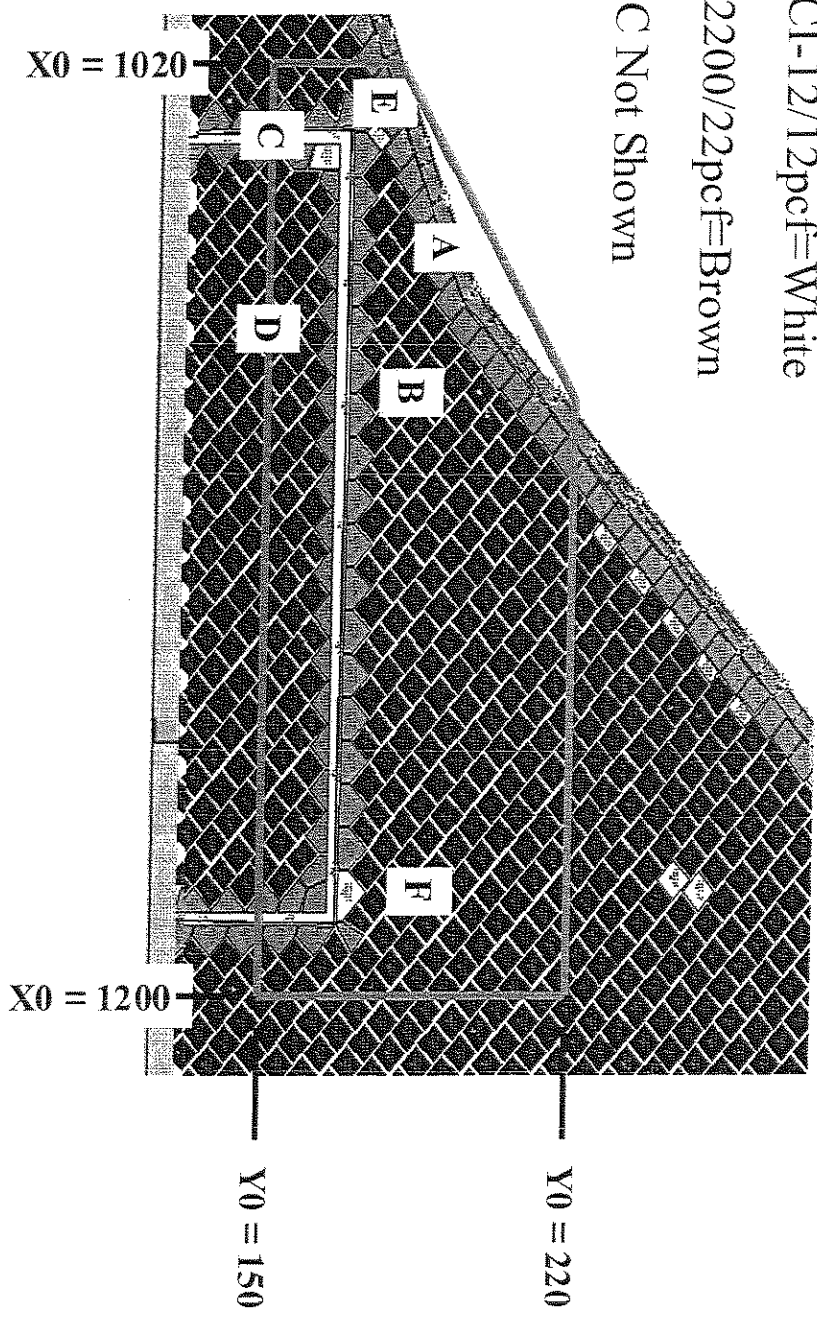# NASA

SECTION 18

10
27

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

X0 = 1020

X0 = 1200

Y0 = 150

Y0 = 220

A

B

C

D

E

F

Tile Thickness

GE 0.200000 and LT 0.509333
GE 0.509333 and LT 0.818667
GE 0.818667 and LT 1.128000
GE 1.128000 and LT 1.437333
GE 1.437333 and LT 1.746667
GE 1.746667 and LT 2.056000
GE 2.056000 and LT 2.365333
GE 2.365333 and LT 2.674667
GE 2.674667 and LT 2.984000
GE 2.984000 and LT 3.293334
GE 3.293334 and LT 3.602667
GE 3.602667 and LT 3.912000
GE 3.912000 and LT 4.221334
GE 4.221334 and LT 4.530667

