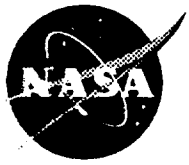

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-76

Jill D. Lin

Technical Memorandum 111675 May 1996

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Kennedy Space Center, Florida

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DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-76

22 March 1996

Contributions By:

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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

Photo 1: Launch of Shuttle Mission STS-76

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 21 March 1996. The detailed walkdown of Pad 39B and MLP-2 also included the primary flight elements OV-104 Atlantis (16th flight), ET-77 (LWT 69), and BI-079 SRB's. There were no significant vehicle or pad anomalies.

The vehicle was cryoloaded for flight on 21 March 1996. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. Due to ambient weather conditions at this time of year, the potential existed for acreage icing. Frost, but no detectable ice, formed on the +Y side of the External Tank. There were no protuberance icing conditions outside of the established data base.

After the 3:13 a.m. (local) launch on 22 March 1996, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. The MLP raised deck steel plate cracked approximately 2.5 hours after launch. The thermally induced stress crack, which extended 65 feet from the left SRB exhaust hole north to the railing, had no appreciable gap, but did have a 1-inch elevation offset.

A total of 88 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission. SSME ignition appeared normal.

A stud hang-up occurred on holddown post #5. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe 2.4 inches before the stud cleared the SRB aft skirt foot. The stud did not appear to gouge aluminum from the stud hole wall. No stud hang-ups occurred on any of the other holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes.

Clusters of light colored debris, most likely pieces of instafoam from the SRB aft skirts, fell out of the SRB plume after the roll maneuver.

Orbiter umbilical camera films showed nominal separation of SRB's from the External Tank.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. From a debris standpoint, both SRB's were in excellent condition. The number of MSA-2 debonds on both frustums was less than average.

Orbiter performance as viewed on landing films and videos during final approach, touchdown, and rollout was nominal. Drag chute operation was also normal.

A post landing debris inspection of OV-104 Atlantis was conducted March 31 - April 2, 1996 at Dryden Flight Research Center/Edwards AFB on runway 22 and in the Mate/Demate Device. The Orbiter TPS sustained a total of 69 hits, of which 15 had a major dimension of 1-inch or larger. Based on these numbers and comparison to statistics from previous missions of similar configuration, both the total number of hits and the number of hits 1-inch or larger was exceptionally less than average.

The Orbiter lower surface sustained a total of 32 hits, of which 5 had a major dimension of 1-inch or larger. Tile damage sites were generally located aft of the vehicle mid point and approximately equally distributed about the vehicle centerline. A cluster of 7 hits occurred just forward of the main landing gear wells and slightly to the +Y side of the centerline.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples from the facility environment, SRB BSM exhaust, Orbiter RCS nozzle cover adhesive, Orbiter TPS, and paints/primers from various sources. These residual sampling data do not indicate a single source of damaging debris as all of the noted materials have previously been documented in post-landing sample reports. The residual sample data showed no debris trends when compared to previous mission data.

A total of two Post Launch Anomalies, but no In-Flight Anomalies (IFA's), were observed during the STS-76 mission assessment.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 19 March 1996 at 1500 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC Shuttle Ice/Debris Systems
J. Lin	NASA - KSC Shuttle Ice/Debris Systems
B. Davis	NASA - KSC Digital Imaging Systems
R. Speece	NASA - KSC Lead, Thermal Protection Systems
B. Bowen	NASA - KSC Infrared Scanning Systems
J. Rivera	NASA - KSC Lead, ET Mechanisms/Structures
M. Bassignani	NASA - KSC ET Mechanisms, Structures
M. Valdivia	LMSO - SPC Supervisor, ET/SRB Mechanical Systems
R. Seale	LMSO - SPC ET Mechanical Systems
J. Blue	LMSO - SPC ET Mechanical Systems
W. Richards	LMSO - SPC ET Mechanical Systems
M. Wollam	LMSO - SPC ET Mechanical Systems
G. Fales	LMSO - SPC ET Mechanical Systems
Z. Byrns	NASA - KSC Level II Integration
J. McClymonds	Rockwell Dny Shuttle Aerodynamics
K. Mayer	Rockwell LSS Systems Integration
L. Jensen	THIO - LSS SRM Processing
S. Otto	LMSO - LSS ET Processing
J. Ramirez	LMSO - LSS ET Processing
D. Maxwell	LMSO - SPC Safety

3.0 LAUNCH

STS-76 was launched at 96:82:08:13:03.999 GMT (3:13 a.m. local) on 22 March 1996.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 21 March 1996. The detailed walkdown of Pad 39B and MLP-2 also included the primary flight elements OV-104 Atlantis (16th flight), ET-77 (LWT 70), and BI-079 SRB's. There were no significant pad anomalies. A total of eight wet and/or green-tinted RCS thruster paper covers (F3L, L4L, L2L, L2U, R1R, R2R, R4D, R4U) were reported to operations. The condition and number of affected covers was accepted for flight.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 21 March 1996 from to 2125 to 2325 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No IPR's were taken. Due to ambient weather conditions at this time of year, the potential existed for acreage icing. Frost, but no detectable ice, formed on the External Tank. There were no protuberance icing conditions outside of the established data base.

A portable Shuttle Thermal Imager (STI) infrared scanning radiometer was utilized to obtain vehicle surface temperature measurements for an overall thermal assessment of the vehicle, particularly those areas not visible from remote fixed scanners, and to scan for unusual temperature gradients (Figures 1 and 2).

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster paper covers were intact and the condition of the eight wet/green-tinted covers (F3L, L4L, L2L, L2U, R1R, R2R, R4D, R4U) previously reported during the prelaunch inspection had not changed. Ice/frost accumulations and condensate were present along the circumference of the SSME #1 and #2 heat shield-to-nozzle interfaces. Ice/frost extended across the SSME #2 engine heat shield to the DMHS closeout blanket at the 6:00 o'clock position. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometer were 49-53 degrees F depending on the wind incidence. Temperatures measured by the SRB Ground Environment Instrumentation (GEI) ranged from 49-56 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature (PMBT) supplied by THIO was 61 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run from 1800 to 0300 hours and the results tabulated in Figure 3. The program predicted ET surface temperatures dropping below 32 degrees Fahrenheit and the formation of ice on most areas of the TPS acreage, with the exception of the LO2 tank ogive, during cryoload.

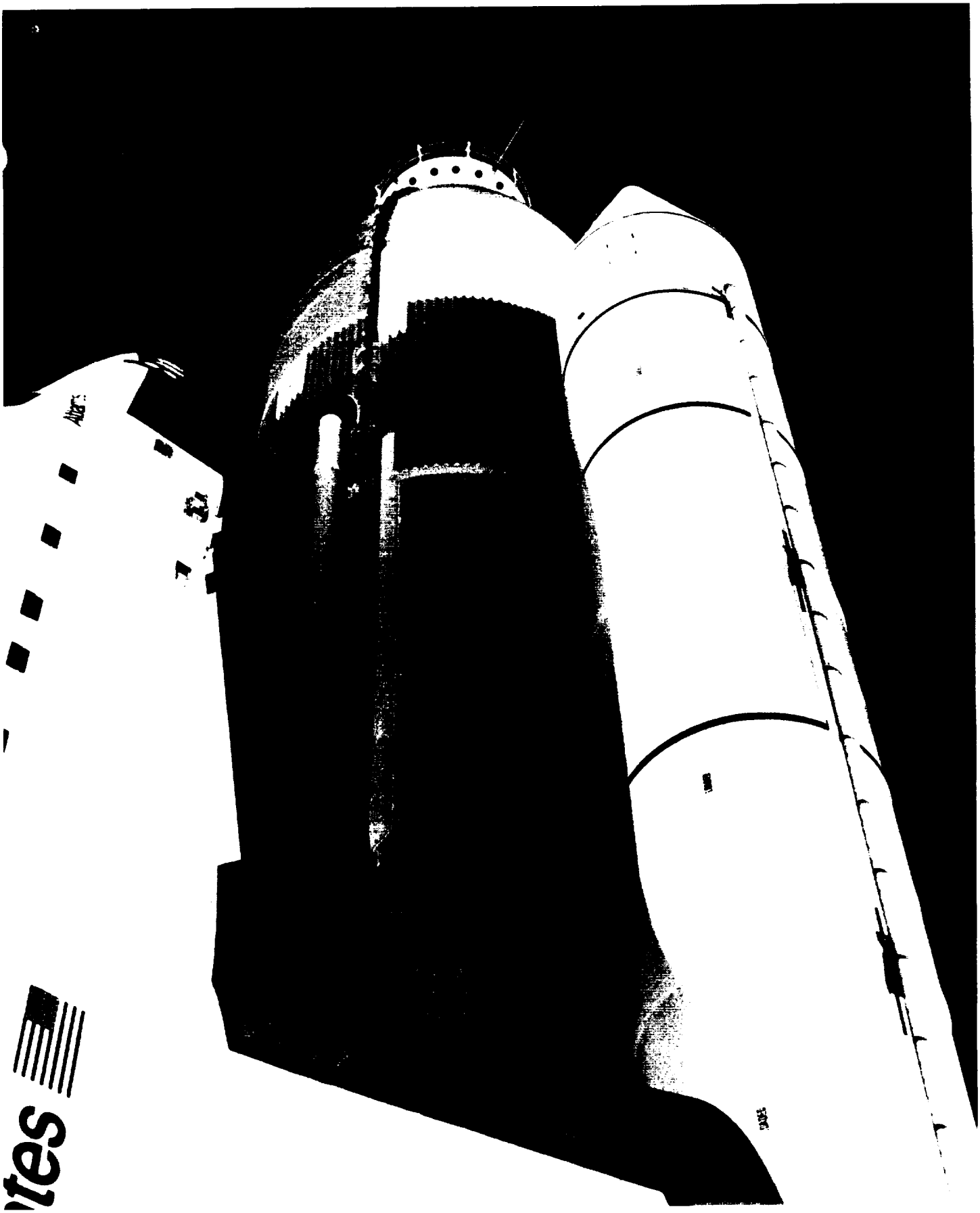


Photo 2: ET-77 Cryoloaded for Launch

The Final Inspection Team observed dry TPS on the LH2 tank. Frost and very light condensate, but no detectable ice, accumulated on the LH2 tank barrel +Y side.

