Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-81

Jill D. Lin
Gregory N. Katnik

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Gregory N. Katnik
Jill D. Lin
Process Engineering/Mechanical System Division/ET-SRB Branch,
Kennedy Space Center, Florida

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12 January 1997

Contributions By:

NASA, United Space Alliance,
Lockheed-Martin, Boeing North American, and Thiokol Members of the
Debris/Ice/TPS and Photographic Analysis Teams

Prepared By:

Jill D. Lin
Shuttle Ice/Debris Systems
NASA/KSC/PK-H7

Approved:

James G. Tatum
Chief, ET/SRB Mech/TPS Systems
NASA/KSC/PK-H7

Gregory N. Katnik
Shuttle Ice/Debris Systems
NASA/KSC/PK-H7

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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-81

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 11 January 1997. The detailed walkdown of Pad 39B and MLP-2 also included the primary flight elements OV-104 Atlantis (18th flight), ET-83 (LWT 76), and BI-082 SRB's. There were no significant vehicle or pad anomalies.

With the January/winter launch and a liftoff time of 4:27 a.m. local, weather conditions were predicted to be favorable for the formation of ice on the External Tank along with the potential for exceeding the Launch Commit Criteria. Based upon weather predictions the day before launch, the SURFICE computer program calculated the surface temperature on the LO2 tank barrel section and the upper LH2 tank would drop below 32 degrees F as early as L-7 hours.

The vehicle was cryoloaded for flight on 11 January 1997. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 violations. No IPR's were taken. Because wind speed and ambient temperatures were greater than expected/predicted, no significant amount of ice was able to form on the LO2 and LH2 tank acreage. There were no protuberance icing conditions outside of the established data base.

Minor damage to the ET nosecone/footprint area was visible after the GOX vent hood was retracted. An 8-inch long by 6-inch wide piece of ET topcoat along with a small piece of TPS, 1-inch long by 3/8-inch wide by 1/8-inch thick, adhered to the lower right side of the northeast GOX vent seal.

After the 4:27 a.m. (local) launch on 12 January 1997, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal.

A total of 107 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.

No stud hang-ups or frangible nut/ordnance debris was observed on any of the holddown posts.

ET-83 separation from the Orbiter was not visible in the ET/ORB umbilical films due to the night launch. After the Orbiter and separated ET crossed the terminator, the resulting lighting conditions provided good resolution of TPS divots in the -Z LH2 tank-to-intertank flange closeout. Seven divots, some of which were estimated to be a large as 20 inches in diameter, were located close to the -Z axis. Some of the divots in the flange closeout extended forward into the intertank stringer head TPS. Six more divots were detected generally aft of the EB-2 fitting in the LH2 tank to +Y thrust panel flange closeout.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. Both frustums were in good condition with less than 30 MSA-2 debonds total. The holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally

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 inspection of OV-104 was conducted 22 January 1997 on SLF runway 33 at the Kennedy Space Center. The Orbiter TPS sustained a total of 100 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 less than average.

The largest lower surface tile damage site was located on the right inboard elevon, spanned two tiles, and measured 8.0-inches long by 2.5-inches wide by 0.675-inch maximum depth. The depth of the damage site indicates a probable impact by ice - possibly from the ET LO2 feedline bellows.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly.

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles (4 hits on window #2, 3 hits on #3, 2 hits on #4, and 6 hits on #5) were attributed to impacts from the FRCS thruster paper covers/RTV adhesive.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 10 January 1997 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
R. Speece	NASA - KSC	Thermal Protection Systems
B. Bowen	NASA - KSC	Infrared Scanning Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
M. Bassignani	NASA - KSC	ET Mechanisms/Structures
B. Davis	NASA - KSC	Digital Imaging Systems
R. Page	NASA - KSC	Level II Integration
M. Valdivia	USA - SPC	Supervisor, ET/SRB Mechanical Systems
R. Seale	USA - SPC	ET Mechanical Systems
J. Blue	USA - SPC	ET Mechanical Systems
W. Richards	USA - SPC	ET Mechanical Systems
M. Wollam	USA - SPC	ET Mechanical Systems
G. Fales	USA - SPC	ET Mechanical Systems
C. Simons	USA - SPC	ET Mechanical Systems
J. Stone	BNA - DNY	Shuttle Aerodynamics
F. Foster	Boeing North American LSS Systems Integration	
W. Atkinson	Boeing North American LSS Systems Integration	
M. Nowling	THIO - LSS SRM Processing	
S. Otto	LMSO - LSS ET Processing	

3.0 LAUNCH

STS-81 was launched at 97:012:09:27:22.984 UTC (4:27 a.m. local) on 12 January 1997.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 11 January 1997. The detailed walkdown of Pad 39B and MLP-2 also included the primary flight elements OV-104 Atlantis (18th flight), ET-83 (LWT 76), and BI-082 SRB's. There were no significant vehicle or launch pad anomalies.

With the January/winter launch and a liftoff time of 4:27 a.m. local, weather conditions were predicted to be favorable for the formation of ice on the External Tank along with the potential for exceeding the Launch Commit Criteria. Based upon weather predictions the day before launch, the SURFICE computer program calculated the surface temperature on the LO2 tank barrel section and the upper LH2 tank would drop below 32 degrees F as early as L-7 hours.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 11-12 January 1997 from 1030 to 0045 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 violations. No Ice, Debris, or TPS IPR's were taken. Because wind speed and ambient temperatures were greater than expected/predicted, no significant amount of ice was able to form on the LO2 and LH2 tank acreage. 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.

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The R4U, R1R, R4R, R2R, L4L, and F3L RCS thruster covers were intact, but tinted green indicating small internal vapor leaks. Ice/frost had formed on SSME #1 and #2 heat shield-to-nozzle interfaces. Condensate was present on the SSME #3 heat shield-to-nozzle interface. 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 radiometers averaged 58-61 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 62 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 1945 to 0415 hours. As-built TPS thicknesses were used in the SURFICE data input along with real-time weather parameters. The program predicted condensate, but no ice, with TPS surface temperatures approaching, but not falling below, 32 degrees F.

The Final Inspection Team observed light condensate and isolated patches of frost, but no ice accumulations, on the LO2 tank. TPS surface temperatures ranged from 31 degrees F (in the frosted areas) to 41 degrees F (on the ogive).

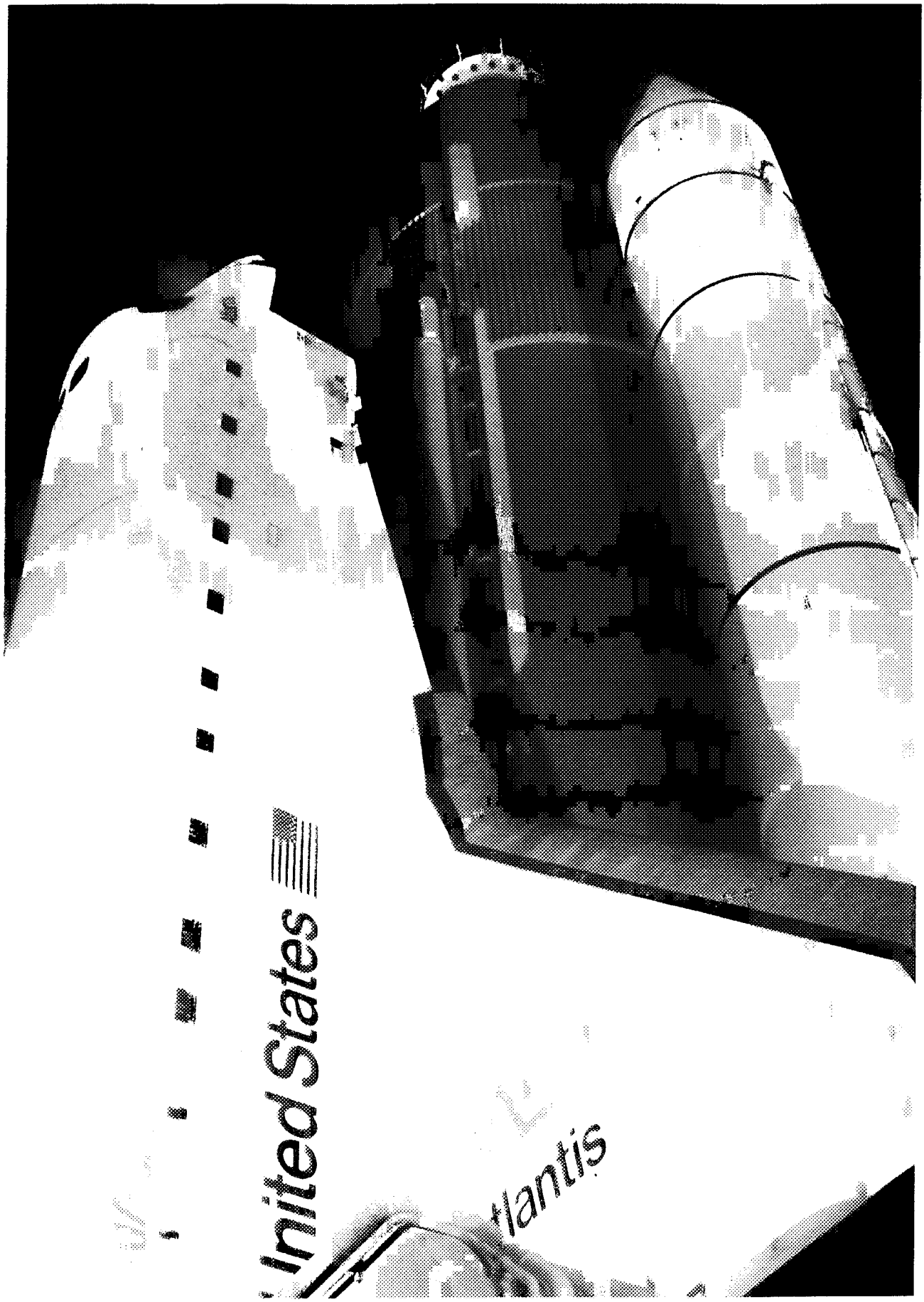


Photo 2: STS-81 Cryoloaded for Flight

OV-104 Atlantis (18th flight), ET-83 (LWT 76), BI-082 SRB's

Photo 3: Ice/frost on #2 Heat Shield-to-Nozzle Interface

Photo 4: ET LO2 Tank and Intertank

Light condensate and isolated patches of frost, but no ice accumulations, were observed on the LO2 tank. TPS surface temperatures ranged from 31 degrees F (in the frosted areas) to 41 degrees F (on the ogive).

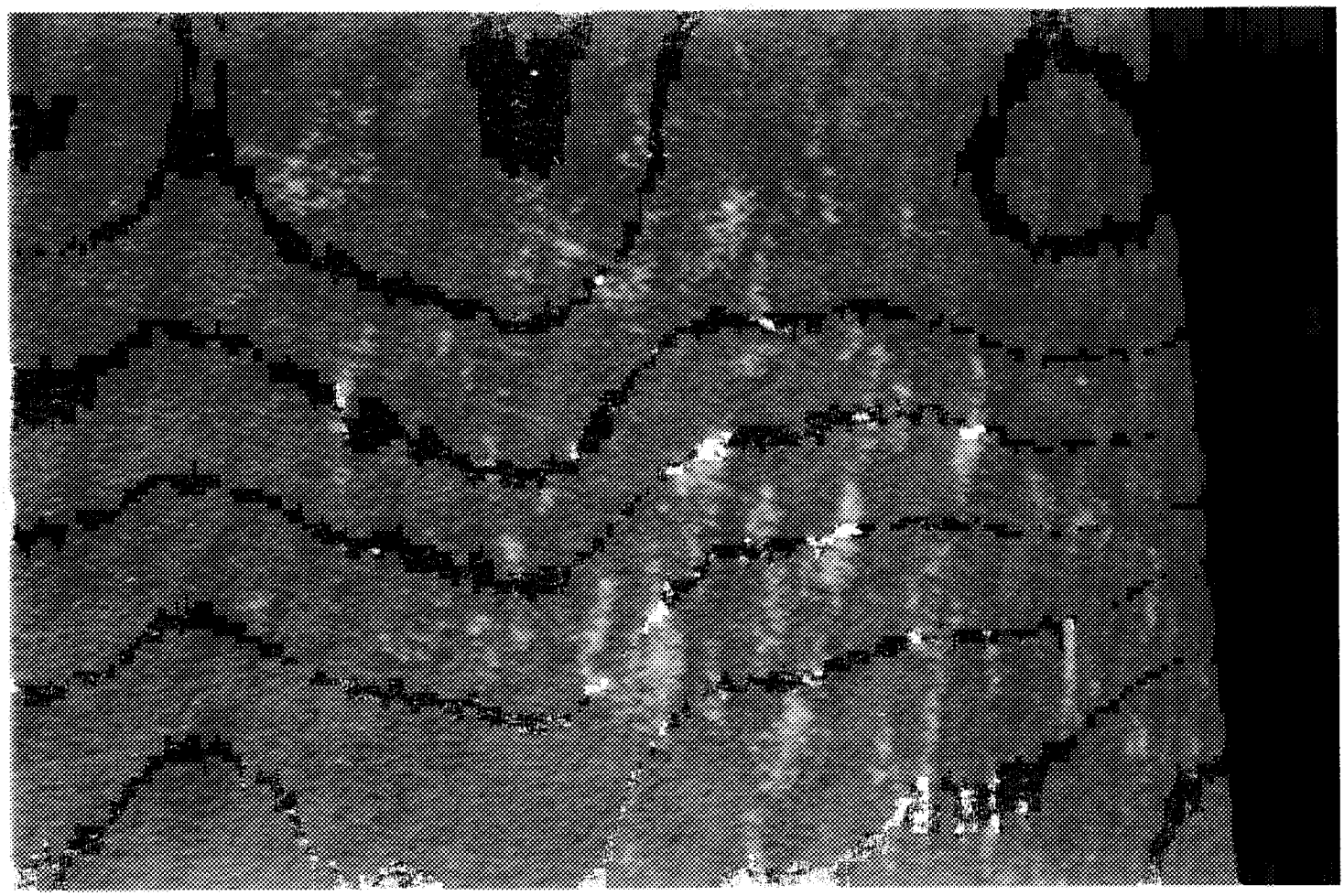


Photo 5: ET LO2 Tank Frost Patch

Isolated patches of frost formed on the LO2 tank.

The intertank acreage exhibited no TPS anomalies. Ice/frost accumulation on the GUCP appeared typical. The portable STI measured an average surface temperature of 59 degrees F on the intertank.
The Final Inspection Team observed light-to-moderate condensate, but no ice or frost accumulations, on the LH2 tank. TPS surface temperatures ranged from 33-36 degrees F as measured by the infrared radiometers. Frost lines were visible along the bipod spindle housing closeouts, PAL ramps, and cable tray ramps.

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

An 7-inch long by ¼-inch wide stress relief crack had formed on the -Y vertical strut forward facing TPS. The presence of the crack was expected and acceptable for flight per the NSTS-08383 criteria.

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

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate.

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

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch.

No leaks were observed on the LO2 and LH2 Orbiter T-0 umbilicals, the GH2 vent line, or the Ground Umbilical Carrier Plate (GUCP).

Minor damage to the ET nosecone/footprint area was visible after the GOX vent hood was retracted. An 8-inch long by 6-inch wide piece of ET topcoat along with a small piece of TPS 1-inch long by 3/8-inch wide by 1/8-inch thick adhered to the lower right side of the northeast GOX vent seal.

