Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-84

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DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-84

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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-84

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 14 May 1997. The detailed walkdown of Pad 39A and MLP-2 also included the primary flight elements OV-104 Atlantis (19th flight), ET-85 (LWT 78), and BI-087 SRB's. There were no significant vehicle or launch pad anomalies.

The Final Inspection of the cryoloaded vehicle was performed on 14-15 May 1997 from 2210 to 0010 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 Ice, Debris, or TPS IPR's were taken. Due to the warm weather conditions, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

After the 4:07 a.m. (local) launch on 15 May 1997, a debris walk down of Pad 39A 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. The GOX vent seals were evaluated from the GVA hood access platform - no damage or topcoat residue was noted on the seals. The flexible part of the south GOX vent duct had separated from the hood flange. A metal ring clamp that attached the flex-duct to the hood lay on the hood access platform. The outer layer of the north flex-duct insulation blanket was torn from the hood flange. All of this damage most likely occurred from SRB plume impingement after the vehicle cleared the tower.

A total of 110 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. A thin, 6-inch long by 1-inch wide light-colored object, believed to be a tile gap filler, first appeared in an area between the SSME heat shields and fell aft at 08:07:44.699 UTC during SSME ignition.

OV-104 was equipped to carry ET/ORB umbilical cameras. SRB separation from the External Tank appeared nominal. ET-84 separation from the Orbiter was not visible due to the dark conditions of a night launch. Some time later, both the Orbiter and External Tank crossed the terminator. The ET was then illuminated.

Three TPS divots were detected in the LH2 tank-to-intertank flange closeout between the bipods. One 6-inch diameter divot was located close to the centerline/+Z axis in the sanded area just aft of the intertank acreage rind while one each somewhat smaller divot appeared at each bipod jack pad standoff closeout sanded area just forward of the LH2 tank upper barrel acreage rind (total of two divots).

Although the intertank acreage TPS was generally in good condition, several small divots were detected: 3 shallow intertank stringer head divots near the LO2 tank PAL ramp, 10 shallow intertank stringer head/valley divots forward of the bipods, 8 shallow intertank stringer head/valley divots around the -Y bipod spindle housing closeout. Other than two shallow divots in the LH2 tank upper barrel acreage just aft of the intertank splice, no other divots were visible in the LO2 and LH2 tank acreage TPS.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. Both frustums were in excellent condition. No TPS was missing and only four debonds were detected over fasteners on the left frustum. All eight BSM aero heat shield covers had locked in the fully opened position. The forward skirts exhibited no debonds or missing TPS. A significant amount of foam was missing from the aft side of both IEA's. The remaining foam was sooted. Some areas of exposed substrate exhibited blistered paint due to ascent plume recirculation or re-entry heating. These findings indicate the foam was lost prior to water impact. Six of the holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally. The HDP #1 DCS plunger was obstructed by frangible nut halves. The HDP #7 plunger was not fully seated, but partially obstructed by a piece of the frangible nut.

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 Atlantis was conducted 24-26 May 1997 at the Kennedy Space Center on SLF runway 33. The Orbiter TPS sustained a total of 103 hits, of which 13 had a major dimension of 1-inch or larger. A comparison of these numbers to statistics from 68 previous missions of similar configuration indicates both the total number of hits, and the number of hits 1-inch or larger, were less than average.

The Orbiter lower surface sustained a total of 67 hits, of which 10 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the Orbiter centerline between the two MLG doors. The site measured 1.5-inches long by 0.5-inch wide by 0.375-inch maximum depth.

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size with the exception of one damage site greater than 1-inch in size in the black perimeter tiles of window #3. The damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the FRCS thrusters.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 13 May 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.

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B. Davis	NASA - KSC	Digital Imaging Systems
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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
F. Foster	BNA - LSS	Systems Integration
G. J. Stone	BNA - DNY	Aerodynamics
R. Harmon	THIO - LSS	SRM Processing
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J. Ramirez	LMSO - LSS	ET Processing
M. Barber	USA - Safety	

3.0 LAUNCH

STS-84 was launched at 97:xxx:15:08:07:48.xxx UTC (4:07 a.m. local) on 15 May 1997.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 14 May 1997. The detailed walkdown of Pad 39A and MLP-2 also included the primary flight elements OV-104 Atlantis (19th flight), ET-85 (LWT 78), and BI-087 SRB's. There were no significant vehicle or launch pad anomalies. Cantilever crane pedestals covers not installed near HDP #3 and #7 were documented in OMI S0007, Appendix K for resolution prior to cryoload.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 14-15 May 1997 from 2210 to 0010 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 Ice, Debris, or TPS IPR's were taken. Due to the warm weather conditions, there were no acreage icing concerns. There were also 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. RCS thruster covers were intact, but the F3F, R1R, and L4L covers were tinted green indicating small internal vapor leaks. Ice/frost and condensate had formed on SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was dry. 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 were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 73 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 as a comparison to infrared scanner point measurements. The program predicted condensate, but no ice or frost, on the ET acreage TPS.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 62 degrees F.

The intertank acreage exhibited no TPS anomalies. Ice/frost accumulation on the GUCP appeared typical.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures averaged 59 degrees F. All TPS repairs on the +Z side of the LH2 tank were intact and in nominal condition.

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

An 2-inch long by 1/8-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 accumulations were limited to small patches on the aft and inboard sides. 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.

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side and forward surface. Smaller than usual 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. All TPS repairs on the umbilical were nominal.