SSV INFRARED SCANNER SURFACE TEMPERATURE SUMMARY DATA

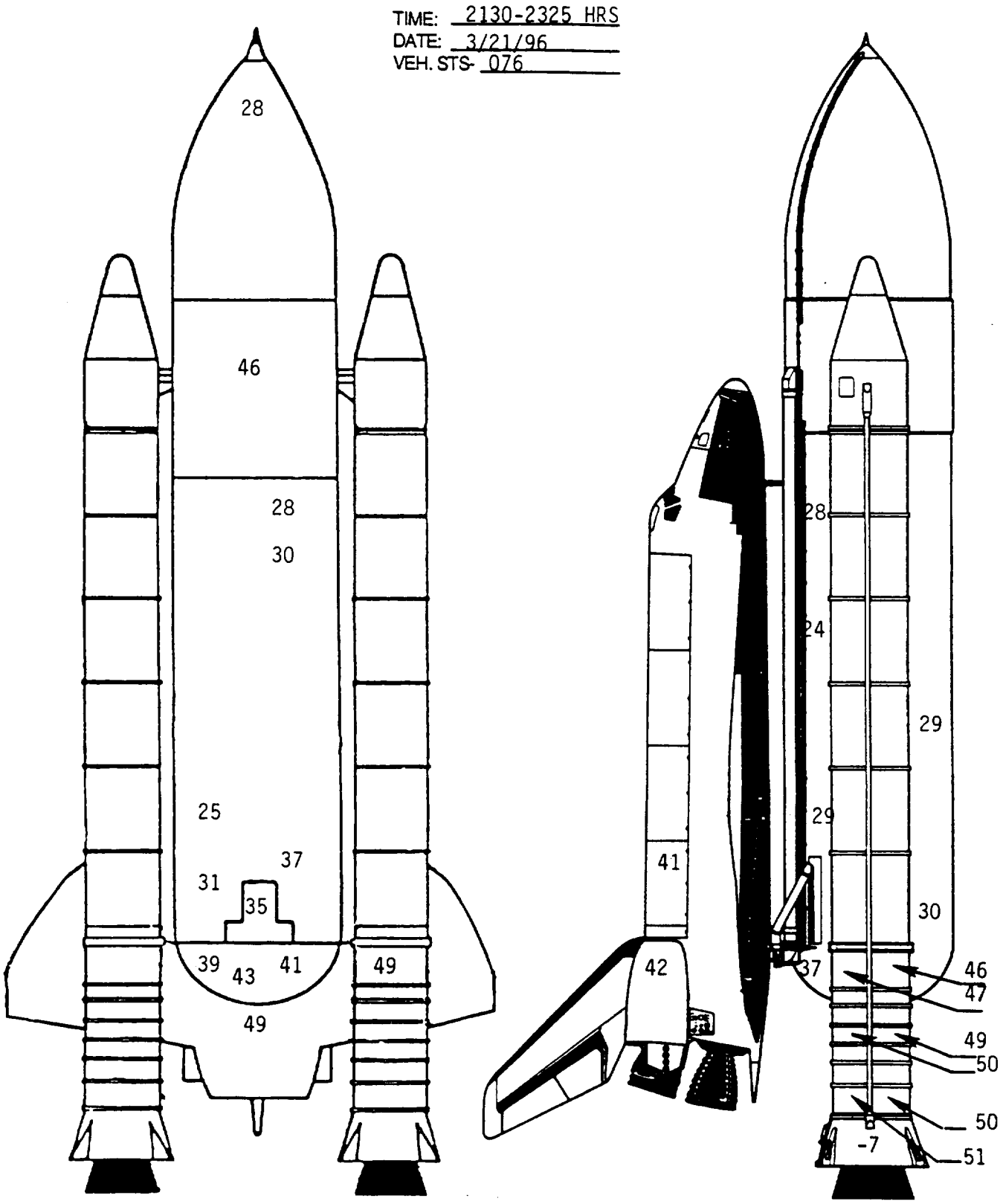


Figure 1: Vehicle Surface Temperature STI Measurements

SSV INFRARED SCANNER
SURFACE TEMPERATURE
SUMMARY DATA

TIME: 2130-2325 HRS
DATE: 3/21/96
VEH. STS- 076

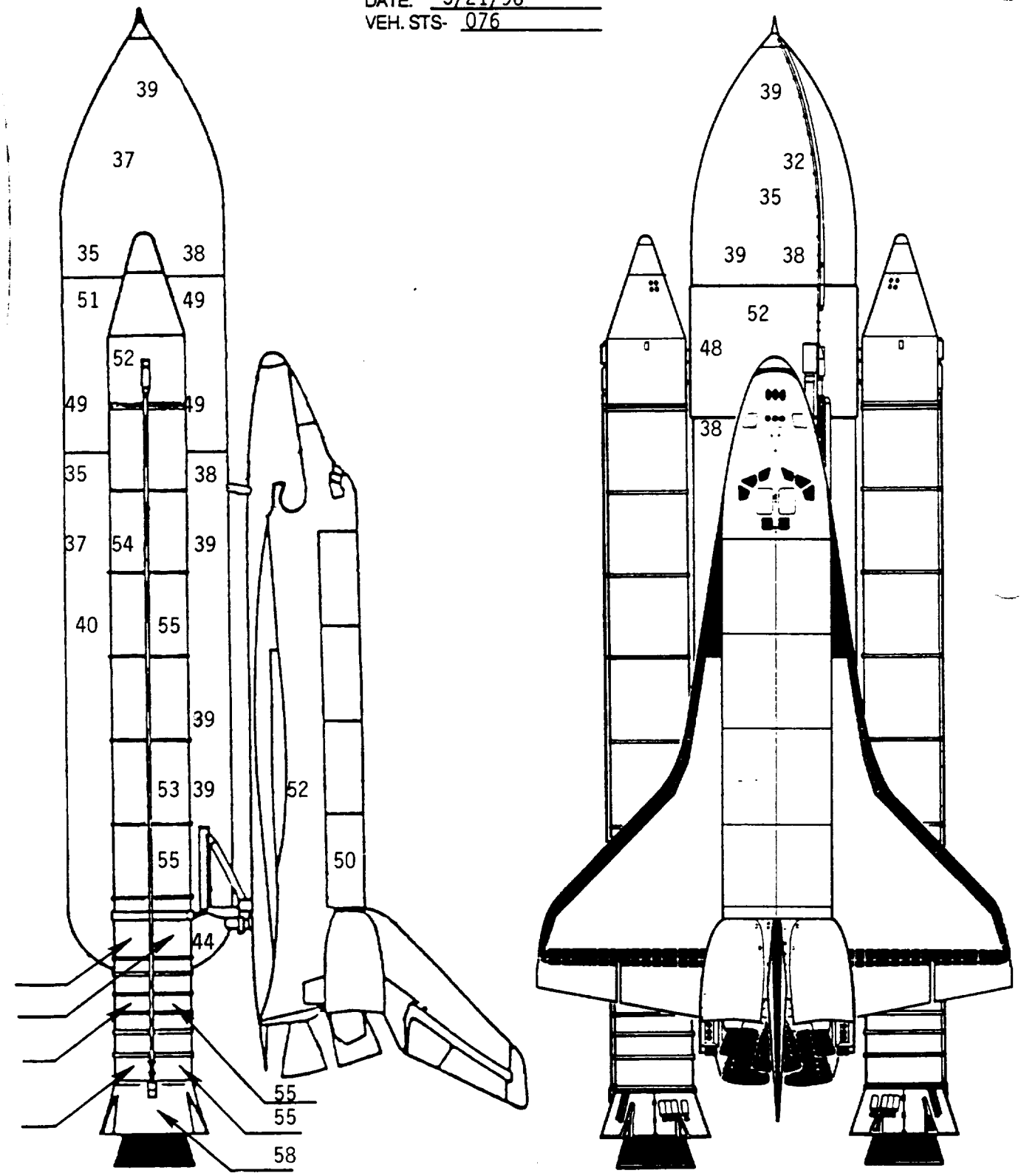


Figure 2: Vehicle Surface Temperature STI Measurements

						LO2 OGIVE				LO2 BARREL				LH2 XT 1120-1380				LH2 XT 1380-2058			
	Ambient	Relative	Wind	Wind	Dew Point	Ogive		Condensate	Ice	Barrel		Condensate	Ice	1120-1380		Condensate	Ice	1380-2058		Condensate	Ice
Time	Temp	Humidity	Speed	Direction	Temp	Wind Speed	Temp	Rate	Rate	Wind Speed	Temp	Rate	Rate	Wind Speed	Temp	Rate	Rate	Wind Speed	Temp	Rate	Rate
1800	56.40	44.90	19	247	34.82	11.21	45.97	0.0000	-0.0855	11.21	41.12	0.0000	-0.0593	6.08	33.57	0.0003	-0.0090	25.84	47.70	0.0000	-0.1811
1815	55.30	49.10	11	252	36.12	6.49	40.75	0.0000	-0.0420	6.49	34.76	0.0003	-0.0163	4.73	31.32	0.0009	0.0044	13.31	41.06	0.0000	-0.0721
1830	54.30	51.70	15	251	36.52	8.85	42.34	0.0000	-0.0604	8.85	36.72	0.0000	-0.0344	6.45	33.46	0.0007	-0.0087	18.15	43.01	0.0000	-0.1091
1845	53.50	55.40	10	250	37.58	5.90	38.36	0.0000	-0.0339	5.90	33.46	0.0009	-0.0082	4.30	29.89	0.0014	0.0110	12.10	38.44	0.0000	-0.0576
1900	53.00	56.90	13	248	37.80	7.67	40.09	0.0000	-0.0485	7.67	35.37	0.0007	-0.0226	5.59	31.99	0.0013	0.0002	15.73	40.53	0.0000	-0.0866
1915	52.30	59.60	10	250	38.36	5.90	37.69	0.0002	-0.0317	5.90	33.05	0.0012	-0.0060	4.30	29.50	0.0016	0.0130	12.10	37.76	0.0003	-0.0544
1930	52.00	60.40	11	251	38.42	6.49	38.05	0.0001	-0.0361	6.49	33.69	0.0012	-0.0103	4.73	30.30	0.0016	0.0099	13.31	38.20	0.0001	-0.0632
1945	51.40	62.30	8	249	38.66	4.72	35.98	0.0005	-0.0191	4.72	31.02	0.0015	0.0064	3.44	26.63	0.0017	0.0225	9.68	35.87	0.0010	-0.0308
2000	51.00	63.50	9	251	38.77	5.31	36.49	0.0005	-0.0233	5.31	31.87	0.0015	0.0023	3.87	27.75	0.0018	0.0196	10.89	36.52	0.0010	-0.0393
2015	50.60	65.10	8	252	39.05	4.72	35.65	0.0007	-0.0176	4.72	30.70	0.0016	0.0080	3.44	26.28	0.0018	0.0239	9.68	35.57	0.0013	-0.0285
2030	49.90	67.30	9	250	39.25	5.31	36.04	0.0007	-0.0209	5.31	31.45	0.0017	0.0047	3.87	27.27	0.0019	0.0217	10.89	36.09	0.0013	-0.0357
2045	49.50	68.60	9	246	39.36	5.31	35.85	0.0008	-0.0200	5.31	31.28	0.0018	0.0056	2.88	23.55	0.0019	0.0309	12.24	36.70	0.0013	-0.0448
2100	49.40	69.70	8	244	39.69	4.72	35.19	0.0009	-0.0154	4.72	30.29	0.0018	0.0101	2.56	22.11	0.0018	0.0335	10.88	36.00	0.0016	-0.0349
2115	49.60	69.90	9	240	39.96	5.31	36.17	0.0009	-0.0216	5.31	31.60	0.0018	0.0040	2.88	23.88	0.0019	0.0299	12.24	37.02	0.0014	-0.0479
2130	49.10	72.50	9	249	40.44	5.31	36.08	0.0010	-0.0212	5.31	31.53	0.0020	0.0045	3.87	27.30	0.0021	0.0218	10.89	36.19	0.0018	-0.0364
2145	48.40	74.90	8	251	40.63	4.72	35.00	0.0012	-0.0145	4.72	30.14	0.0021	0.0111	3.44	25.57	0.0022	0.0270	9.68	35.00	0.0022	-0.0241
2200	48.10	76.00	8	251	40.72	4.72	34.85	0.0012	-0.0138	4.72	30.00	0.0021	0.0118	3.44	25.42	0.0022	0.0276	9.68	34.87	0.0022	-0.0231
2215	48.00	76.10	9	249	40.66	5.31	35.51	0.0012	-0.0183	5.31	31.01	0.0021	0.0074	3.87	26.72	0.0022	0.0243	10.89	35.66	0.0022	-0.0319
2230	47.80	77.10	9	251	40.81	5.31	35.46	0.0012	-0.0180	5.31	30.96	0.0022	0.0077	3.87	26.66	0.0023	0.0246	10.89	35.61	0.0023	-0.0315
2245	47.60	78.00	9	253	40.92	5.31	35.39	0.0013	-0.0177	5.31	30.90	0.0022	0.0080	3.87	26.58	0.0023	0.0249	10.89	35.55	0.0023	-0.0310
2300	47.40	79.20	8	254	41.13	4.72	34.60	0.0014	-0.0127	4.72	29.79	0.0023	0.0130	3.44	25.15	0.0023	0.0287	9.68	34.65	0.0025	-0.0214
2315	47.10	79.80	8	251	41.03	4.72	34.37	0.0014	-0.0116	4.72	29.57	0.0023	0.0140	3.44	24.91	0.0023	0.0295	9.68	34.43	0.0025	-0.0197
2330	46.90	80.40	8	250	41.04	4.72	34.25	0.0014	-0.0110	4.72	29.45	0.0023	0.0146	3.44	24.78	0.0023	0.0300	9.68	34.32	0.0026	-0.0188
2345	46.60	81.60	8	245	41.14	4.72	34.11	0.0015	-0.0104	4.72	29.32	0.0023	0.0152	2.56	20.81	0.0021	0.0378	10.88	35.07	0.0026	-0.0269
2400	46.50	82.40	8	246	41.30	4.72	34.12	0.0015	-0.0104	4.72	29.34	0.0024	0.0152	2.56	20.82	0.0021	0.0378	10.88	35.09	0.0027	-0.0271
0015	46.30	82.10	8	246	41.00	4.72	33.86	0.0015	-0.0092	4.72	29.08	0.0024	0.0164	2.56	20.54	0.0021	0.0386	10.88	34.82	0.0027	-0.0249
0030	46.50	81.10	8	254	40.87	4.72	33.92	0.0014	-0.0095	4.72	29.14	0.0023	0.0161	3.44	24.45	0.0023	0.0313	9.68	34.00	0.0026	-0.0164
0045	46.50	81.10	8	251	40.87	4.72	33.92	0.0014	-0.0095	4.72	29.14	0.0023	0.0161	3.44	24.45	0.0023	0.0313	9.68	34.00	0.0026	-0.0164
0100	46.80	80.90	9	255	41.10	5.31	34.98	0.0014	-0.0156	5.31	30.55	0.0023	0.0101	3.87	26.16	0.0024	0.0267	10.89	35.17	0.0026	-0.0278
0115	46.60	81.60	8	256	41.14	4.72	34.11	0.0015	-0.0104	4.72	29.32	0.0023	0.0152	3.44	24.64	0.0024	0.0306	9.68	34.19	0.0027	-0.0178
0130	46.10	83.30	7	257	41.19	4.13	32.96	0.0015	-0.0044	4.13	27.70	0.0023	0.0211	3.01	22.64	0.0023	0.0351	8.47	32.91	0.0028	-0.0067
0145	45.40	84.80	6	252	40.98	3.54	31.78	0.0015	0.0025	3.54	25.47	0.0023	0.0278	2.58	20.00	0.0022	0.0404	7.26	31.60	0.0028	0.0056
0200	45.00	85.90	6	244	40.92	3.54	31.52	0.0015	0.0035	3.54	25.19	0.0023	0.0289	1.92	15.40	0.0019	0.0464	8.16	31.99	0.0029	0.0005
0215	44.90	87.00	7	238	41.16	4.13	32.24	0.0017	-0.0011	4.13	26.95	0.0025	0.0244	2.24	17.65	0.0021	0.0438	9.52	33.12	0.0030	-0.0091
0230	44.90	86.40	7	240	40.98	4.13	32.15	0.0016	-0.0007	4.13	26.86	0.0024	0.0247	2.24	17.57	0.0021	0.0440	9.52	33.03	0.0030	-0.0084
0245	44.90	86.10	8	246	40.89	4.72	32.99	0.0016	-0.0049	4.72	28.21	0.0025	0.0206	2.56	19.50	0.0022	0.0417	10.88	33.95	0.0029	-0.0175
0300	44.90	85.50	8	249	40.70	4.72	32.91	0.0016	-0.0045	4.72	28.11	0.0025	0.0210	3.44	23.31	0.0024	0.0354	9.68	33.03	0.0029	-0.0085
T-0	45.00	84.80	7	249	40.58	4.13	31.99	0.0016	-0.0002	4.13	26.73	0.0024	0.0252	3.01	21.61	0.0023	0.0385	8.47	31.99	0.0029	-0.0001

Figure 3: SURFICE Computer Predictions

The Final Inspection Team observed dry TPS on the LO2 tank ogive. Frost and very light condensate, but no detectable ice, accumulated on the LO2 tank barrel +Y side. There were no TPS anomalies. The portable STI and the Raytek handheld spot radiometer measured surface temperatures ranging from 34 to 41 degrees Fahrenheit on the ogive and 33 to 40 degrees F on the barrel with the exception of the frost-covered areas (29 degrees F) on the barrel. SURFICE predicted temperatures of 36 degrees F on the ogive and 30 degrees on the barrel at the time of the inspection.

The intertank acreage exhibited no TPS anomalies. Heavy frost had formed on the GUCP and the ET umbilical carrier plate. The portable STI and Raytek measured an average surface temperature of 49 degrees F on the intertank.

There were no LH2 tank TPS acreage anomalies. Light condensate and frost, but no detectable ice accumulation, was present on the acreage. Most of the frost had formed in the +Y+Z and +Y-Z quadrants. The portable STI measured surface temperatures that ranged from 35 to 40 degrees F on the upper LH2 tank. The lower LH2 tank was generally 30 to 35 degrees F with the exception of the frost covered areas, which measured in the 20's. SURFICE predicted temperatures of 26 degrees F on the upper tank and 35 degrees F on the lower tank. Frost had formed along the PAL, pressurization line, and cable tray ramp-to-acreage interfaces. The aft dome and manhole cover closeouts were dry.

There were no anomalies on the bipod jack pad closeouts. Two cracks, 10-inches long by 3/8-inches wide and 4-inches long by 1/4-inch wide, were assessed by the Ice/Debris Team and found acceptable for flight.

More than usual amounts of ice/frost had accumulated in the LO2 feedline bellows and support brackets.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical. Some frost had formed on the acreage.

Ice and frost in the LH2 recirculation line bellows and on both burst disks, and in the LH2 feedline bellows was expected given the ambient weather conditions.

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were also present on the pyro canister, plate gap purge vents, and cable tray drain hole. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

The summary of Ice/Frost Team observations/anomalies, which were all acceptable for launch per the NSTS-08303 criteria, consisted of five OTV recorded items.

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch (LCC requirement).

No leaks were observed on the GUCP or either of the LO2 and LH2 Orbiter T-0 umbilicals.

Photo 3: ET/ORB LH2 Umbilical

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier top and outboard sides. Typical ice/frost fingers were also present on the pyro canister, plate gap purge vents, and cable tray drain hole. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch

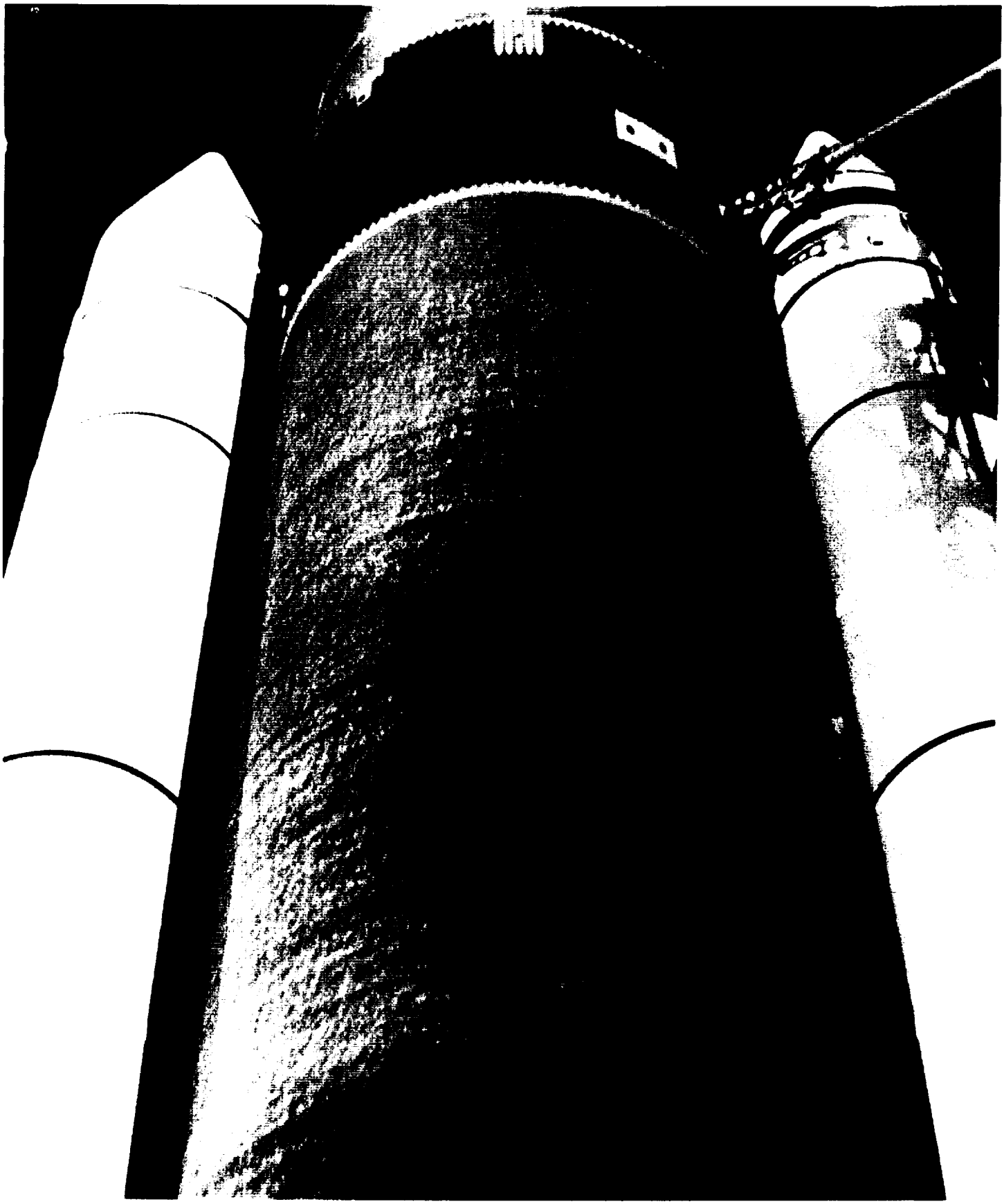


Photo 4: ET Intertank and LH2 Tank Barrel After Cryoload

The intertank acreage exhibited no TPS anomalies. Light condensate and frost, but no detectable ice accumulation, was present on the acreage. Most of the frost had formed in the +Y+Z and +Y-Z quadrants.

Photo 5: LO2 Feedline Bellows

Typical amounts of ice/frost had accumulated in the LO2 feedline bellows.

Photo 6: ET Acreage

Light condensate and frost, but no detectable ice accumulation, was present on the acreage. The portable STI measured surface temperatures that ranged from 35 to 40 degrees F on the upper LH2 tank. The lower LH2 tank was generally 30 to 35 degrees F with the exception of the frost covered areas, which measured in the 20's.

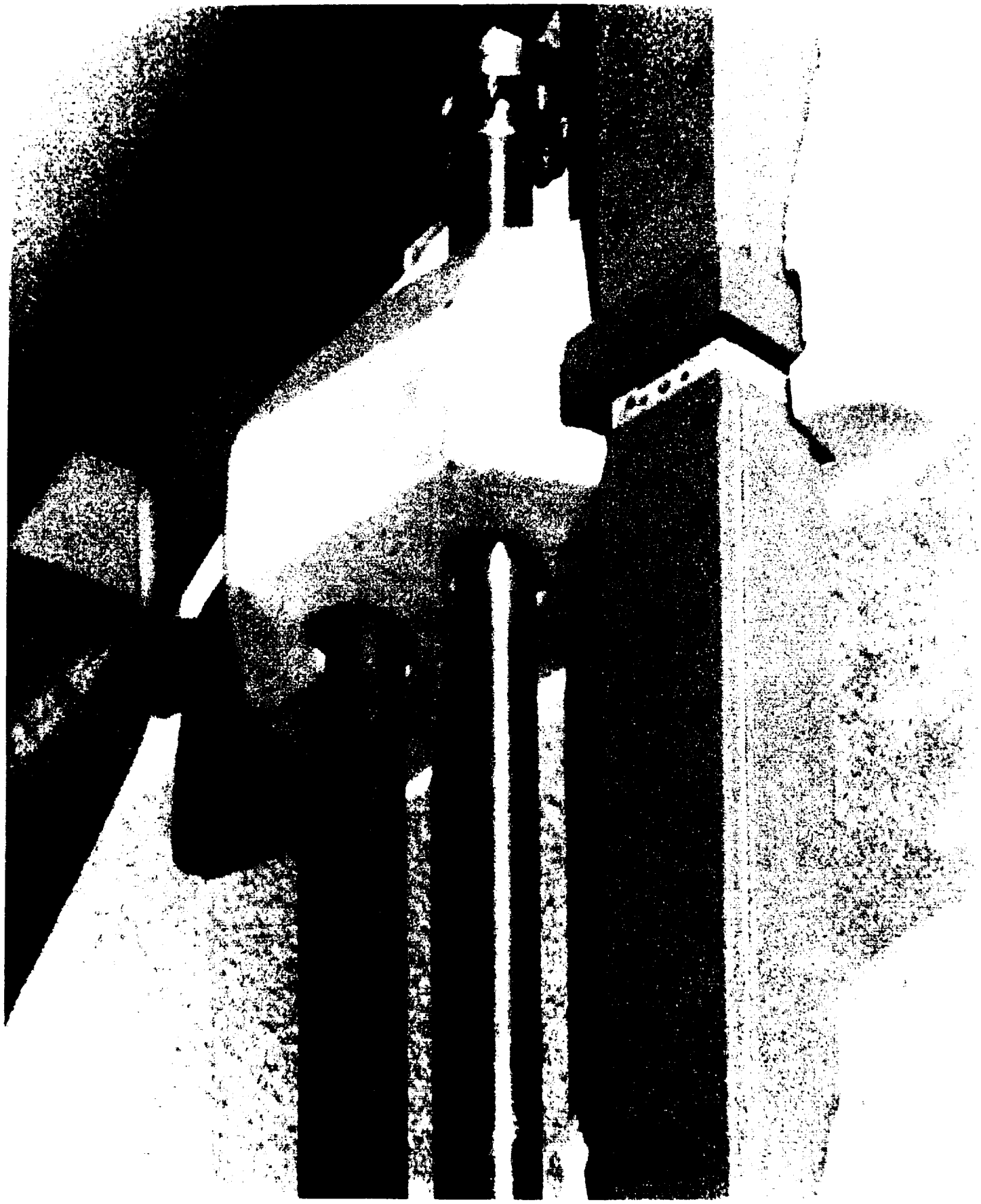


Photo 7: ET Pressurization Line

Ice/frost had formed along the pressurization line and cable tray ramp-to-ET acreage interfaces.

Photo 8: SSME #2 After Cryoload

Ice/frost extended across the SSME #2 engine heat shield to the DMHS closeout blanket at the 6:00 o'clock position. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shield.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS, RSS, and Pad B crawlerway/acreage was conducted on 22 March 1996 for two hours starting at Launch + 2 hours.

No flight hardware or TPS materials were found.

South SRB HDP erosion was typical. All south HDP shoe shim material was intact. Although there was no visual indication of a holddown post stud hang-up, a 0.17g lateral acceleration in the Orbiter liftoff data reported by Rockwell-Downey indicates a stud hang-up probably occurred. All of the north HDP doghouse blast covers were in the closed position. Erosion of the blast covers was typical.

The Tail Service Masts (TSM) and Orbiter Access Arm (OAA) appeared undamaged. TPS was damaged on the GOX vent hood northeast duct. A pip pin lock was missing from the southwest vent hood door. No topcoat from the External Tank nose cone adhered to the GOX seals.

The GH2 vent line had no loose cables (static retract lanyard), and appeared to have latched properly with no rebound. The GUCP legs and crossbeam showed no obvious signs of contact by the static retract lanyard. The vent line was latched on the eighth tooth of the latching mechanism. The RSS cable had disconnected properly.

The MLP raised deck steel plate cracked approximately 2.5 hours after launch. The thermally induced stress relief crack extended 65 feet from the left SRB exhaust hole north to the railing. The crack had no appreciable gap, but did have a 1-inch elevation offset. In addition to the large crack, six smaller cracks in the MLP deck, ranging in size from 6 inches to 3 feet in length, were identified.