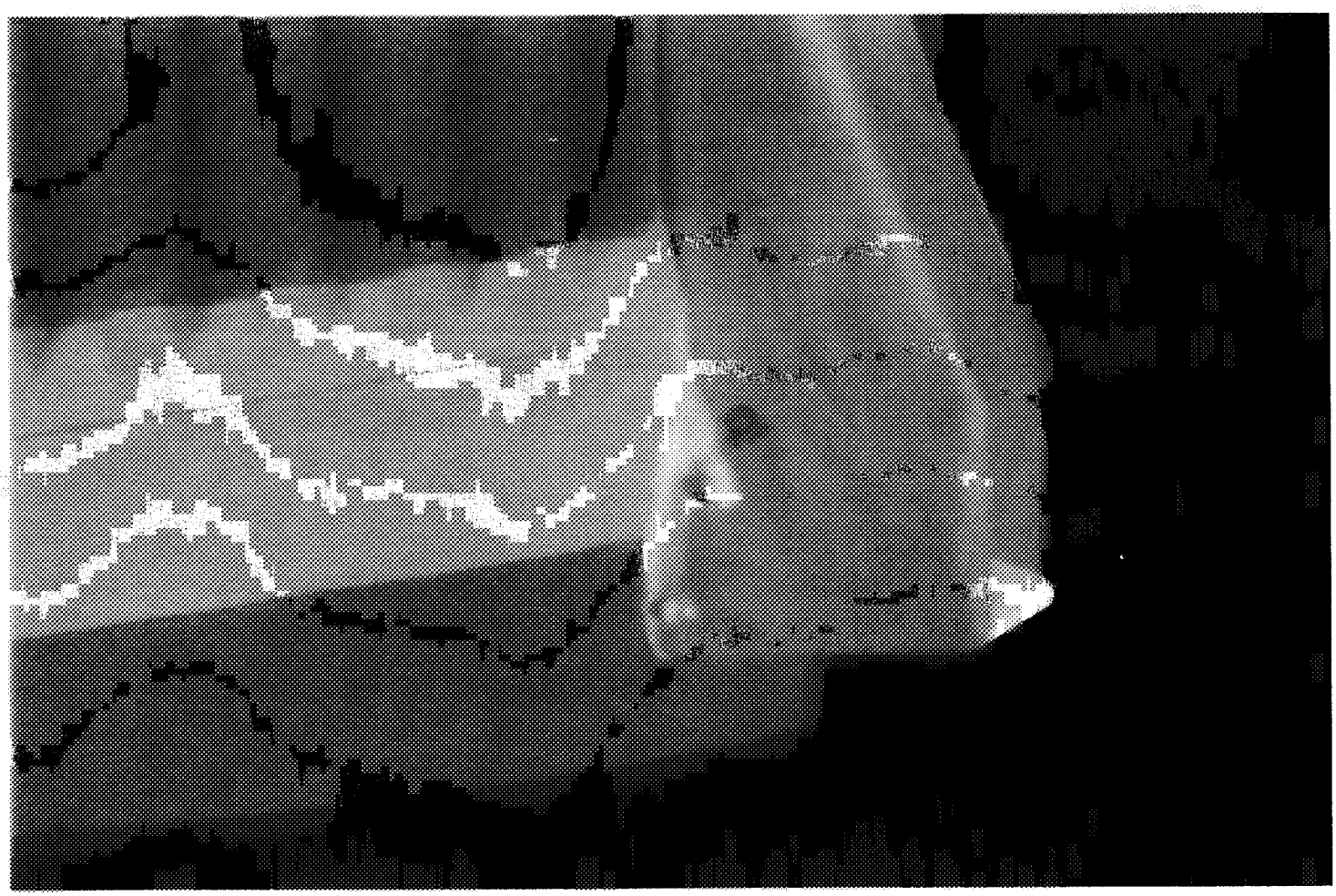


Photo 6: Frost on Bipod Spindle Housing Closeout

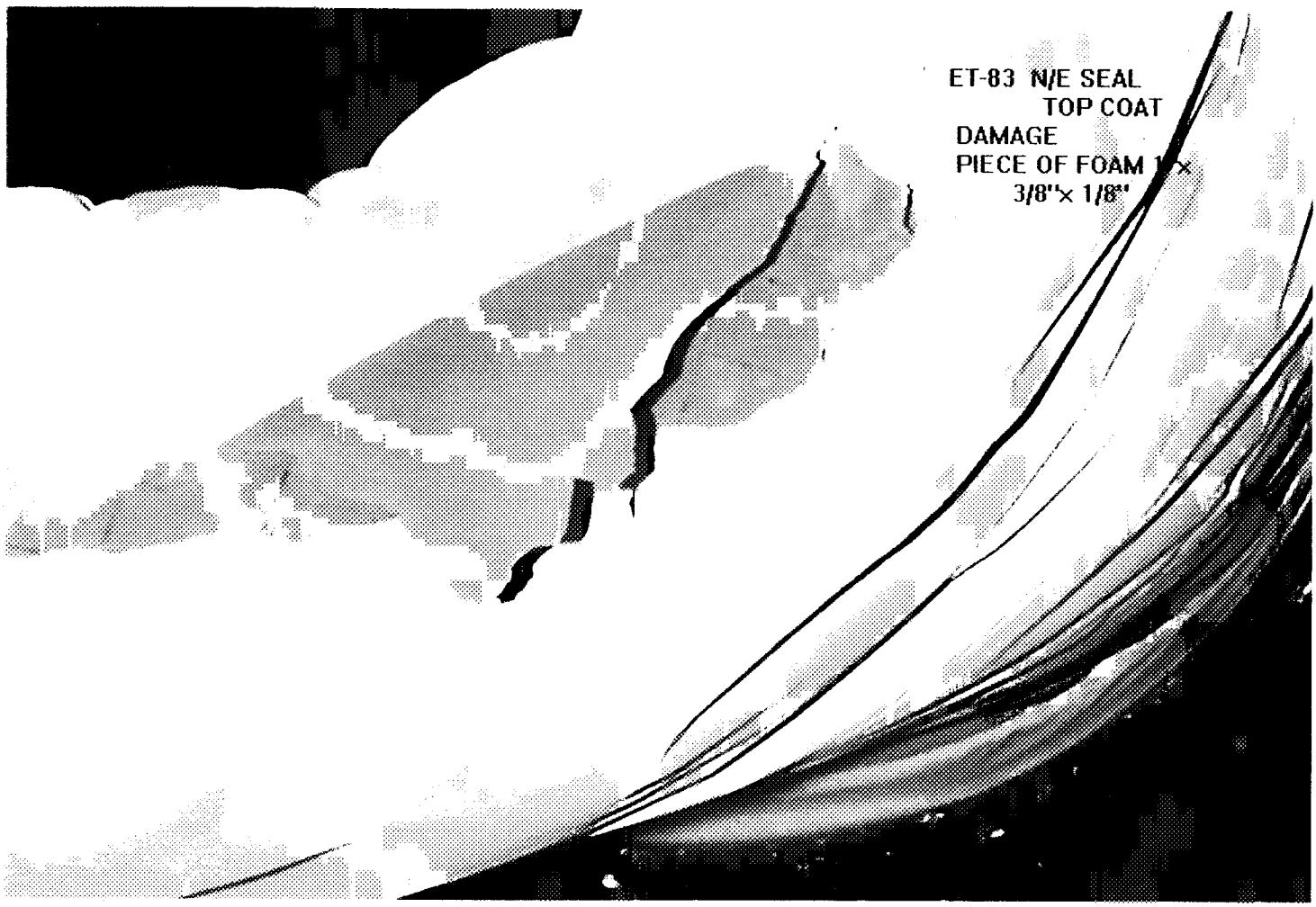


Photo 7: Topcoat Adhered to GOX Vent Seals

Minor damage to the ET nosecone/footprint area was visible after the GOX vent hood was retracted. An 8-inch long by 6-inch wide piece of ET topcoat along with a small piece of TPS, 1-inch long by 3/8-inch wide by 1/8-inch thick, adhered to the lower right side of the northeast GOX vent seal.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 2, Pad B, FSS, and RSS was conducted on 12 January 1997 for 1.5 hours starting at Launch + 1.5.

SRB Hold Down Post (HDP) erosion was typical. Ten inches of the HDP #2 shim was debonded from the shoe. The reported Orbiter lateral accelerometer measurement of 0.09 g's most likely indicated a clean launch with no stud hang-ups, which have occurred on previous missions with lateral accelerations ranging from 0.14 to 0.31 g's. HDP film analysis and more detailed HDP/SRB aft skirt inspections verified there were no stud hang ups. The HDP blast covers had closed properly. Aft skirt purge lines and T-0 umbilicals exhibited typical exhaust plume damage. The concrete buttress on the northwest corner of the LH2 TSM was damaged. Pieces of the buttress were found on the pad apron.

The Tail Service Masts (TSM), Orbiter Access Arm, and GOX Vent Arm had no visible indications of damage. TSM doors had closed normally.

The GH2 vent line was latched on the sixth of eight teeth of the latching mechanism. The ET GUCP had been struck by the retract lanyard as indicated by cable marks/impressions on the LH pivot assembly.

An 8-inch long by 6-inch wide piece of ET topcoat along with a small piece of TPS 1-inch long by 3/8-inch wide by 1/8-inch thick adhered to the lower right side of the northeast GOX vent seal. This material had been pulled loose from the ET nose cone during GOX vent hood retraction at T-2:30 minutes.

Miscellaneous facility straps and clamps were found on the pad apron/acreage.

Overall, damage to the pad appeared minimal.

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.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 84 films and videos, which included twenty-nine 16mm films, sixteen 35mm films, and thirty-nine videos, were reviewed starting on launch day.

Green-tinted vapors between SSME #1 and the LH2 TSM appeared to be associated with hydrogen igniter activation, but may also have been caused by the green laser illumination test. Free burning hydrogen, rising to the APCS pods during SSME ignition, appeared orange in color as previously observed (E-77; OTV-170 and -171).

SSME ignition appeared normal (OTV-151, -163, -170, -171, TV-4; E-76). RCS paper cover debris caused streaks in the SSME exhaust plume during start-up 09:27:20.807 (E-15). A flash in the SSME #2 Mach diamond may have been caused by propellant impurities (E-16).

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-163 and -164). A white object, believed to be a piece of umbilical purge barrier baggie, or RCS paper cover, was observed at the bottom of the frame passing under the body flap (OTV-163).

Tile surface coating material was lost during ignition from two places on the base heatshield outboard of SSME #2 (E-17), from four places on the body flap upper surface +Y side (E-19, E-76, OTV 170), one place on the base heatshield adjacent to SSME #3 (E-19), and one place on the base heatshield between SSME #1 and #2 (E-20).

Launch vibration caused three pieces of ice to shake loose from the LOX feedline upper bellows. One piece made a glancing impact with orbiter tiles, but no damage occurred (OTV-161; TV-7; E-34, -52).

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

GUCP disconnect from the ET was nominal (OTV-103 and -104). A typical amount of frost, but no TPS damage, was visible around the lower half of the ET umbilical carrier plate (E-33).

No stud hang-ups or frangible nut/ordnance debris was observed on any of the holddown posts.

A rigid debris object, similar to a welding rod and approximately 12 inches long, lay on the MLP deck near the HDP #5 portable crane pedestal prior to liftoff. The object rolled into an expansion joint at T-0 (E-12).

Numerous pieces of SRB throat plug were ejected from the SRB exhaust holes and north flame trench at T-0. None of the pieces contacted the vehicle (E-59, -60).

A considerable amount of condensate or facility water (blown by the northwest winds) fell aft from the rudder/speed brake through tower clear and beginning of the roll maneuver (E-52, -213). Water draining from the split in the rudder/speed brake shortly after liftoff was also visible in film items E-57 and E-60.

Photo 8: Green-Tinted Vapors Between SSME #1 and LH2 TSM

Green-tinted vapors between SSME #1 and the LH2 TSM appeared to be associated with hydrogen igniter activation, but may also have been caused by the green laser illumination test.

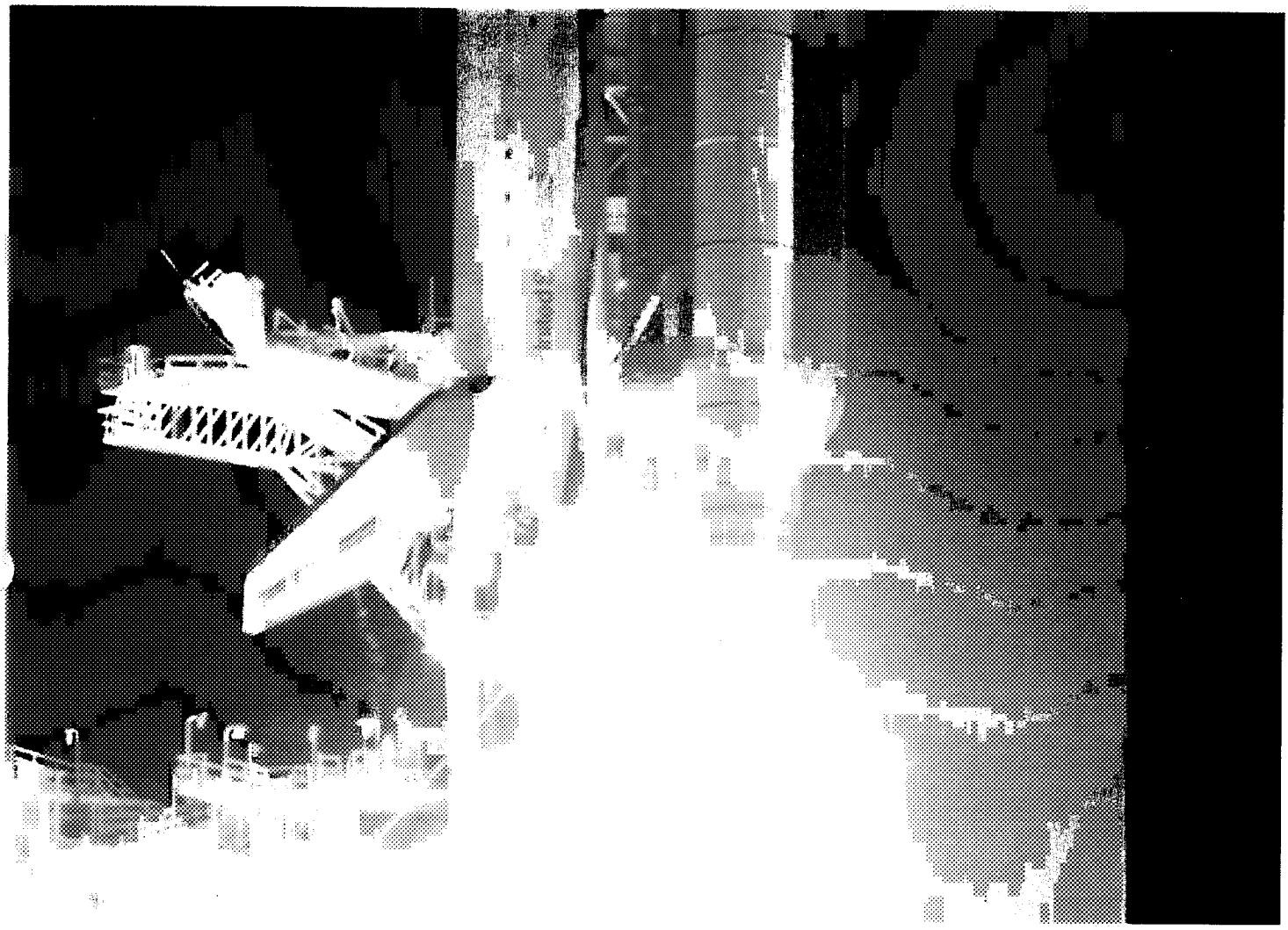


Photo 9: Condensate or Facility Water Falling Aft From the Rudder/Speed Brake

A considerable amount of condensate or facility water (blown by the northwest winds) fell aft from the rudder/speed brake through tower clear and beginning of the roll maneuver.

Most of the ET/ORB umbilical purge barrier material came loose and fell aft at the beginning of the roll maneuver 27:37.1 UTC (E-207, -222).

Debris streaks occurred in the SSME exhaust plume during ascent at 27.43 and 27.46 seconds UTC (E-207, -222).

Body flap movement (amplitude and frequency) was clearly visible in film item E-207 and E-212.

Three light colored particles, most likely SRB aft skirt insta-foam, fell from the SRB exhaust plume between T + 55 seconds and T + 78 seconds (TV-4).

Exhaust plume recirculation was typical (E-207).

SRB separation appeared normal. Due to the dark conditions of the night launch, numerous pieces of slag were readily visible falling from the SRB plume during and after separation (TV-13, TV-4, E-207, -208 and -212).

