Oliu-1, Armando

From: Ortiz, Carlos [Carlos.Ortiz@boeing.com]
Sent: Friday, January 24, 2003 3:50 PM
To: Khodadoust, Abdollah; Jorge.E.Rivera@nasa.gov; David.S.Otto@zodiac.maf.nasa.gov; Armando.Oliu-1@nasa.gov
Subject: STS-107 Debris Assessment

STS-107 MMT Orbiter Impact
ebris Traj Assessmage Assessme

> Guys,
>
> The results of the debris impact analysis and debris impact damage assessment were presented today at the MMT meeting. In a nutshell, Orbiter ruled out the concern for serious (catastrophic) damage to the Orbiter TPS system and does not feel it is a concern for safety of flight. Although, impact damage analysis shows large TPS damage, the thermal analysis does not violate the M/OD criteria that allows for significant temperature exceedance and even some burn through to occur.
>
> Attached please find the two briefings presented today on the subject matter.
>
> > <<STS-107 MMT Debris Traj Assessment.ppt>> > > <<Orbiter Impact Damage Assessment.ppt>>
>
> I will like to extend my sincere appreciation for your support.
>
> Carlos Ortiz
> SSP Integrated Vehicle Analysis
> 2100 Space Park Dr. 4C43
> M/C HS4-30
> Houston, TX 77058
> Office: 281-226-5775
>

Debris Transport Assessment of Debris Impacting Orbiter Lower Surface in STS-107 Mission

STS-107 MMT

January 24, 2003

Subcontract 1970483303

W.B.S. 1.2.2.1 / 20037

PDRD SC004

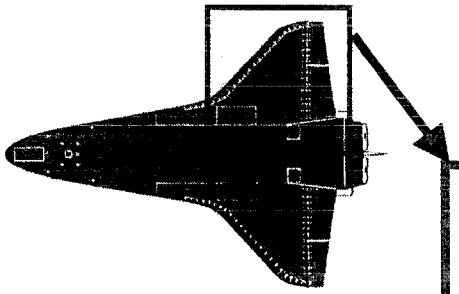
Carlos Ortiz (281) 226-5775

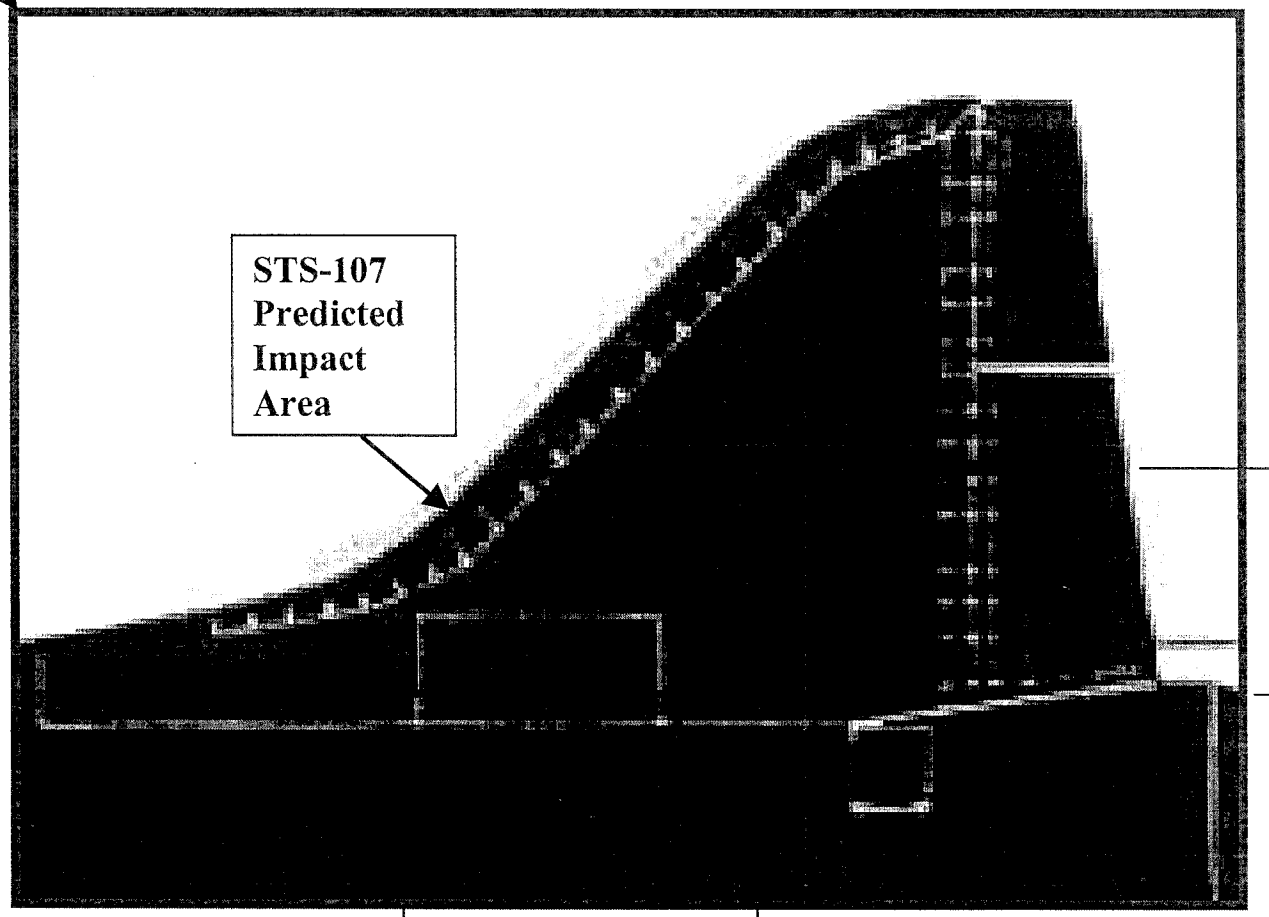
Debris Impact Conditions to Be Evaluated for Area on Orbiter Lower Surface