Typical pad damage included:

Several east side stadium lights damaged

3-foot by 2.5-foot cover separated from the OWP control box

Separated light fixture on the north side of the FSS 175 foot level

Post launch pad inspection anomalies are listed in Section 9.

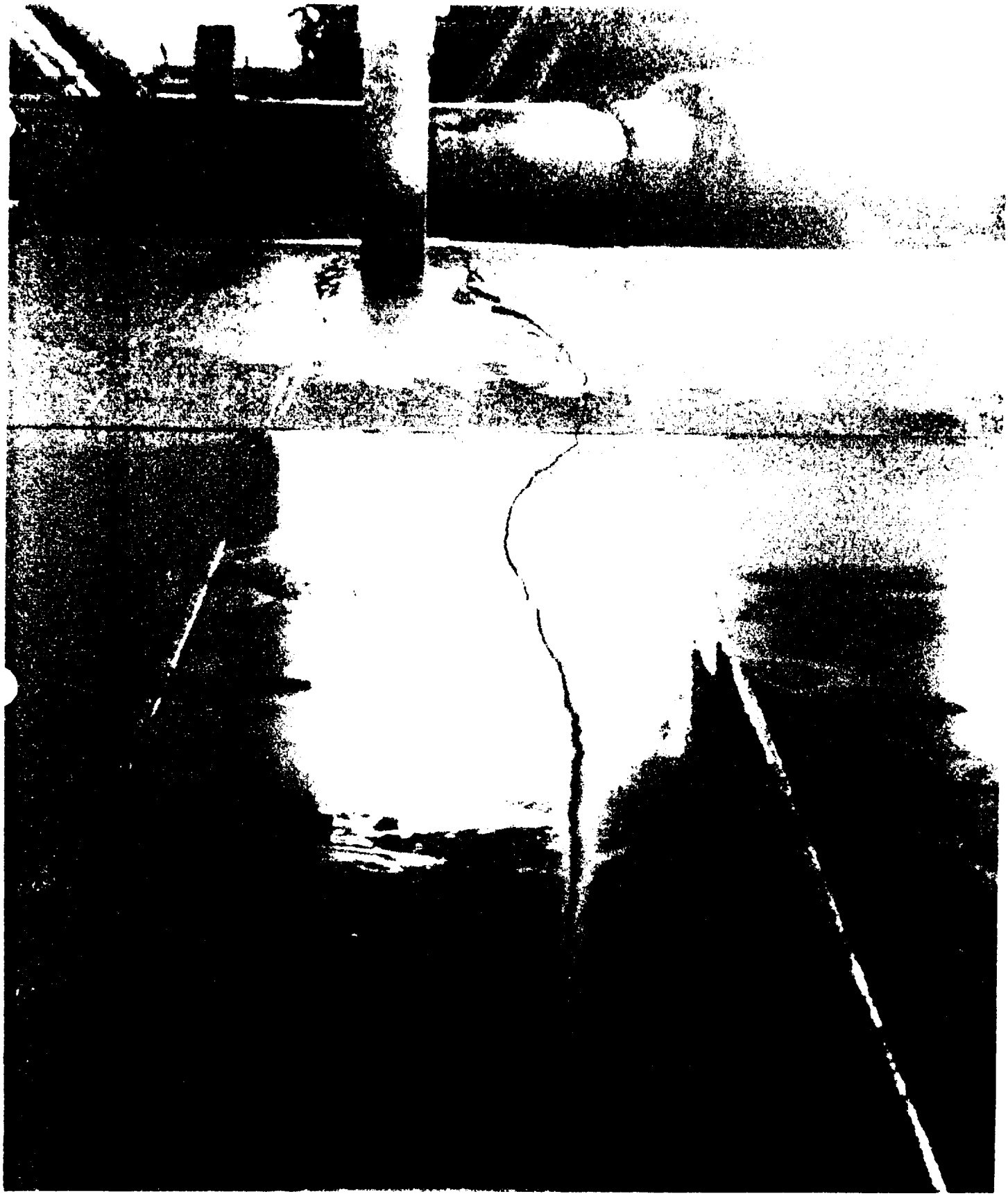


Photo 9: MLP Raised Steel Deck Crack

The MLP raised deck steel plate cracked approximately 2.5 hours after launch. The thermally induced stress crack extended 65 feet from the left SRB exhaust hole north to the railing.

Photo 10: MLP Raised Steel Deck Crack

The MLP raised deck steel crack had no appreciable gap, but did have a 1-inch elevation offset.

5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. No IPR's or IFA's were generated as a result of the film review. Post flight anomalies are listed in Section 9.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 88 films and videos, which included twenty-seven 16mm films, eighteen 35mm films, and thirty-eight videos, were reviewed starting on launch day. The reduction in the number of films analyzed is a result of the Photo PRD scrub which reduced the number of films generated by the Bionetics Lab by approximately 24%.

Frost, but no detectable ice, was present on the LO2 barrel and LH2 tank acreage TPS +Y side (OTV 160, 165).

SSME ignition appeared normal. Free burning hydrogen drifted north under the body flap and upward to the OMS pods during start-up (OTV 151, 170, 171).

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals. Several pieces of ice contacted the LH2 umbilical cavity sill and were deflected outward. No tile damage was visible (OTV 109, 164). Other pieces of ice from the pyro canister purge vent impacted the cable tray clam shell without causing TPS damage (OTV 109). A 5-inch by 1-inch piece of umbilical purge barrier mylar tape fell from the ET door hinge area (OTV 109).

Light spots on black tiles may be indicative of lost surface coating material: one place on the aft surface of the right RCS stinger (OTV 149); two places on the base heat shield (OTV 150); and as many as eight places on the body flap +Z side outboard of SSME #3 (OTV 170).

A stud hang-up occurred on holddown post #5. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe 2.4 inches before the stud cleared the SRB aft skirt foot (Figure 4). The stud did not appear to gouge aluminum from the stud hole wall. Unlike the STS-75 stud hang-up, no aluminum was observed in the stud threads or falling away from the stud hole. No loose ordnance fragments or frangible nut pieces from the DCS were detected (E-8). No stud hang-ups occurred on any of the other holddown posts. No ordnance fragments or frangible nut pieces fell from any of the DCS/stud holes.

A 2-inch by 2-inch debris object came into view at liftoff from an area behind the aft skirt rain curtain attach strip (E-16).

A 3-inch diameter piece of instafoam fell from the RH SRB aft skirt in the area near HDP #4 (E-7).

Debris particles, most likely pieces of SRB throat plug material, and numerous pieces of shredded SRB sound suppression water trough material, were ejected out of the SRB exhaust holes and passed by the SRB aft skirts moving away from the vehicle shortly after T-0. A 3-inch by 6-inch debris object moved from left to right in front of RH SRB HDP #1. The origin of the object was not determined (E-9).

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 149, 150, 170, 171).

GUCP disconnect from the ET was nominal. No foam was damaged by the disconnect and retraction (E-33, OTV 104).

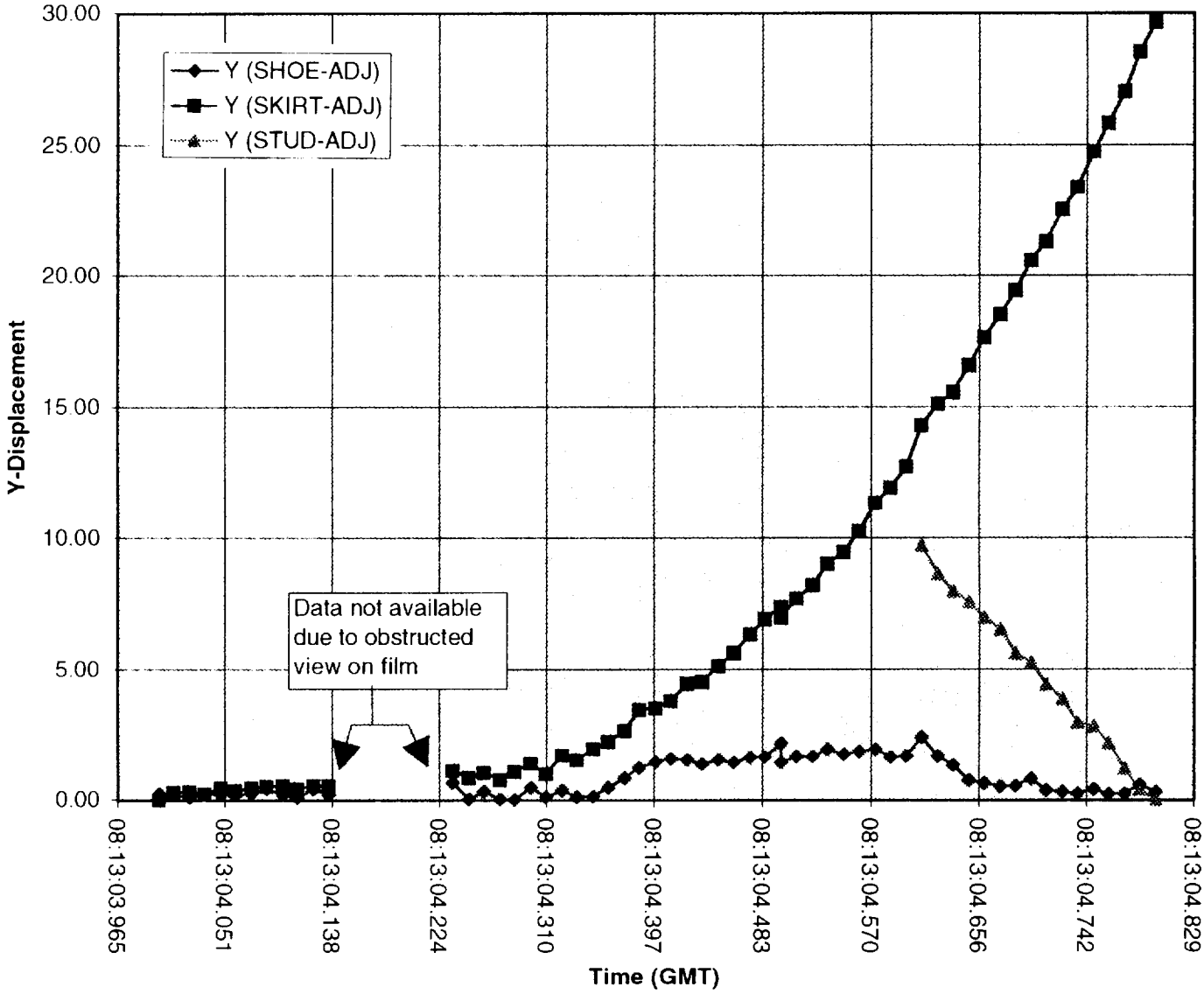


Figure 4: Holddown Post #5 Stud Hang-Up

Photo 11: HDP #5 Stud Hang-Up

A stud hang-up occurred on holddown post #5. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe 2.4 inches before the stud cleared the SRB aft skirt foot. The stud did not appear to gouge aluminum from the stud hole wall.

Photo 12: Debris in Vicinity of Righthand SRB Exhaust Hole

A 3-inch by 6-inch debris object moved from left to right in front of RH SRB HDP #1. The origin of the object was not determined (E-9).

Pieces of ice from the GUCP fell near the Orbiter left wing during liftoff, but no impacts were observed (E-4). Similarly, ice was shaken loose from the EB fittings and fell past the RH SRB without making contact (E-2).

Launch vibration caused four pieces of ice to fall from the LO2 feedline upper bellows, but no contact with Orbiter tiles was observed (OTV 165, 166; E-40, -54).

A large portion of the LH2 ET/ORB umbilical purge barrier came loose prior to tower clear (E-40). Several more pieces of LH2 and LO2 umbilical purge barrier fell aft during the roll maneuver (E-52, -54, -213, -220, -222).

Clusters of light-colored debris, most likely pieces of instafoam from the SRB aft skirts, fell out of the SRB plume after the roll maneuver (E-57, -59; TV-4B). The foam pieces appeared to originate from the RH SRB aft skirt area at 08:13:16 - 08:13:20 and 08:13:22 - 08:13:30 GMT. Foam pieces fell aft from the LH SRB aft skirt area at 08:13:17 GMT. Liftoff occurred at 08:13:04 GMT.

Four flares occurred in the SSME plume during ascent (E-205, -213, -220, -222).

Body flap movement (amplitude and frequency) appeared similar to previous flights (E-213, -222)

ET aft dome charring was typical. SRB separation appeared normal. (E-207, -208, -212).

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-104 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Data was obtained from the two 16mm cameras during SRB separation. No anomalies were noted. No data was obtained for ET separation due to the dark conditions of a night launch.

5.3 LANDING FILM AND VIDEO SUMMARY

A minimum set of three films (three 35mm) was provided for the landing at Edwards AFB. The films were generally underexposed and little engineering data was obtained.

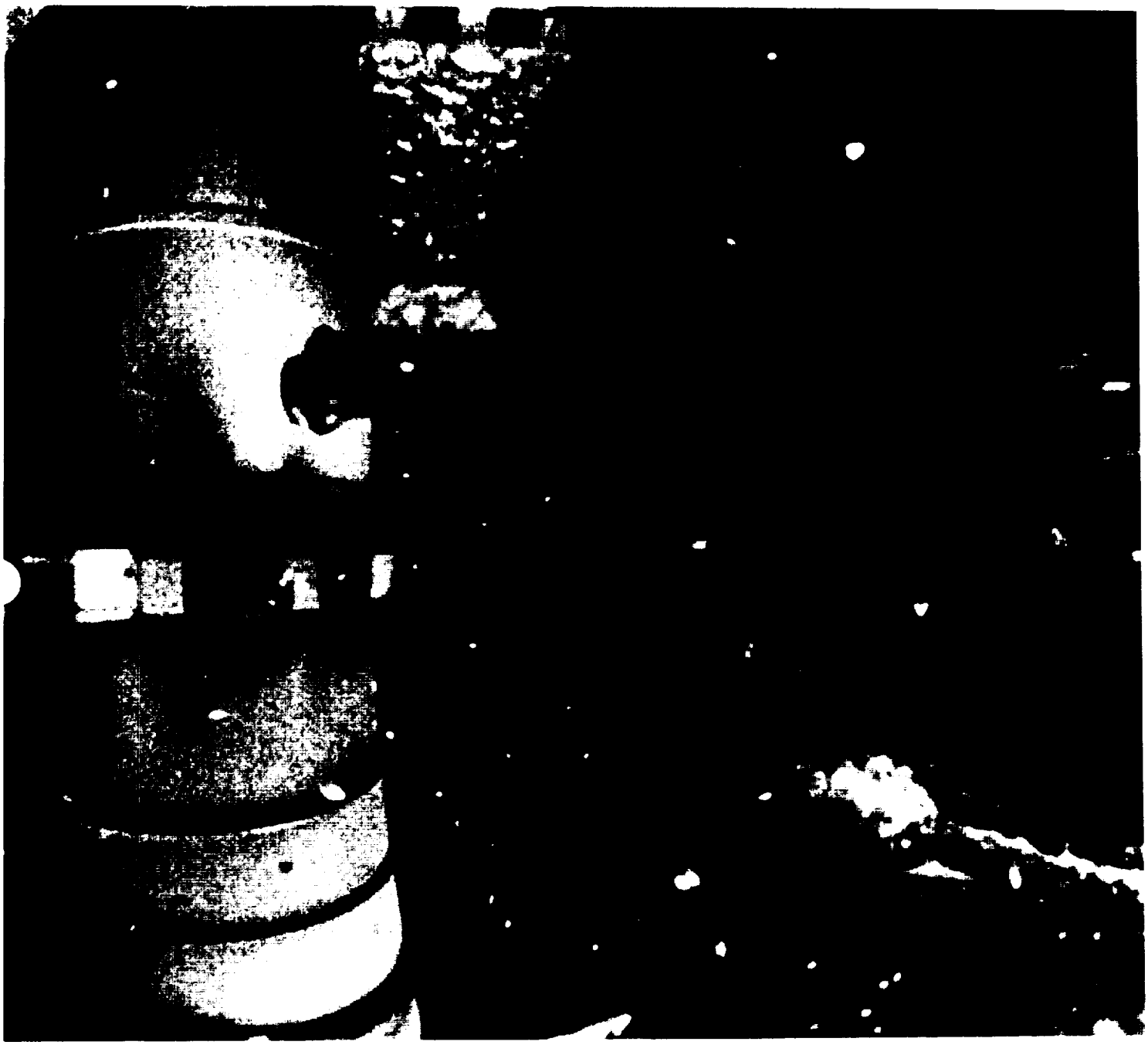


Photo 13: SRB Separation from External Tank

SRB separation from the External Tank was nominal. Foam was missing or eroded from the horizontal (clamshell) section of the cable tray and the aft surface of the -Y vertical strut.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-079 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 25 March 1996. From a debris standpoint, both SRB's were in excellent condition.

6.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The RH frustum was missing no TPS. The number of debonds over fasteners (11) was less than average (Figure 4). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position.

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. One pin was missing and several retainer clips were deformed at the frustum severance ring 190 degree position. Strands of nylon fiber caught on adjacent clips indicated the damage had been caused by the parachute risers after splashdown.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

Aft skirt MSA-2 was intact. More than usual amounts of foam were missing from the aft skirt aft ring. This condition was probably the result of the foam adhesion problem documented prior to launch. Launch films showed numerous light colored particles, believed to be pieces of foam, falling along side the SRB plumes during ascent. The HDP Debris Containment Systems (DCS) appeared to have functioned properly and all the plungers were seated.