3.2.4 FACILITY

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

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

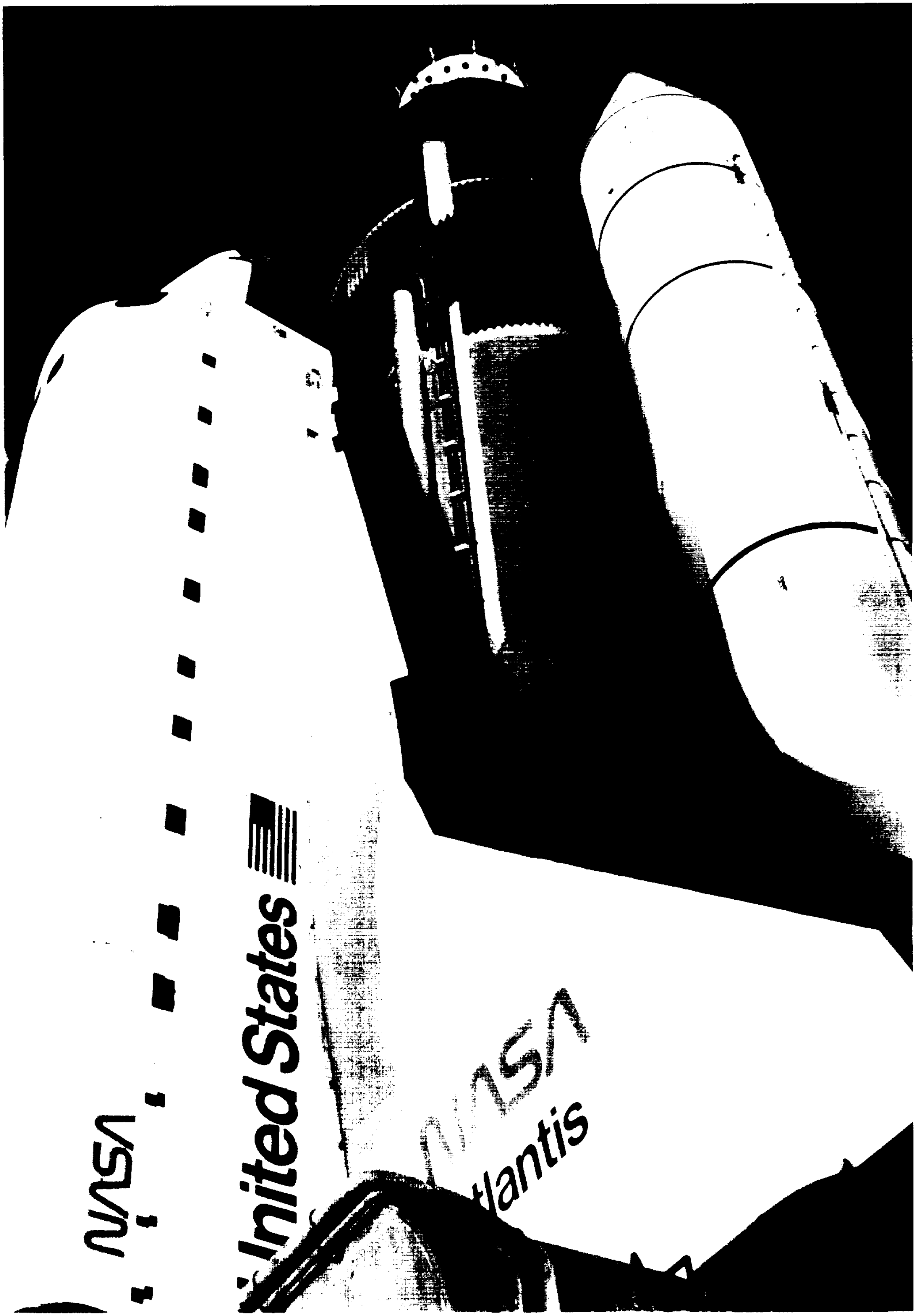


Photo 2: STS-84 Ready for Launch

OV-104 (19th flight), ET-85 (LWT 78), BI-087 SRB's

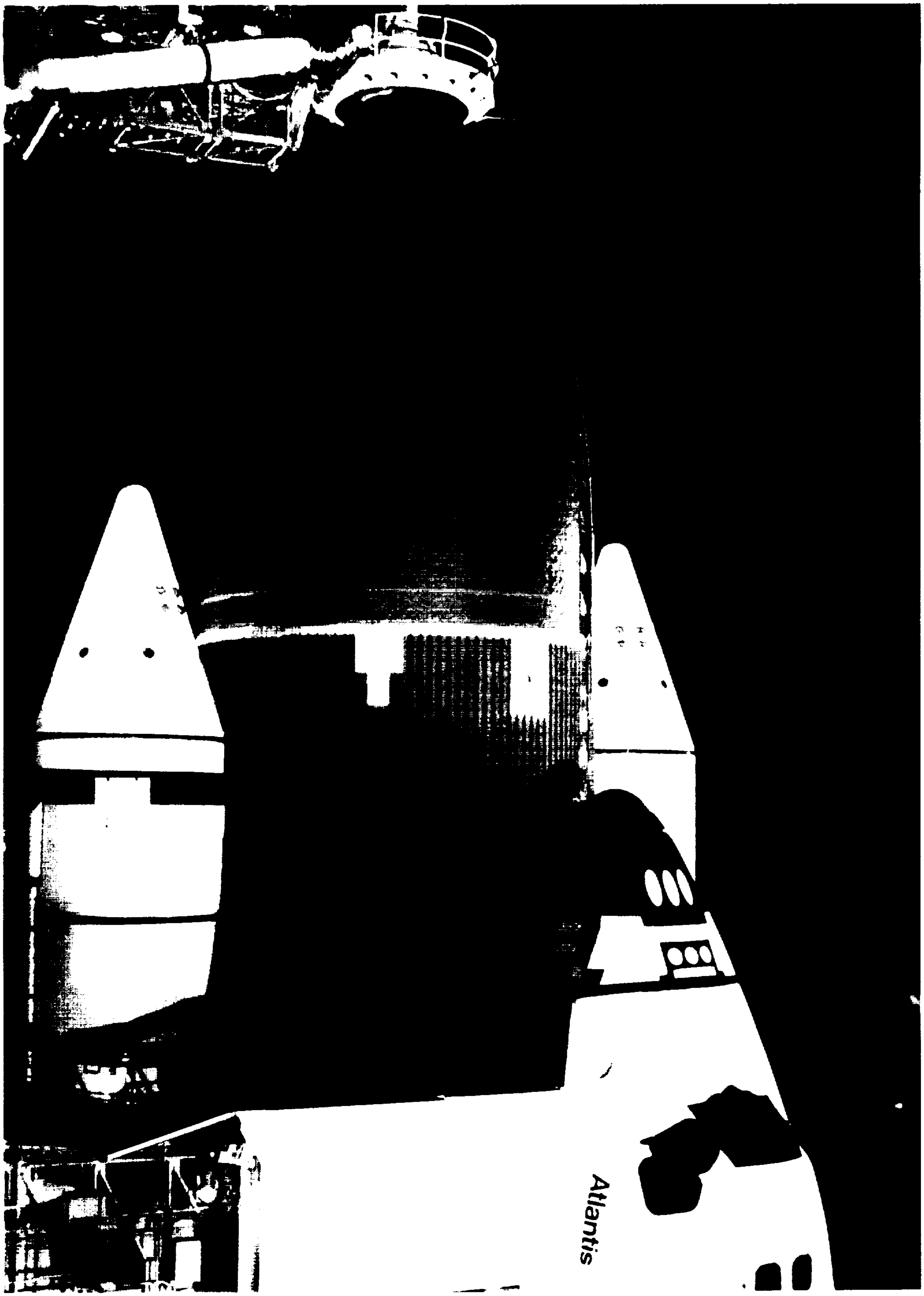


Photo 3: LO2 Tank and Intertank After Cryoload

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank. TPS surface temperatures averaged 62 degrees F.

Photo 4: ET/Orbiter LH2 Umbilical

Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side and forward surface. Smaller than usual ice/frost fingers were present on the pyro canister and plate gap purge vents.

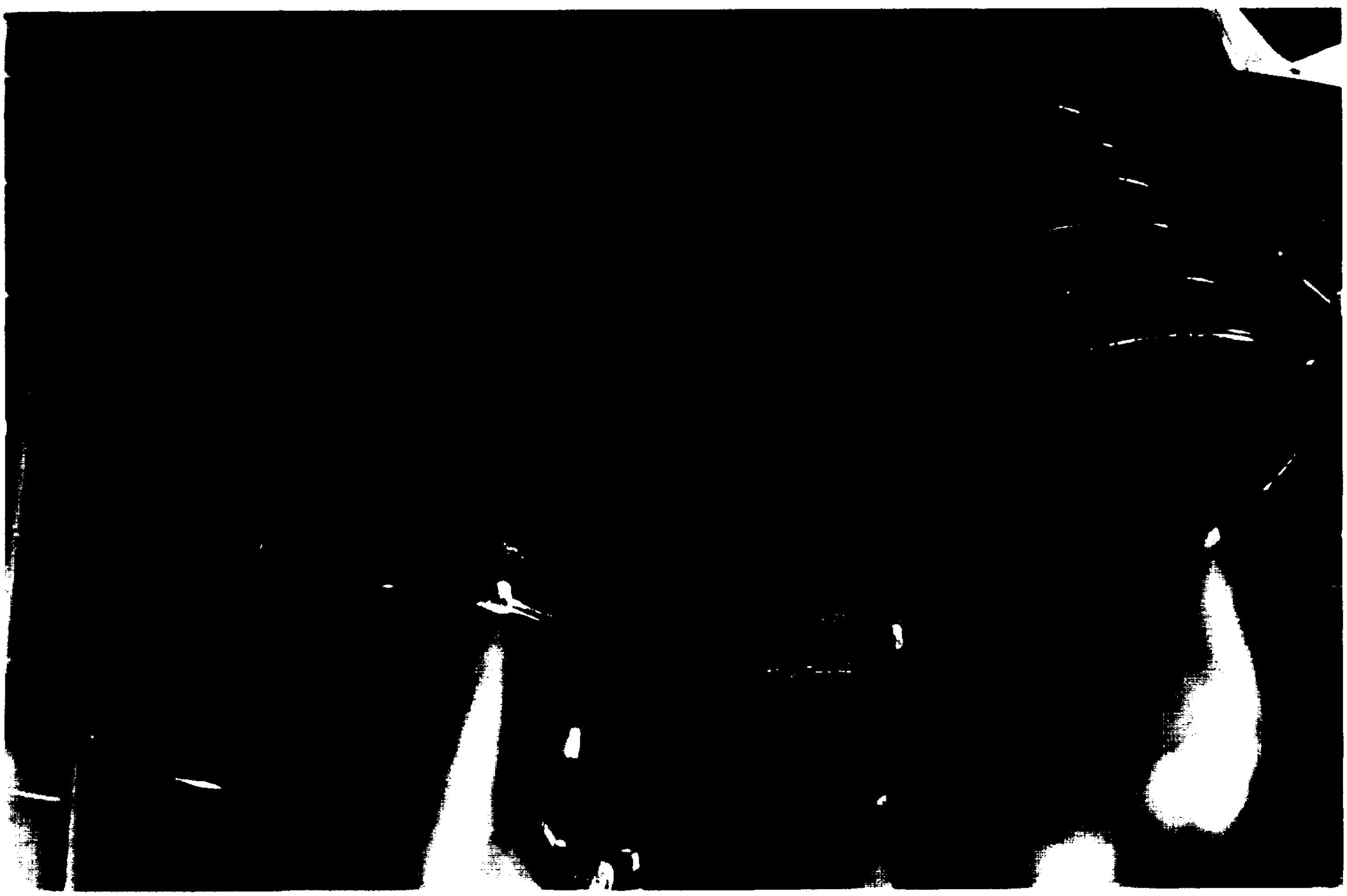


Photo 5: Overall View of SSME's

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 2, Pad A FSS/RSS was conducted on 15 May 1997 from Launch + 1.5 to 4 hours.

SRB Hold Down Post (HDP) erosion generally was typical with the exception of a 2-inch by 2-inch hole melted in the HDP #3 blast cover. A 2-inch by 1-inch piece of steel was missing from the corner of the HDP #7 blast cover. Boeing - Downey reported a lateral acceleration of 0.06 g's, which is well below the previously established stud hang-up threshold of 0.14 g's. Aft skirt purge lines and T-0 umbilicals exhibited typical exhaust plume damage. Pad safety reported material loss and damage to the firewall in the south flame trench with pieces of ablative material scattered down the crawlerway to the pad gate. Two pieces of metal, a 3-inch by 3-inch by ¼-inch thick plate and a clamp, found in the SSME flame trench originated from the flame trench railing and were not a threat to the vehicle.

The Tail Service Masts (TSM) and Orbiter Access Arm (OAA) had no visible damage. The TSM bonnets were closed.

The GOX vent seals were evaluated from the GVA hood access platform - no damage or topcoat residue was noted on the seals. The flexible part of the south GOX vent duct had separated from the hood flange. A metal ring clamp that attached the flex-duct to the hood lay on the hood access platform. The outer layer of the north flex-duct insulation blanket was torn from the hood flange. All of this damage most likely occurred from SRB plume impingement after the vehicle cleared the tower.

The GH2 vent line was latched in the sixth of eight teeth of the latching mechanism. The ET GUCP had not been struck by the retract lanyard. The GUCP seal appeared undamaged.

Four lights had failed in the east and northeast stadium light banks.

Preliminary inspections seemed to indicate minimal damage to the pad.