- **Issue** – At about 82 seconds into the flight, multiple pieces of debris were seen emanating from the ET bipod area and later seen impacting the Orbiter lower surface
- **Film Analysis Results indicate impact at about 1/3 of the wing from vehicle centerline**
  - 3 pieces of debris were observed
  - Debris can be 20" long
  - Debris appeared to break-up upon Orbiter impact
    - A shower of debris is seen soon after impact
- **Debris Trajectory Analysis estimated the impact conditions for what was observed**
  - Assumed debris particle emanates from bipod ramp area (XO 389, YO 50)
  - Three debris sizes analyzed:
    - 20" x 16" x 6" (representing bipod ramp)
    - 20" x 10" x 6" (representing bipod ramp)
    - 20" x 10" x 2" (representing flange foam)
  - Debris material considered to be foam (density = 2.4 lb/ft3)
  - Trajectories based on ballistic coefficient for Mach = 2.5 alpha 3.0
  - The distribution of impact conditions on predicted impact area estimated from combination of trajectory results and existing debris database
- **Film review continuing to better define impact area**

BOEING

Predicted Impact Area Derived from Film Observations and Trajectory Analysis





STS-107 Debris Impacting Orbiter Wing

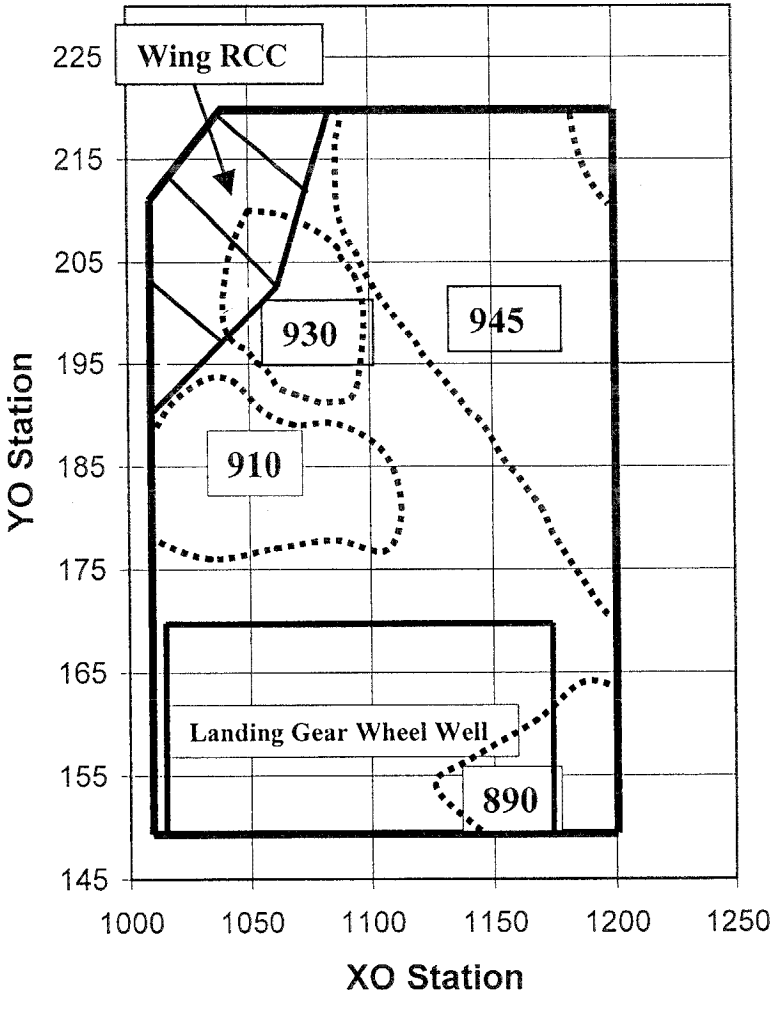
BOEING

Velocity and Impact Angle Distribution Inside Impact Area

(Debris Size = 20" x 10" x 2", Density = 2.4 lb/ft3)