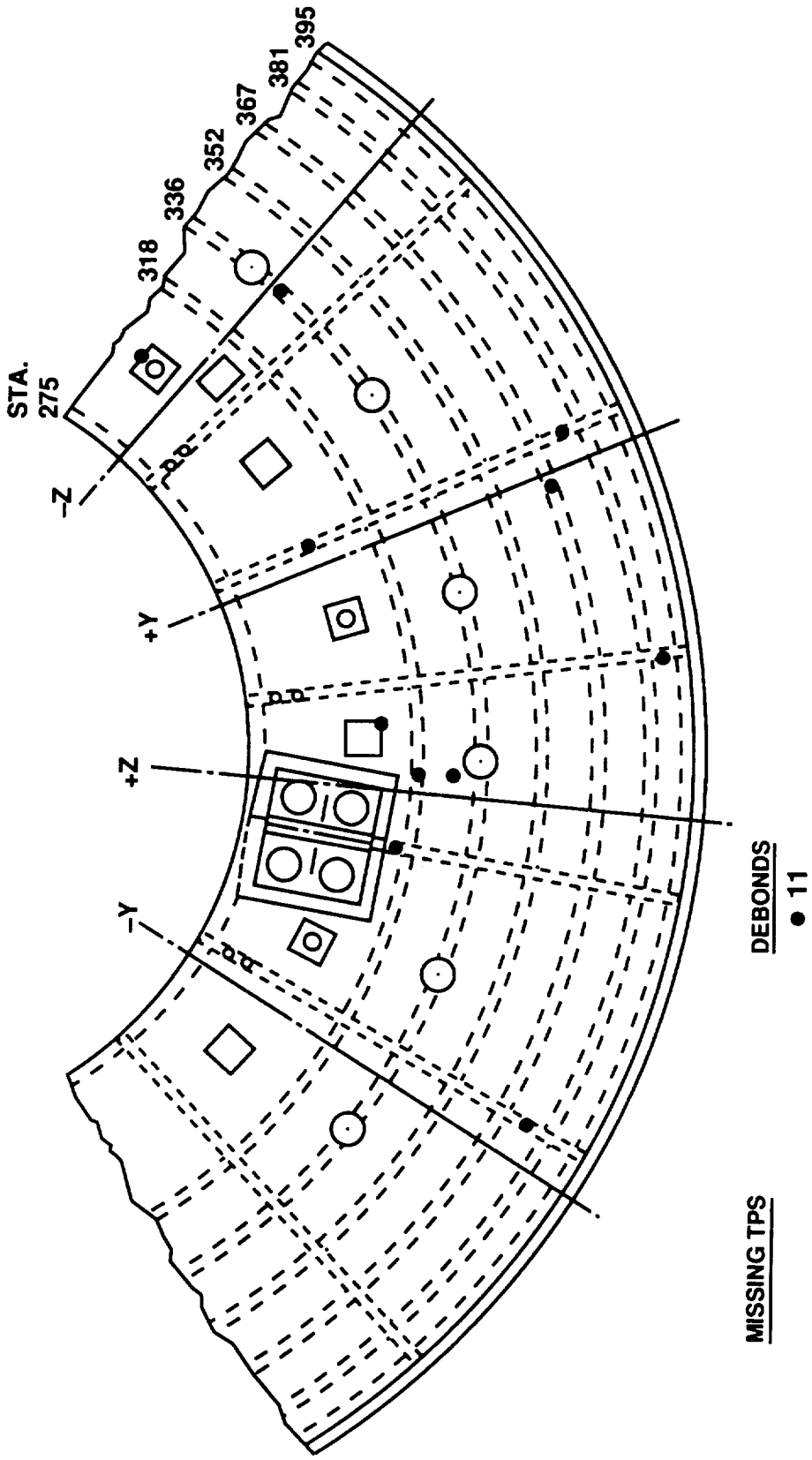


Figure 5: RH SRB Frustum

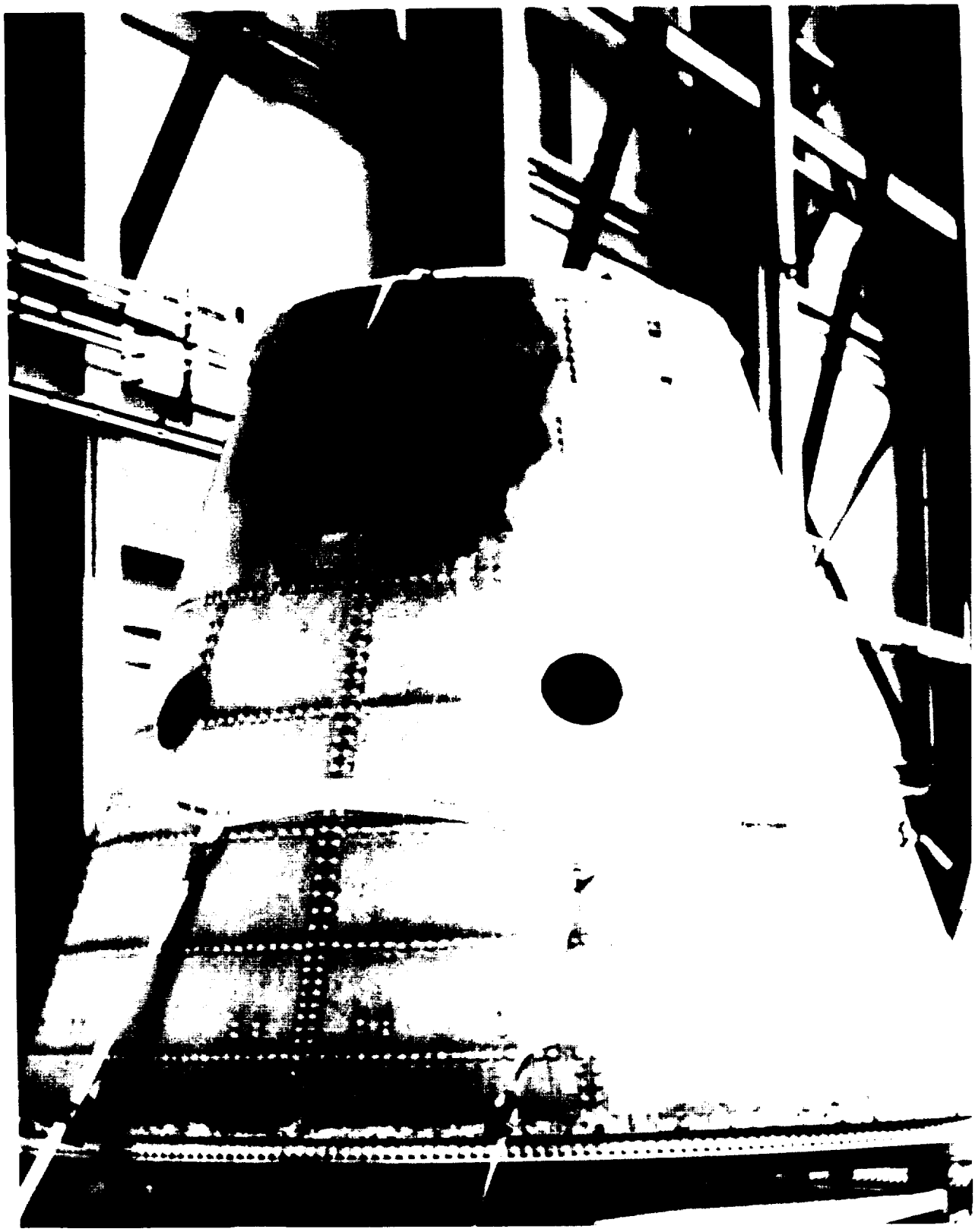


Photo 14: RH Frustum

The RH frustum was missing no TPS. The number of debonds over fasteners (11) was less than average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position.

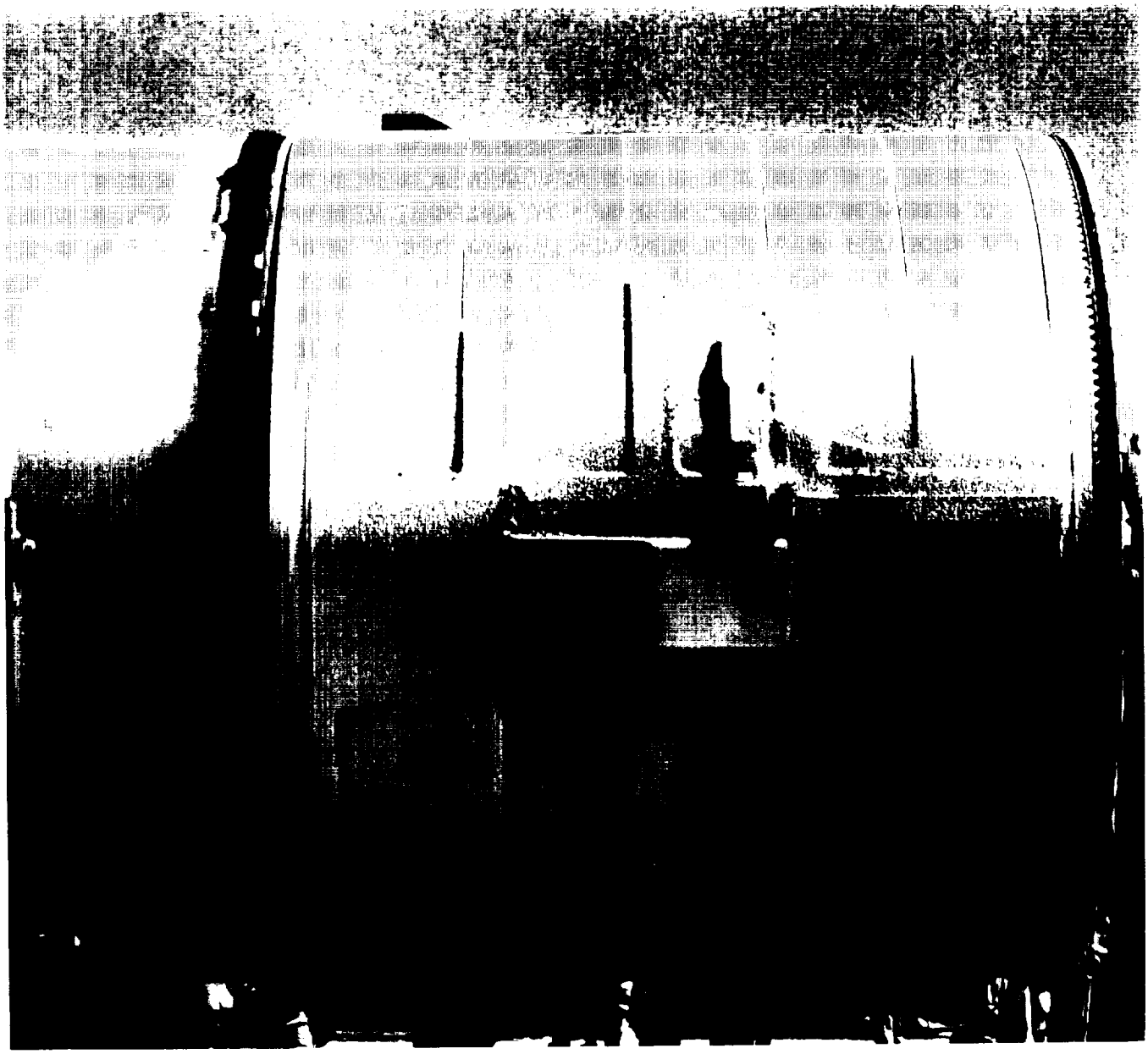


Photo 15: RH Forward Skirt

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied.

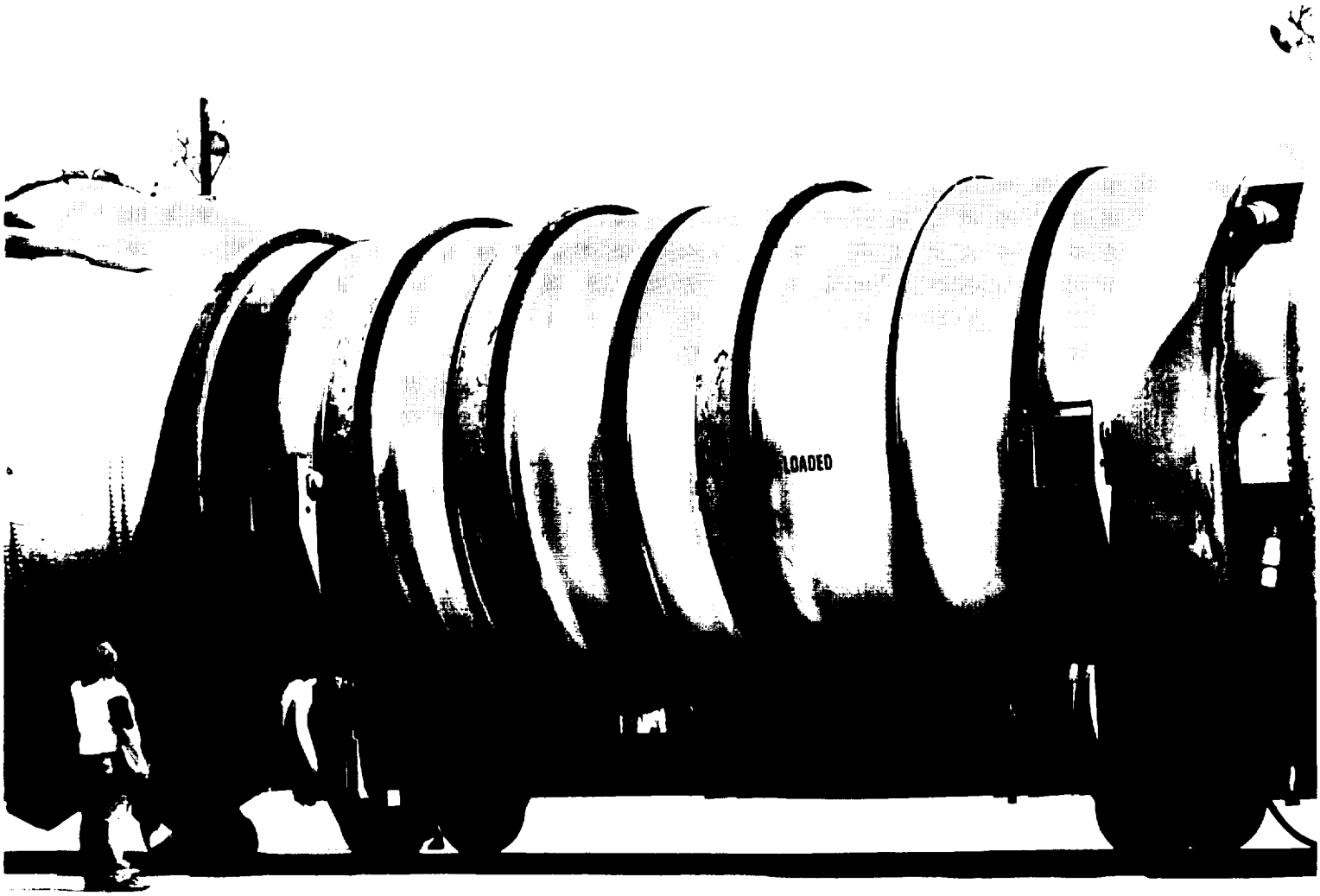


Photo 16: RH Aft Booster/ Aft Skirt

6.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The LH frustum was missing no TPS. The number of MSA-2 debonds over fasteners (8) was less than average (Figure 5). Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position though the right two cover attach rings had been bent by parachute entanglement.

The LH forward skirt exhibited no TPS debonds. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. No pins or retainer clips from the frustum severance ring were missing or damaged.

The Field Joint Protection System (FJPS) closeouts were generally in good condition. Trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ETA ring, IEA, IEA covers, and stiffener rings appeared undamaged. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

Aft skirt MSA-2 was intact. More than usual amounts of foam were missing from the aft skirt aft ring. This condition was probably the result of the foam adhesion problem documented prior to launch. Launch films showed numerous light colored particles, believed to be pieces of foam, falling along side the SRB plumes during ascent. The HDP Debris Containment Systems (DCS) appeared to have functioned properly and all the plungers were seated.

SRB Post Launch Anomalies are listed in Section 9.

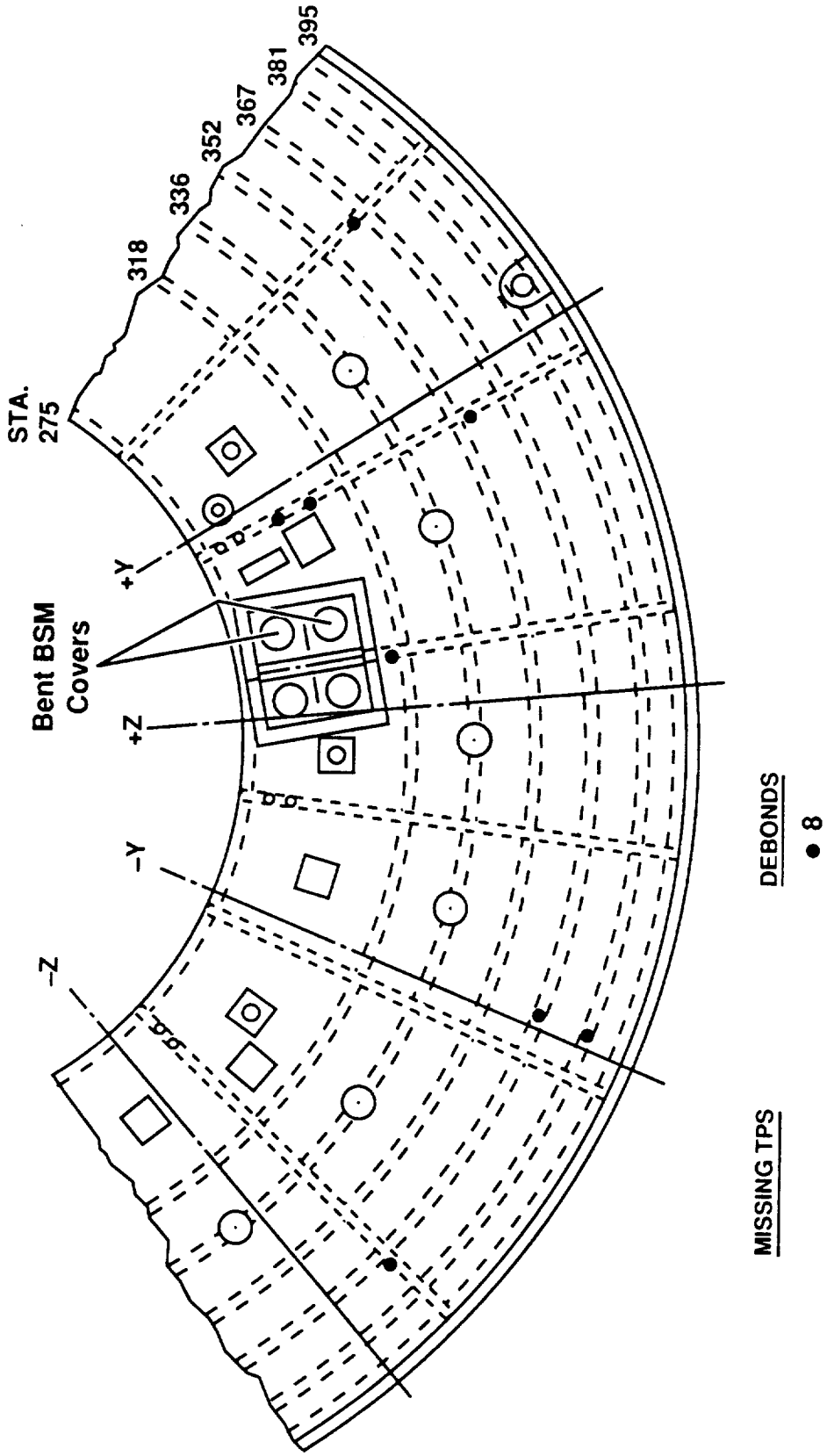


Figure 6: LH SRB Frustum

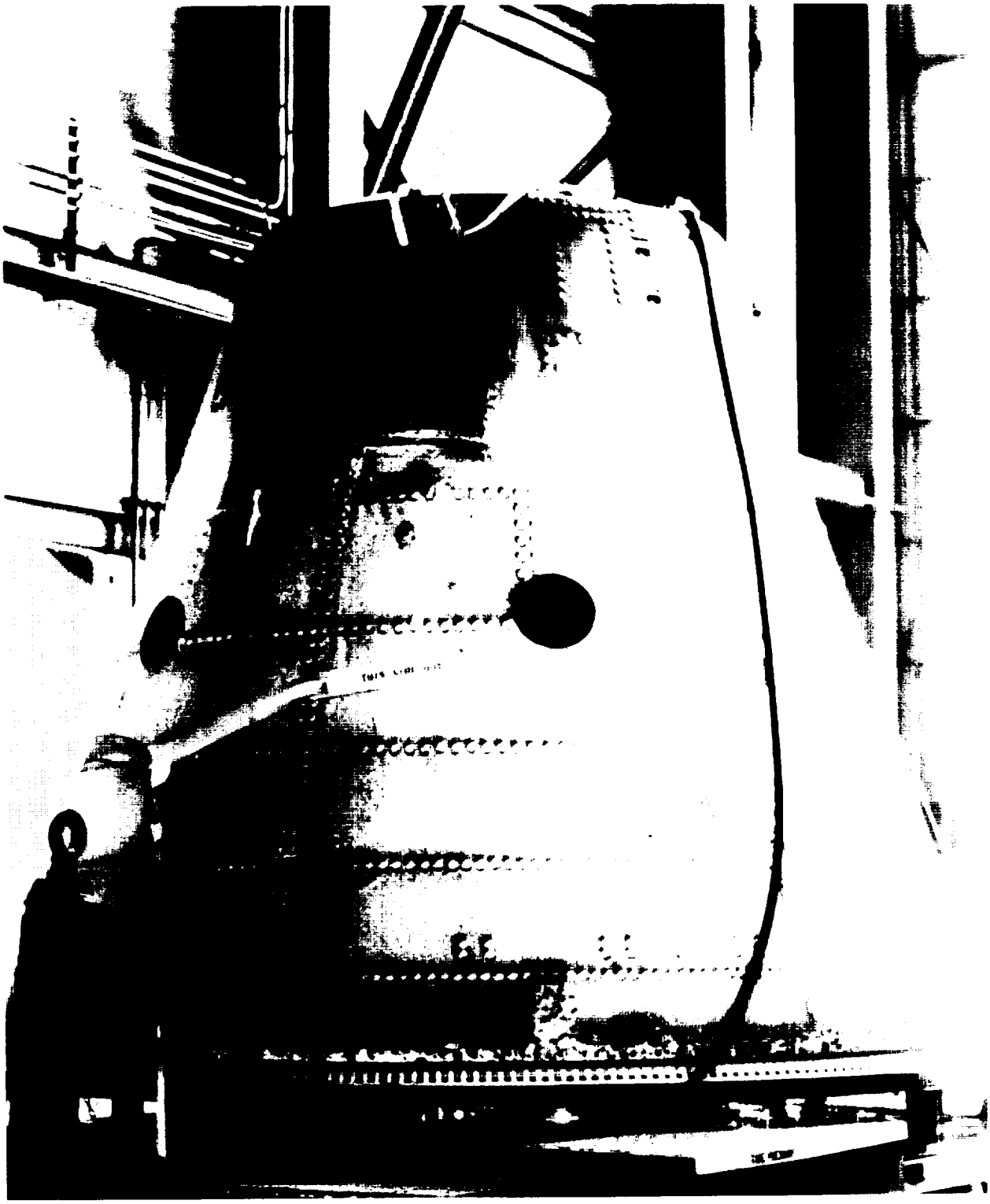


Photo 17: LH Frustum

The LH frustum was missing no TPS. The number of MSA-2 debonds over fasteners (8) was less than average. Hypalon paint was blistered/missing along the XB-395 ring frame where BTA closeouts had been applied. However, most of the exposed BTA substrate was not sooted. The BSM aero heat shield covers had locked in the fully opened position though the right two cover attach rings had been bent by parachute entanglement