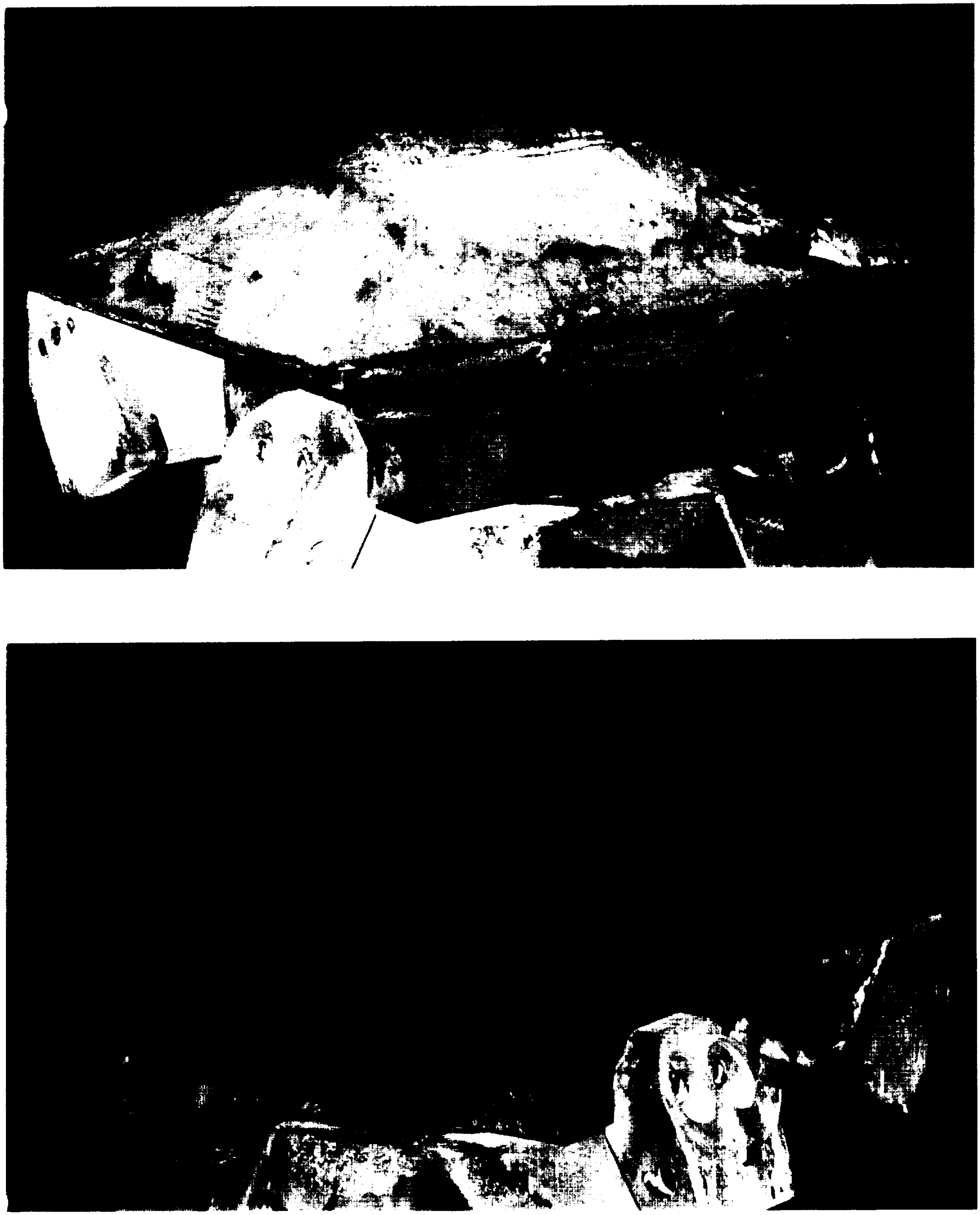


Photo 6: Holddown Post # 3 and #7 Blast Covers

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 82 films and videos, which included twenty-seven 16mm films, seventeen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

SSME ignition and Mach diamond formation appeared normal (OTV-051, -071).

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-009).

A thin, 6-inch long by 1-inch wide light-colored object, believed to be a tile gap filler, first appeared in an area between the SSME heat shields and fell aft at 08:07:44.699 UTC during SSME ignition (E-19, E-20).

Tile surface coating material was lost during ignition from one place on the base heatshield outboard of SSME #3, one place on the base heat shield between the SSME's, two places on the aft surface of the LH RCS stinger, and one place on the aft surface of the RH RCS stinger. Surface coating material was also lost from several tiles on the body flap +Z side in the general vicinity of SSME #3 (E-17, -18, -19, -20).

Although the camera viewing HDP #7 did not run, no stud hang-ups were observed on the other holddown posts. No ordnance debris or frangible nut pieces fell from the DCS/stud holes.

GUCP disconnect from the ET and GH2 vent line retraction was nominal (E-33, -36).

SRB sound suppression water trough material was ejected from the SRB exhaust hole north of the vehicle after liftoff (E-52).

Ice was still present in the LO2 feedline upper bellows during lift-off (OTV 066).

Water/condensate fell from the rudder/speed brake split through tower clear (E-52).

A light-colored object, which may have been a small bird or moth, entered the field of view from above at 08:07:51.824 UTC and fell aft along the vehicle without contact (E-59).

Three debris-induced streaks occurred in the SSME exhaust plume during ascent (E-212, -222, -223).

Several particles, most likely pieces of instafoam from SRB aft skirt aft rings, fell along side the SRB exhaust plume during ascent (E-54).

Typical body flap movement (amplitude and frequency) was visible in film items E-207, -212, and -222.

SRB exhaust plume recirculation also appeared typical (E-207).

SRB separation appeared normal. Slag fell from the exhaust plumes just before (tailoff), during, and after separation (E-207, -208, -212).

Photo 7: Tile Gap Filler

A thin, 6-inch long by 1-inch wide light-colored object, believed to be a tile gap filler, first appeared in an area between the SSME heat shields and fell aft at 08:07:44.699 UTC during SSME ignition

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. Hand-held photography by the flight crew, which consisted of eight still 35mm images, showed the aft dome and -Z side of the ET. Approximately 10 minutes of hand held camcorder video footage showed most areas of the ET.

SRB separation from the External Tank appeared nominal.

Very thin, charred layers of TPS were observed falling away from the aft surface of the -Y upper strut fairing closeout just before SRB separation. This is a normal occurrence.

ET-84 separation from the Orbiter was not visible due to the dark conditions of a night launch. Some time later, both the Orbiter and External Tank crossed the terminator. The forward half of the ET was then illuminated.

Three TPS divots were detected in the LH2 tank-to-intertank flange closeout between the bipods. One 6-inch diameter divot was located close to the centerline/+Z axis in the sanded area just aft of the intertank acreage rind while one each somewhat smaller divot appeared at each bipod jack pad standoff closeout sanded area just forward of the LH2 tank upper barrel acreage rind (total of two divots).

Although the intertank acreage TPS was generally in good condition, several small divots were detected: 3 shallow intertank stringer head divots near the LO2 tank PAL ramp, 10 shallow intertank stringer head/valley divots forward of the bipods, 8 shallow intertank stringer head/valley divots around the -Y bipod spindle housing closeout.

Other than two shallow divots in the LH2 tank upper barrel acreage just aft of the intertank splice, no other divots were visible in the LO2 and LH2 tank acreage TPS.

Erosion of the -Y thrust strut flange TPS closeout was typical.

Note: during post landing destow operations, USA FCS technicians found the LO2 ET/ORB umbilical 35mm camera dislodged from the inboard dove-tailed interface fitting. A theory suggests that insulation around the camera may have been pinched in the fitting preventing the camera from seating properly. A PR was initiated and work steps written to reinstall the camera using all of the same flight hardware (bolts, washers, peelable shim pack, etc.) to check for proper camera fit. The camera and all associated hardware were fitchecked twice with no problems. Installation was successfully accomplished as designed. Review of the 35mm on-orbit film showed no anomalies in field-of-view and focus thereby indicating the camera was in proper position during ascent through ET separation. Since it is unlikely that on-orbit operations/maneuvering caused the camera to come loose, this event probably occurred with the vibration of re-entry or the impact of touchdown on the runway.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 23 films and videos, which included nine 35mm large format films, two 16mm films, and twelve videos, were reviewed.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. The right main landing gear contacted the runway first. The Orbiter rolled west of the runway centerline, then east of the centerline before being steered back onto the centerline. Drag chute deployment appeared nominal. Touchdown of the nose landing gear was smooth. Rollout and wheel stop were uneventful. APU exhaust on the left side of the vertical stabilizer was more visible than usual. No significant TPS damage was visible in the films.

Photo 8: SRB Separation from External Tank

Very thin, charred layers of TPS fell away from the aft surface of the -Y upper strut fairing closeout just before SRB separation leaving light-colored areas (arrow). This is a normal occurrence. Note typical erosion of TPS on the aft side of the LH2 ET/Orbiter umbilical cable tray and blistering of the umbilical topcoat (arrows).