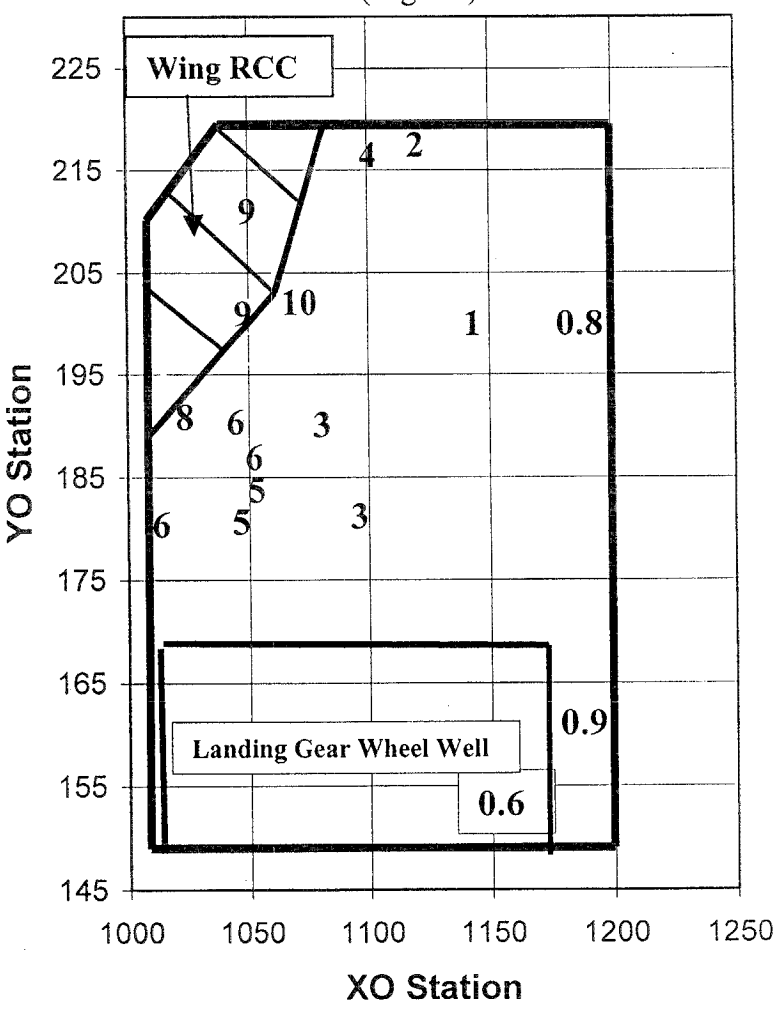
Impact Velocity

(ft/sec.)



Impact Angle

(degrees)



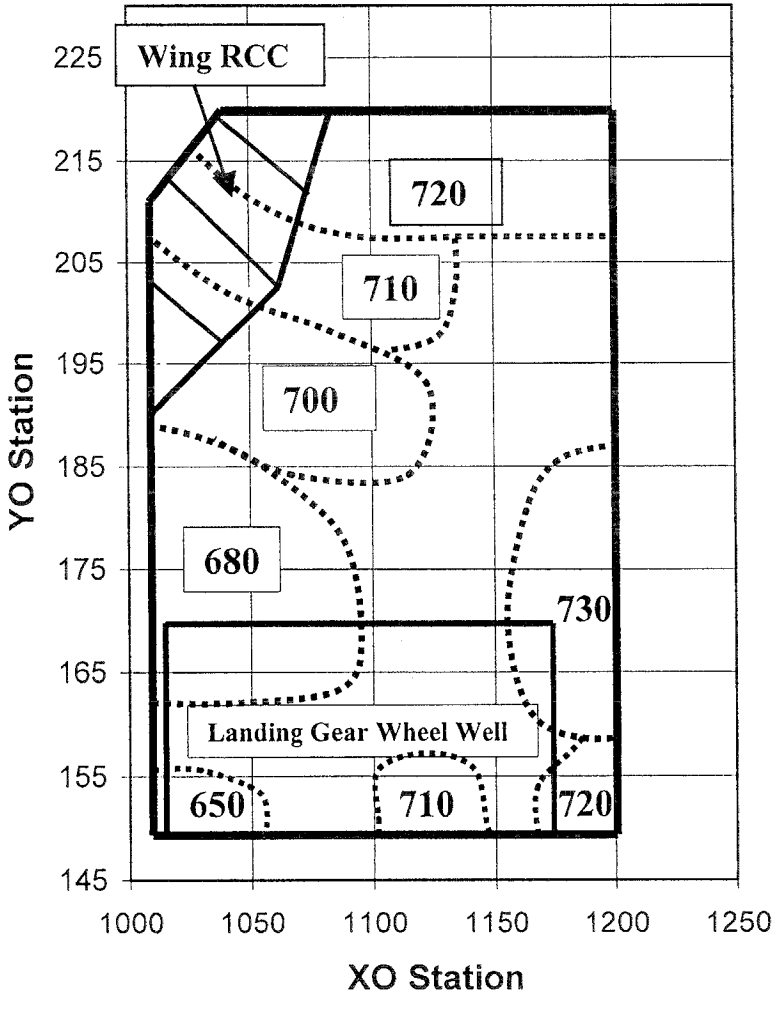
BOEING

Velocity and Impact Angle Distribution Inside Impact Area

(Debris Size = 20" x 10" x 6", Density = 2.4 lb/ft3)