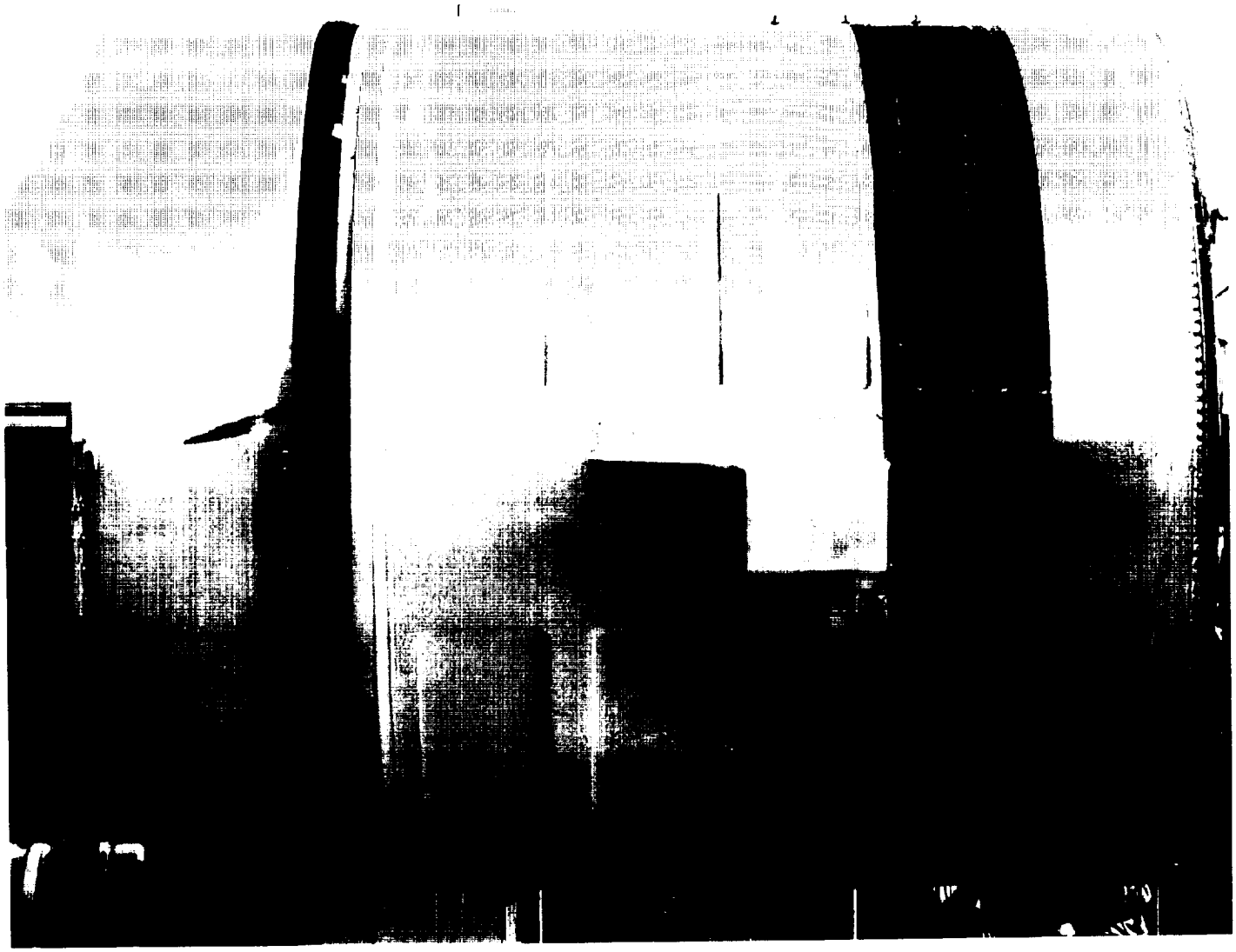


Photo 18: LH Forward Skirt

The LH forward skirt exhibited no TPS debonds. Both RSS antennae covers/phenolic base plates were intact. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. No pins or retainer clips from the frustum severance ring were missing or damaged.

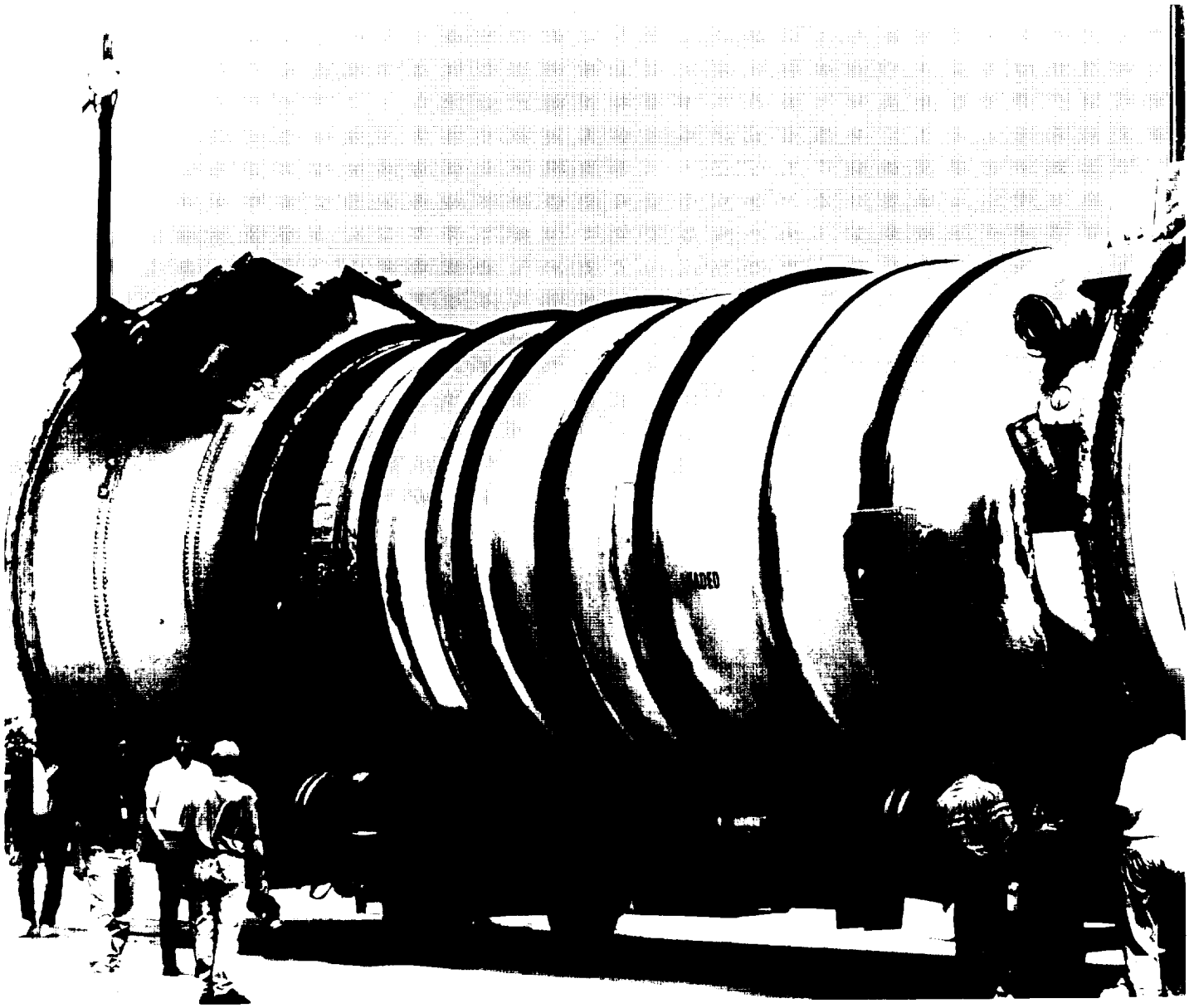


Photo 19: LH Aft Booster/ Aft Skirt

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing debris inspection of OV-104 Atlantis was conducted March 31 - April 2, 1996 at Dryden Flight Research Center/Edwards AFB on runway 22 and in the Mate/Demate Device. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 69 hits, of which 15 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 60 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was exceptionally less than average (reference Figures 6-9).

The following table breaks down the STS-76 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	5	32
Upper surface	5	19
Right side	2	8
Left side	0	1
Right OMS Pod	1	3
Left OMS Pod	2	6
TOTALS	15	69

The Orbiter lower surface sustained a total of 32 hits, of which 5 had a major dimension of 1-inch or larger. Tile damage sites were generally located aft of the vehicle mid point and approximately equally distributed about the vehicle centerline. A cluster of 7 hits occurred just forward of the main landing gear wells and slightly +Y side of centerline.

Very few tile damage sites were recorded aft of the ET/ORB LH2 and LO2 umbilicals. Damage sites in this area are typically caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream. Possible reasons for this unusual finding was the loss of purge barrier material early in flight just after tower clear and significant quantities of umbilical ice shaken loose during SSME ignition prior to liftoff. Therefore, less material impacted Orbiter tiles at high speed later in flight.

No tile damage from micrometeorites or on-orbit debris was identified during the inspection.

The tires and brakes were reported to be in good condition for a landing on a concrete runway.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly. A few clips were missing from both EO-2 and EO-3 fitting "salad bowls". Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect. No debris was found on the runway under the umbilical cavities.

Tile damage on the base heat shield was less than usual. The Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition with the exception of torn and/or missing material at the SSME #1 6:00 to 8:00 o'clock position. There were 3 tile damage sites on the vertical stabilizer stinger lower surface as well as a chipped tile edge immediately below the drag chute door opening. Damage to these areas most likely occurred during drag chute deployment.

No ice adhered to the payload bay door. A white residue was observed around the waste water dump nozzles. Some tile damage sites, including one site measuring 6-inches long by 0.75-inches wide by 0.50-inches deep, were documented on the leading edges of the OMS pods. This damage may have been caused by impacts from ice on the waste water dump nozzle.

Light hazing was visible on windows #3 and #4 with streaks on windows #2, 3, and 4. Typical damage sites on window #2, 3, 4, and 5 perimeter tiles was most likely caused by impacts from FRCS thruster paper covers and RTV adhesive.

The post landing walkdown of Runway 22 was performed after landing. The Runway Measurements Team and Air Force personnel found no flight hardware debris on the runway. All drag chute hardware was recovered with the exception of the mortar cover. The drag chute appeared to have functioned normally and no significant damage was observed on any of the chute components.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was significantly less than average when compared to previous missions.

Orbiter Post Launch Debris Anomalies are listed in Section 9.