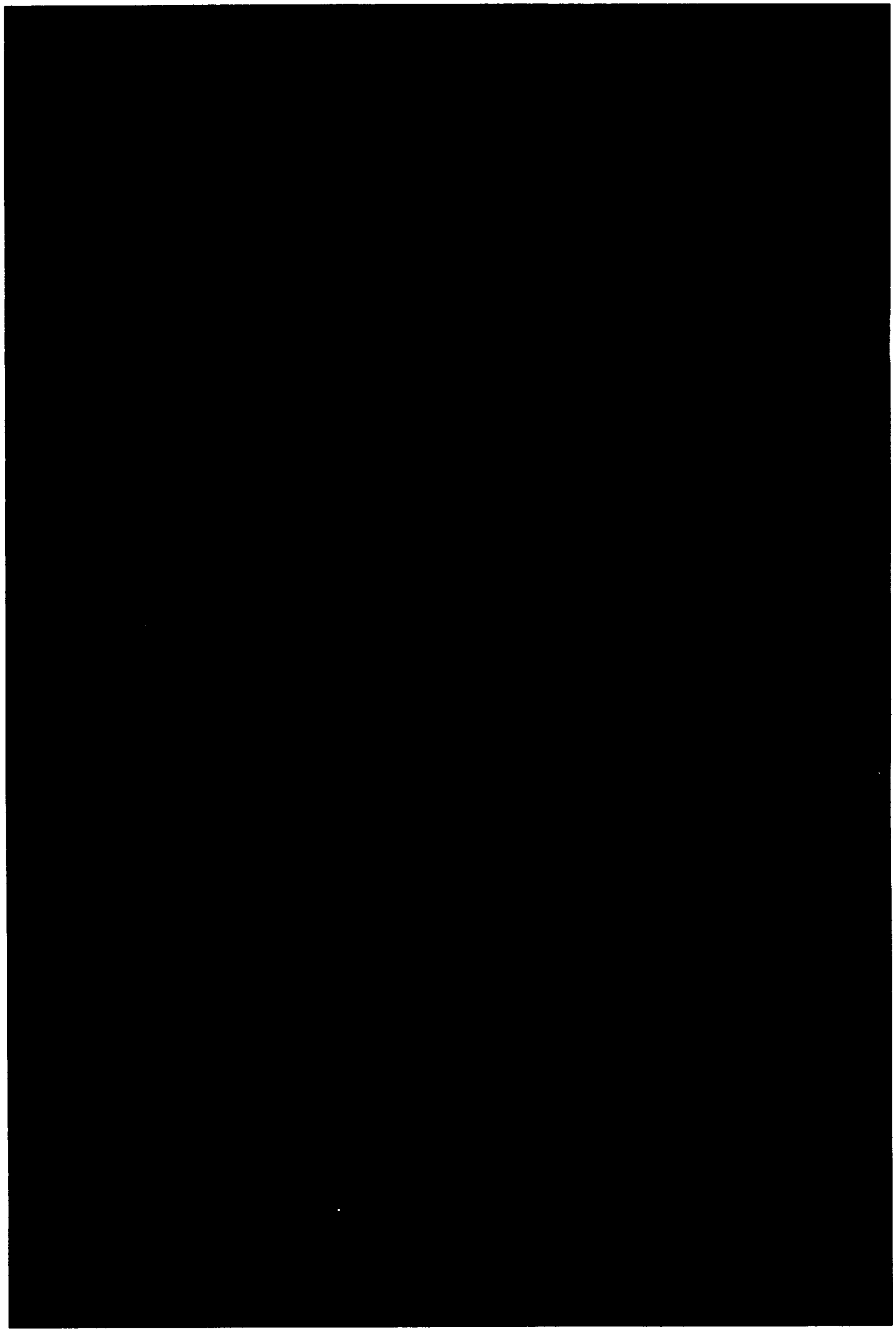


Photo 9: TPS Divots

Three TPS divots were detected in the LH2 tank-to-intertank flange closeout between the bipods. One 6-inch diameter divot was located close to the centerline/+Z axis in the sanded area just aft of the intertank acreage rind while one each somewhat smaller divot appeared at each bipod jack pad standoff closeout sanded area just forward of the LH2 tank upper barrel acreage rind (total of two divots). Although the intertank acreage TPS was generally in good condition, 21 small stringer head/valley divots were visible forward of the bipods and -Y spindle housing closeout.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-087 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 17 May 1997.

Both frustums were in excellent condition. No TPS was missing and only four debonds were detected over fasteners on the left frustum. None of the Hypalon paint had blistered. All eight BSM aero heat shield covers had locked in the fully opened position.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. The +Z antenna base plate on the left SRB exhibited two delaminated phenolic layers. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. One pin, but no retainer clips, was missing from the left SRB frustum severance ring. Three nearby retainer clips were bent. The missing pin and bent retainer clips were most likely caused by parachute riser entanglement.

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. A significant amount of foam was missing from the aft side of both IEA's. The remaining foam was sooted. Some areas of exposed substrate exhibited blistered paint due to ascent plume recirculation or re-entry heating. These findings indicate the foam was lost prior to water impact.

TPS on the external surface of both aft skirts was intact and in good condition. Internally, less than usual amounts of foam were missing on the aft skirt aft rings.

Six of the holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally. The HDP #1 DCS plunger was obstructed by frangible nut halves. The HDP #7 plunger was not fully seated, but partially obstructed by a piece of the frangible nut.

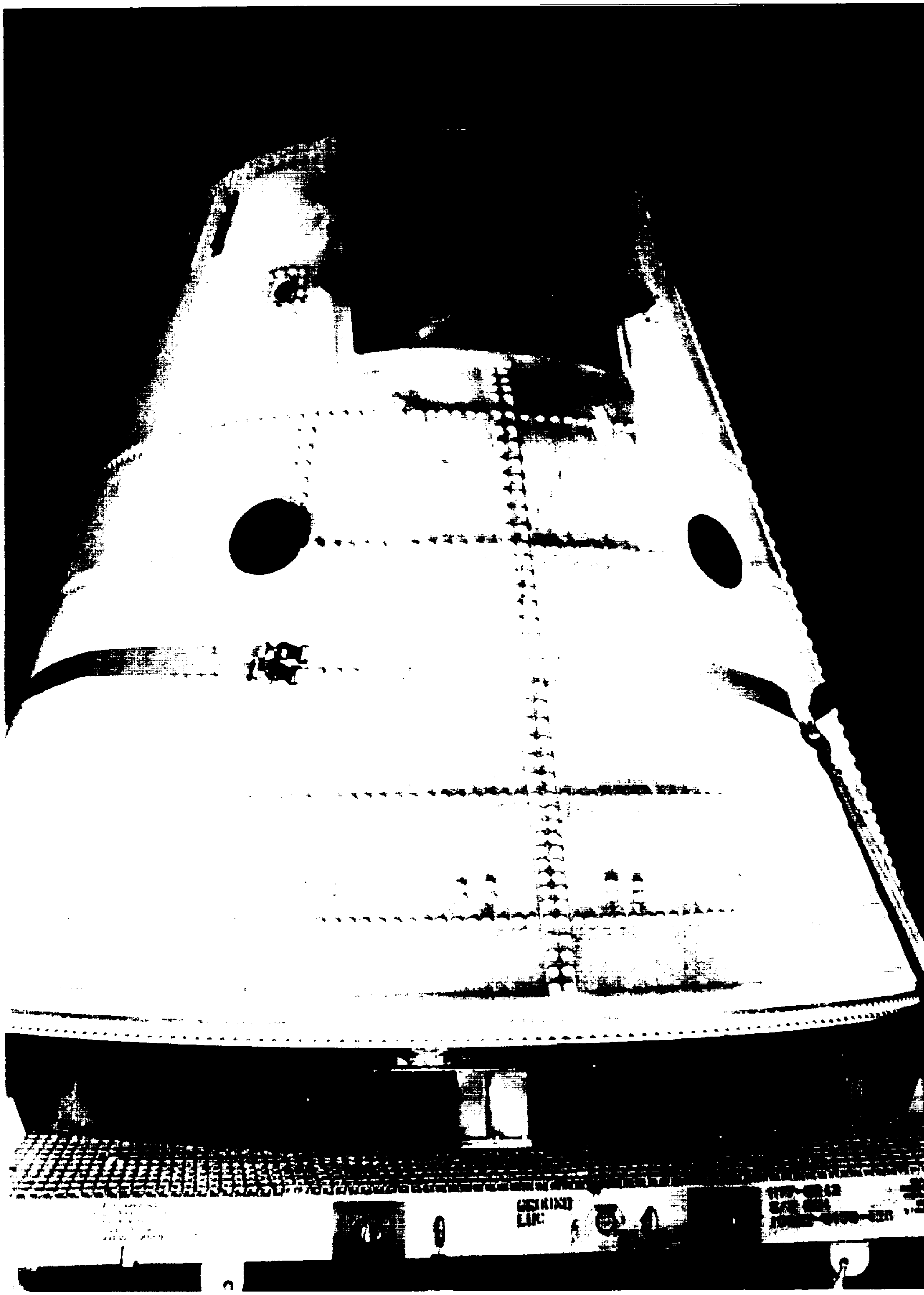
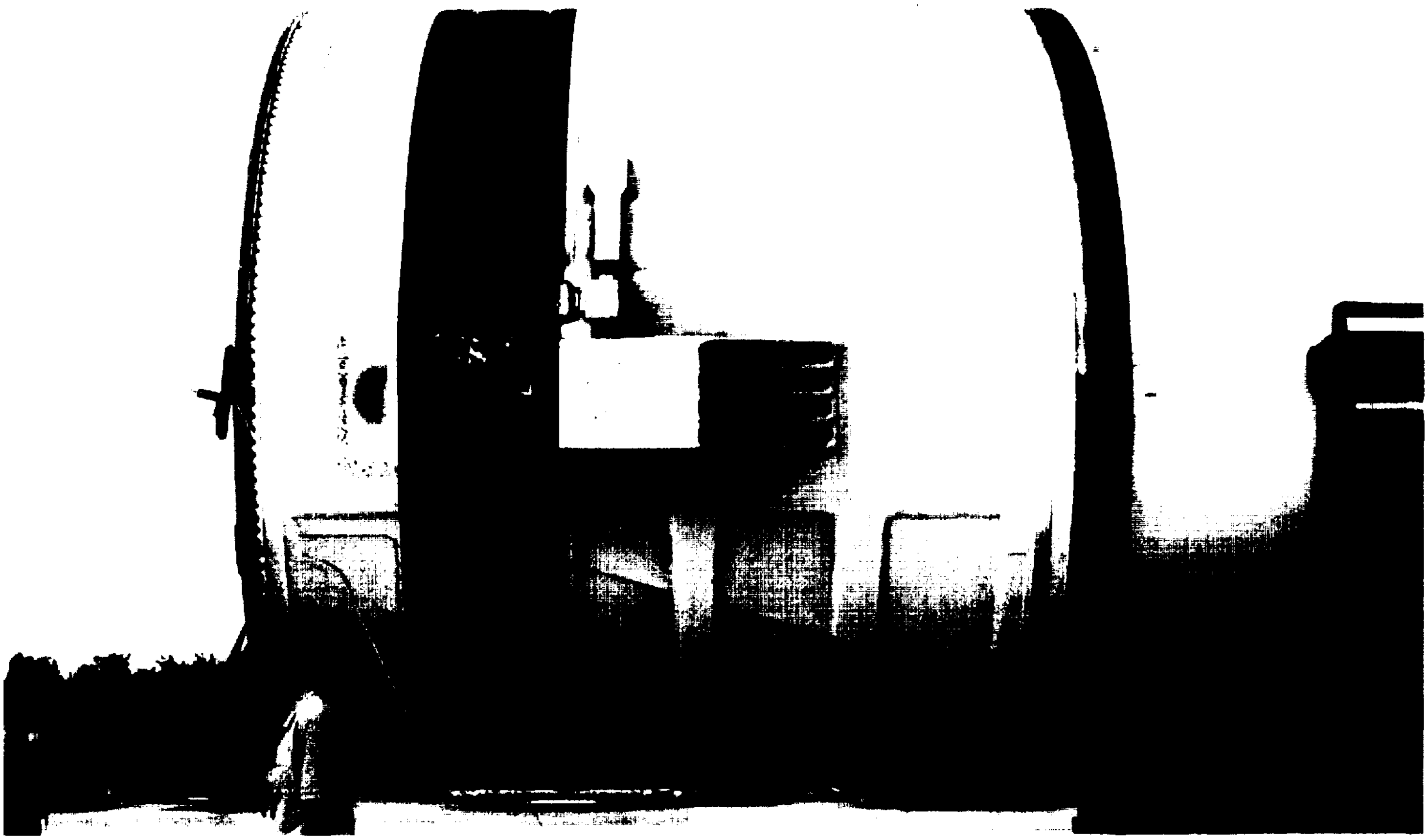