1.7 - 2.0

2.3 - 2.6

1.4 - 1.7
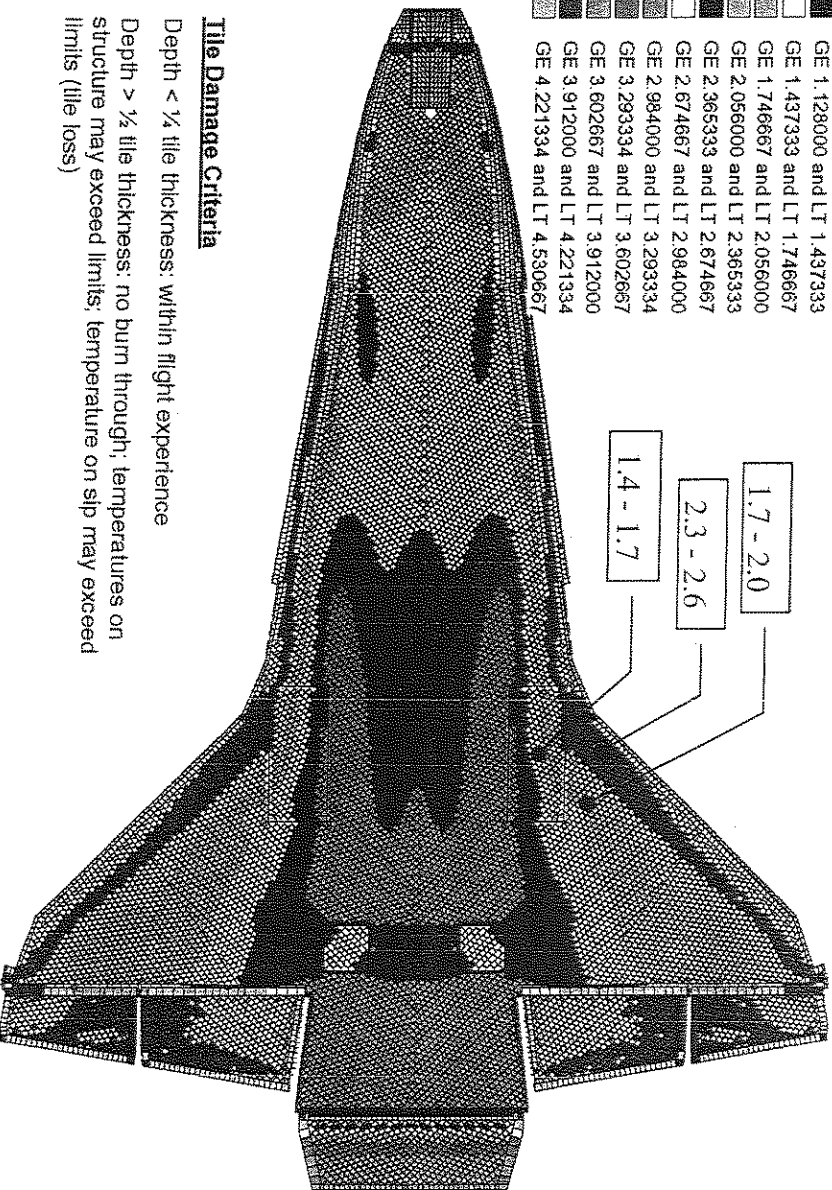
Tile Damage Criteria

Depth < ¼ tile thickness: within flight experience

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

BOEING
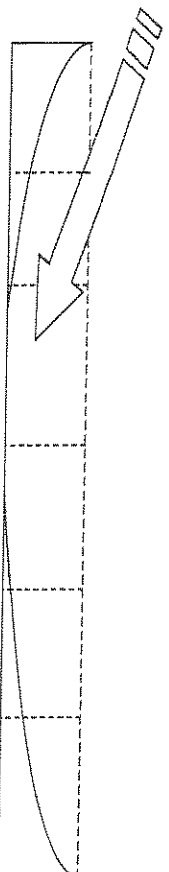
Review of Test Data Indicates Conservatism for Tile Penetration

- **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 (depth)	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	650C	1.0		542	test
0.33	450C	0.8	3.5	375	test
1.00	320C	0.8		267	test
3.00	250C	1.0		208	test
1920	40C	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