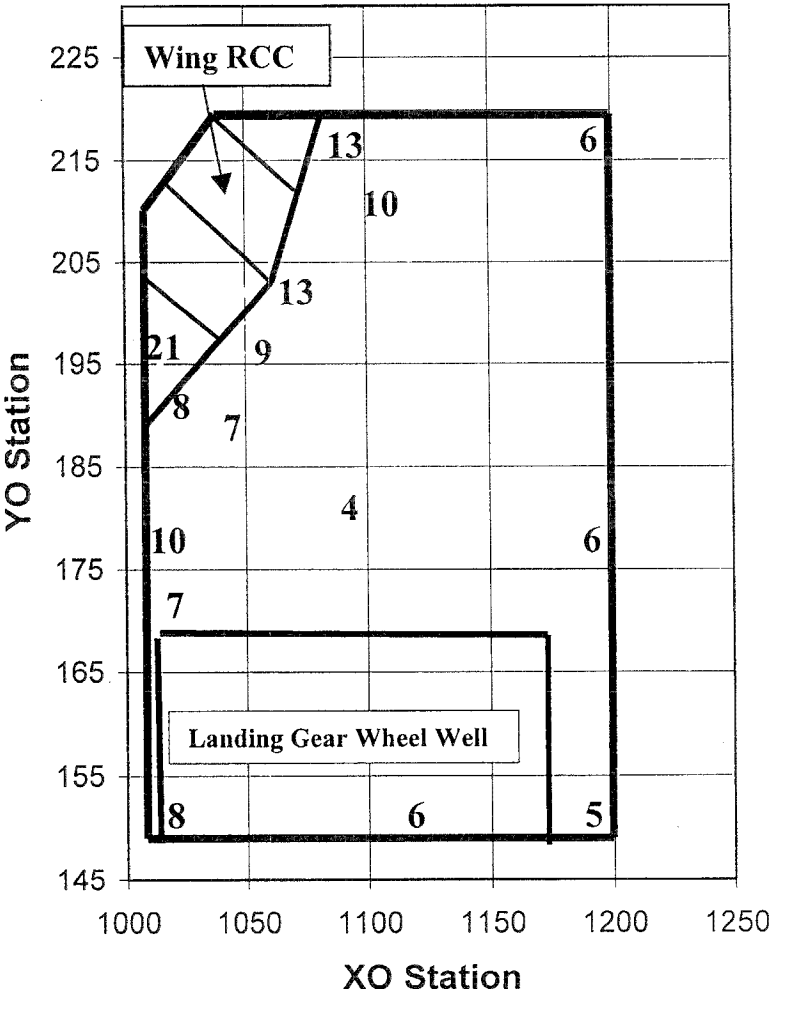
Impact Velocity

(ft/sec.)



Impact Angle

(degrees)



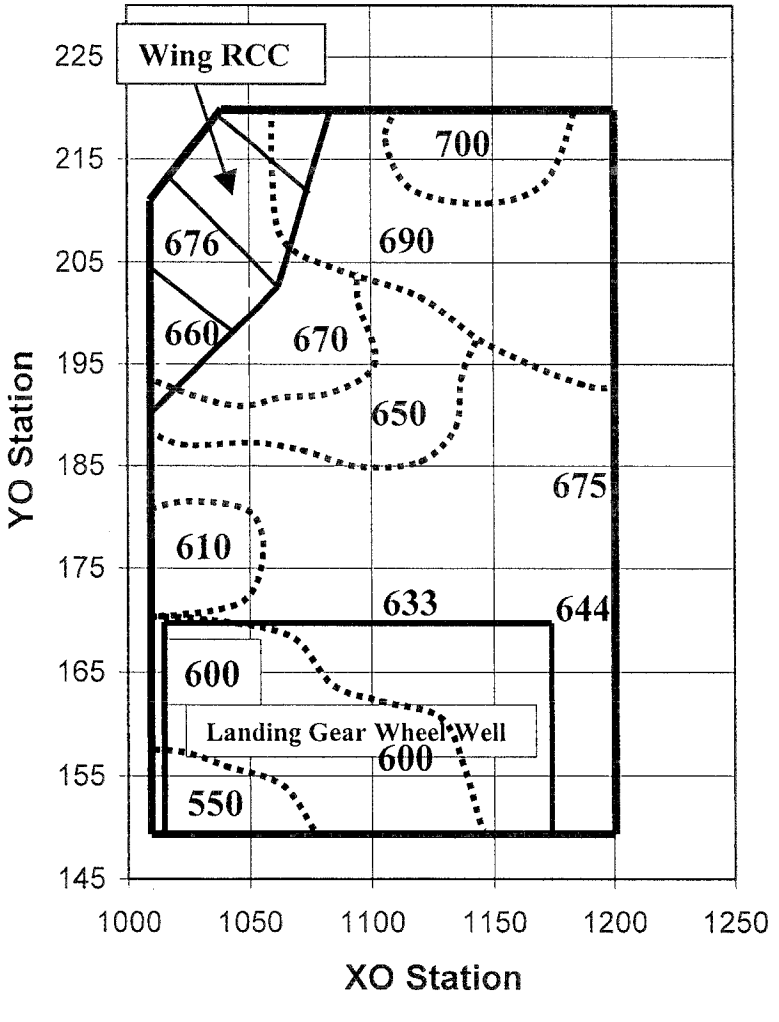
BOEING

Velocity and Impact Angle Distribution Inside Impact Area

(Debris Size = 20" x 16" x 6", Density = 2.4 lb/ft3)

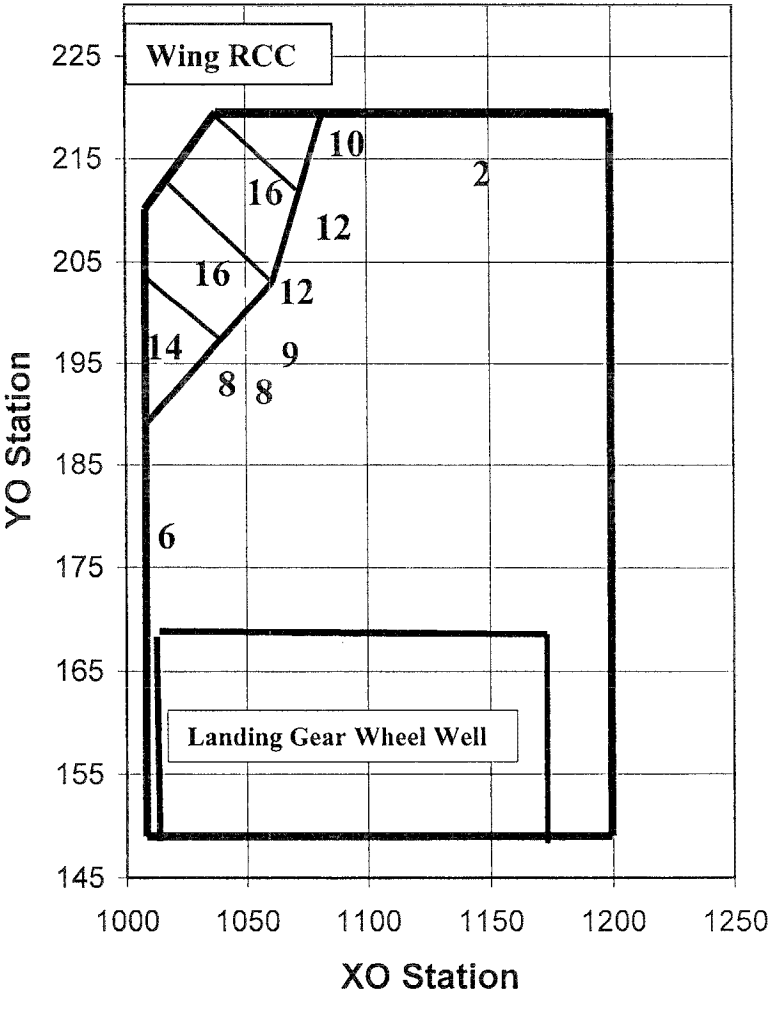
Impact Velocity

(ft/sec.)