Photo 10: Right Frustum



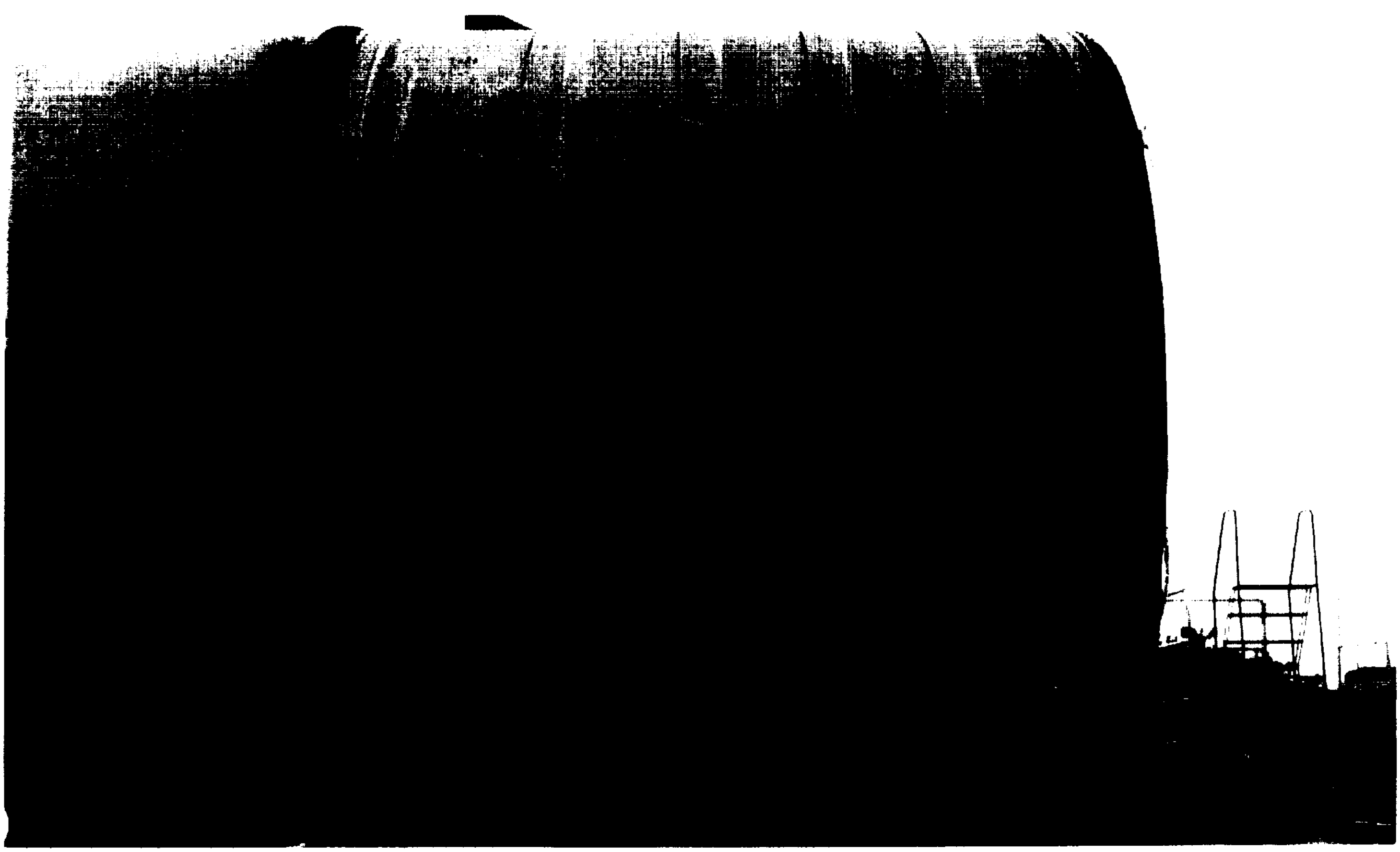


Photo 11: Left and Right Forward Skirts

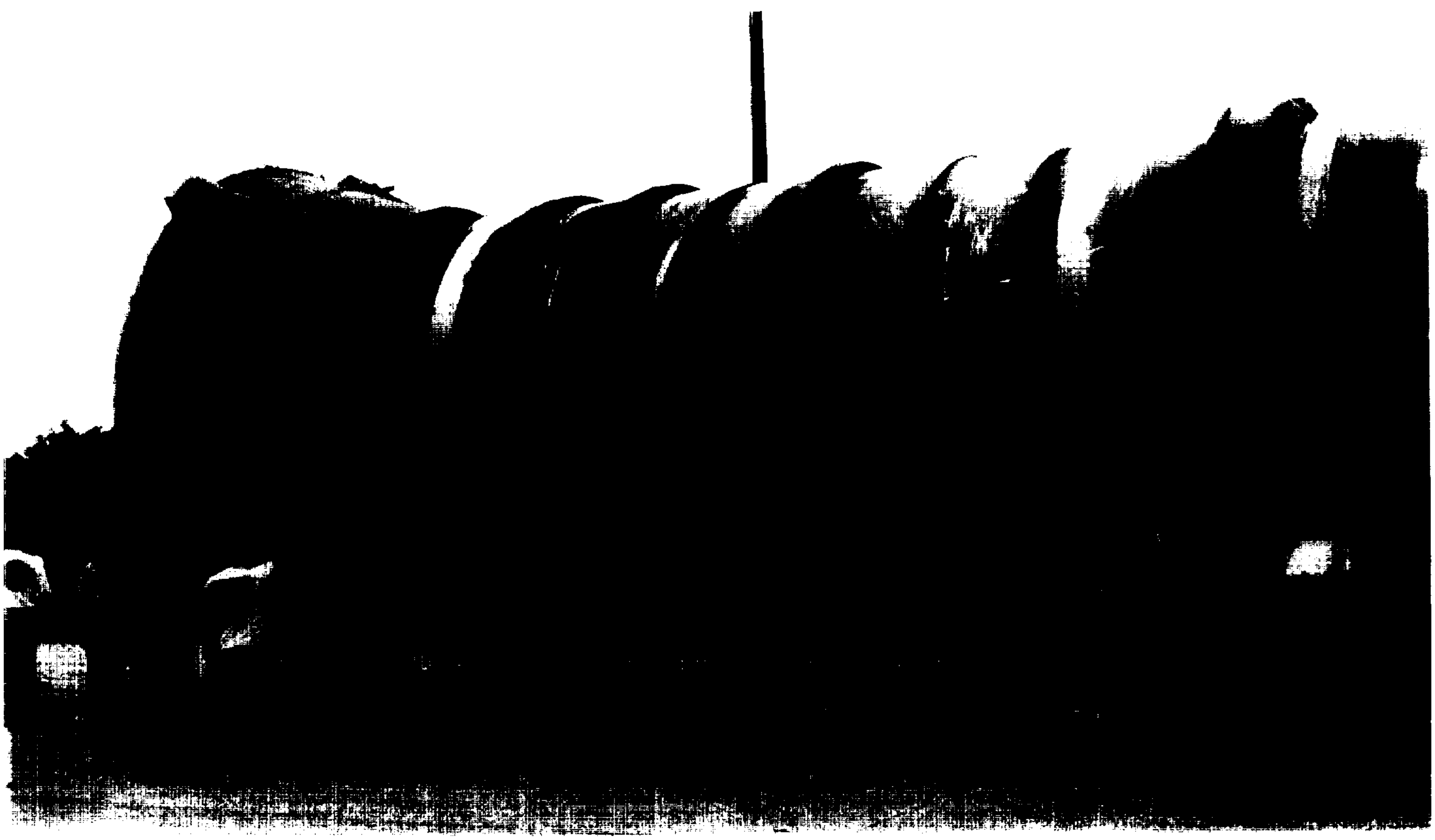


Photo 12: Left and Right Aft Boosters

Photo 13: Holddown Post #1 DCS Plunger

The HDP #1 DCS plunger was obstructed by frangible nut halves

Photo 14: Blistered Topcoat Over Ablator

A significant amount of foam was missing from the aft side of both IEA's. The remaining foam was sooted. Some areas of exposed substrate exhibited blistered paint/topcoat due to ascent plume recirculation or re-entry heating. These findings indicate the foam was lost prior to water impact.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-104 Atlantis was conducted 24-26 May 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 103 hits, of which 13 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 68 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 (Reference Figures 1-4).

The following table breaks down the STS-84 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	10	67
Upper surface	2	23
Right side	0	5
Left side	0	3
Right OMS Pod	0	2
Left OMS Pod	1	3
TOTALS	13	103

The Orbiter lower surface sustained a total of 67 hits, of which 10 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the Orbiter centerline between the two MLG doors. The site measured 1.5-inches long by 0.5-inch wide by 0.375-inch maximum depth.

Tile damage sites around the LH2 and LO2 ET/ORB umbilicals were typical. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream, both of which were observed in launch films.

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

The tires were reported to be in average condition for a landing on the KSC concrete runway. Some ply undercutting occurred on the MLG tires with the worst undercutting observed on the right outboard tire. Very small pieces of rubber were found on the runway scattered along the rollout ground track.

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. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect. EO-2 and EO-3 retainer springs were dislodged. This condition has been observed on previous flights.

The SSME Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition with no fraying or tearing. A corner was missing from a tile located on the base heat shield near SSME #2 and the body flap hinge.

Tiles on the vertical stabilizer "stinger" were intact and undamaged. A trailing edge tile near the split in the rudder/speed brake exhibited cracks and missing surface coating material, though there was no measurable depth. The damage is believed to be the result of SSME ignition vibration and acoustics rather than a debris impact.

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

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size with the exception of one damage site greater than 1-inch in size in the black perimeter tiles of window #3. The damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the FRCS thrusters.

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 previous missions (Reference Figure 5).