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

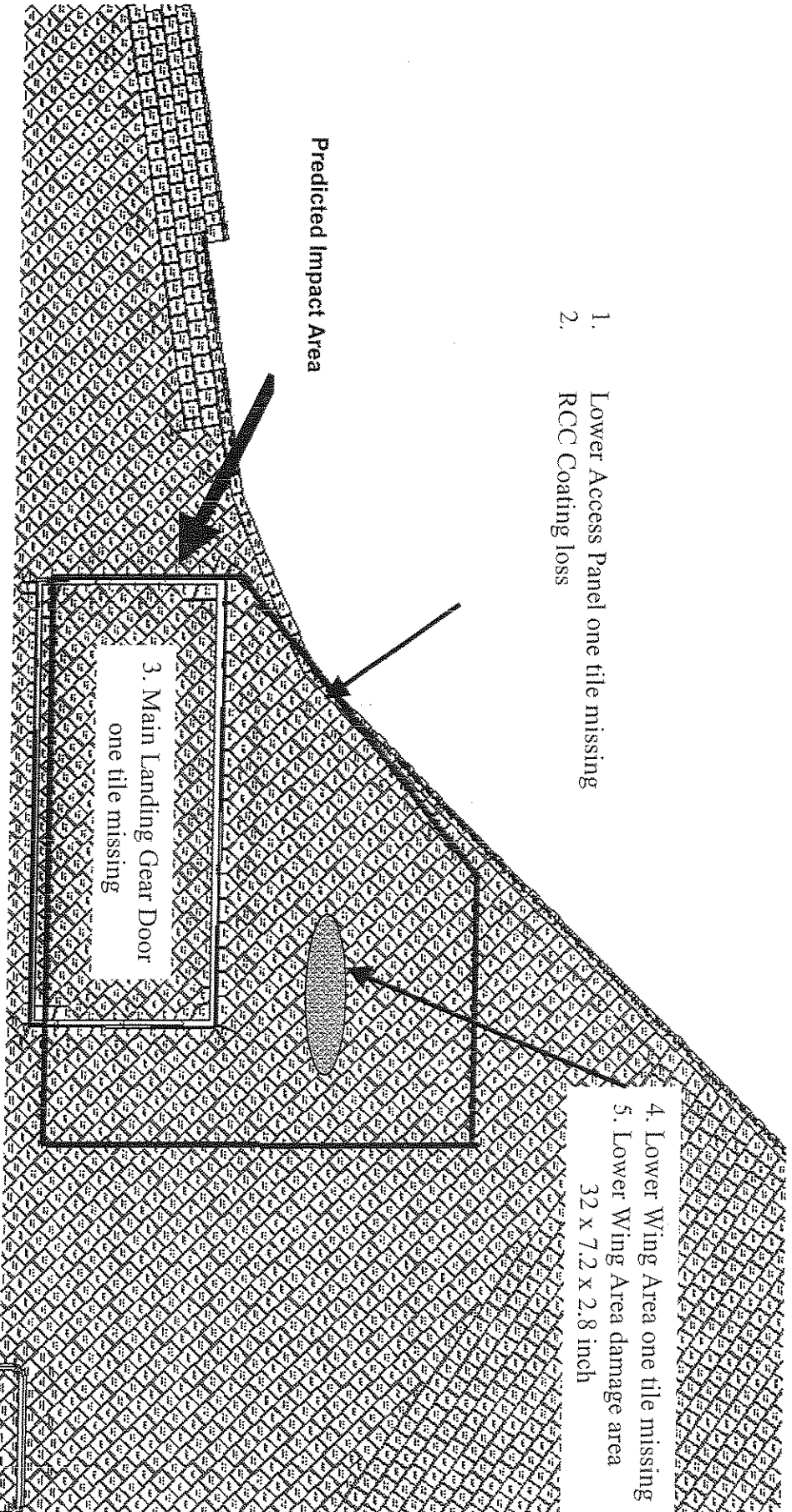Debris Size = 20" x 10" x 6" 45° angle of wing was taken into account

Density = 2.4 lb/ft³ 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

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

1. Lower Access Panel one tile missing
2. RCC Coating loss

Predicted Impact Area

3. Main Landing Gear Door
one tile missing

4. Lower Wing Area one tile missing
5. Lower Wing Area damage area
32 x 7.2 x 2.8 inch

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3/19/2003

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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

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Wing Lower Surface M/OD Failure Criteria

ACCEPTABLE DAMAGE LIMIT

1) TILE DAMAGE - Impact damage allowed as long as
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		
Top Side	3) COMP. DAMAGE	3) COMP. DAMAGE
Bottom Side	1) TILE DAMAGE	2) SKIN PERF.

	REMAINDER OF WING
	5) OPP. SIDE CRITERIA
	4) 1" THRU-HOLE

Yo 105
Yo 135

Xo 807

Yo 167

Xo 1071, Yo 193

Yo 314

Yo 372

Yo 427

Yo 447

Xo 1438

1009 1040
1029

1180
1191
1202
1238
1249
1260
1296
1307
1312
1354
1365
1395
1498

Yo 131
Xo 1485 Yo 144
Xo 1473 Yo 146
Xo 1473 Yo 208
Yo 212
Xo 1460 Yo 278
Yo 282
Xo 1449 Yo 338
Yo 342
Xo 1441 Yo 384
Yo 388
Xo 1431 Yo 431
Yo 435
Yo 466