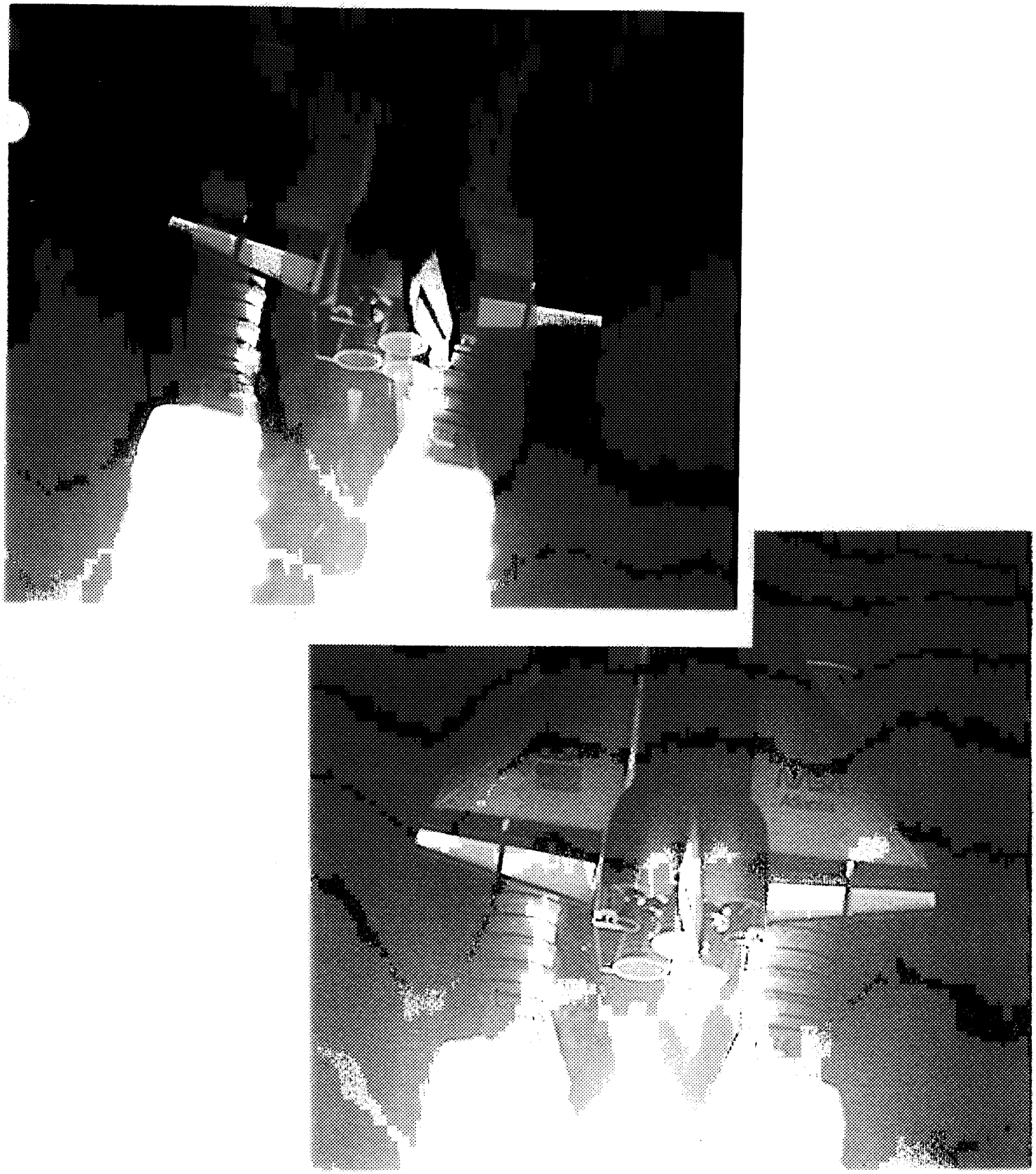


Photo 10: Loose ET/ORB Umbilical Purge Barrier

Most of the ET/ORB umbilical purge barrier came loose and fell aft at the beginning of the roll maneuver.

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. An early OMS-2 attitude pitch maneuver was performed on this flight. Handheld photography by the flight crew consisted of twenty still 35mm images.

SRB separation from the External Tank appeared nominal.

Erosion and charring of TPS on the aft surfaces of the LH2 ET/ORB umbilical cable tray and -Y vertical strut was typical. Divots from missing TPS on the -Y upper strut splice plate closeouts were analyzed and judged to be shallow.

ET-83 separation from the Orbiter was not visible in the ET/ORB umbilical films due to the night launch.

After the Orbiter and separated ET crossed the terminator, the resulting lighting conditions provided good resolution of TPS divots in the -Z LH2 tank-to-intertank flange closeout. Seven divots, some of which were estimated to be a large as 20 inches in diameter, were located close to the -Z axis. Some of the divots in the flange closeout extended forward into the intertank stringer head TPS. Six more divots were detected generally aft of the EB-2 fitting in the LH2 tank to +Y thrust panel flange closeout.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 20 films and videos, which included nine 35mm large format films and eleven videos, were reviewed. The films were generally dark due to the pre-dawn lighting conditions.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. Left and right main landing gear touchdown was virtually simultaneous at approximately 3,000 feet from the runway threshold. The Orbiter stayed close to the runway centerline during rollout.

Drag chute deployment appeared nominal.

Touchdown of the nose landing gear was smooth. Rollout and wheel stop were uneventful.

No significant TPS damage was visible in the films.

Photo 11: SRB Separation

SRB separation from the External Tank appeared nominal.

Photo 12: ET After Separation

After the Orbiter and separated ET crossed the terminator, the resulting lighting conditions provided good resolution of TPS divots in the -Z LH2 tank-to-intertank flange closeout. Seven divots, some of which were estimated to be a large as 20 inches in diameter, were located close to the -Z axis. Some of the divots in the flange closeout extended forward into the intertank stringer head TPS. Six more divots were detected generally aft of the EB-2 fitting in the LH2 tank to +Y thrust panel flange closeout.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-082 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 14 January 1997.

Both frustums were in excellent condition. No TPS was missing. The LH frustum exhibited 17 MSA-2 debonds over fasteners (Figure 1) while the RH frustum exhibited 10 debonds over fasteners and three debonds over acreage (Figure 2). Hypalon paint was blistered/missing along the XB-395 ring frames. All eight BSM aero heat shield covers were undamaged and locked in the fully opened position.

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

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, and IEA covers appeared undamaged from splashdown.

TPS on the external surface of both aft skirts was intact and in good condition. Internally, foam was missing and substrate exposed on the aft skirt aft rings.

The holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally. There were no indications of any stud hang-ups.

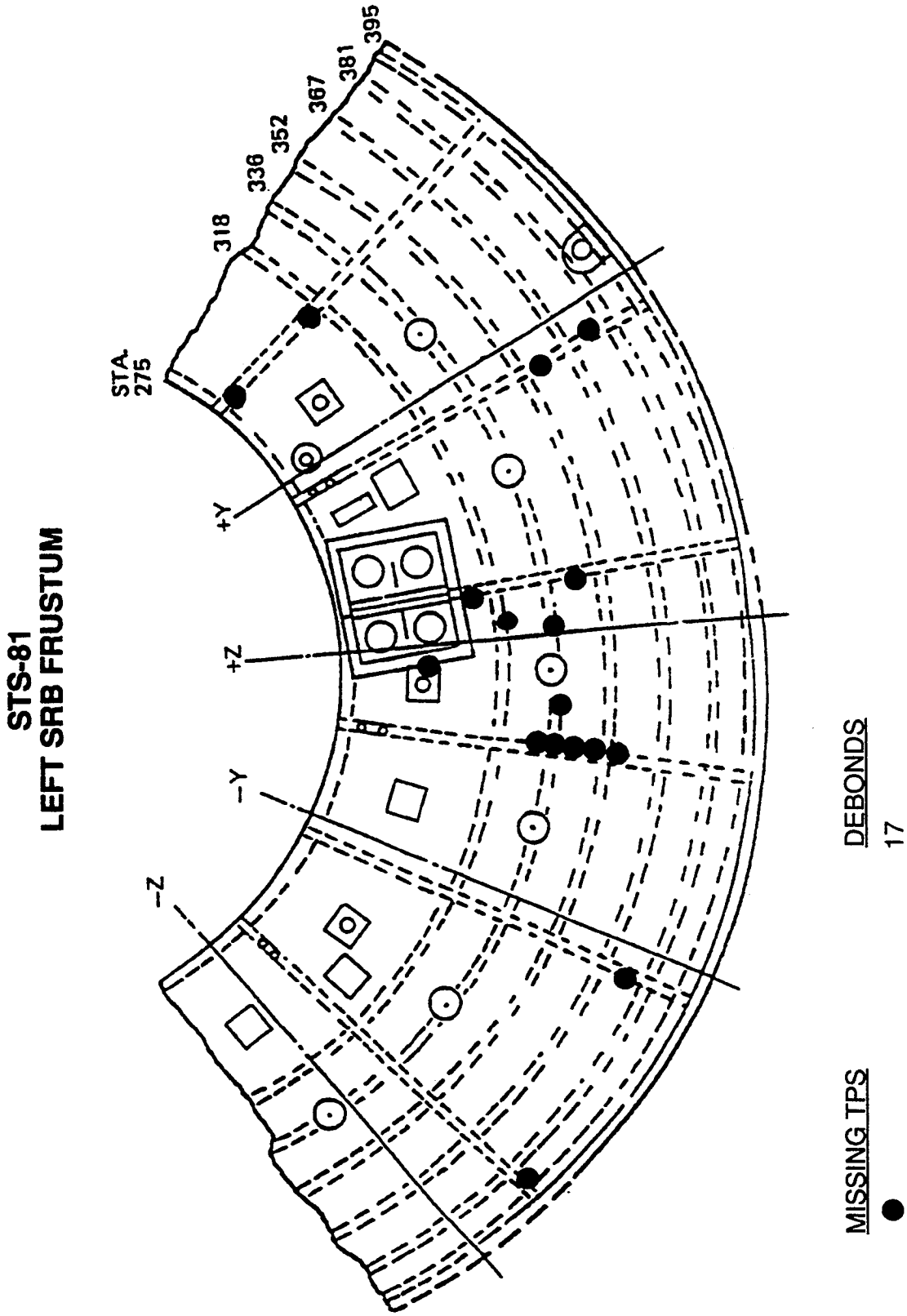


Figure 1: LH Frustum

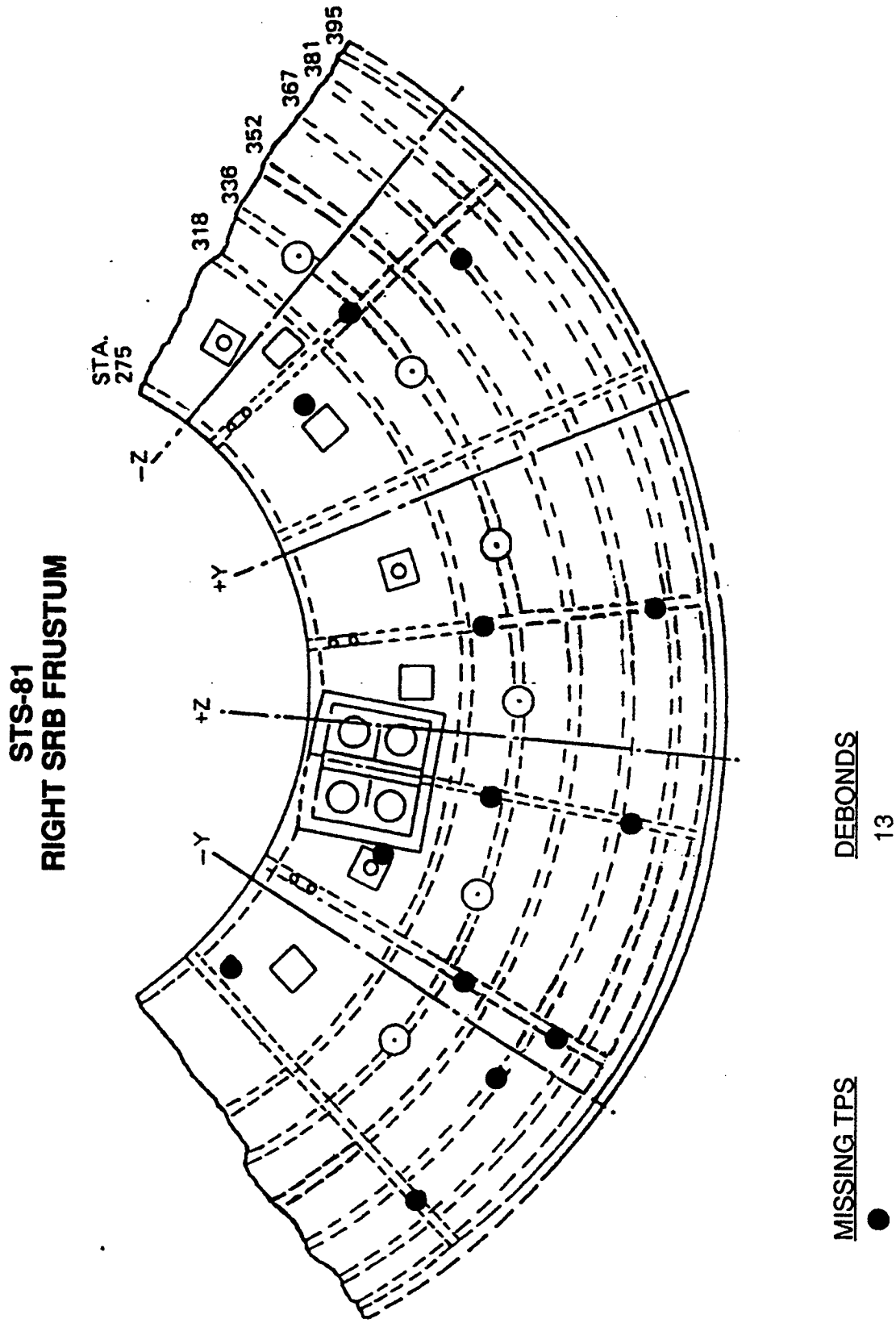


Figure 2: RH Frustum

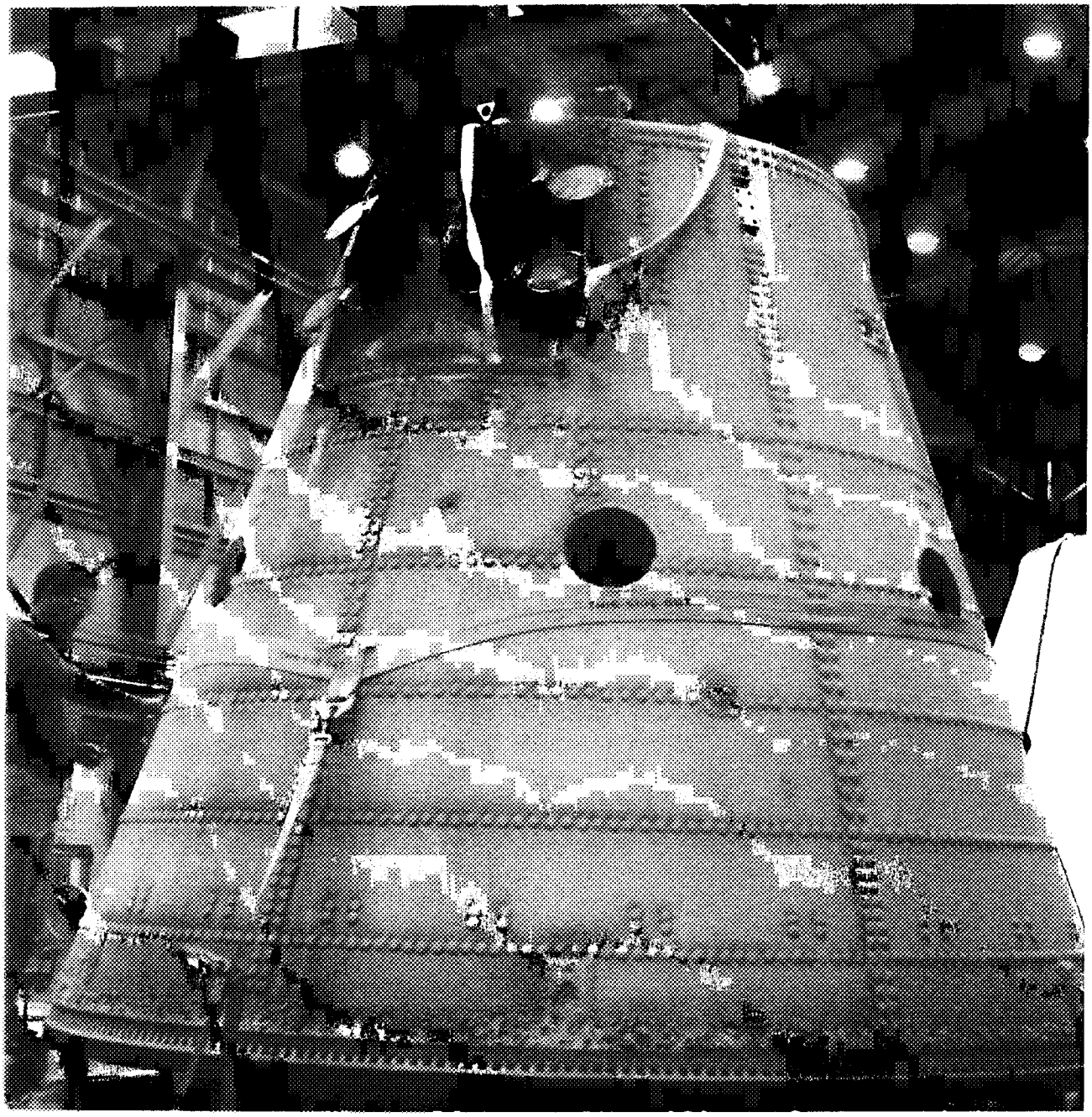


Photo 13: LH Frustum

The LH frustum exhibited 17 MSA-2 debonds over fasteners. Hypalon paint was blistered/missing along the XB-395 ring frame. All four BSM aero heat shield covers were undamaged and locked in the fully opened position.