Impact Angle

(degrees)

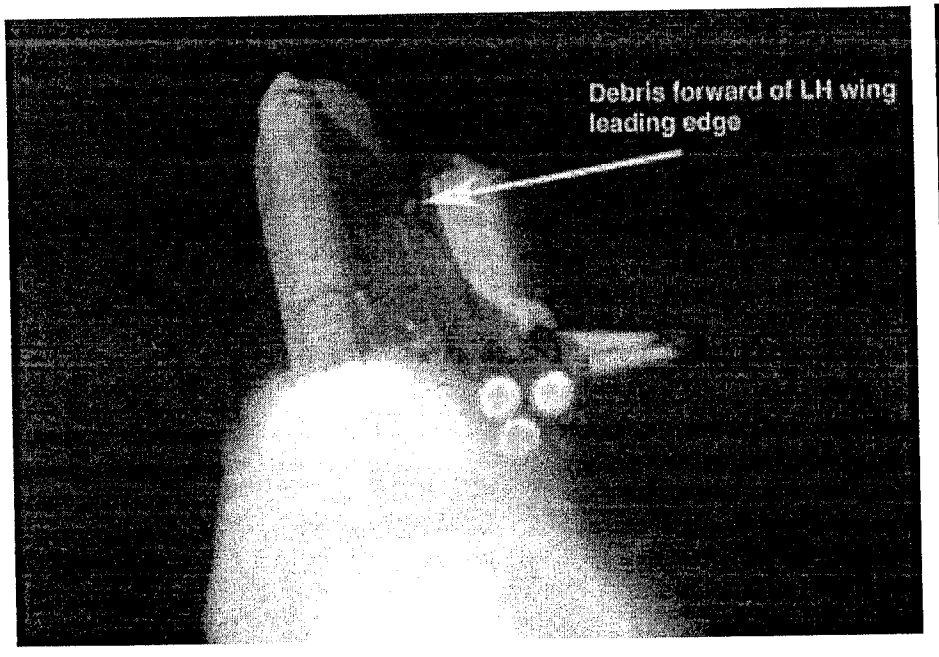


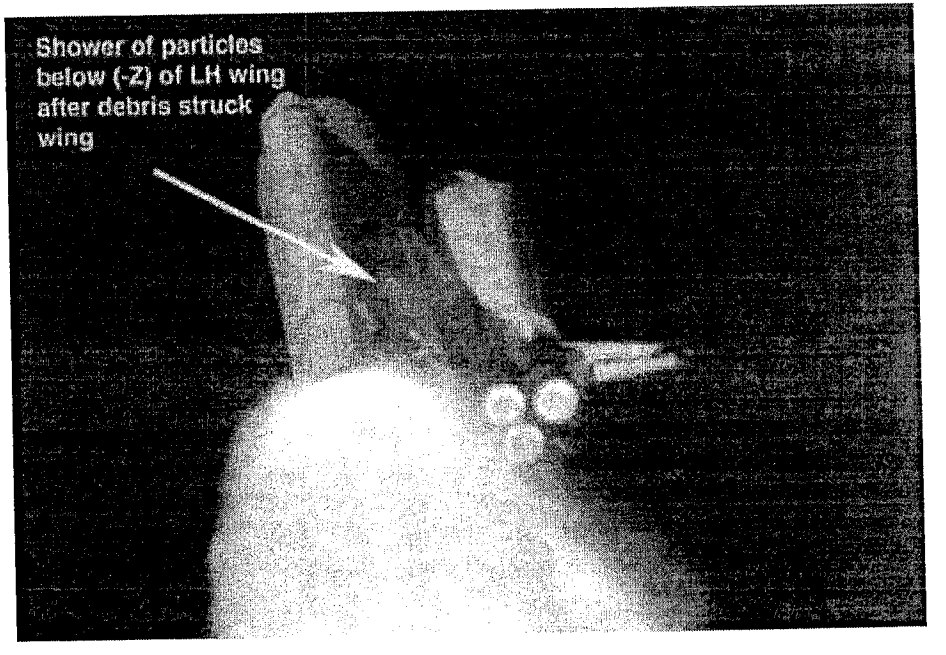
BOEING

Back-Up

Debris Emanating From Bipod Area Impacts Orbiter Lower Wing

Issue - At about 82 seconds into the flight, multiple pieces of debris were seen emanating from the ET bipod area and later seen impacting the Orbiter lower surface