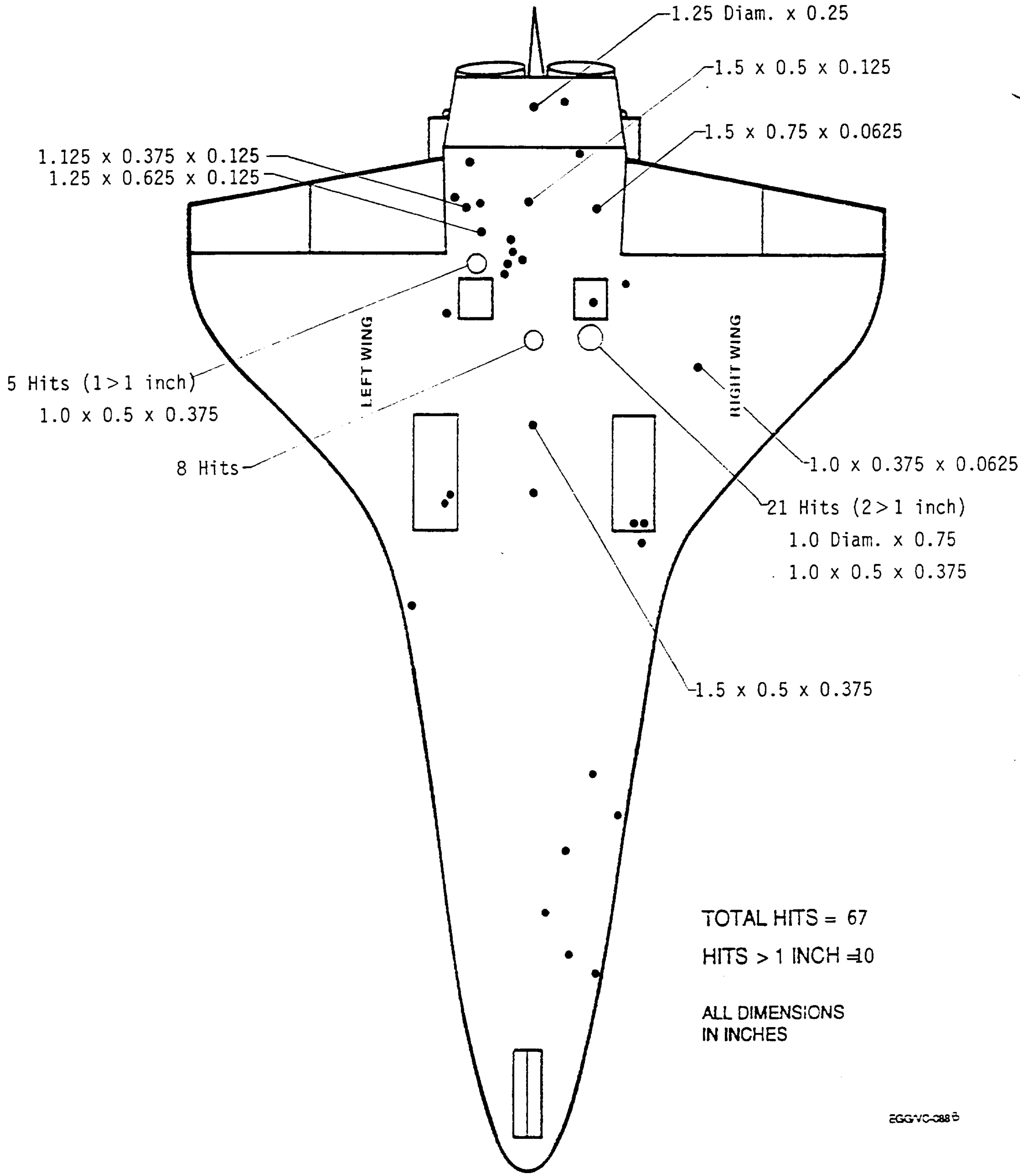


Figure 1: Orbiter Lower Surface Debris Damage Map

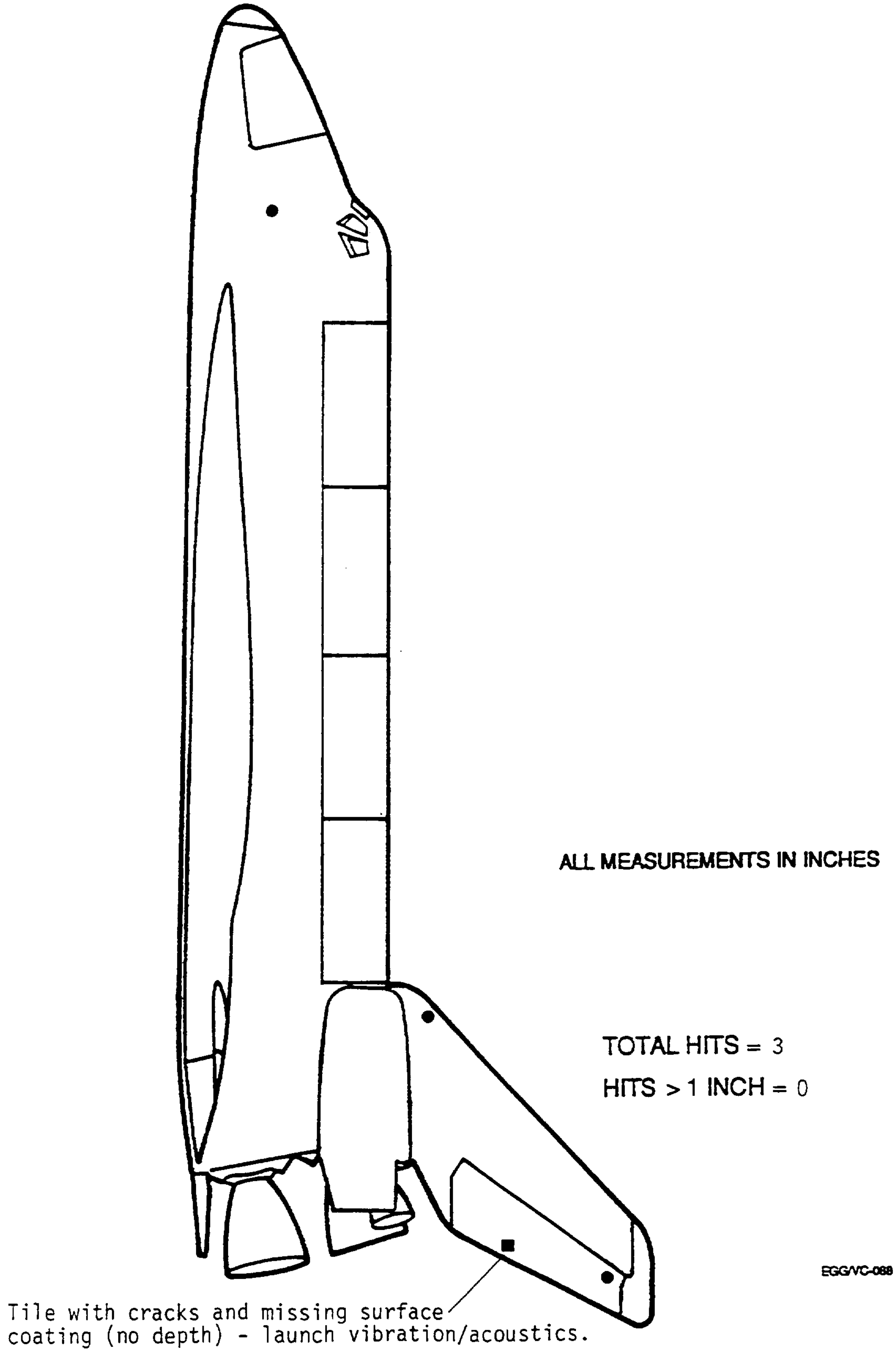


Figure 2: Orbiter Left Side Debris Damage Map

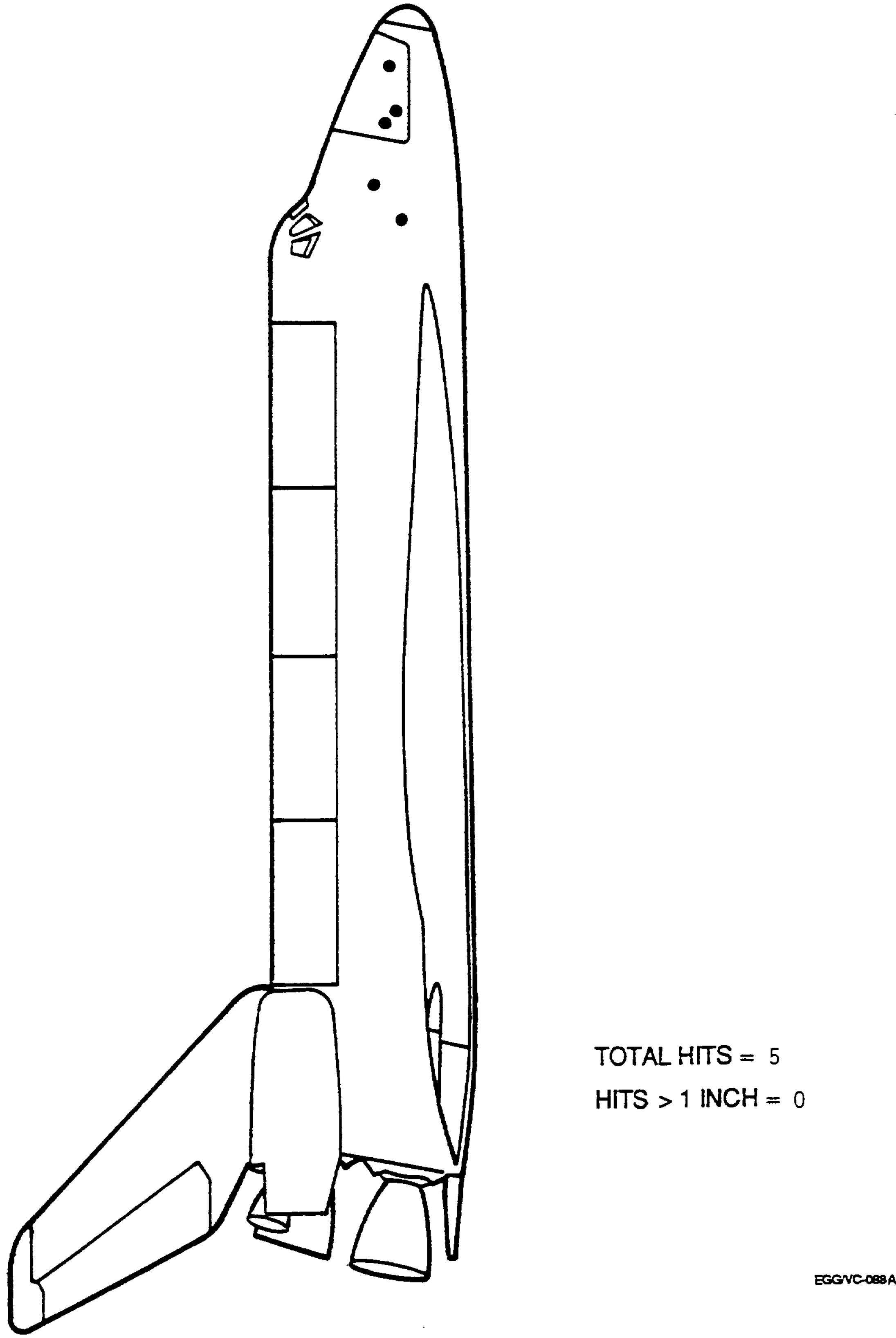


Figure 3: Orbiter Right Side Debris Damage Map

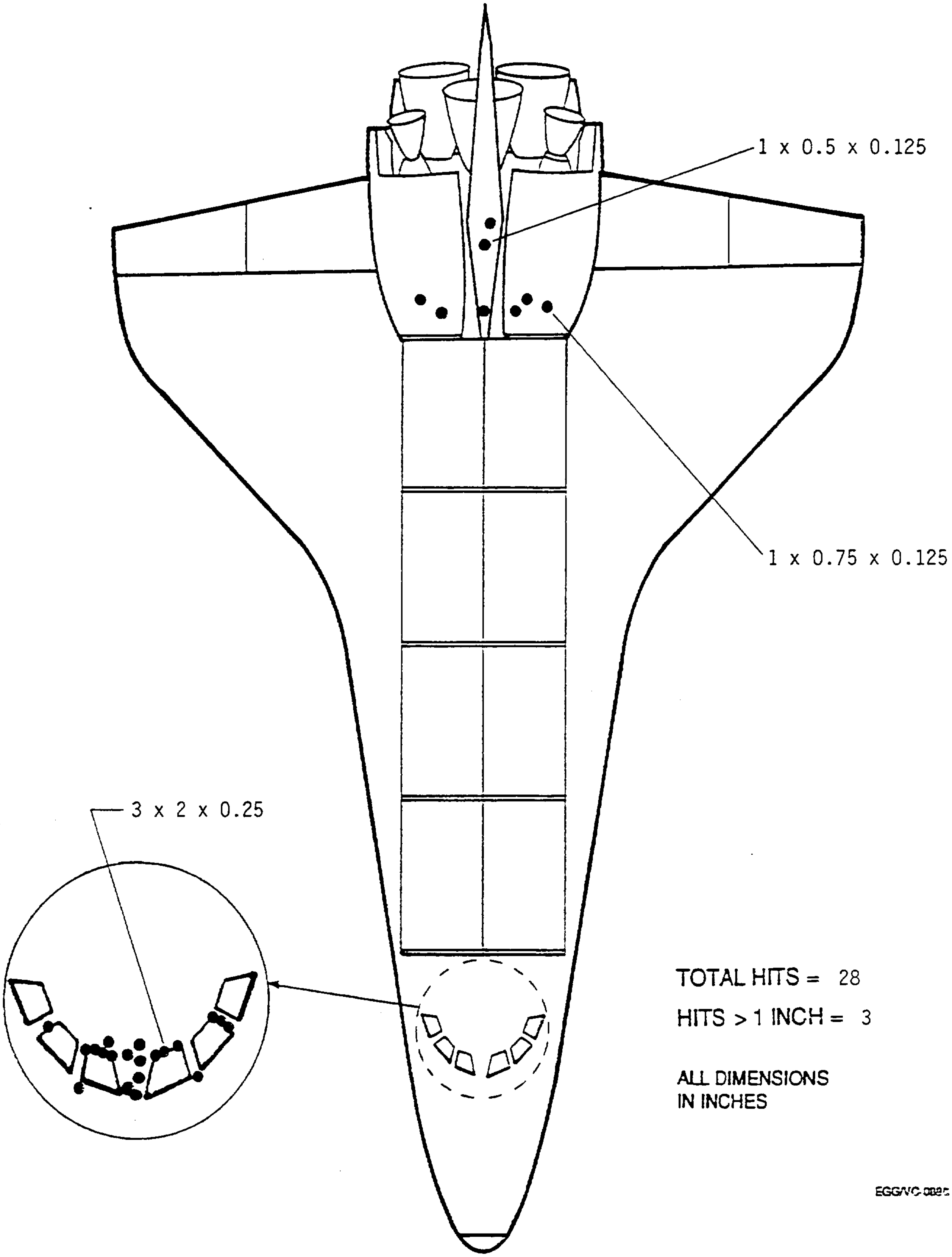


Figure 4: Orbiter Upper Surface Debris Damage Map

	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
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
AVERAGE	13.5	84.9	19.9	125.4
SIGMA	7.2	44.0	9.5	52.7
STS-84	10	67	13	103

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 5: Orbiter Post Flight Debris Damage Summary