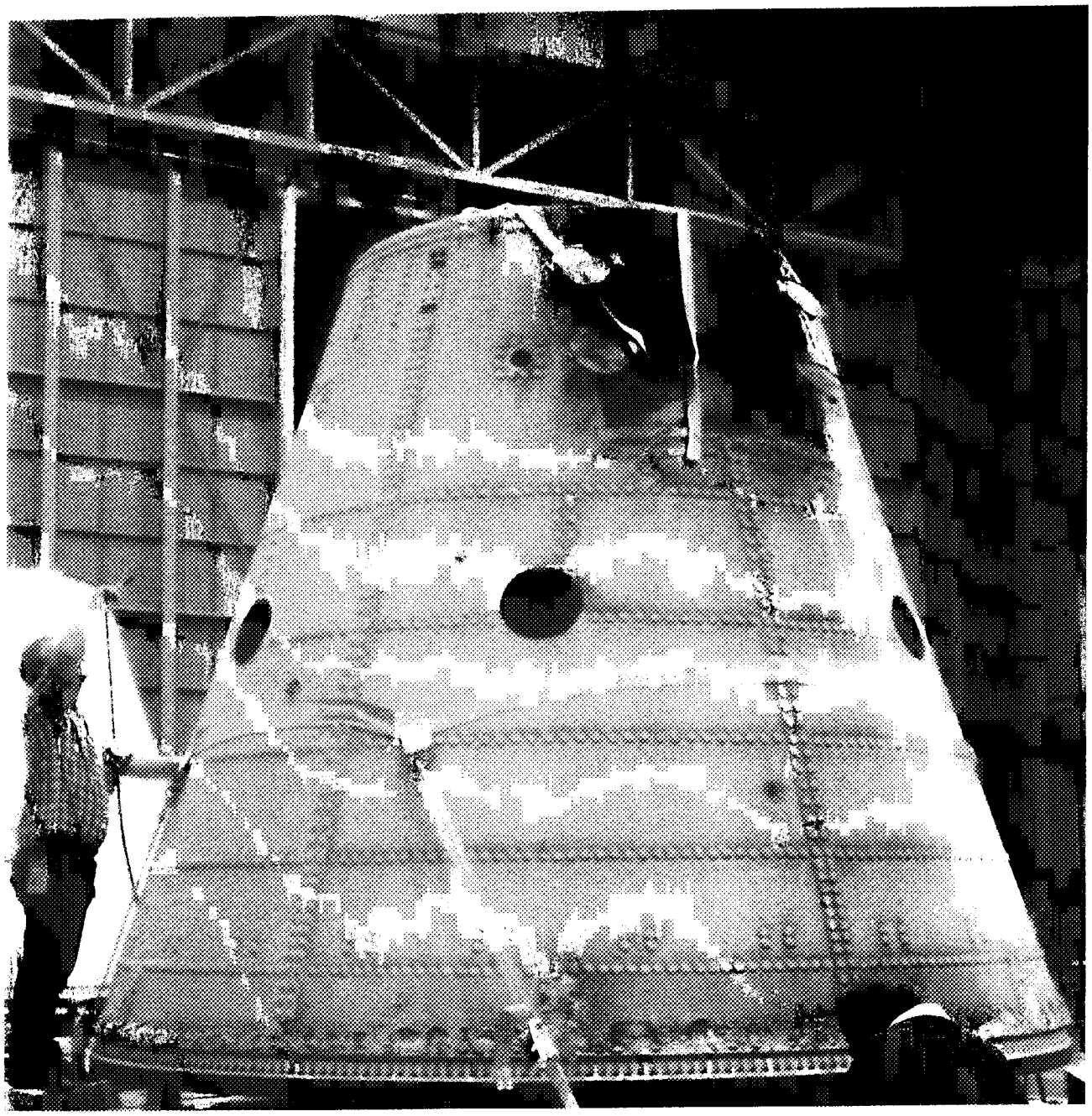


Photo 14: RH Frustum

The RH frustum exhibited 10 debonds over fasteners and three debonds over acreage. Hypalon paint was blistered/missing along the XB-395 ring frame. All four BSM aero heat shield covers were undamaged and locked in the fully opened position.

Photo 15: LH Forward Skirt

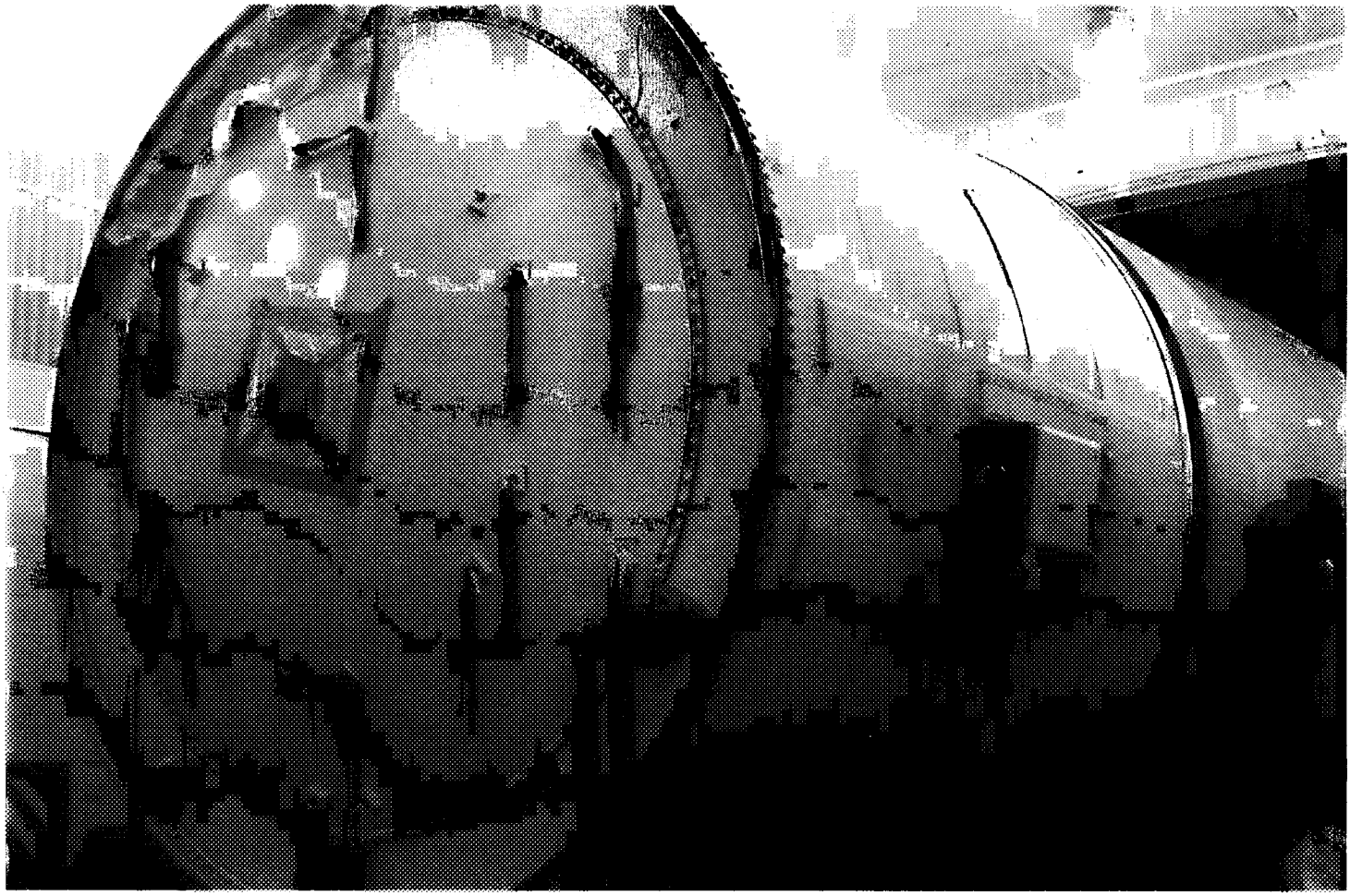


Photo 16: RH Forward Skirt

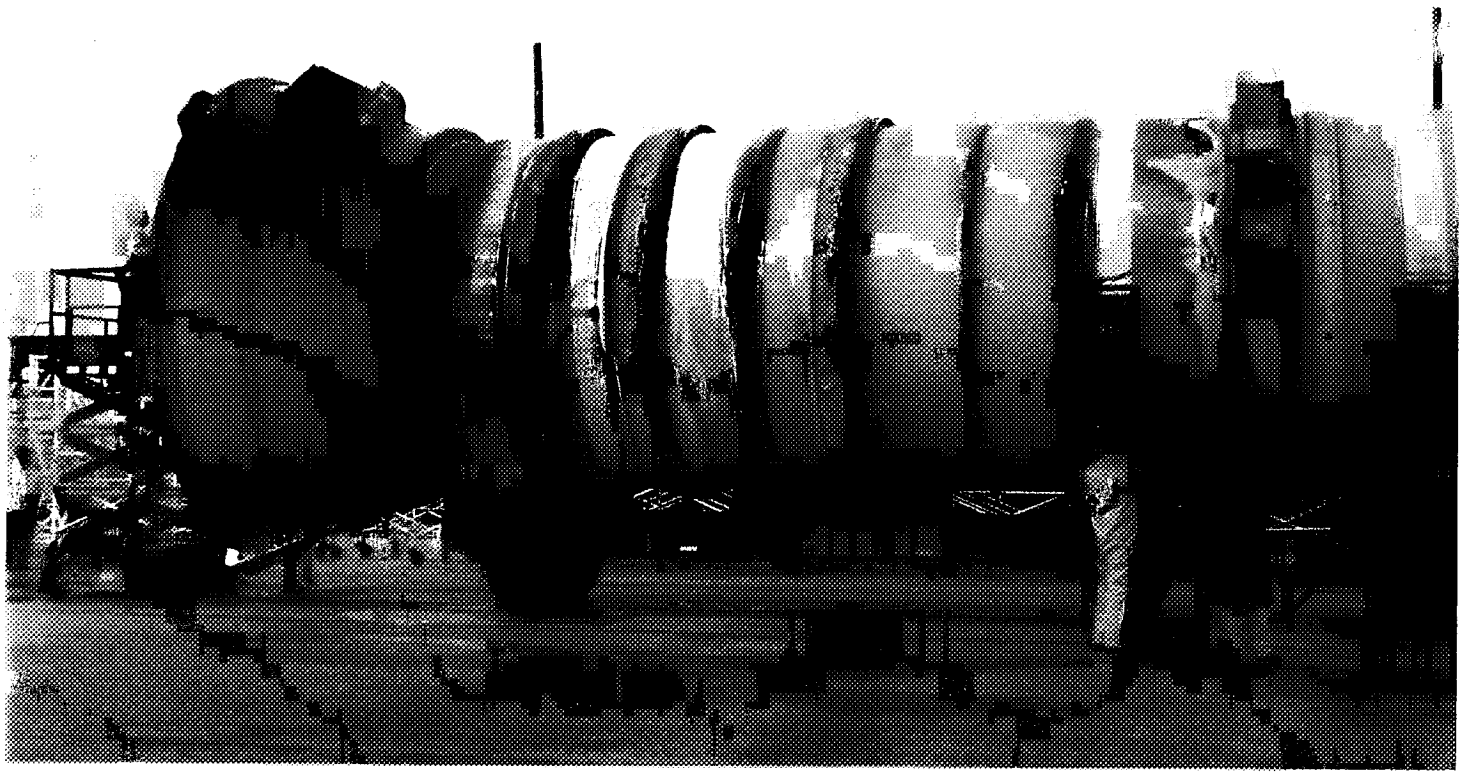


Photo 17: LH Aft Booster

Photo 18: RH Aft Booster

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-104 Atlantis was conducted 22-24 January 1997 at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #3. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 100 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 65 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 were less than average (Figures 3-6).

The following table breaks down the STS-81 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	14	48
Upper surface	0	31
Right side	0	7
Left side	0	7
Right OMS Pod	1	3
Left OMS Pod	0	4
TOTALS	15	100

The largest lower surface tile damage site was located on the right inboard elevon, spanned two tiles, and measured 8.0-inches long by 2.5-inches wide by 0.675-inch maximum depth. The depth of the damage site indicates a probable impact by ice - possibly from the ET LO2 feedline bellows.

Tile damage sites aft of the LH2 ET/ORB umbilical were typical. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the air stream.

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

The tires and brakes were reported to be in good condition for a landing on the KSC concrete runway. There was no ply undercutting visible on any of the tires.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. Two spring clips were missing from the EO-3 "salad bowl". No ordnance fragments were found on the runway beneath the umbilical cavities. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect. However, loose pieces of white RTV hung from several of the umbilical pyro separation devices.

The SSME #2 and #3 Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition. The SSME #1 blankets were torn/frayed at the 7:00-8:00 o'clock position.

Tiles on the vertical stabilizer "stinger" were intact and undamaged with the exception of one small area near the hinge of the drag chute door.

No ice adhered to the payload bay door. No unusual tile damage occurred on the leading edges of the vertical stabilizer and OMS pods.

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles (4 hits on window #2, 3 hits on #3, 2 hits on #4, and 6 hits on #5) were attributed to impacts from the FRCS thruster paper covers/RTV adhesive.

The post landing walkdown of Runway 33 was performed immediately after landing. No debris concerns were identified. All drag chute hardware was recovered and appeared to have functioned normally.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were less than average when compared to the average of previous missions (Figure 7).