BOEING

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**

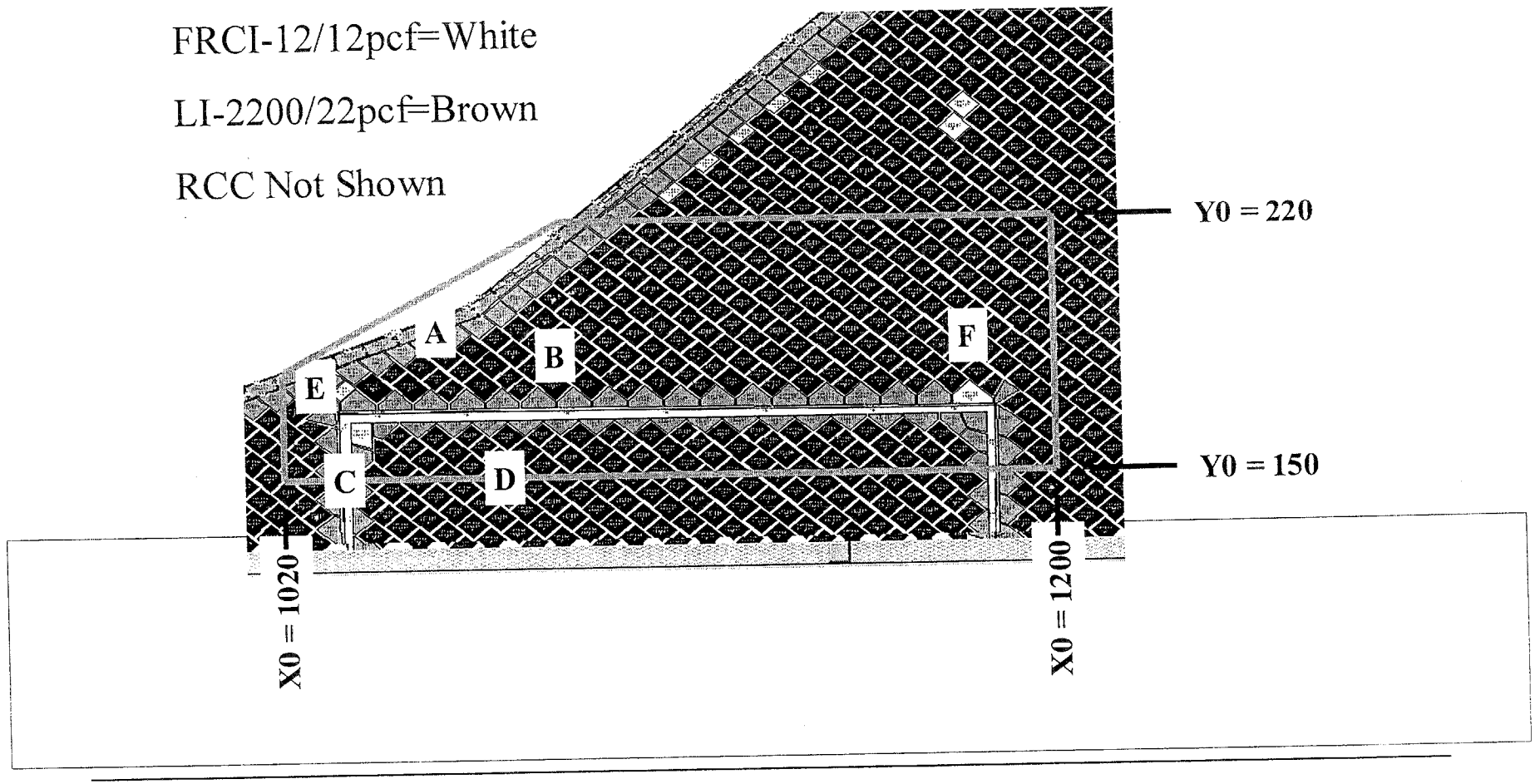
System Integration Inputs Were Matched Against Orbiter Tile/RCC to Determine Critical Locations