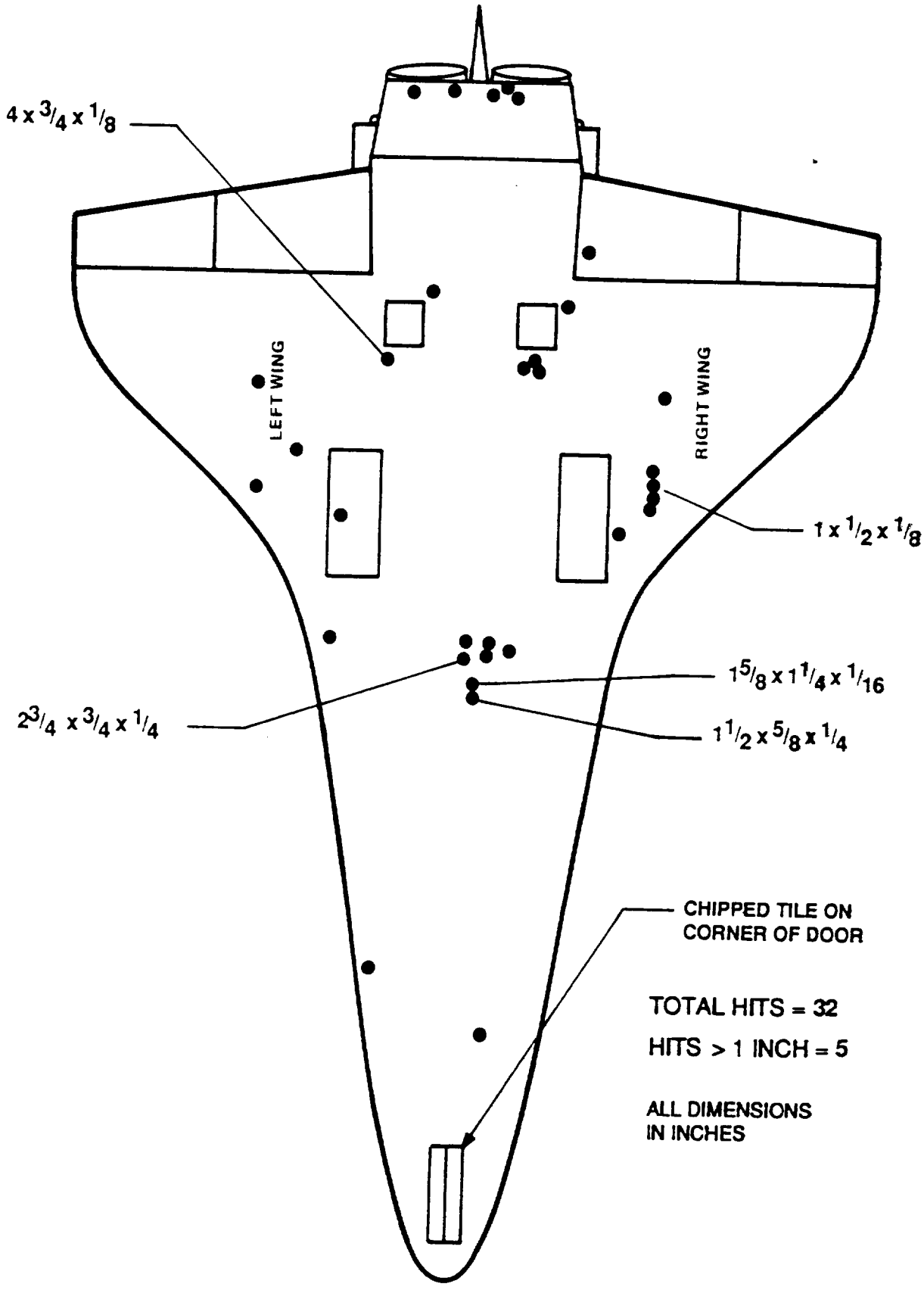


Figure 7: Orbiter Lower Surface Debris Map

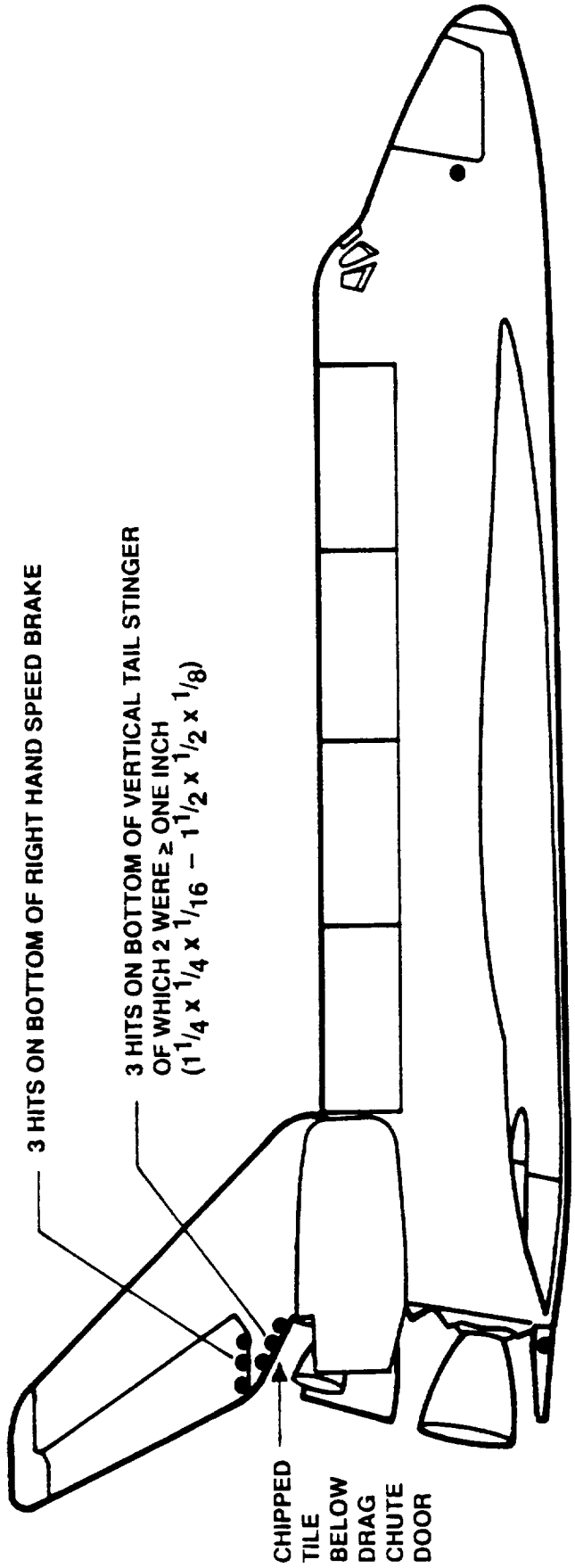


Figure 8: Orbiter Right Side Debris Map

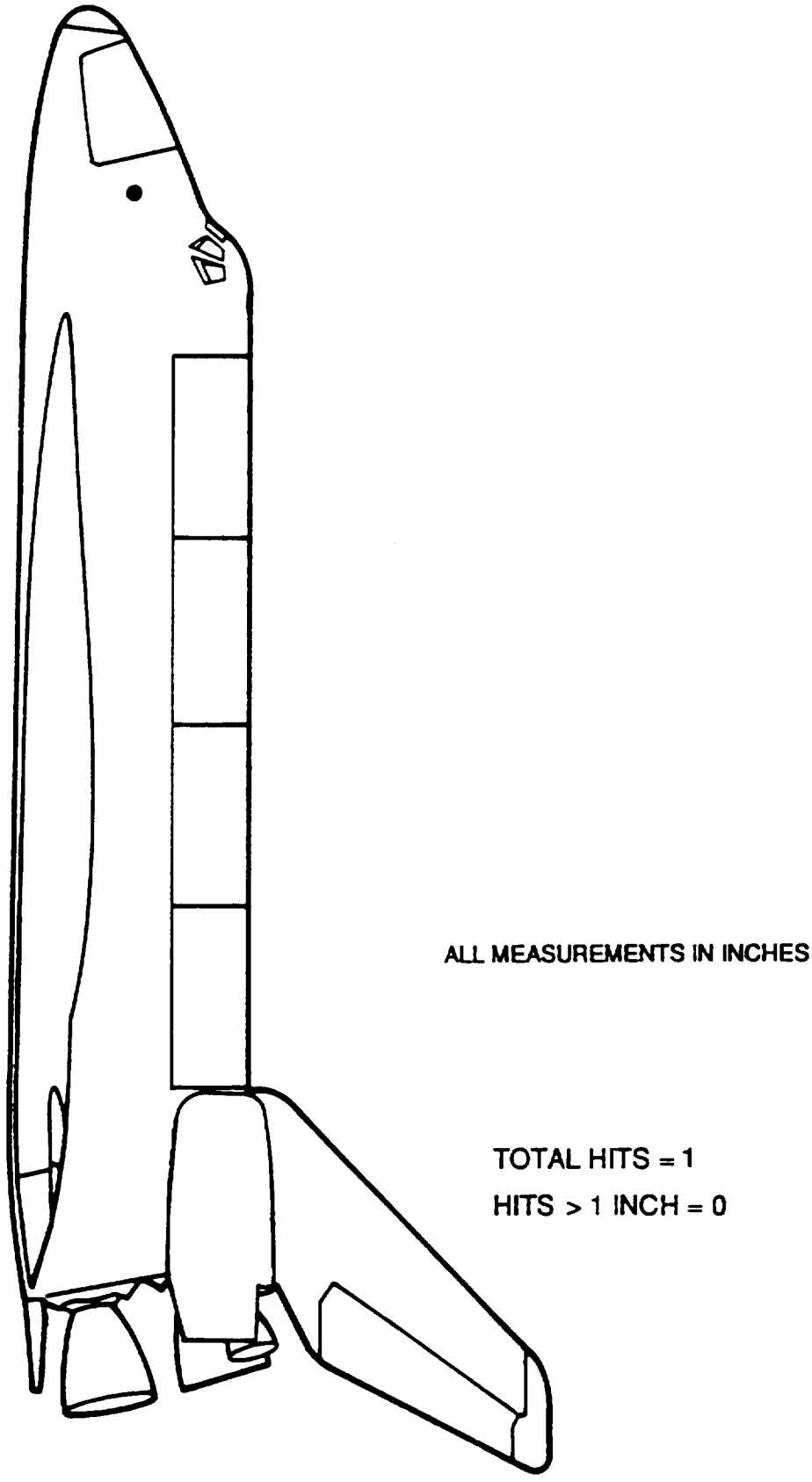


Figure 9: Orbiter Left Side Debris Map

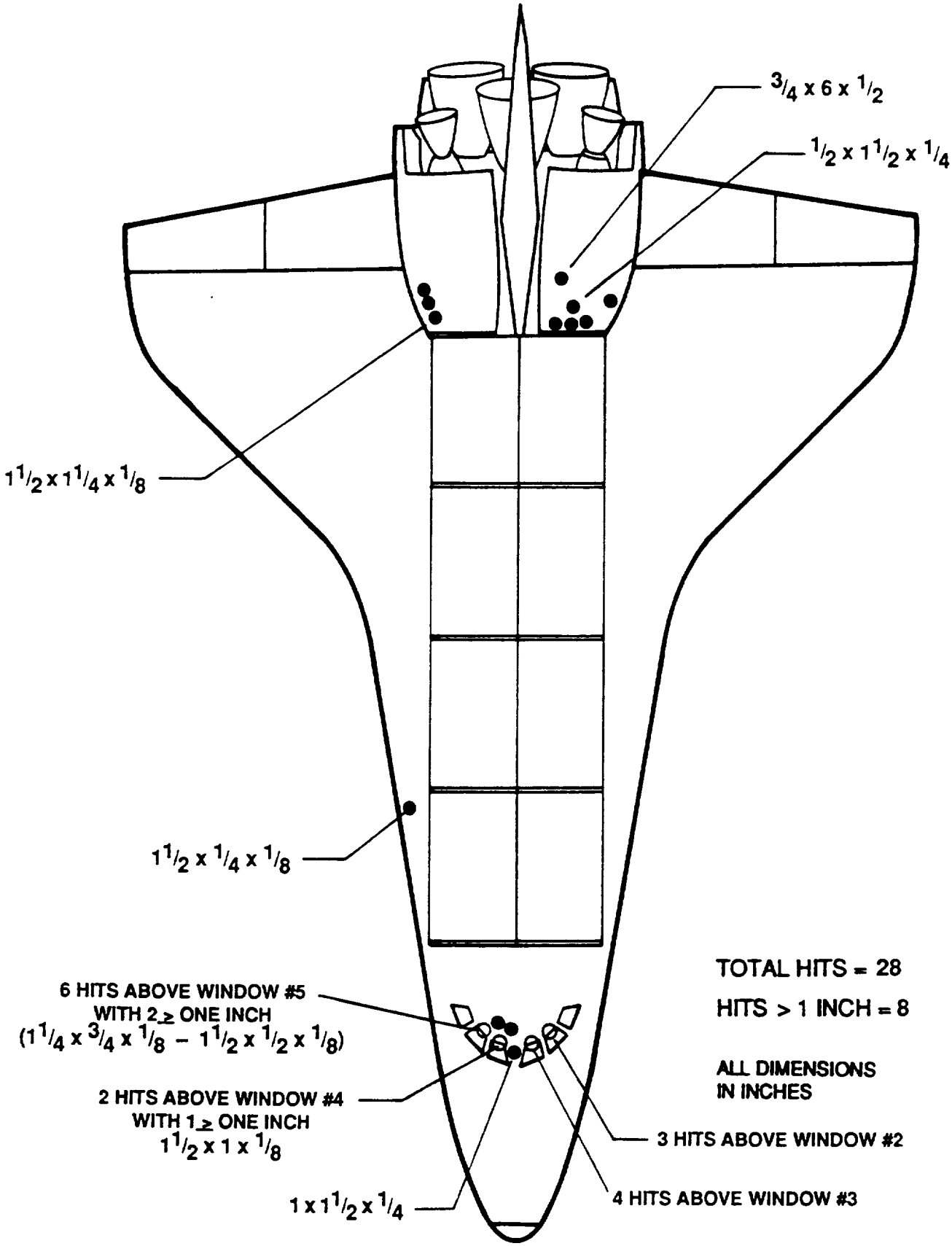


Figure 10: Orbiter Upper Surface Debris Map

	LOWER SURFACE		ENTIRE VEHICLE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	21	89	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	148
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
AVERAGE	14.1	90.3	20.8	130.2
SIGMA	7.2	43.6	9.7	53.8
STS-76	5	32	15	69

MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSIS SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 11: Orbiter Post Flight Debris Damage Summary

Photo 20: Overall View of Orbiter Left Side

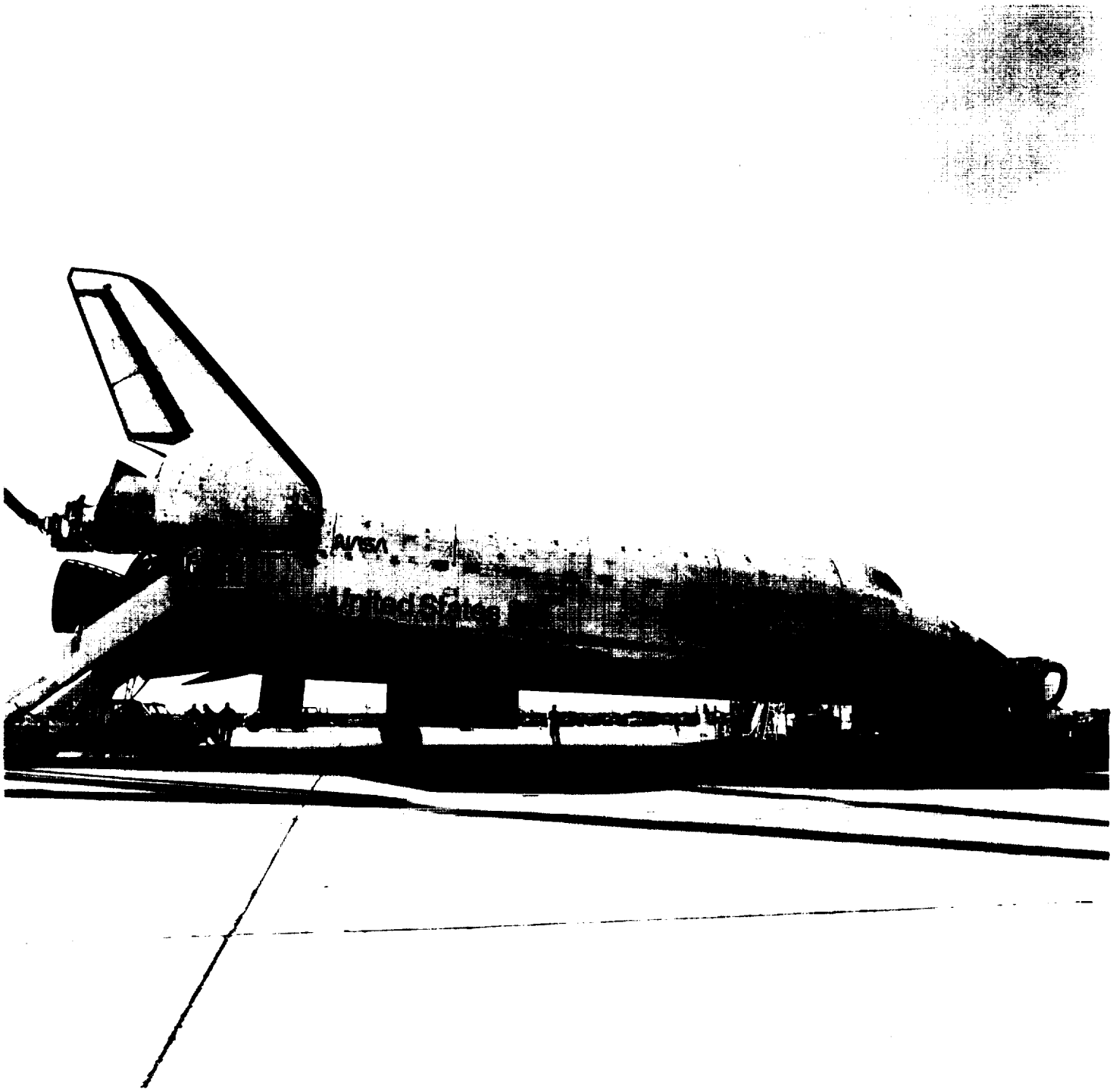


Photo 21: Overall View of Orbiter Right Side

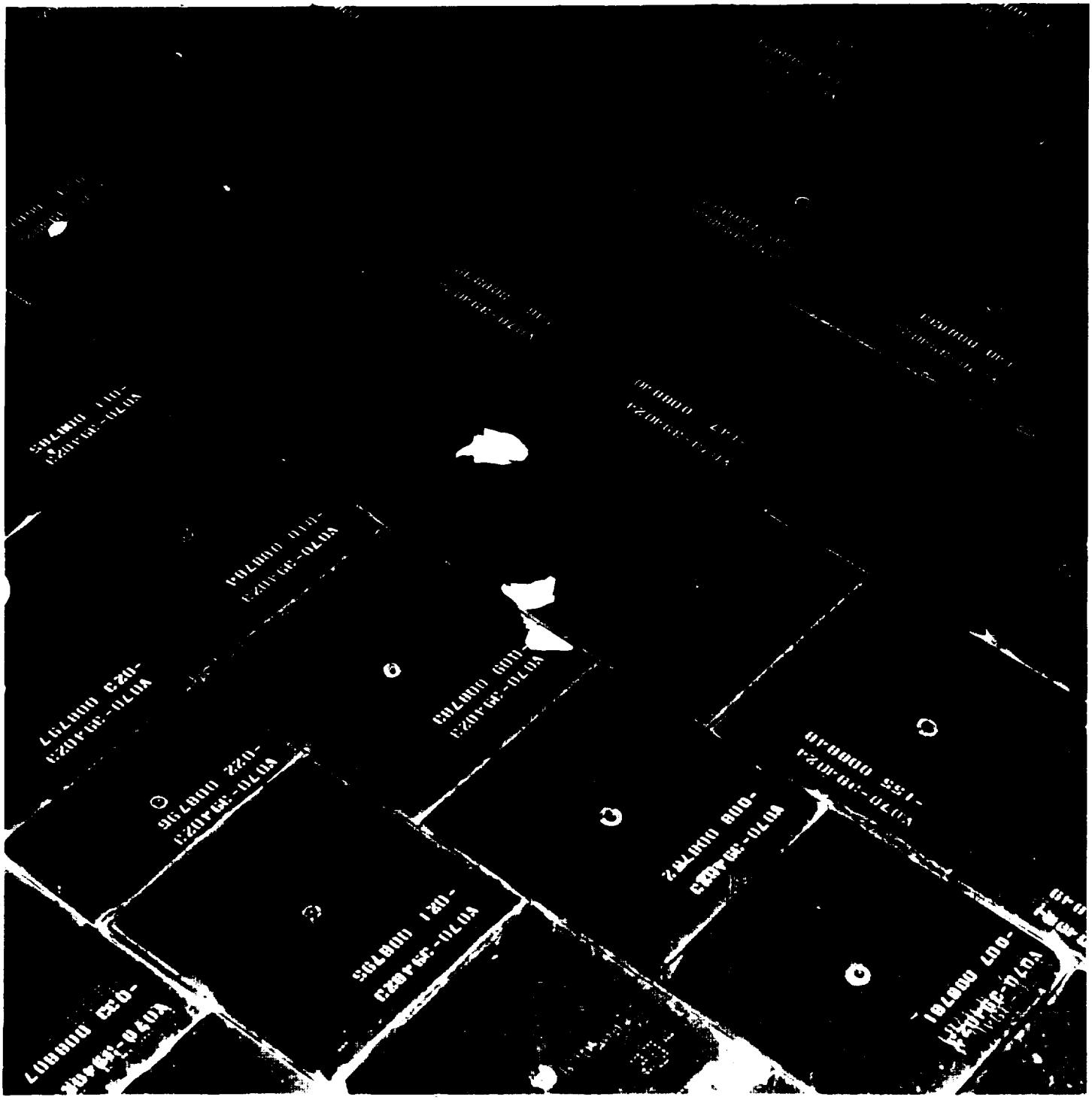


Photo 22: Lower Surface Tile Damage

The Orbiter lower surface sustained a total of 32 hits, of which 5 had a major dimension of 1-inch or larger.