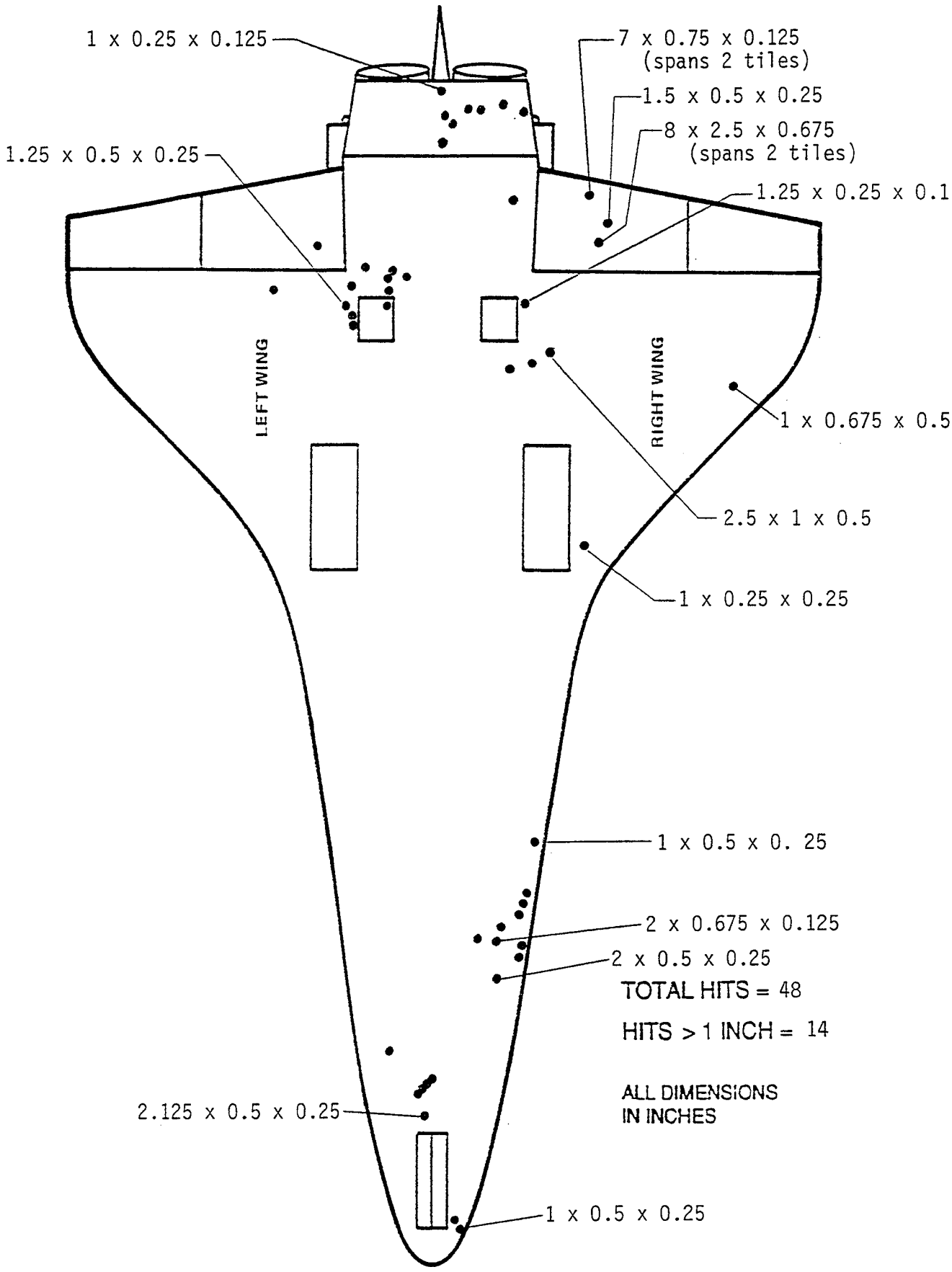
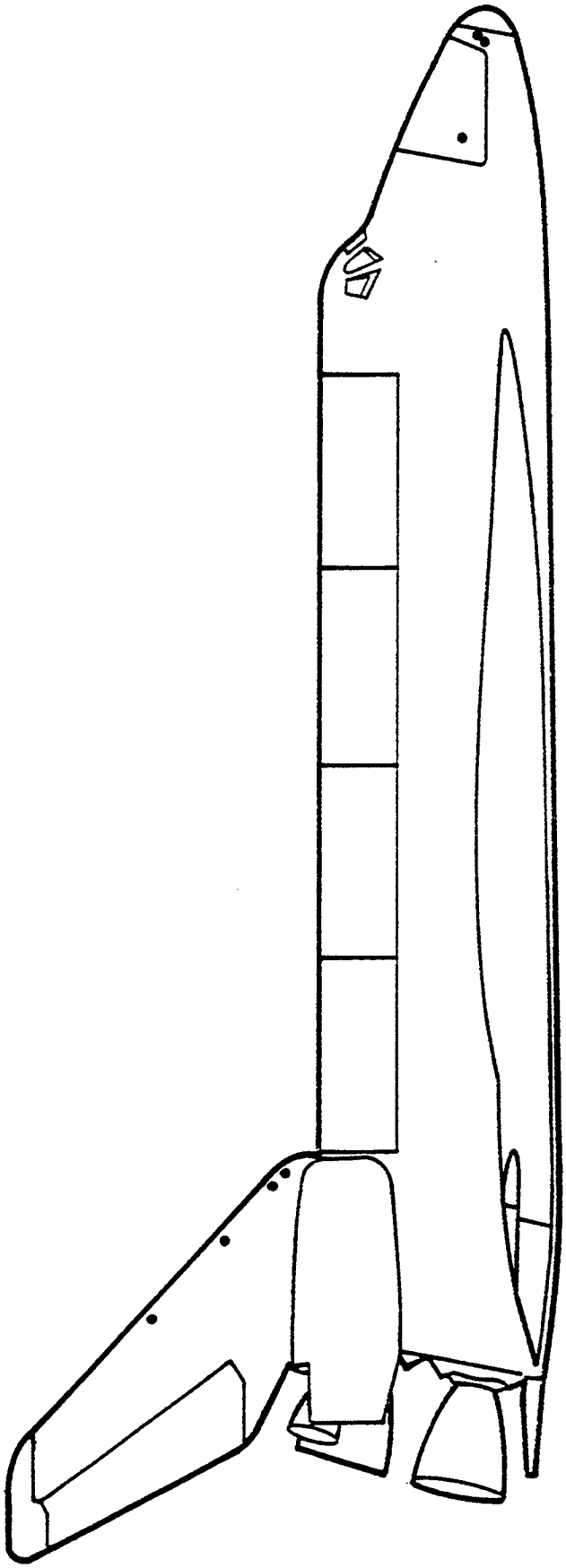


Figure 3: Orbiter Lower Surface Debris Map



TOTAL HITS = 7

HITS > 1 INCH = 0

Figure 4: Orbiter Right Side Debris Map

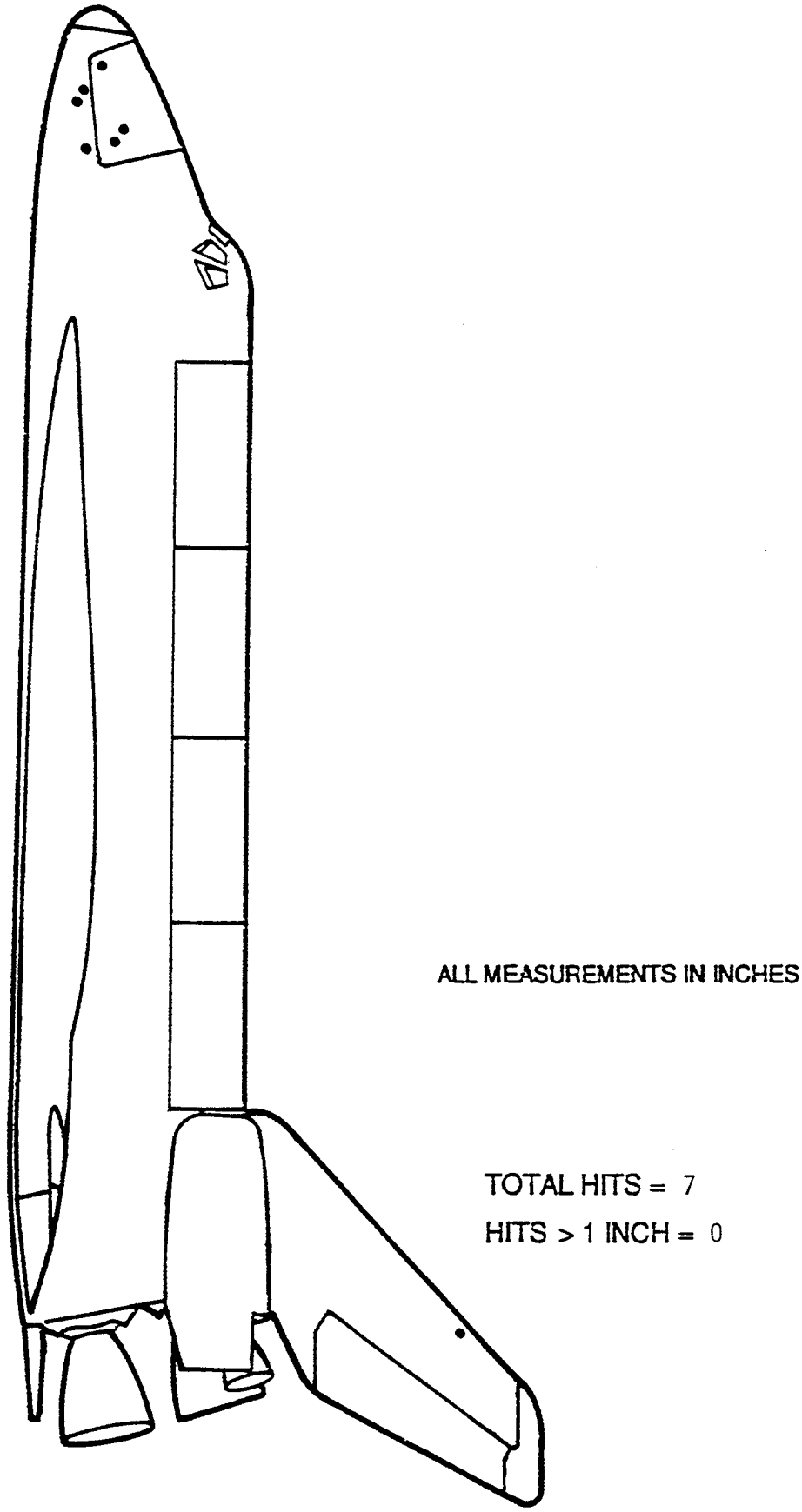


Figure 5: Orbiter Left Side Debris Map

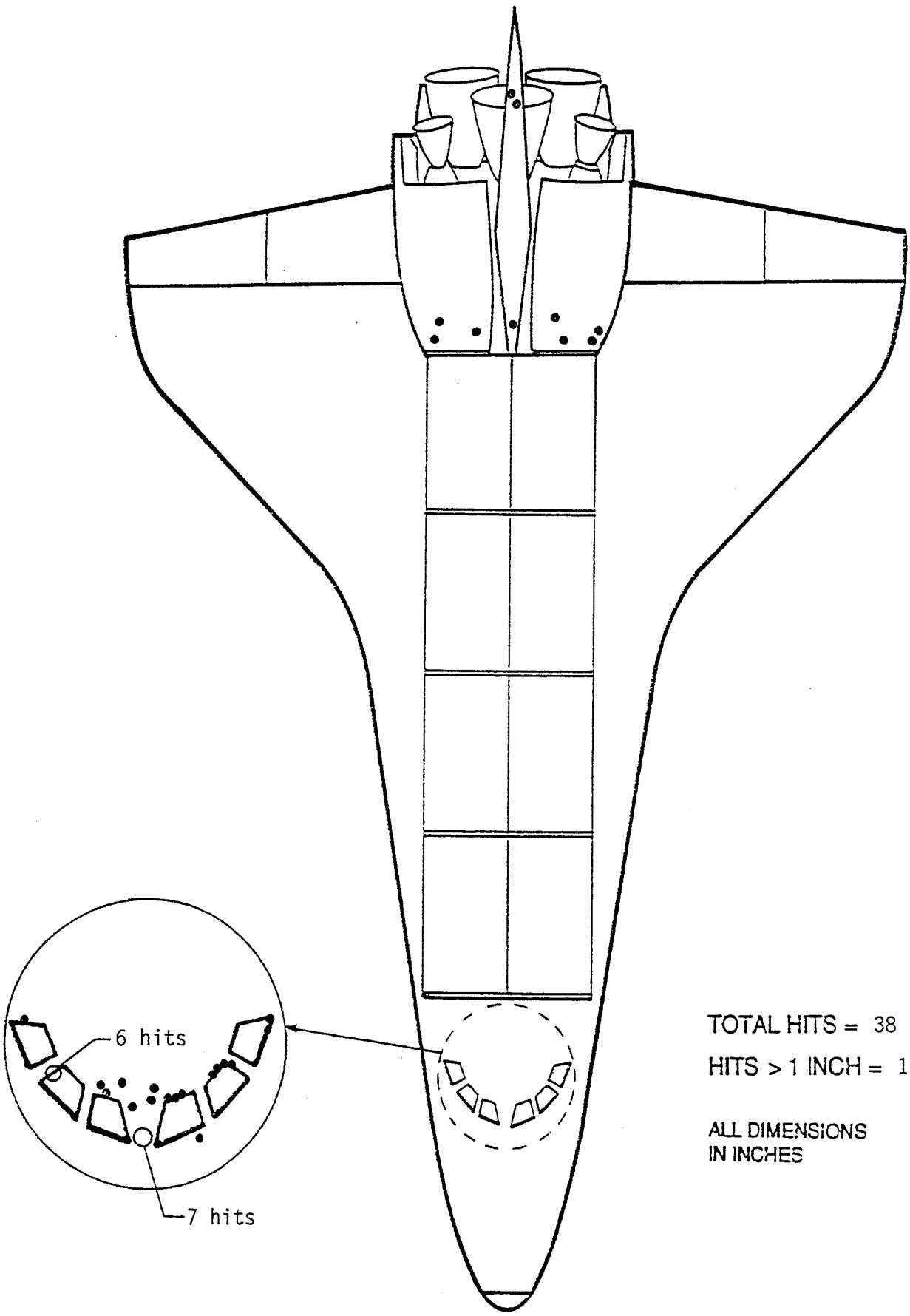


Figure 6: Orbiter Upper Surface Debris Map

	LOWER SURFACE		ENTIRE SURFACE	
	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	118
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

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
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
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
AVERAGE	13.5	86.6	20.1	126.8
SIGMA	7.3	44.2	9.7	53.5
STS-81	14	48	15	100

MISSIONS STS-23,24,25,26,26R,27R,30R,AND42R ARE NOT INCLUDED IN THIS ANALYSIS SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 7: Orbiter Post Flight Debris Damage Summary