LI-900/9pcf=Black

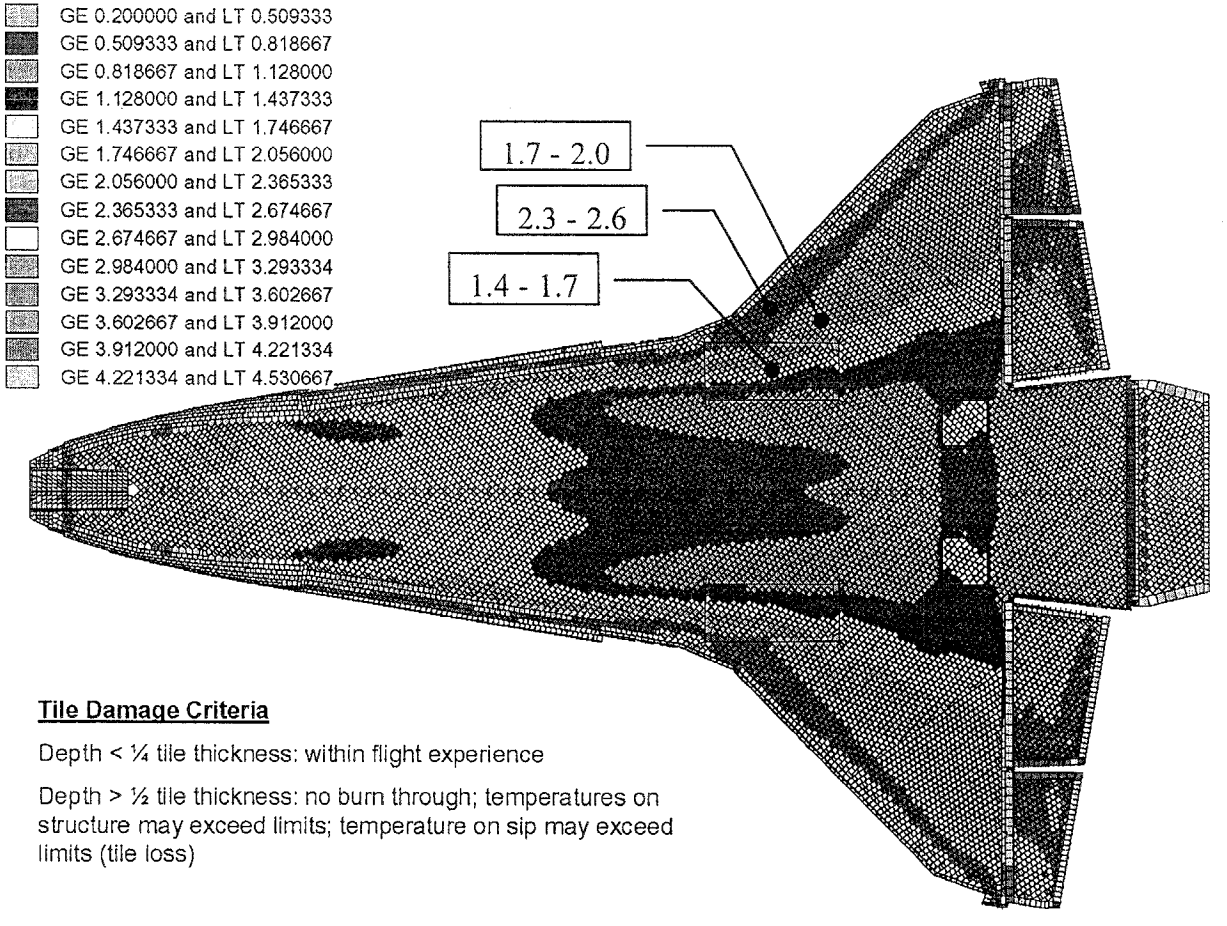
FRCI-12/12pcf=White

LI-2200/22pcf=Brown

RCC Not Shown



Tile Thickness



Tile Damage Criteria

Depth < ¼ tile thickness: within flight experience

Depth > ½ tile thickness: no burn through; temperatures on structure may exceed limits; temperature on sip may exceed limits (tile loss)

Damage Results From "Crater" Equations Show Significant Tile Damage

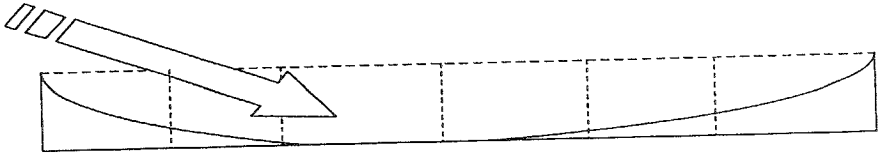
- "Crater" indicates that multiple tiles would be taken down to densified layer
  - However, program was designed to be conservative due to large number of unknowns
  - Crater reports damage for test conditions that show no damage

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)	
400	0.0195	0.0014	0.0052	53	219912

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

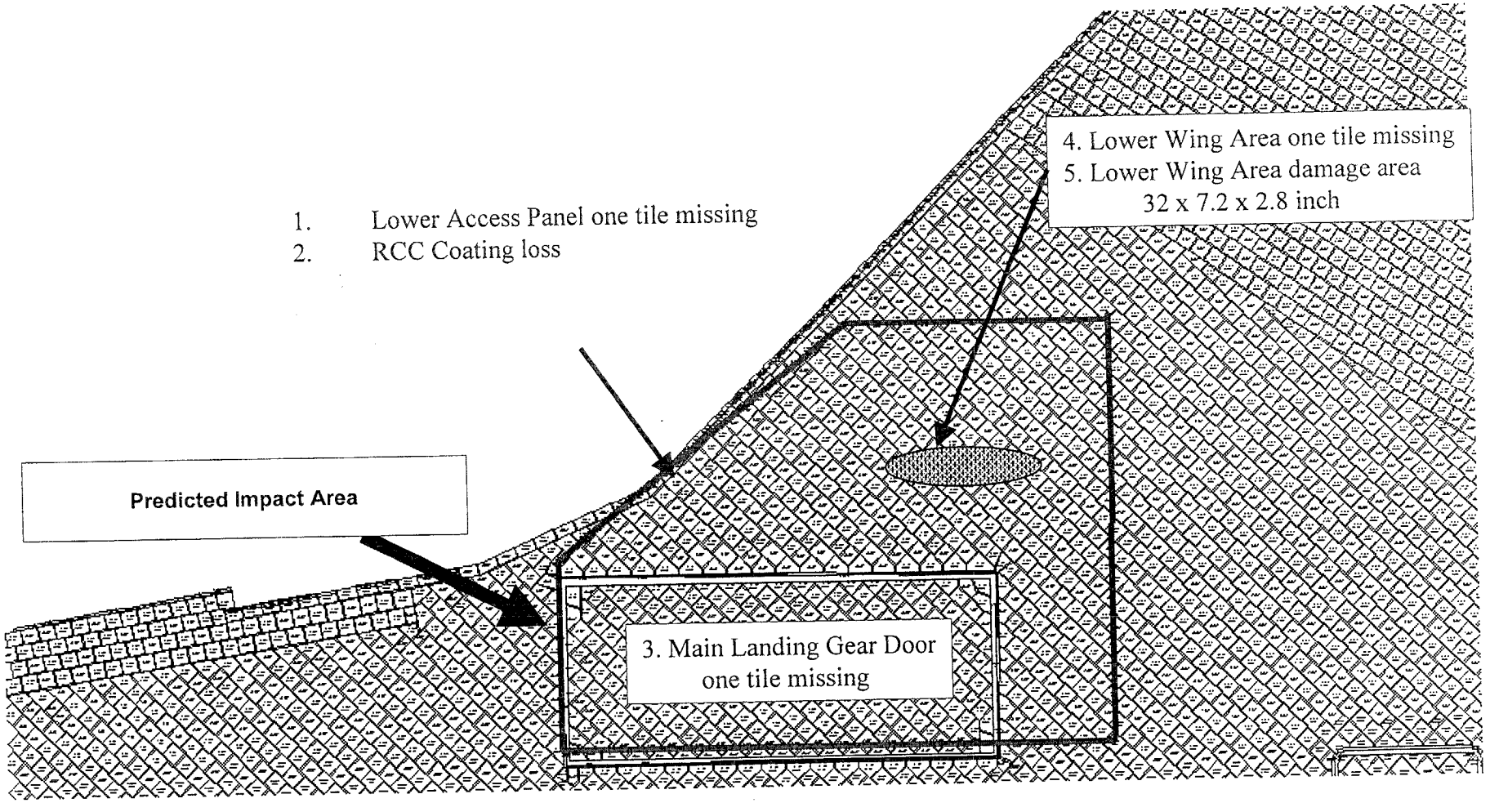
45° angle of wing was taken into account

