access Panel (one tile missing)	Loss to last layer of TMM Densified layer ~ .2 inches	Temperature of Al Tube Carrier 790 °F No issue
2	RCC Panel 9 Lower Flange OML (Coating Missing)	Coating loss and Carbon substrate exposed	Substrate thickness: 0.193 inches Loss .09 inches No issue
3	Main Landing Gear Door (one tile missing)	Loss to last 2 layers of TMM Densified layer ~ .4 inches	Temperature of Structure 540 °F No issue
4	Lower Wing Area (one tile missing)	Loss to last 2 layers of TMM Densified layer ~ .4 inches	Temperature below 350 °F design req. No issue
5	Lower Wing Area (32 x 7.2 x 2.8 inch) Damage	Loss to last layers of TMM Densified layer ~ .2 inches	
6	Main Landing Gear Door (several tiles Lost)	Loss to last layers of TMM Densified layer ~ .2 inches	

Structural Assessment Provides for Intact Contingency Landing with Damaged Tiles

- Criteria for M/OD study were to assess on-orbit risk that cannot be controlled
- Study allowed for significant degradation beyond design criteria
  - Structural temperatures well beyond 350F design (due to loss of tile)
    - Repair of structure required
  - Small holes in structure, allowing internal plasma flow, were permissible if not in critical area
    - Not expected for STS-107
  - Factor of Safety not maintained for design conditions
  - Critical subsystems were included in evaluation
    - Wing has few subsytems except in landing gear box and elevon cove
    - Wing spars are considered critical structures
- Conditions identified to ensure intact contingency landing



Summary and Conclusion

- Impact analysis ("Crater") indicates potential for large TPS damage
  - Review of test data shows wide variation in impact response
  - RCC damage limited to coating based on soft SOFI
- Thermal analysis of wing with missing tile is in work
  - Single tile missing shows local structural damage is possible, but no burn through
  - Multiple tile missing analysis is on-going
- M/OD criteria used to assess structural impacts of tile loss
  - Allows significant temperature exceedance, even some burn through
    - Impact to vehicle turnaround possible, but maintains safe return capability

<u>Conclusion</u>

- Contingent on multiple tile loss thermal analysis showing no violation of M/OD criteria, safe return indicated even with significant tile damage