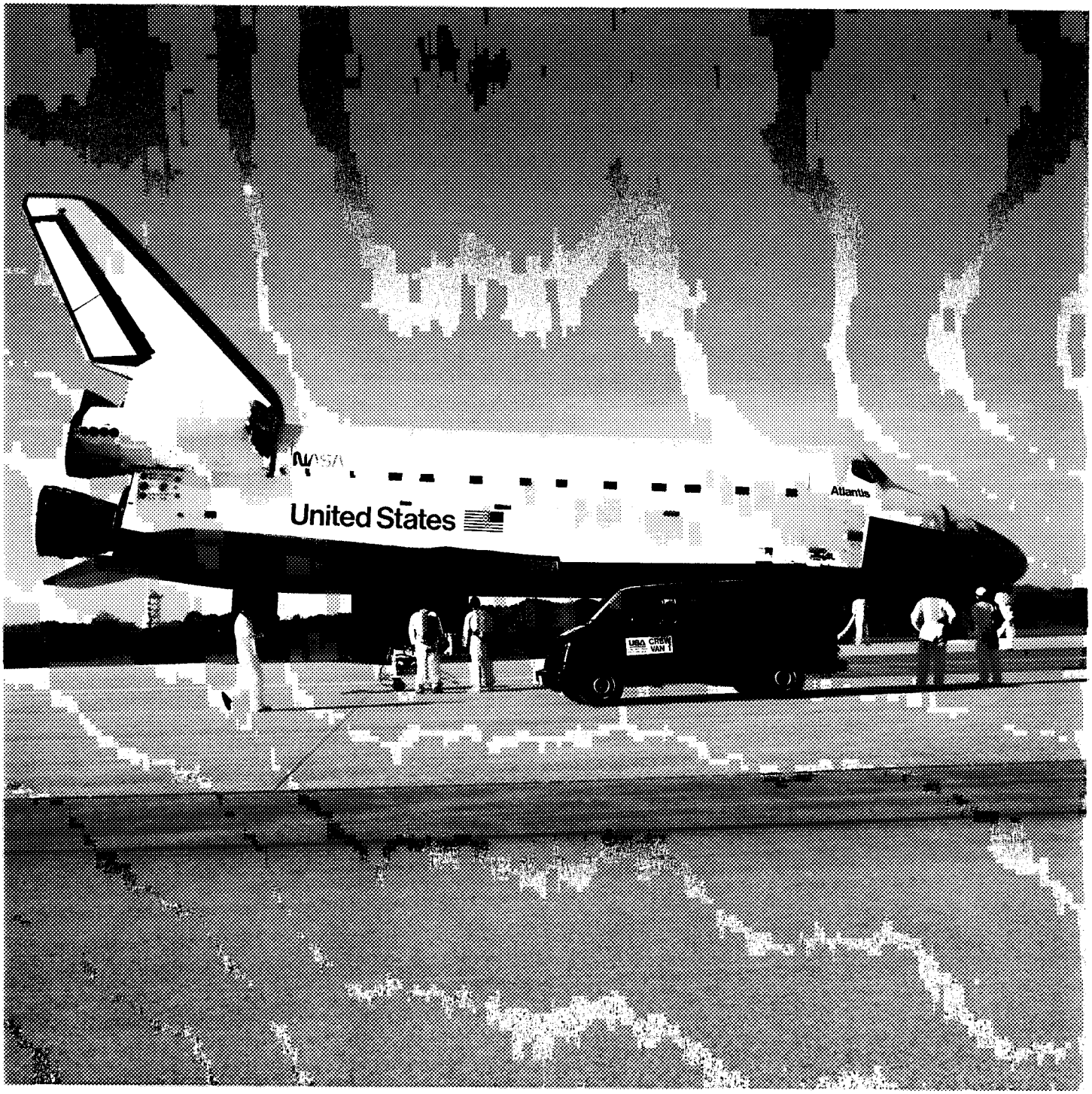


Photo 19: Overall View of Orbiter Right Side

Photo 20: Overall View of Orbiter Left Side

Photo 21: Overall View of Orbiter Nose

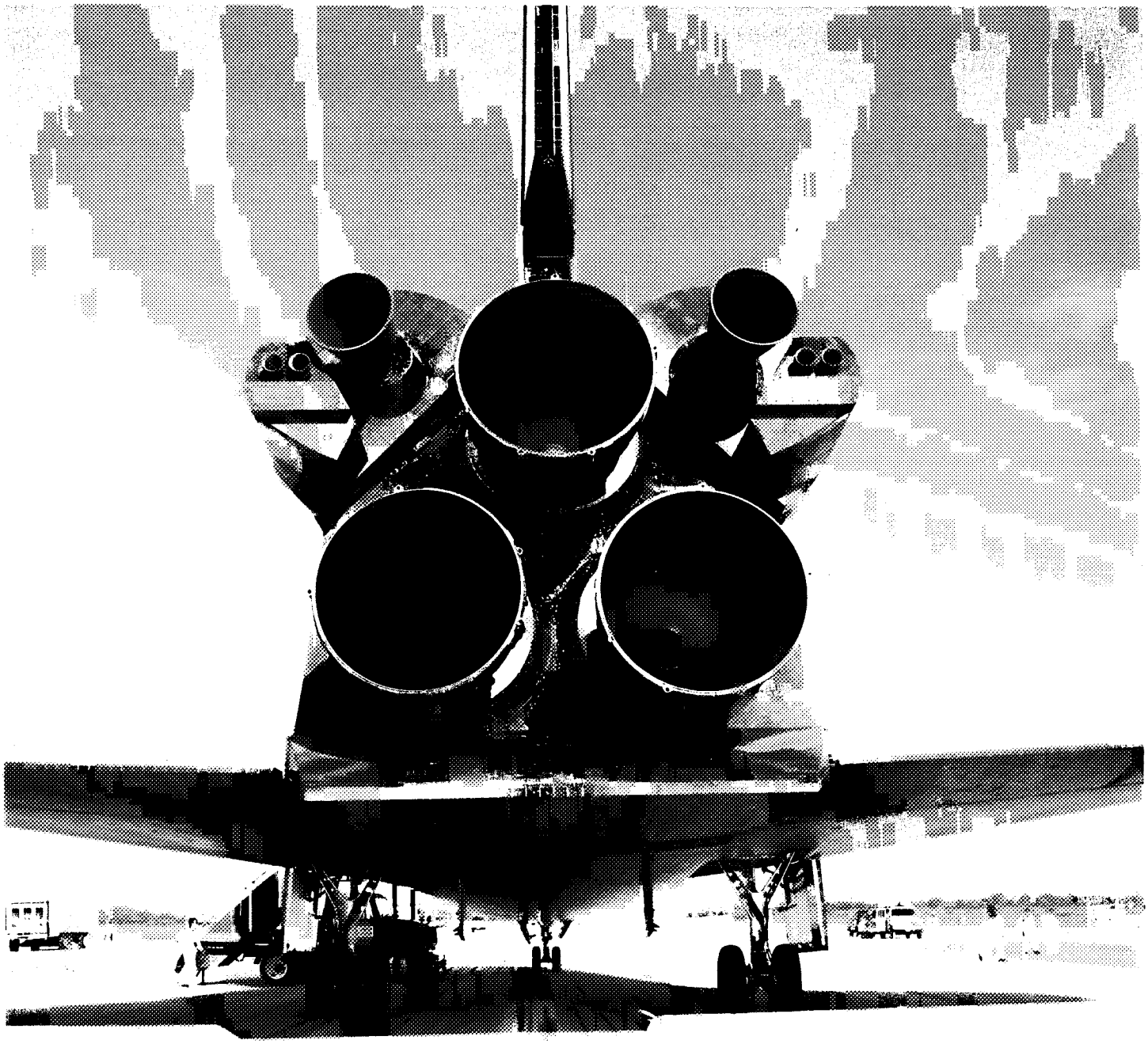


Photo 22: Overall View of Base Heat Shield

Photo 23: Lower Surface Tile Damage

The largest lower surface tile damage site was located on the right inboard elevon, spanned two tiles, and measured 8.0-inches long by 2.5-inches wide by 0.675-inch maximum depth. The depth of the damage site indicates a probable impact by ice - possibly from the ET LO2 feedline bellows.

Photo 24: LO2 Umbilical

Two spring clips were missing from the EO-3 "salad bowl"

Photo 25: LH2 Umbilical

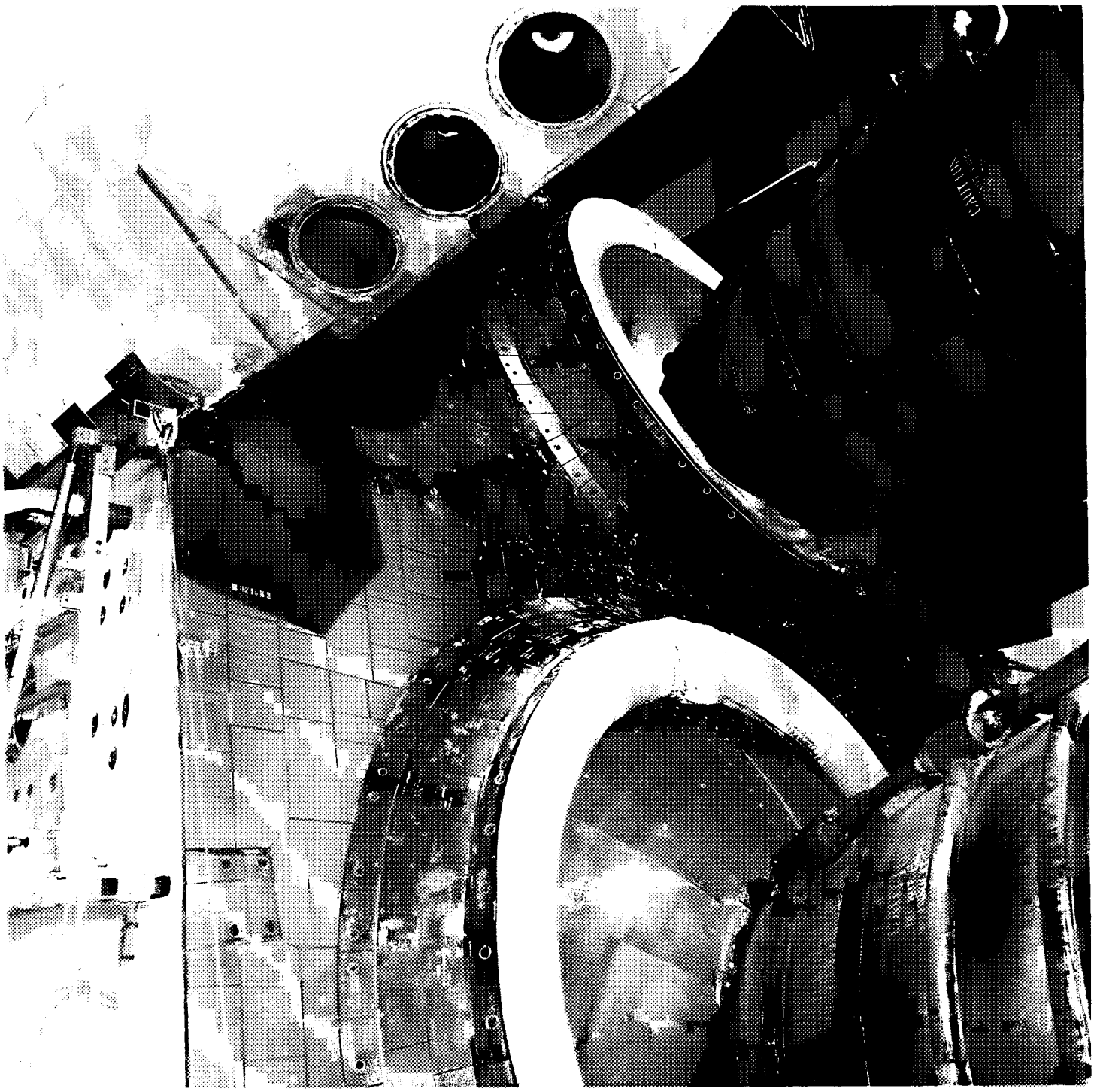


Photo 26: DMHS Blanket Damage

The SSME #1 blankets were torn/frayed at the 7:00-8:00 o'clock position.

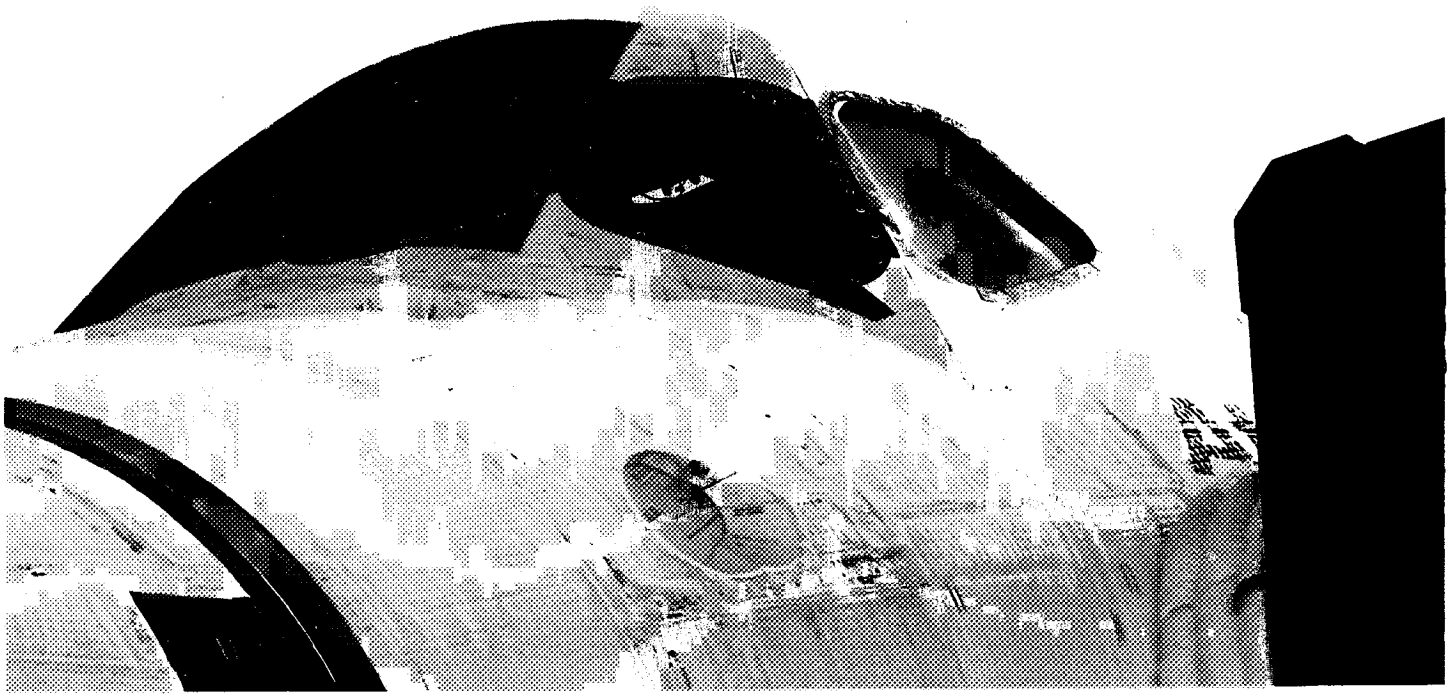


Photo 27: Orbiter Windows 1 - 3

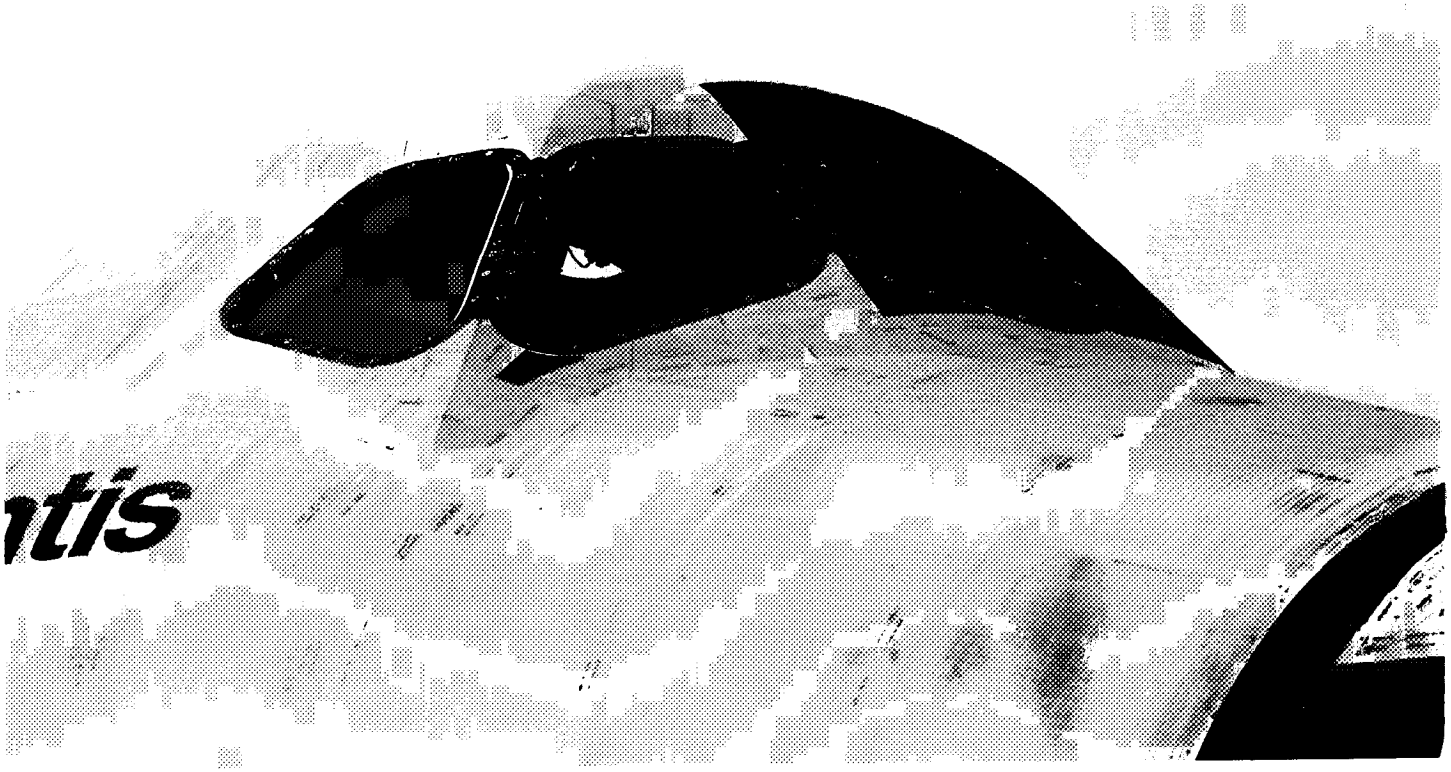


Photo 28: Orbiter Windows 4 - 6

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

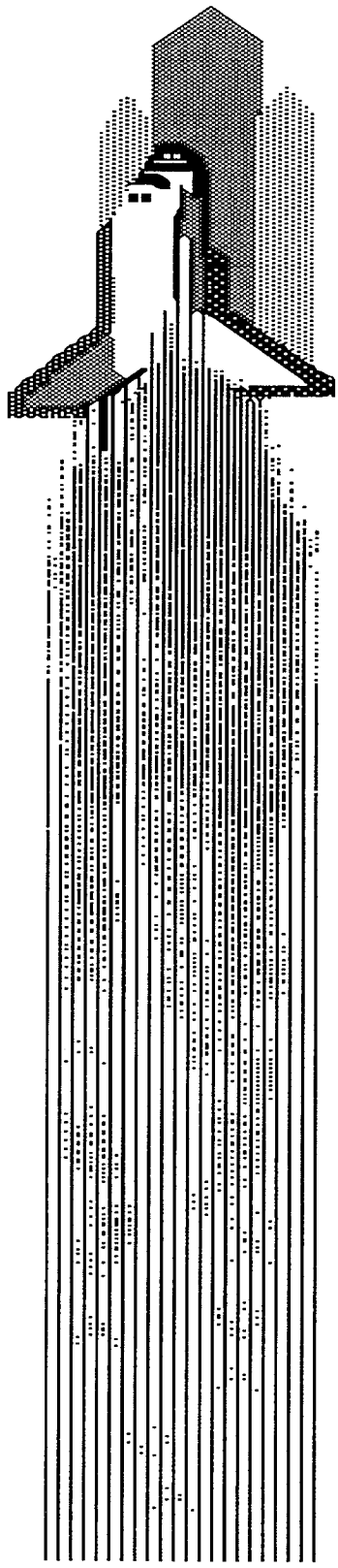
Space Shuttle

Earth Science Branch

Image Science and Analysis Group

STS-81 Summary of Significant Events

February 11, 1997



Space Shuttle Image Science and Analysis Group

STS-81 Summary of Significant Events

Project Work Order - SN-5LA

Approved By

Lockheed Martin

Jon Disler 2/11/97

Jon Disler, Project Analyst
Image Science and Analysis Group

M. H. Trenchard

M. H. Trenchard, Project Manager
Image Analysis Projects

Jess G. Carnes

Jess G. Carnes, Operations Manager
Basic and Applied Research Department

NASA

Mike Gaunce

Mike Gaunce, Lead
Image Science and Analysis Group
Earth Science Branch

Prepared By

Lockheed Martin Engineering and Sciences Company
for
Earth Science Branch
Earth Sciences and Solar System Exploration Division
Space and Life Sciences Directorate

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1.2 TIMING ACTIVITIES

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

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

Event Description	Time (UTC)	Camera
Landing Gear - Doors Opened	022:14:22:23.663	KTV20L
Right Main Wheel Touchdown	022:14:22:43.623	SLF S
Left Main Wheel Touchdown	022:14:22:43.723	SLF S
Drag Chute Initiation	022:14:22:46.292	SLF S
Pilot Chute at Full Inflation	022:14:22:47.317	KTV33L
Bag Release	022:14:22:47.884	KTV33L
Drag Chute Inflation in Reefed Configuration	022:14:22:48.751	KTV33L
Drag Chute Inflation in Dis-reefed Configuration	022:14:22:52.188	KTV33L
Nose Wheel Touchdown	022:14:22:55.158	KTV33L
Drag Chute Release	022:14:23:25.488	KTV33L
Wheel Stop	022:14:23:50.485	KTV15L

Table 1.2 Landing Video Timing Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition, at the time of SRB ignition, and aft of the launch vehicle after liftoff. Most of the debris were umbilical ice and RCS paper. No damage to the vehicle was noted. No follow-up action was requested.