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



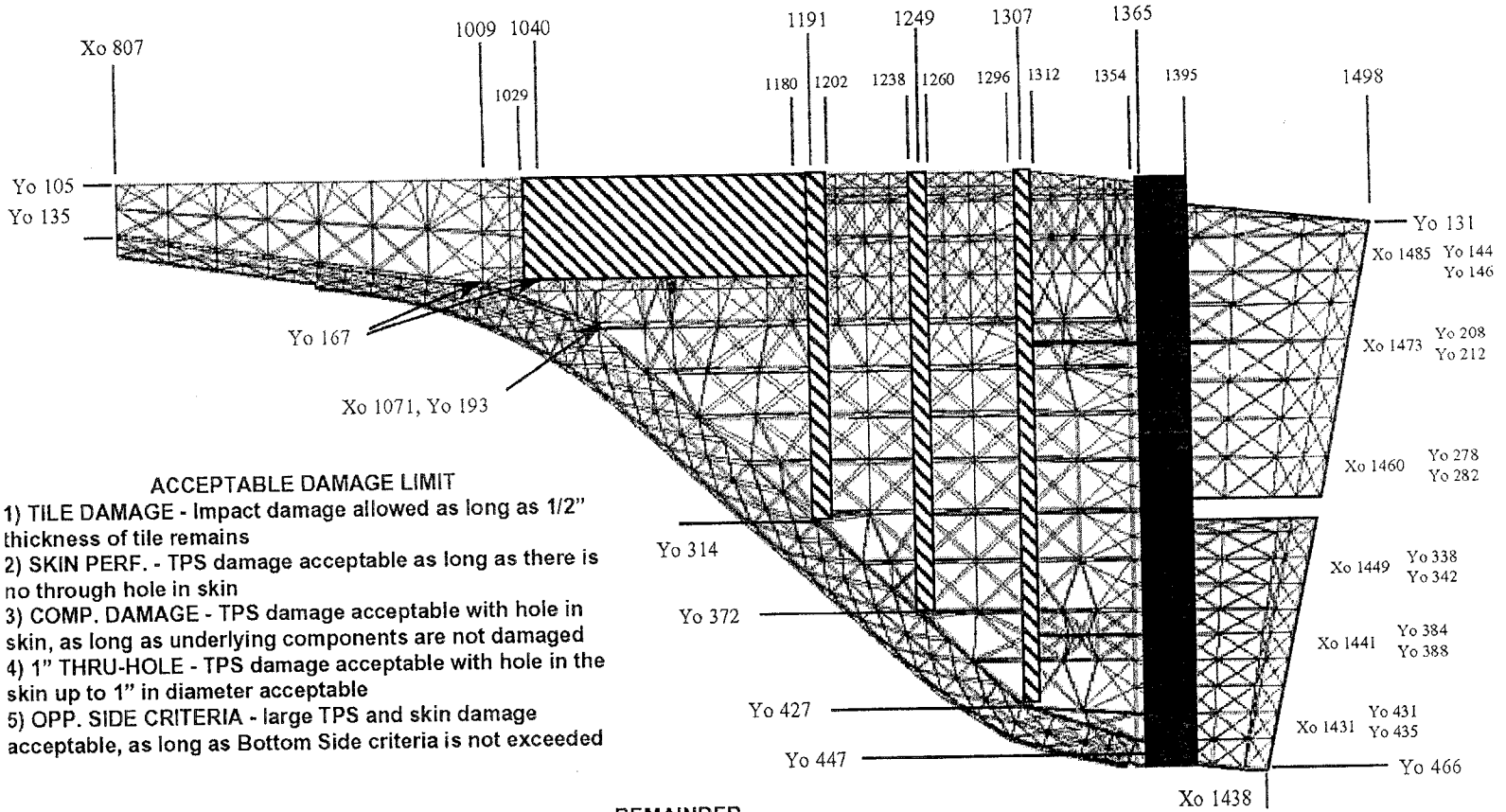
Impacted Lower Surface Location Thermal Predictions

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

Wing Lower Surface M/OD Failure Criteria



ACCEPTABLE DAMAGE LIMIT

1) TILE DAMAGE - Impact damage allowed as long as 1/2" thickness of tile remains
2) SKIN PERF. - TPS damage acceptable as long as there is no through hole in skin
3) COMP. DAMAGE - TPS damage acceptable with hole in skin, as long as underlying components are not damaged
4) 1" THRU-HOLE - TPS damage acceptable with hole in the skin up to 1" in diameter acceptable
5) OPP. SIDE CRITERIA - large TPS and skin damage acceptable, as long as Bottom Side criteria is not exceeded

AREA			REMAINDER OF WING
Top Side	3) COMP. DAMAGE	3) COMP. DAMAGE	5) OPP. SIDE CRITERIA
Bottom Side	1) TILE DAMAGE	2) SKIN PERF.	4) 1" THRU-HOLE

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