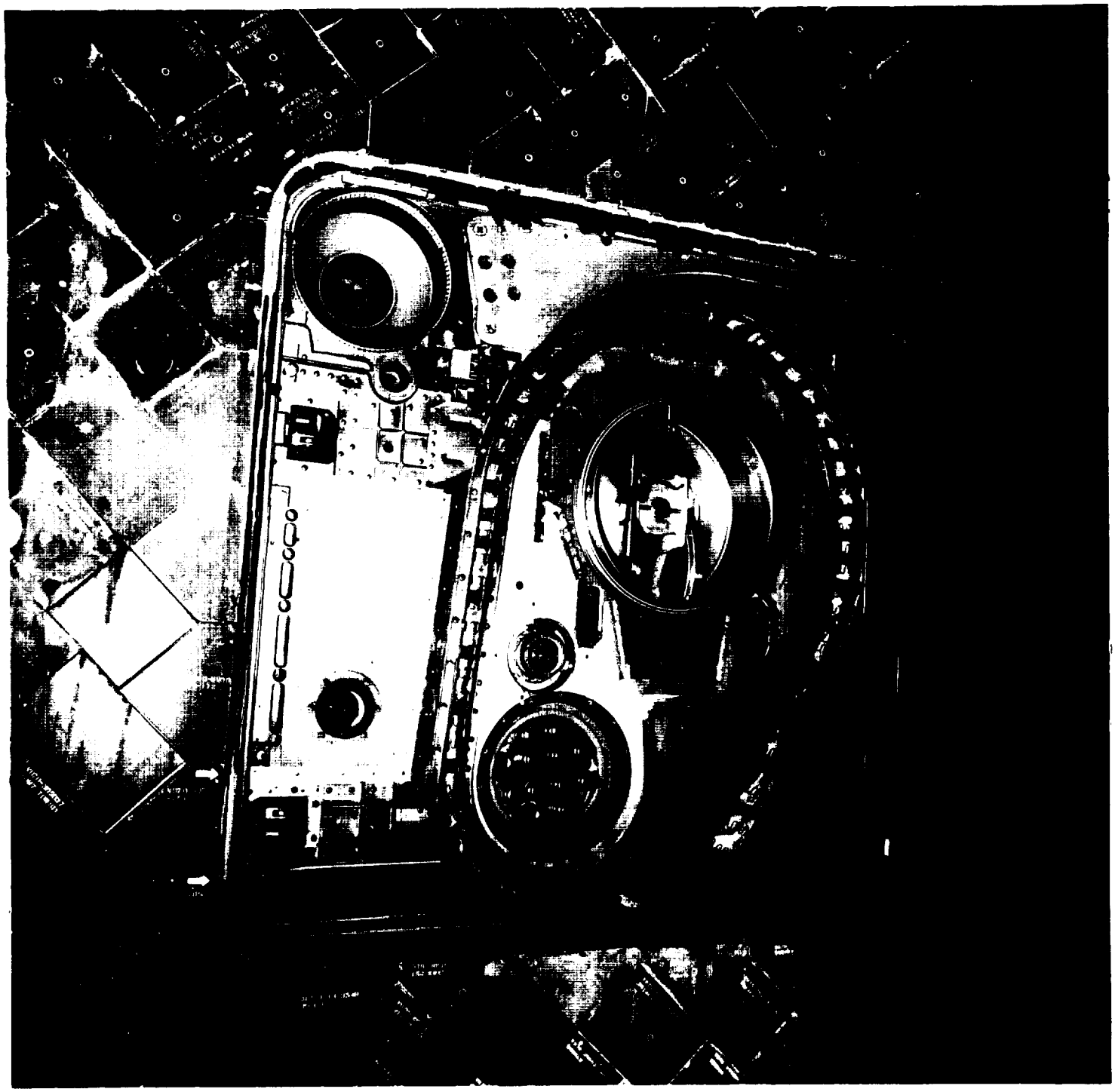


Photo 23: LO2 ET/ORB Umbilical

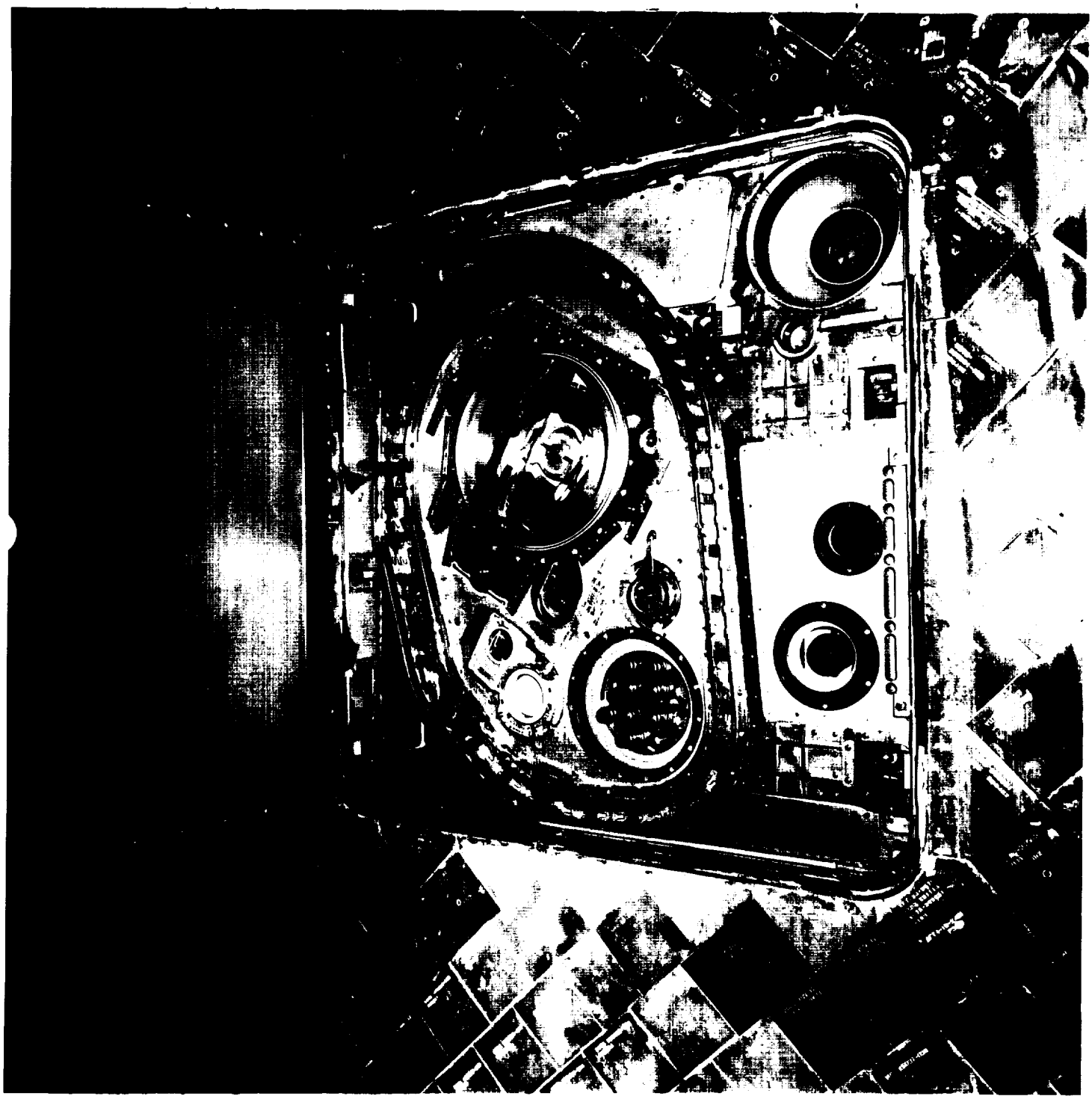


Photo 24: LH2 ET/ORB Umbilical

8.0 DEBRIS SAMPLE LAB REPORTS

A total of eight samples were obtained from OV-104 Atlantis during the STS-76 landing activities at Dryden Flight Research Center (EAFB). The submitted samples consisted of 8 wipes from Orbiter windows #1-8 taken at postlanding. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves both the placing and the correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results/analyses are listed by Orbiter location in the following summaries.

8.1 ORBITER WINDOWS

Samples from the Orbiter windows indicated exposure to facility environment (including metallic particulate), landing site materials (earth minerals), Orbiter Thermal Protection System (glass insulation), Orbiter window polish residue, building type insulation, paints and primer from various sources. There was no apparent vehicle damage related to these residuals.

8.2 ORGANIC ANALYSIS

The results of the STS-76 organic analysis are pending.

8.3 STS-72 ORGANIC ANALYSIS

The results of the STS-72 organic analysis indicated no variation in particulate type compared to previous STS sample results. Organic particulate was consistent throughout the samples and appear to have originated from the wipe and window cover materials. Polyamide, polycarbonate, cellulosic and silicone materials (including RTV) were identified in the samples.

8.4 STS-75 ORGANIC ANALYSIS

Results from the STS-75 organic analysis were consistent throughout the samples and within the data base of that noted in previous mission sampling. Materials identified microscopically included polyamide, cellulosic and silicone particulates. These identified elements appear to have originated from the wipe and window cover materials.

8.5 NEW FINDINGS

This set of prelaunch residual samples provided some repeated data for a DFRC landing in the form of earth minerals, and process unique data in the form of window cover polymers. A new finding from the window #8 sample contained carbon black with copper alloy, the precise source of which is still under investigation. The continued organic sample analysis and source data helps in the analytical differentiation of particulate for debris (reference Figure 11).

STS	Sample Location				
	Windows	Wing RCC	Lower Tile Surface	Umbilical	Other
76	Metallics - Fac Env /BSM Residue(SRB) Tile repair (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics Window polish residue Paint and primer				
75	Metallics - Fac Env /BSM Residue(SRB) Tile repair (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics - Plastics, cellulosic Window polish residue Paint and primer				
72	Metallics - Fac.Env /BSM Residue(SRB) RTV, Tile, Tile repair (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics - Plastics, cellulosic Window polish residue Paint and primer				Pre-launch Window Cover Metallic-Fac.Env.;RTV,Tile-(TPS) Insulation Glass - (ORB TPS) Earth Minerals; Organics--phenolic, urethane, isocyanurate foam Pre-launch Window: Metallic - Fac.Env.;Window polish res RTV,Tile,Tile repair,Ins glass (TPS), Earth Minerals,Paint/primer;Organics-phenolic,urethane,isocyanurate foam
74	Metallics - Fac.Env /BSM Residue(SRB) RTV (ORB TPS) Insulation Glass (ORB TPS) Building type insulation Earth Minerals Organics - Plastic polymers, sealant, RTV(RCS thruster nozzle cover adhesive) SRB sealant Paint and primer				
73	Metallics - Fac. Env /BSM Residue (SRB) Tile, Tile filler (ORB TPS) Insulation Glass (ORB TPS) Earth Minerals Organics - Plastic polymers, sealant, RTV(RCS thruster nozzle cover adhesive) Paint and primer				

For data on previous missions refer to mission report STS-75

Figure 12: Orbiter Post Landing Microchemical Sample Results

9.0 POST LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, 2 post launch anomalies, but no In-Flight Anomalies (IFA's), were observed on the STS-76 mission.

9.1 LAUNCH PAD/SHUTTLE LANDING FACILITY

1. No items.

9.2 SOLID ROCKET BOOSTERS

1. A stud hang-up occurred on holddown post #5. Drag from the stud hang-up and the rising vehicle lifted the holddown post shoe 2.4 inches before the stud cleared the SRB aft skirt foot. The stud did not appear to gouge aluminum from the stud hole wall. Unlike the STS-75 stud hang-up, no aluminum was observed in the stud threads or falling away from the stud hole. No loose ordnance fragments or frangible nut pieces from the DCS were detected.

2. Clusters of light-colored debris, most likely pieces of instafoam from the SRB aft skirts, fell out of the SRB plume after the roll maneuver. The foam pieces appeared to originate from the RH SRB aft skirt area at 08:13:16 - 08:13:20 and 08:13:22 - 08:13:30 GMT. Foam pieces fell aft from the LH SRB aft skirt area at 08:13:17 GMT. Liftoff occurred at 08:13:04 GMT.

9.3 EXTERNAL TANK

1. No significant items.

9.4 ORBITER

1. No items.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

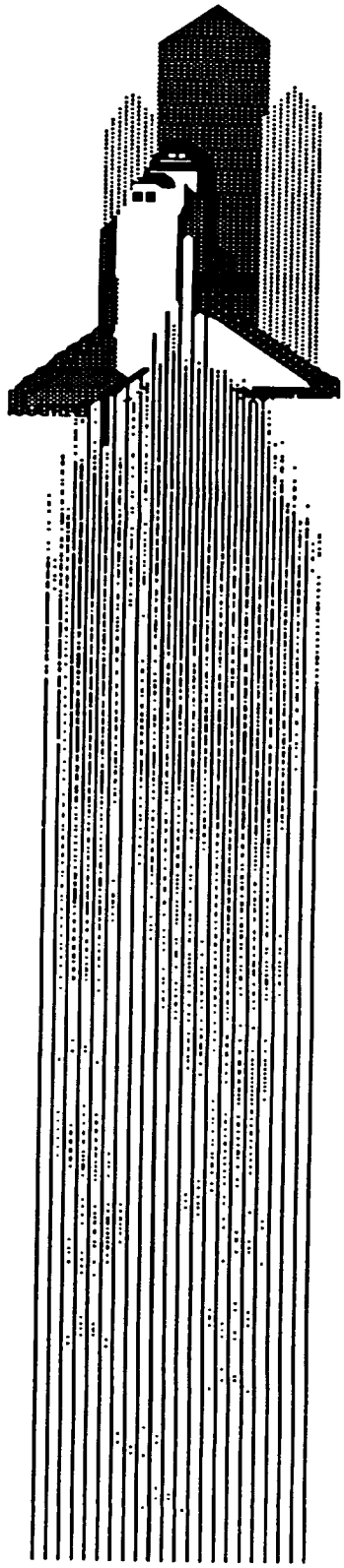
Space Shuttle

Earth Science Branch

Image Science and
Analysis Group

STS-76 Summary of Significant Events

May 13, 1996



Space Shuttle Image Science and Analysis Group

STS-76 Summary of Significant Events

Project Work Order - SN-5CR

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Table of Contents

1. STS-76 (OV-104): FILM / VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-76 launch of Atlantis (OV-104) from pad B occurred on Friday, March 22, 1996, (day 082) 08:13:04.010 Coordinated Universal Time (UTC) as seen on camera E9. Solid Rocket Booster (SRB) separation occurred at 08:15:09.868 UTC as seen on camera ET212.

On launch day, 24 of 24 expected videos were received and screened. Following launch day, 42 films were screened. No potential anomalies were observed during launch.

Detailed Test Objective 312, photography of SRB separation and the external tank after separation, was performed using the Orbiter umbilical well cameras (method 1). Due to inadequate lighting, images of the ET were not acquired.

1.1.2 Landing

Atlantis landed on runway 22 at Dryden Flight Research Center on March 31, 1996. Six videos and thirteen films (six landing films, and seven Contraves long range tracker views) of the Orbiter's approach and landing were received.

No major anomalies were noted in any of the approach, landing, or roll-out video views screened. The drag chute deployment appeared normal.

1.2 TIMING ACTIVITIES

Launch:

The time codes from videos and films were used to identify specific events during the initial screening process.

Video cameras: ET204, ET 207, ET208, ET212, ET213, KTV2, KTV5, KTV13, KTV4B, KTV7B, KTV21B, KTV11B, OTV150, OTV160, OTV109, OTV141, OTV148, OTV149, OTV151, OTV154, OTV161, ORTV163, OTV170, OTV171 had IRIG timing.

Film cameras: E31, E41, E204, E207, E208, E212, and E213 had IRIG timing. E1, E2, E3, E4, E6, E7, E8, E9, E10, E11, E12, E13, E14, E15, E16, E17, E18, E19, E20, E33, E34, E36, E40, E52, E54, E57, E59, E60, E62, E63, E76, E77, and E222 had in-frame alphanumeric timing.

Landing:

Video cameras: Of the six videos screened on landing day, LRO-1, Radar-5, Runway, TV1, TV2, and TV3 had IRIG timing.

Film cameras: Three film cameras E1005, E1008, and E1035, had in-frame alphanumeric timing; seven Contraves cameras C1, C5, C6, C7, C9, E-TL, and W-TL had IRIG timing; G406 (views 1L, 3L, and 4L) did not have timing.

The landing and drag chute event times are provided in Table 1.2.

Event Description	Time (UTC)	Camera
Landing Gear - Doors Opened	121:13:28:35.782	TV1
Right Main Wheel Touchdown	121:13:28:56.336	TV1
Left Main Wheel Touchdown	121:13:28:56.439	TV1
Drag Chute Initiation	121:13:29:00.400	TV3
Pilot Chute at Full Inflation	121:13:29:01.174	TV1
Bag Release	121:13:29:01.801	TV3
Drag Chute Inflation in Reefed Configuration	121:13:29:02.809	TV1
Drag Chute Inflation in Disreefed Configuration	121:13:29:06.978	TV1
Nose Wheel Touchdown	121:13:29:07.713	TV1
Drag Chute Release	121:13:29:31.437	TV1
Wheel Stop	121:13:29:51.724	TV1

Table 1.2 Landing Video Timing Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS

2.1.1 Debris Near the Time of SSME Ignition

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition. Most of the debris was umbilical ice and RCS paper. No follow-up action was requested.

2.1.1.1 Debris Strikes Umbilical Sill
(Camera: OTV109)

Multiple pieces of debris (probably ice) were seen to strike the umbilical sill at SSME ignition. Debris striking the umbilical sill has been seen on previous missions. No follow-up action was requested.

2.1.2 Debris Near the Time of SRB Ignition

As on previous missions, multiple pieces of debris were seen near the time of SRB ignition. No follow-up action was requested.

2.1.2.1 Bolt Hang-Up on the LSRB Holddown Post M-5
(Camera: E12)

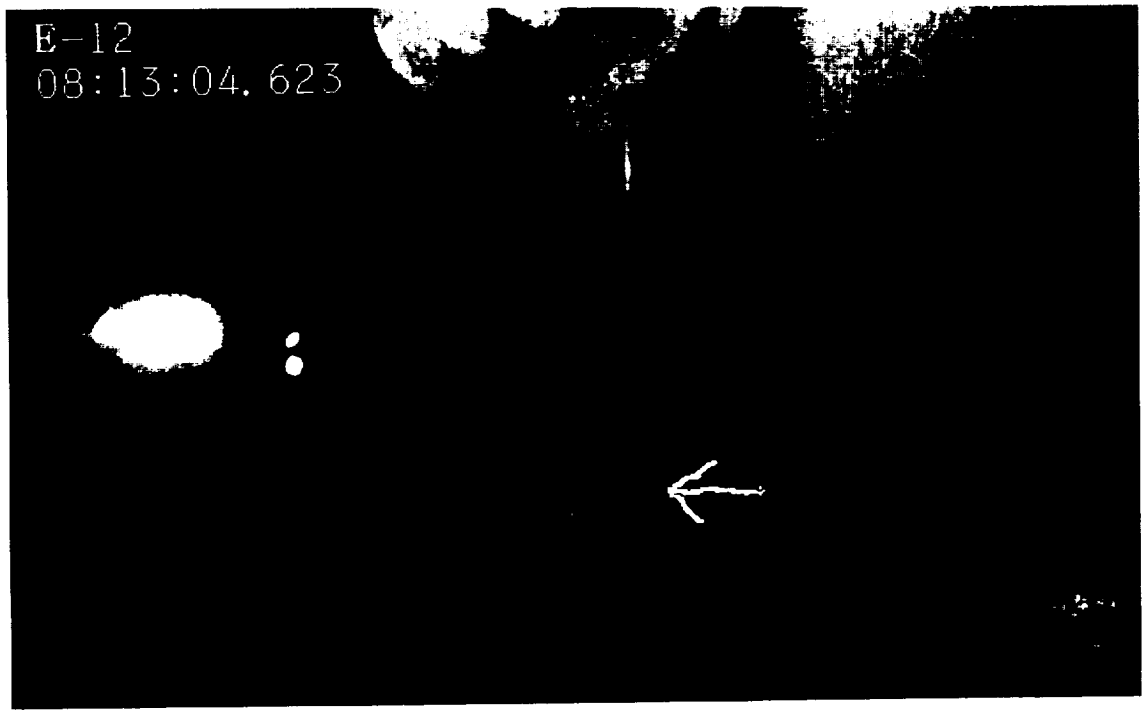

Figure 2.1.2.1 Holddown Post Bolt Hang-Up

A bolt hang-up occurred on the LSRB holddown post M-5 at liftoff. Slight holddown post shoe movement was visible prior to the bolt release (08:13:04.623 UTC). No follow-up action was requested.

MISSION	LOCATION OF HANG-UP
STS-34	RSRB holddown post M-2
STS-33	RSRB holddown post M-3
STS-39	RSRB holddown post M-1
STS-43	LSRB holddown post M-7
STS-45	RSRB holddown post M-4
STS-50	RSRB holddown post M-4
STS-46	LSRB holddown post M-7
STS-53	RSRB holddown post M-1
STS-73	RSRB holddown post M-2
STS-75	LSRB holddown post M-5

Table 2.1.2.1 SRB Holddown Post Bolt Hang-Ups Seen on Previous Missions

2.1.2.2 Debris seen near Holddown Post M-4

(Camera: E7)

A small, dark piece of debris was seen near the DCS area of holddown post M-4 at liftoff (08:13:04.552 UTC). No follow-up action was requested.

2.1.2.3 Light-colored Debris seen at Liftoff

(Camera: OTV149)

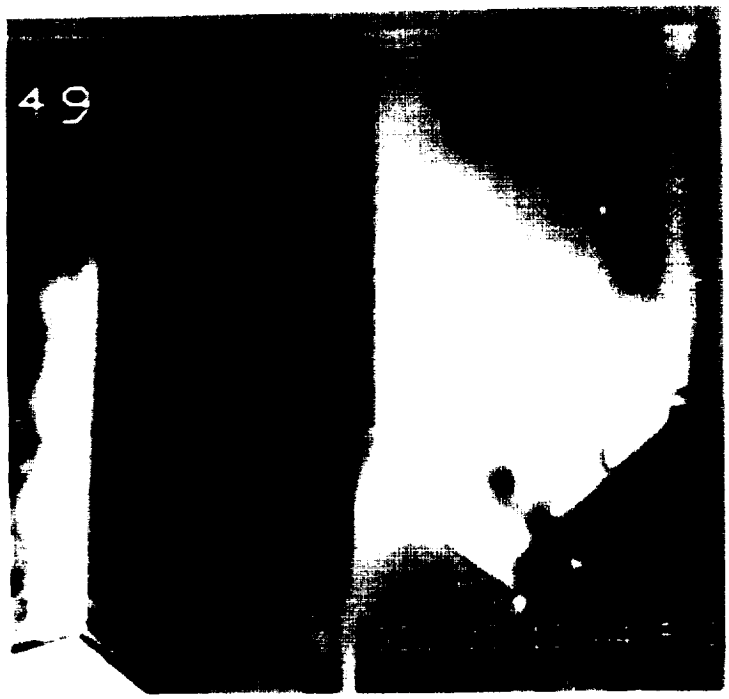

Figure 2.1.2.3 Light-colored Debris seen at Liftoff

Several small, light-colored pieces of debris were seen on the Orbiter side of the LO2 TSM umbilical at liftoff (08:13:04.578 UTC). No follow-up action was requested.

2.1.2.4 Debris seen near ET/Orbiter Aft Attach at Liftoff
(Camera: OTV154)

Multiple pieces of light colored debris (probably ice) were seen falling from the ET/Orbiter aft attach at liftoff. No follow-up action was requested.