Figure 2.1 (A) Debris Striking L02 Umbilical Well Door Sill

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals during SSME ignition. Ice debris was seen to strike the body flap (09:27:20.726 UTC) and the LO2 umbilical well door sill (09:27:19.625 UTC). None of the debris seen to contact the vehicle appeared to cause damage. (Cameras OTV109, OTV154)

A single light-colored piece of debris, first seen near the LSRB aft ET/SRB attach strut, fell aft during SSME ignition (27:19.788 UTC). (Camera E31)

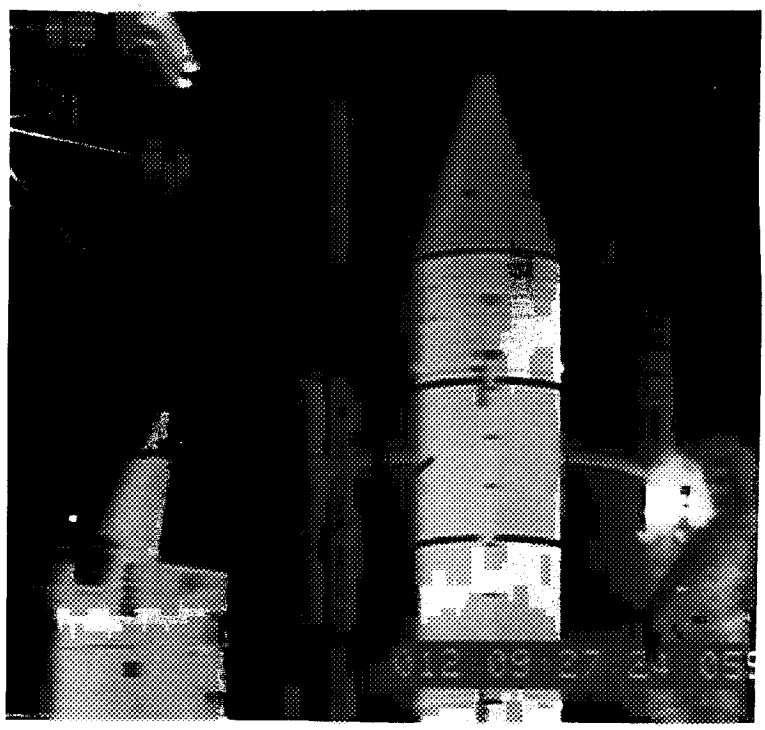

Figure 2.1 (B) Debris Near ET LO2 Feedline

Three pieces of light-colored debris (probably ice) were seen falling aft between the Orbiter and the ET during liftoff (27:25.188 UTC). This debris was first seen near the forward end of the LO2 feedline. The debris was not seen to contact the vehicle. No damage was noted. (Camera E34, KTV7B)

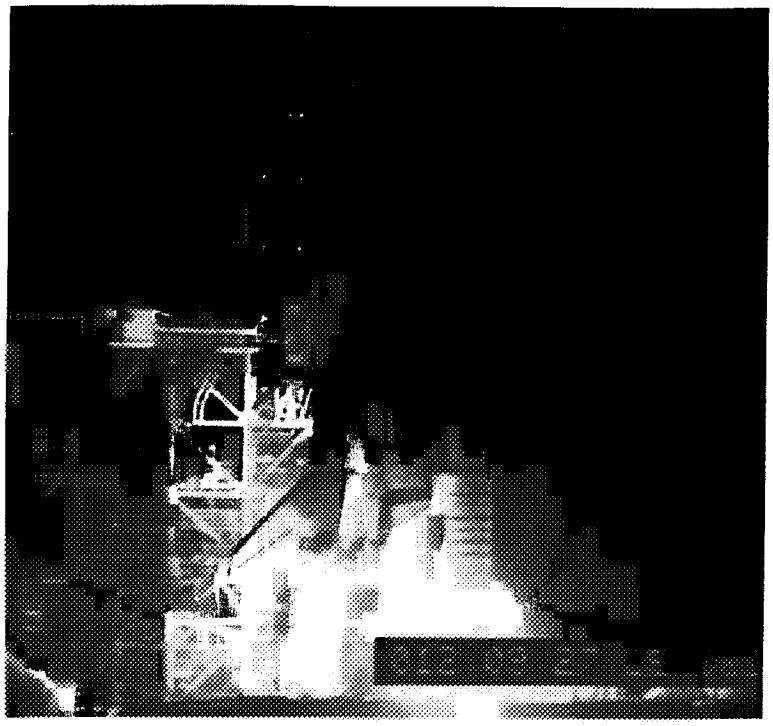

Figure 2.1 (C) Debris North of Launch Vehicle at Liftoff

A single, large piece of debris was seen traveling in a northerly direction from the SRB flame trench area (possibly SRB throat plug material) at liftoff (09:27:24.9 UTC). Debris north of the launch vehicle at liftoff has been seen on previous missions. This debris piece was not seen to contact the vehicle (Camera E54, E52, ET213).

A single light-colored piece of debris (probably flame duct material), first seen between the SRBs, traveled toward the body flap at SRB ignition (Camera E5 - 27:23.462 UTC). This debris was not seen to contact the vehicle.

Multiple pieces of debris (probably umbilical ice and RCS paper) fell aft of the launch vehicle from liftoff through the roll maneuver. A single piece of debris, probably RCS paper, was seen near the Orbiter crew cabin after tower clear (27:27.307 UTC). Several pieces of debris (probably RCS paper) were seen falling aft from the mid-fuselage level of the Orbiter at 27:28.338 UTC. (E52, E53)

Figure 2.1 (D) Debris near Body Flap During Ascent

Debris, probably ET/Orbiter purge barrier material, was seen falling aft of the body flap after liftoff (27:37.056 UTC). At 27:41.365 UTC, RCS paper debris was seen falling aft near the vertical stabilizer. Debris-induced streaks in the SSME exhaust plume were seen between 27:43 and 27:46 UTC (Camera E222). Similar ascent debris events have been seen on previous mission imagery.

Figure 2.1 (E) Debris near SRB Exhaust Plume During Ascent

Multiple pieces of debris were seen near the SRB exhaust plume during ascent between 09:28:18.8 - 09:28:48.3 UTC (Camera KTV4B). Debris near the SRB exhaust plume during ascent has been seen on previous missions.

2.2 MOBILE LAUNCH PLATFORM (MLP) EVENTS

The SSME Mach diamond formation appeared to occur out of sequence (the SSME #1 and SSME #2 Mach diamonds appeared to start to form, disappear, and re-form) (Camera E19, E76). The times of the Mach diamond formation were:

SSME #3 - 09:27:19.737 UTC
SSME #2 - 09:27:19.870 UTC
SSME #2 - 09:27:19.876 UTC
SSME #3 - 09:27:19.883 UTC
SSME #1 - 09:27:19.999 UTC
SSME #1 - 09:27:20.157 UTC

These times were provided to engineers at the MSFC SSME project office. No follow-up action was requested.

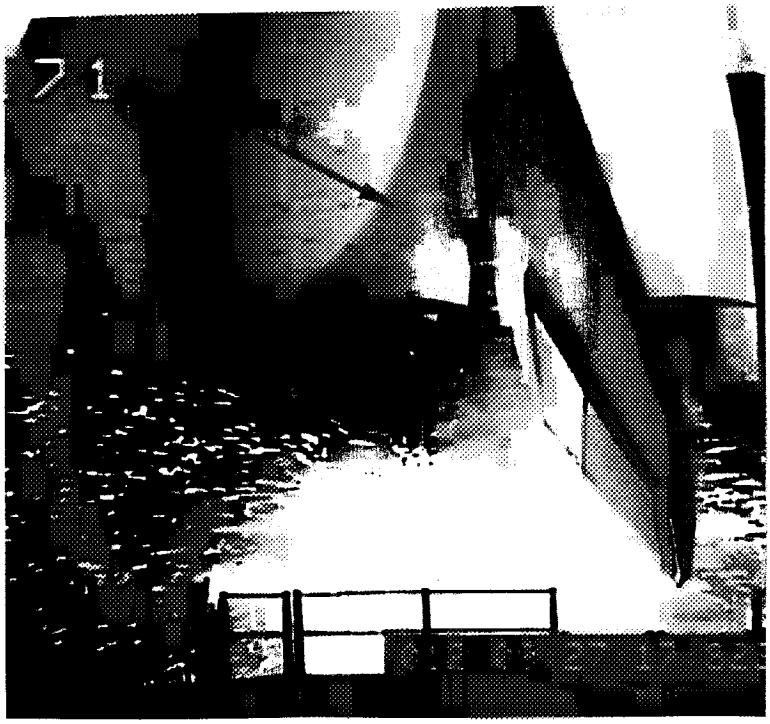

Figure 2.2 (A) Orange Vapor Seen During SSME Ignition

Orange vapor, probably free burning hydrogen, was seen above the SSME rim exit plane, near the body flap, and along the vertical stabilizer during SSME ignition (09:27:17.7 UTC). Orange vapors have been seen on previous missions. (Cameras OTV170, OTV171, E2, E4, E5, E17, E19, E20, E36, E52, E76)

Two small areas of base heat shield TPS tile surface erosion were seen near the base of SSME #3 during SSME ignition (27:23.188 UTC). Erosion of base heat shield tile surface material has been seen on previous missions. (Cameras E17, E20)

2.3 ASCENT EVENTS

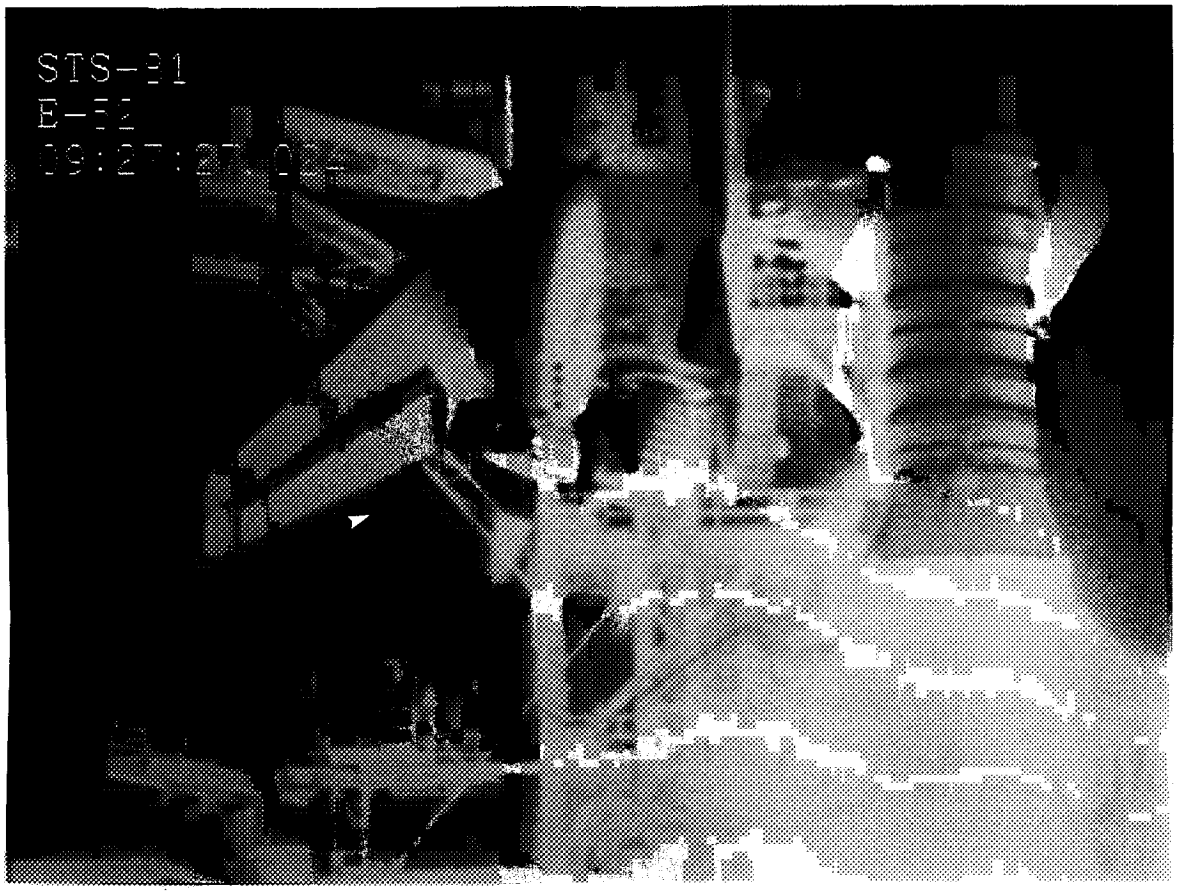

Figure 2.3 (A) Vapor from Vertical Stabilizer Speed Brake Drain after Liftoff

Vapor appeared to be coming from the drain on the trailing edge of vertical stabilizer speed brake after liftoff (27:27.02 UTC) (E52, E222). This has been seen on previous missions.

2.4 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (DTO-312)

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

The umbilical well camera views of the external tank were dark and unusable due to the nighttime conditions. Good umbilical well film coverage of the LSRB separation was acquired.

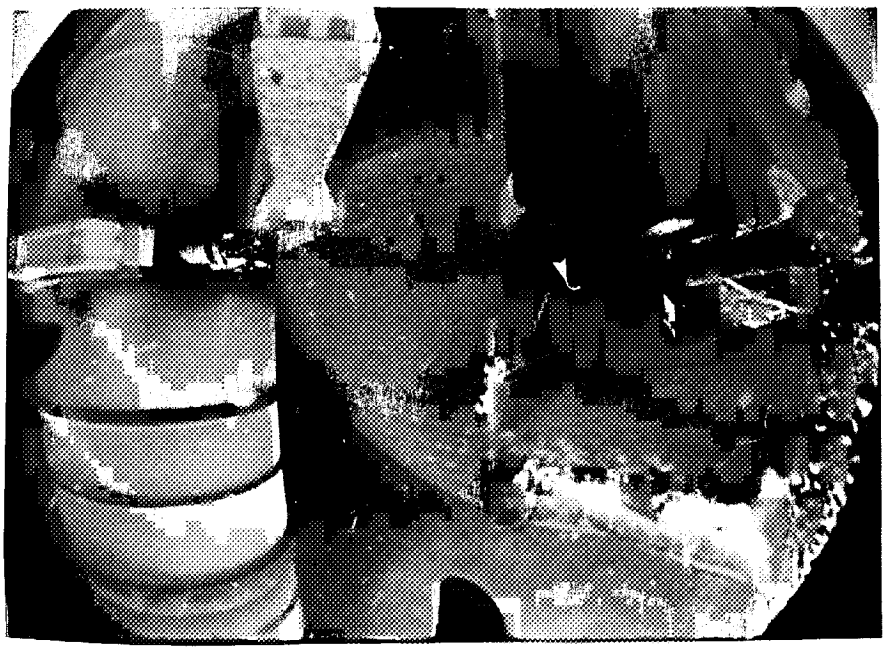

Figure 2.4.1 (A) Debris Striking LH2 Electric Cable Tray

Numerous light-colored pieces of debris (probably insulation) and dark debris (probably charred insulation) were seen throughout the SRB film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the horizontal section of the -Y ET/SRB vertical strut was seen. Ablation of the TPS on the aft dome was less than was seen on STS-80. The charring of the ET aft dome TPS was typical of previous missions. A light-colored piece of debris (probably a piece of insulation) was seen to strike the LH2 electric cable tray. No damage was noted. The LSRB separation appeared normal. The 16mm films had good focus and good exposures. Timing data is present on the umbilical well films.

2.4.2 Analysis of Handheld Photography of the ET (Task #3)

DTO-312 (method 4) photography of the STS-81 external tank was acquired after separation with a Nikon 35 mm camera using 400mm lens and a 2X extender. The OMS-2 attitude pitch maneuver was performed early to assist the crew members in acquiring the ET visually.

Twenty excellent quality views of the external tank were acquired (roll 338). The +Y/ -Z axis of the ET was imaged. Timing data is present on the hand-held film. The first picture was taken at 09:47:28 UTC (approximately 20 minutes after liftoff) and the last picture was taken at 09:48:32 UTC.

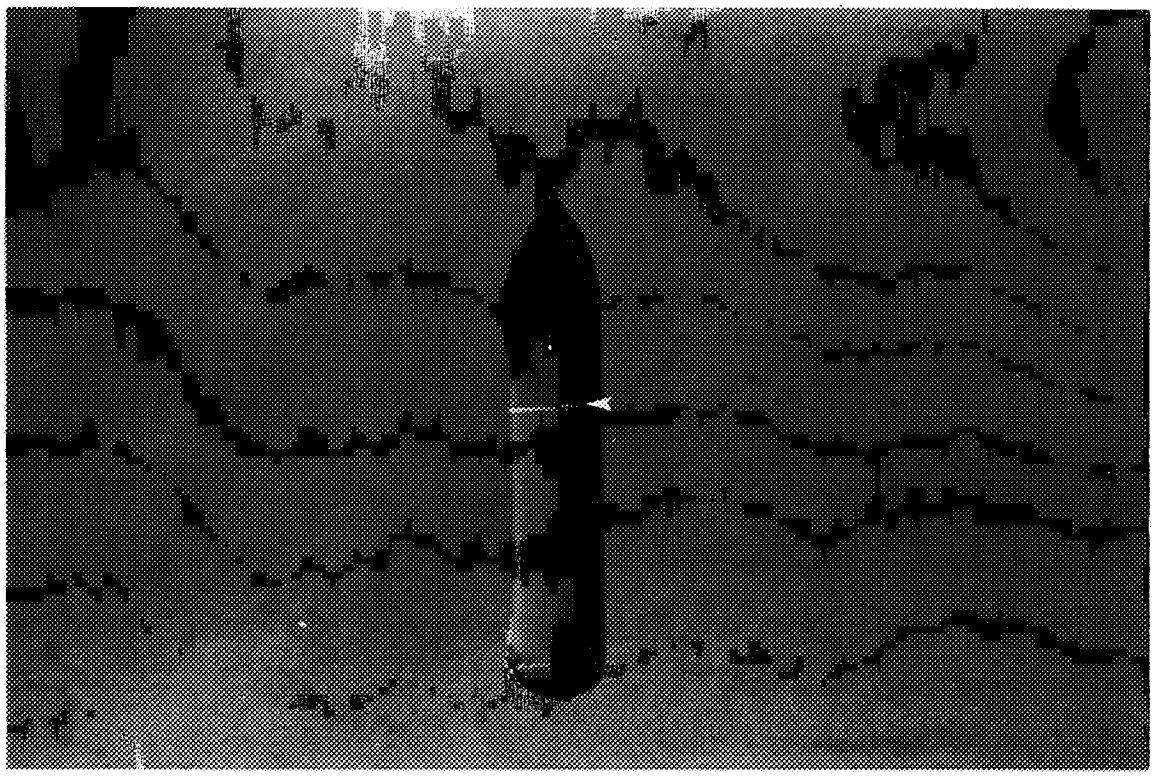

Figure 2.4.2 (A) Divots on the LH2/Intertank Closeout Flange

Eight divots are clearly visible on or very near the LH2/intertank closeout flange. Charring and small "popcorn" divots are visible on the ET aft dome. The normal SRB separation motor burn scars and aero heating marks are visible on the ET TPS. The ET was measured to be 2.3 kilometers from the Orbiter on the first ET picture. The ET separation rate was calculated to be 4.2 meters per second (typical of previous missions). The new intertank access door was not visible on the handheld photography.

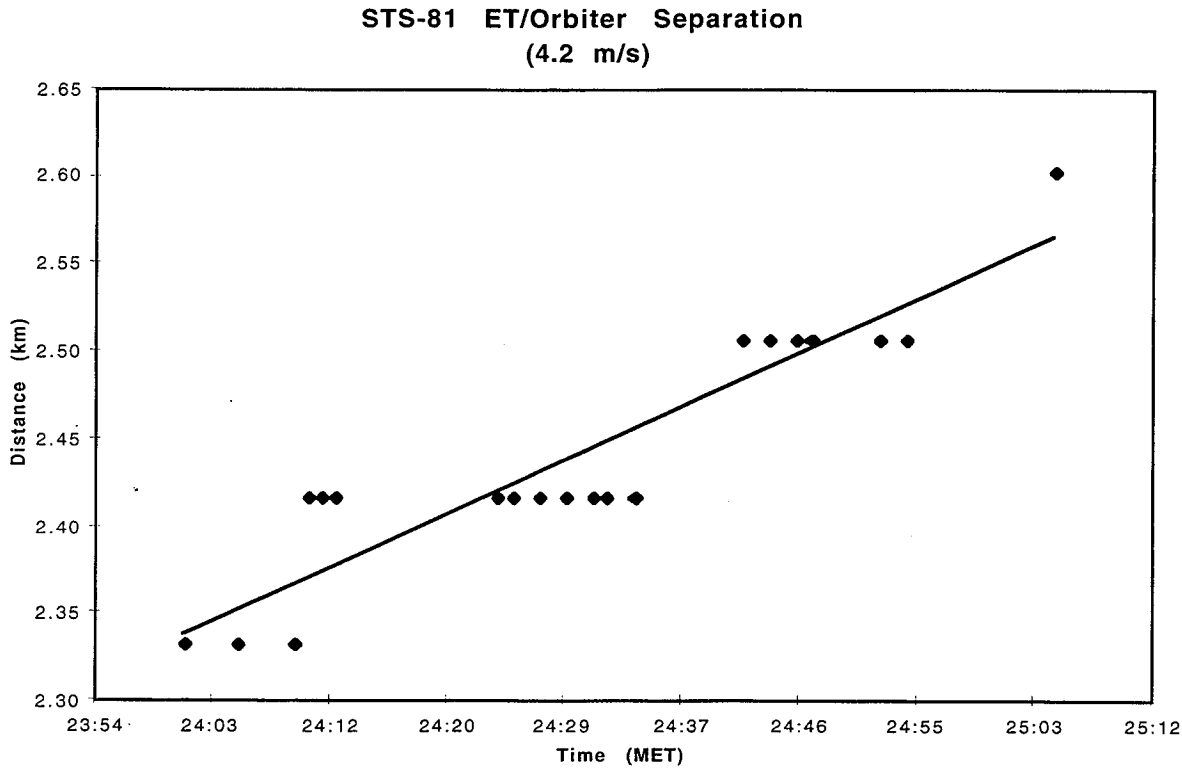

Figure 2.4.2 (B) ET Separation Velocity

The distance of the external tank was calculated over a twenty-frame sequence using the handheld photography. The external tank was calculated to be a distance of 2.3 km away from the Orbiter at 24:01 MET. The tank was calculated one minute four seconds later (25:05 MET) to be at a distance of 2.6 km. The tank separation velocity was determined to be 4.2 m/s with an uncertainty of approximately 0.1 m/s. See figure 2.4.2 (B). (Note that the distance of the ET appears to remain constant over multiple frames due to the resolution limitations of the imagery). The separation velocity was similar to previous mission measurements. The tank tumble rate was estimated to be 0.3 deg/sec and the roll rate was too small to be measured.

2.5 LANDING EVENTS

2.5.1 Landing Sink Rate Analysis (Task #1)

Film camera EL-9 was used to determine the landing sink rate of the main gear. Landing film EL-7 was used to determine the nose gear sink rate. The sink rates of the Orbiter were determined over a one-second time period prior to main and nose gear touchdown.

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-81 Orbiter was reported to be 214,916 lb.). The sink rate measurements for STS-81 are given in Table 2.5.1. In Figure 2.5.1 (A), and 2.5.1(B), the trend of the measured data points for the image data is illustrated.

Prior to Touchdown (1 Second)	Sink Rate: Film
Main Gear	1.4 ft/sec
Nose Gear	5.0 ft/sec

Table 2.5.1 Sink Rate Measurements

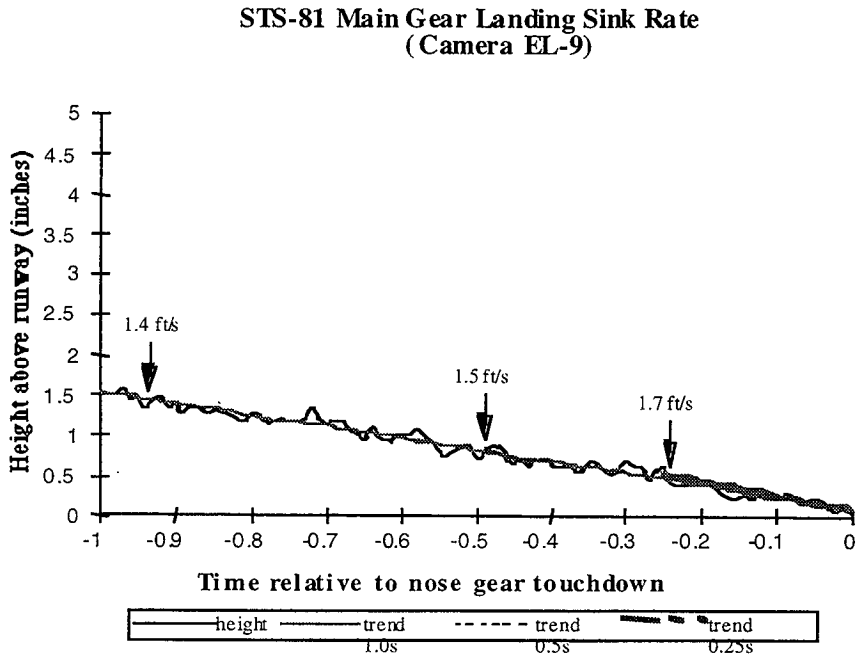

Figure 2.5.1 (A) Main Gear Height Versus Time Prior To Touchdown (Video)

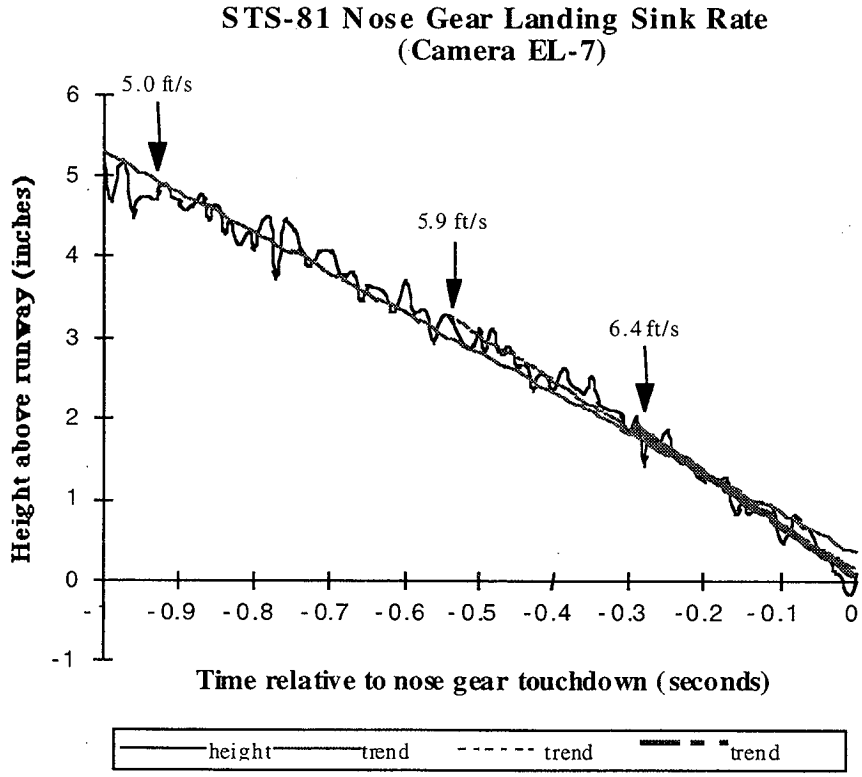

Figure 2.5.1 (B) Nose Gear Height Versus Time Prior To Touchdown (Film)

2.6 OTHER

2.6.1 Normal Events:

Other normal events observed include: ice and vapor from the ET/Orbiter umbilical areas from SSME ignition through liftoff, inboard and outboard elevon motion at SSME ignition, RCS paper debris during SSME ignition through liftoff, ET twang, multiple pieces of light-colored debris falling from the LH2 and LO2 TSM T-0 umbilicals prior to and 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, debris in the exhaust cloud after liftoff, roll maneuver, body flap motion during ascent, linear optical effects, ET aft dome charring, expansion waves, condensation around the launch vehicle during ascent, recirculation, SRB plume brightening prior to SRB separation, SRB separation, and SRB slag material in the SRB exhaust plume before, during, and after SRB separation.

2.6.2 Pad Events

A rod-shaped object was seen to roll into a crevice near the left SRB hold down post #5 at liftoff (27:24.550 UTC). (Camera E12)

A single piece of barrier material tape was seen extending from the LH2 TSM at liftoff (prior to door closure). (Camera E18)

Normal hydrogen burn ignitor operation, FSS deluge water operation, GH2 vent arm retraction, LH2 and LO2 TSM door closure, MLP deluge water operation, and sound suppression system water operation was observed.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Reply to Attn of:

EP42 (97-011) February 7, 1997

TO: Distribution

FROM: EP42/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-81

The launch of space shuttle mission STS-81, the eighteenth flight of the Orbiter Atlantis occurred on January 12, 1997, at approximately 3:27 A.M. Central Standard Time from Launch Complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Photographic and video coverage has been evaluated to determine proper operation of the flight hardware.

The dark sky conditions at the time of launch reduced the information recorded by the ground cameras. Tracking cameras only recorded the aft portion of the SSV during ascent. MLP camera E6 which views the LO2 17 inch disconnect did not run. MLP camera E13 which views the SRB holddown post M-6 was obscured by water from the water deluge system. Tracking cameras E220 and E223 experienced mechanical problems during acquisition resulting in no data.

The astronauts recorded 20 images of the ET after separation. These images were of excellent quality and recorded the +Y and -Z sides of the ET. The Orbiter Atlantis carried two 16mm motion picture cameras in the LH2 umbilical well which recorded the SRB separation event. ET separation was not recorded due to insufficient lighting.

The mach diamonds from ME-1 and ME-3 cycle from opaque to transparent, then back to opaque (normal condition) during the engine start transient. A plume streak was observed in ME-1 after reaching mainstage at 09:27:20.807 UTC.

Several pieces of debris were ejected upward out of the SRB secondary blast holes at SRM ignition. Most of this debris appears to be foam type debris.

Three pieces of ice/frost were observed falling from the forward portion of the LO2 feedline at liftoff. One piece appears to bounce down the Orbiter's underside with glancing blows. No TPS damage was noted. This event was recorded by video camera OTV-161 and film camera E34. Camera TV-7B also shows a similar if not one of the same pieces falling from the forward portion of the LO2 feedline at liftoff.

Tracking camera E54 shows a small piece of ice/frost which falls from the LO2 feedline forward bellows at approximately T+4.2 seconds MET. This piece traveled down the feedline without impacting the vehicle.

Several tracking cameras recorded a large piece of the ET/Orbiter disconnects purge barrier falling aft of the vehicle during the roll maneuver. This type of debris has been observed before.

Several pieces of glowing debris particles were observed exiting from the SRM plume during ascent (approximately 56, 72, and 123 seconds MET) and at SRB separation. The dark sky conditions enhanced the image contrast to make this type of event easily visible.

The hand-held images of the ET recorded several shallow divots at the intertank/LH2 tank scarf joint. Five divots were located in-line with the -Z axis. These divots appear to extend forward into the intertank TPS acreage. Six divots were located in-line with the +Y axis, aft of the forward SRB attach point. The aft dome and forward nose cone of the ET exhibited typical charring.

The following event times were acquired.

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	09:27:22.991	Camera E9
M-2 PIC Firing	09:27:22.991	Camera E8
M-5 PIC Firing	09:27:22.991	Camera E12
M-6 PIC Firing	could not use	Camera E13
SRB separation	09:29:28.72	Camera E212

This report and additional information are available on the World Wide Web at URL:
http://photo4.msfc.nasa.gov/STS/sts81/sts81.html

For further information concerning this report contact Tom Rieckhoff at 205-544-7677 or Jeff Hixson, Boeing North American at 205-971-3082.

Tom Rieckhoff

Thomas J. Rieckhoff

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Gregory N. Katnik
Jill D. Lin

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John F. Kennedy Space Center, NASA
Process Engineering/Mechanical Systems Division
ET/SRB Branch PK-H7
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13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-81. 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-81 and the resulting effect on the Space Shuttle Program.

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