2.1.2.5 Large Piece of Debris seen near the Port Elevon at Liftoff
(Camera: E18)

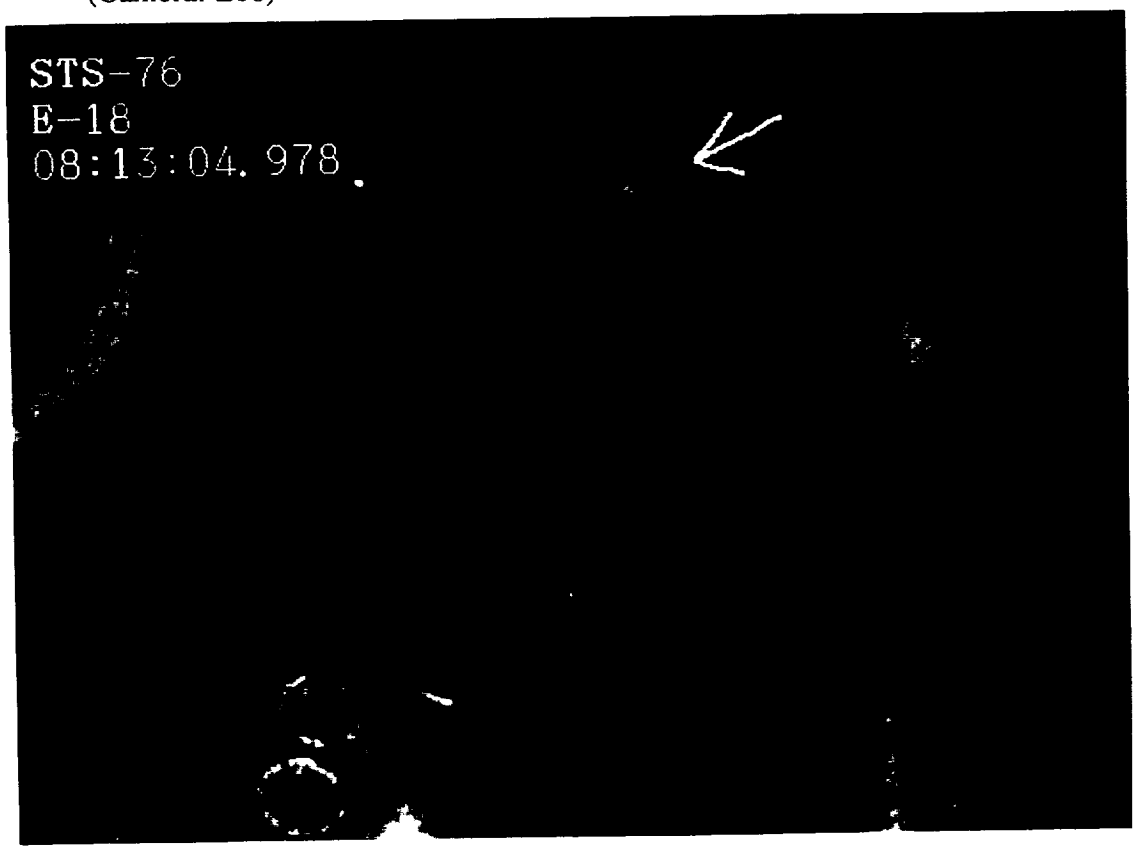

Figure 2.1.2.5 Debris seen near the Port Elevon at Liftoff

A large, irregularly shaped, light colored piece of debris was seen near the underside of the port elevon at liftoff (08:13:04.978 UTC). The origin of the debris was not seen. The debris did not appear to strike the vehicle. No follow-up action was requested.

2.1.2.6 Large Rectangular Debris exits RSRB Flame Duct
(Camera: E9)

Figure 2.1.2.6 Debris seen near RSRB Howddown Post #1

A large, dark, rectangular shaped piece of SRB flame duct debris was seen exiting the RSRB flame duct during liftoff (08:13:05.368 UTC). The debris did not appear to strike the vehicle. No follow-up action was requested.

2.1.2.7 Debris seen North of the Vehicle
(Camera: E60)

A single dark colored piece of debris (possible throat plug material) was seen north of the vehicle at liftoff. The debris was not seen to contact the launch vehicle. No follow-up action was requested.

2.1.2.8 Flame Duct Debris
(Cameras: E8, E12)

Orange colored debris (probable water baffle material) was seen exiting from the SRB flame ducts at liftoff. The debris did not appear to strike the vehicle. No follow-up action was requested.

2.1.3 Debris After Liftoff

(Cameras: E40, E52, E57, E59, E213, E220, E222, E223)

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) after liftoff on the launch tracking views. The debris was probably reaction control system (RCS) paper and ice from the ET/Orbiter umbilicals. None of the debris was seen to contact the launch vehicle. No follow-up action was requested.

2.1.3.1 Multiple Pieces of Debris Fell Aft into the SSME Plume

(Cameras: E52, E54, E57, ET207, E213, E220, E222)

Multiple pieces of light colored debris (more than 30 pieces) (probable ice and RCS paper debris) fell aft of the launch vehicle into the SSME plume from tower clear through the roll maneuver (08:13:08.247 - 08:13:22.146 UTC). No follow-up action was requested.

2.1.3.2 Tape Debris Seen Aft of the ET/Orbiter Umbilical

(Cameras: E40, E52, E54)

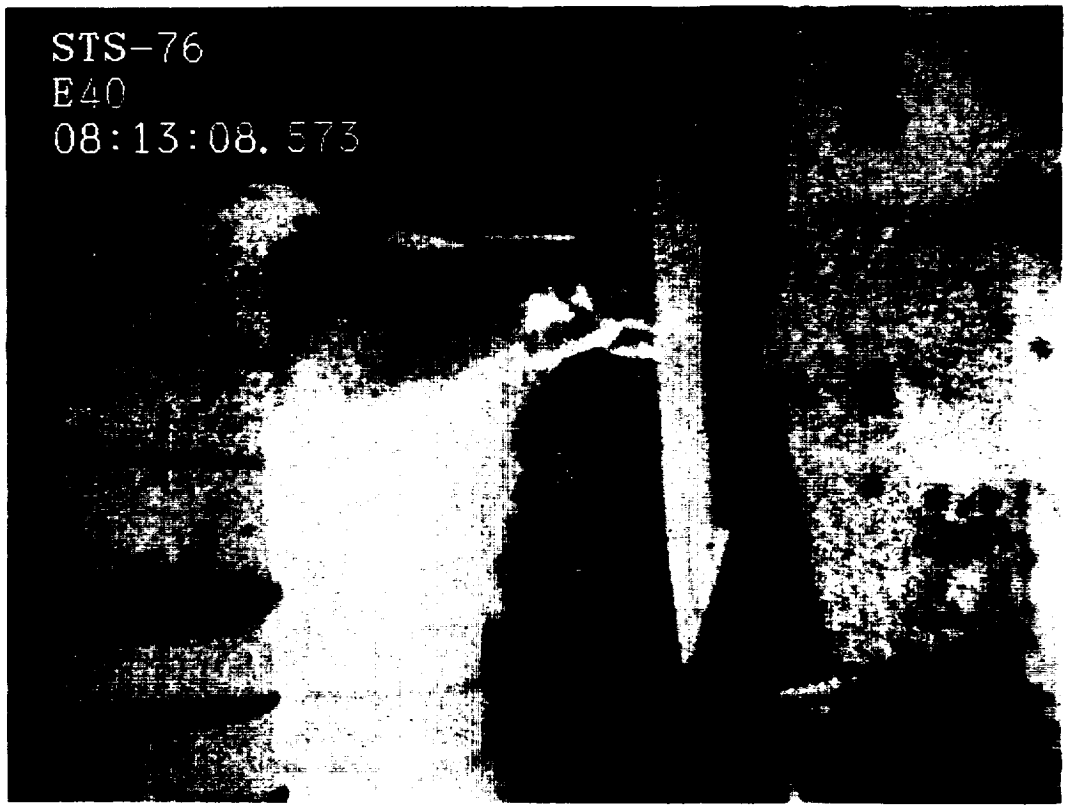

Figure 2.1.3.2 Tape Debris seen aft of the ET/Orbiter Umbilical

Two large tape like pieces of debris, (probable ET umbilical baggy tape) were first seen near the ET/Orbiter umbilical, and fell aft along the body flap into the SSME plume (08:13:08.573 - 08:13:13.928 UTC). No follow-up action was requested.

2.1.3.3 Orange Debris seen Aft of Body Flap
(Cameras: E207, E220)

Several pieces of orange debris (possible umbilical baggy material) fell along the body flap and aft into the SSME plume prior to the roll maneuver. No follow-up action was requested.

2.1.3.4 Debris Seen Falling along the SRB Plume
(Camera: KTV4B)

Several light-colored pieces of debris were seen falling along the SRB plume after liftoff (08:14:03.170 - 08:14:05.639 UTC). No follow-up action was requested.

2.1.3.5 Multiple Pieces of Debris Fell Aft into the SRB Plume
(Cameras: E57, E59, E207, E212, E213, E222)

Figure 2.1.3.5 Multiple Pieces of Debris Fell Aft into the SRB Plume

Multiple pieces of light colored debris (more then 20) were first seen behind the body flap and fell aft of the SLV along the SRB plumes. (08:13:15- 08:13:28 UTC). No follow-up action was requested.

2.1.3.6 Debris seen in Exhaust Cloud after Liftoff
(Camera: E1)

Several large rope-like pieces of pad debris were seen in the exhaust cloud after liftoff. No follow-up action was requested.

2.1.3.7 Debris seen after SRB Separation
(Camera: ET208)

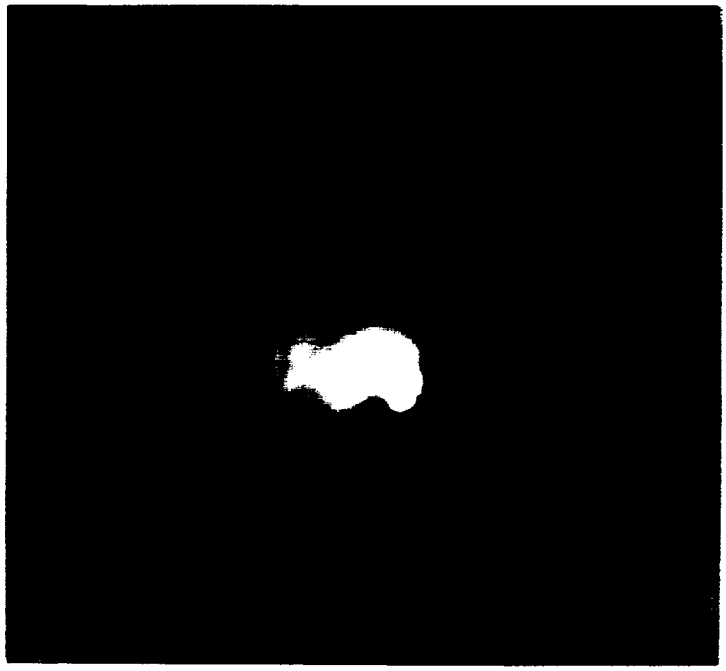

Figure 2.1.3.7 Debris seen after SRB Separation

A single piece of debris was seen falling along the SRB plume after SRB separation (08:15:12.055 UTC). No follow-up action was requested.

2.2 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.2.1 Orange Vapor

(Cameras: E2, E15, E16, E17, E18, E36, E76, OTV163, OTV170, OTV171, KTV4B, KTV7B, KTV21B)

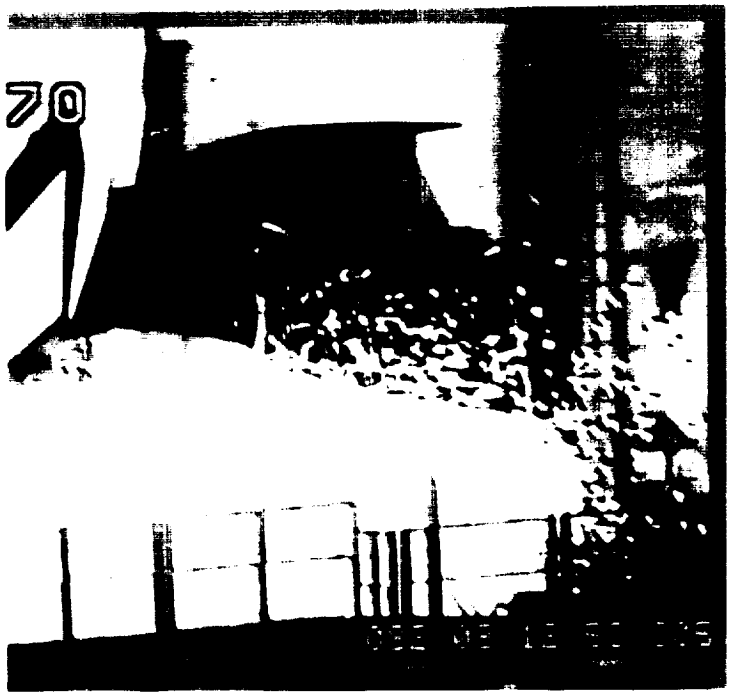

Figure 2.2.1 Orange Vapor

Orange vapor, probably free burning hydrogen, was seen behind the body flap (08:12:58:872 UTC) and near the base of the vertical stabilizer prior to liftoff (08:12:58:805 UTC). Also, multiple occurrences of orange vapor were seen near SSME #1 and SSME #3 above the engine bells throughout SSME ignition (08:13:04.944 UTC). Orange vapor has been seen on previous missions and is not considered anomalous. No follow-up action was requested.

2.2.1.1 Erosion on Port RCS Stinger

(Camera: E20)

TPS erosion was seen on the base of the port RCS stinger during SSME ignition (08:12:59.566 UTC). TPS erosion of the RCS stingers has been seen on previous missions. No follow-up action was requested.

2.2.2 SSME Mach Diamond Formation

(Camera: E76)

The SSME mach diamonds formed in the normal sequence. The times of the mach diamond formation were:

SSME #3 - 08:13:00.684 UTC
SSME #2 - 08:13:00.942 UTC
SSME #1 - 08:13:00.962 UTC

2.2.3 Flashes in SSME #1 Exhaust Plume
(Camera: E2)

Flashes were seen in SSME #1 exhaust plume at liftoff (08:13:03.877, 08:13:03.975 UTC). Similar flashes in the SSME exhaust plumes have been seen on previous missions. No follow-up action was requested.

2.2.4 Dark Debris Seen Near FSS
(Camera: E4)

At least two large, dark pieces of debris were seen to traverse the field of view from the direction of the FSS toward the LSRB at liftoff. The origin of the debris was not seen. The debris did not appear to strike the vehicle (08:13:05.640 UTC). No follow-up action was requested.

2.3 ASCENT EVENTS

2.3.1 Flares in SSME Exhaust Plume
(Cameras: ET207, ET212, ET213, E222)

Figure 2.3.1 Flares in SSME Exhaust Plume

Several flares were seen in the SSME exhaust plume from liftoff until after the roll maneuver. Flares in the SSME exhaust plume have been seen on previous missions. No follow-up action was requested.

2.3.2 Analysis of the Umbilical Well Camera Films (Task #2)

Three rolls of STS-76 umbilical well camera film were acquired: the 16 mm film (5 mm lens) and the 16 mm film (10 mm lens) from the LH2 umbilical, and the 35mm film from the LO2 umbilical. Neither the +X translation nor pitch maneuvers were performed on STS-76.

As on previous missions, multiple pieces of debris were seen throughout SRB separation. Most of the debris was TPS insulation. No follow-up action was requested.

Images of the External Tank were not acquired from the umbilical well cameras due to inadequate lighting.

2.4 LANDING EVENTS

2.4.1 Landing Sink Rate Analysis (Task #3)

The main gear sink rate of the Orbiter was determined using landing video over a one-second time period prior to main gear touchdown. Nose gear sink rate was not determined due to inadequate lighting.

The measured main gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb. vehicle and 6.0 ft/sec for a 240,000 lb. vehicle (the landing weight of the STS-76 Orbiter was reported to be 210,000 lb.). The sink rate measurements for STS-76 are given in Table 2.4.1. In Figure 2.4.1, the trend of the measured data points for film image data is illustrated.

Prior to Touchdown (1 Second)	Sink Rate: Film
Main Gear	2.4 ft/sec

Table 2.4.1 Sink Rate Measurements

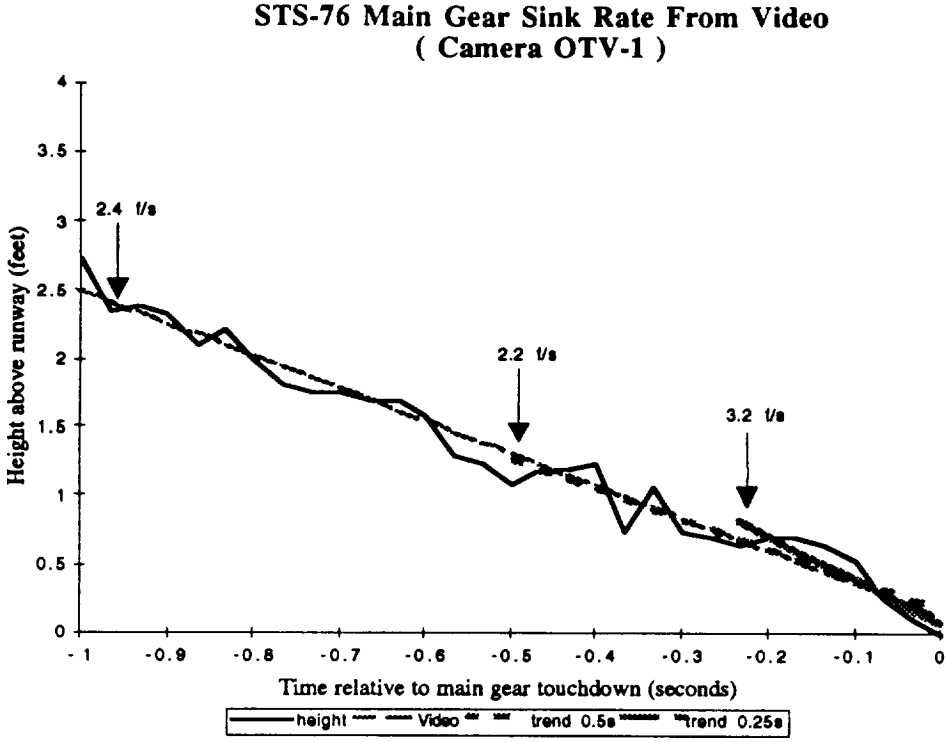

Figure 2.4.1 Main Gear Height versus Time Prior to Touchdown (Video)

2.5 OTHER

2.5.1 Normal Events

Other normal events observed include: Frost on and around the ET vent louvers, frost on the ET LO2 barrel and LH2 tank acreage TPS (+Y side), ice and vapor from the ET/Orbiter umbilical areas from SSME ignition through liftoff, inboard and outboard elevon motion at SSME ignition, body flap motion during SSME ignition and at liftoff, SRB flame duct and MLP debris at liftoff, ET twang, multiple pieces of light colored debris falling from the LH2 and LO2 TSM T-0 umbilicals at disconnect, ET aft dome outgassing and vapor off the SRB stiffener rings during liftoff, vapor and ice from the GUCP area during ET GH2 vent arm retraction, acoustic waves at liftoff, roll maneuver, linear optical effects, ET aft dome charring, recirculation, SRB plume brightening prior to SRB separation, SRB separation, and SRB slag material after SRB separation.

Normal events seen that are related to the pad are: hydrogen ignitor operation, fixed service structure (FSS) deluge water activation, GH2 vent arm retraction, sound suppression water initiation, mobile launch platform (MLP) water dump activation, LH2 and LO2 TSM T-0 umbilical disconnect, and TSM door closure at liftoff.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	May 1996	Final 22-31 March 1996

4. TITLE AND SUBTITLE
Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-76

5. FUNDING NUMBERS
OMRS00U0

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
NASA-TM-111675

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Blanket Release

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-76. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the ice/debris/thermal protection system conditions and integrated photographic analysis of Shuttle mission STS-76 and the resulting effect on the Space Shuttle Program.

14. SUBJECT TERMS
SUBJECT CATEGORY: 15, 16
STS-76 Thermal Protection System (TPS)
Ice Debris Photographic Analysis

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

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