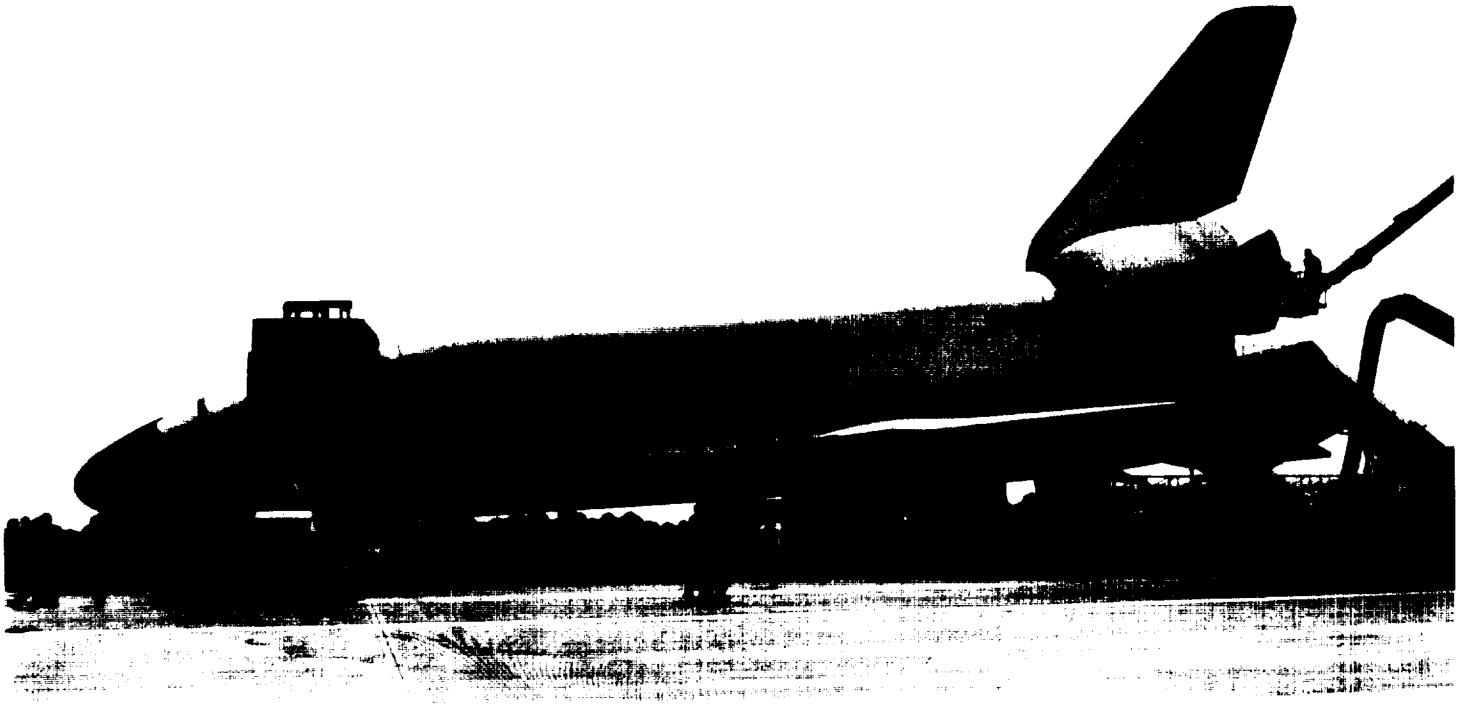


Photo 15: Overall View Orbiter Left and Right Sides

Photo 16: Overall View Orbiter Nose and Windows

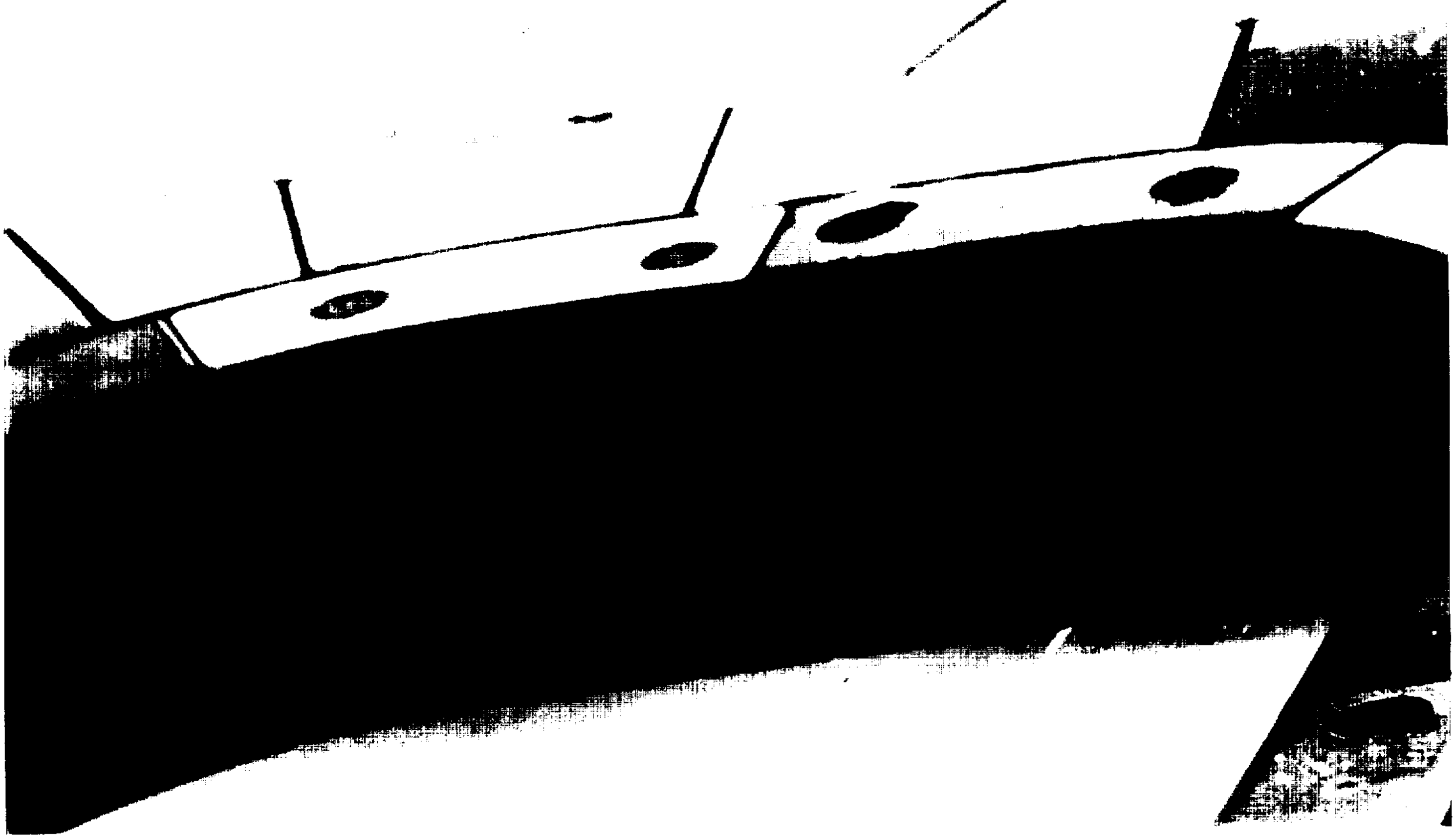


Photo 17: Window #3 Perimeter Tile Damage

Damage sites on the window perimeter tiles appeared to be greater than usual in quantity and size. These damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the FRCS thrusters.

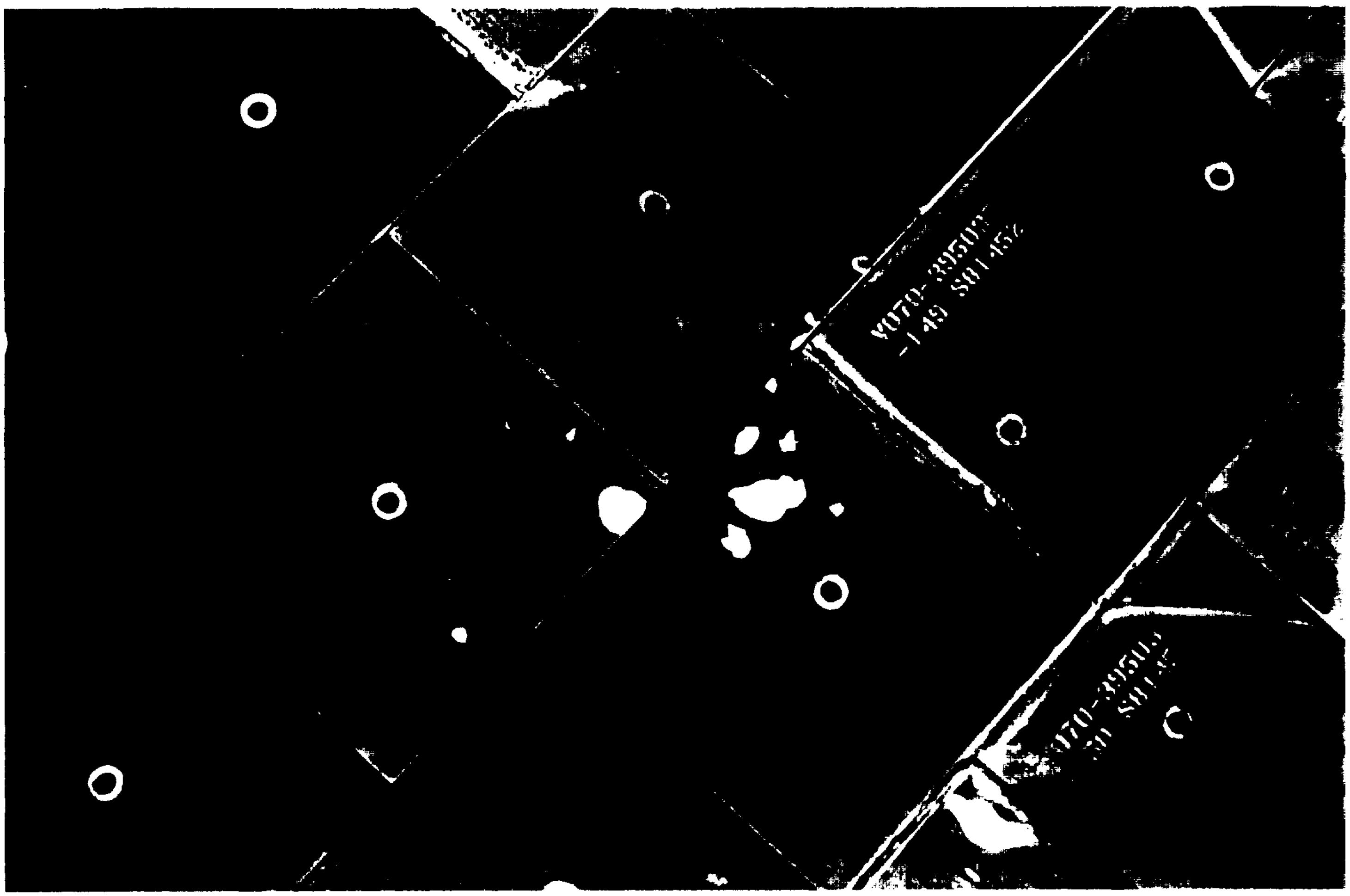


Photo 18: Typical Lower Surface Tile Damage

Tile damage sites aft of the LH2 and LO2 ET/ORB umbilicals were typical in size and quantity. The damage was most likely caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream, both of which were observed in launch films.

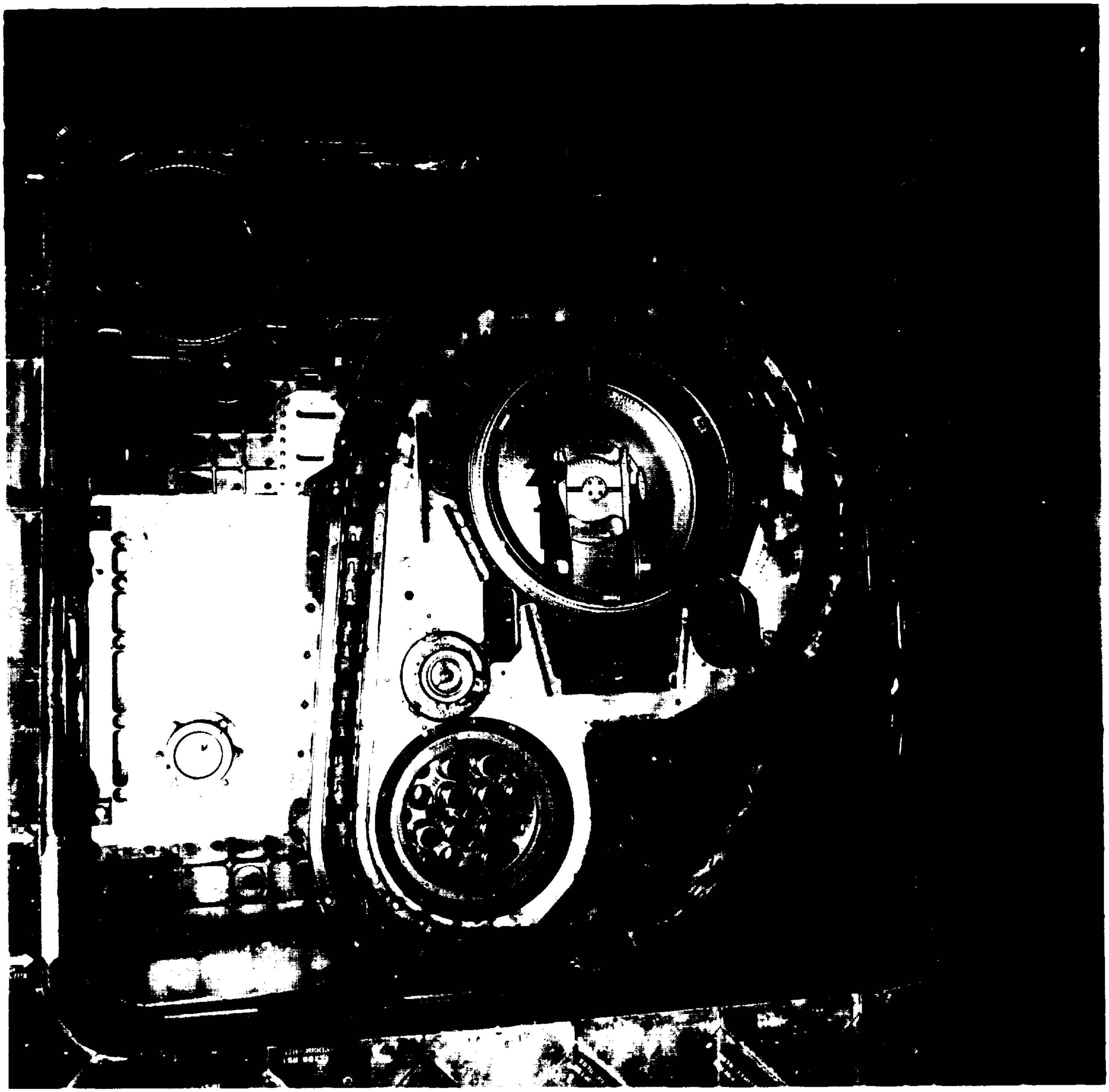


Photo 19: LO2 ET/ORB Umbilical

Photo 20: LH2 ET/ORB Umbilical

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

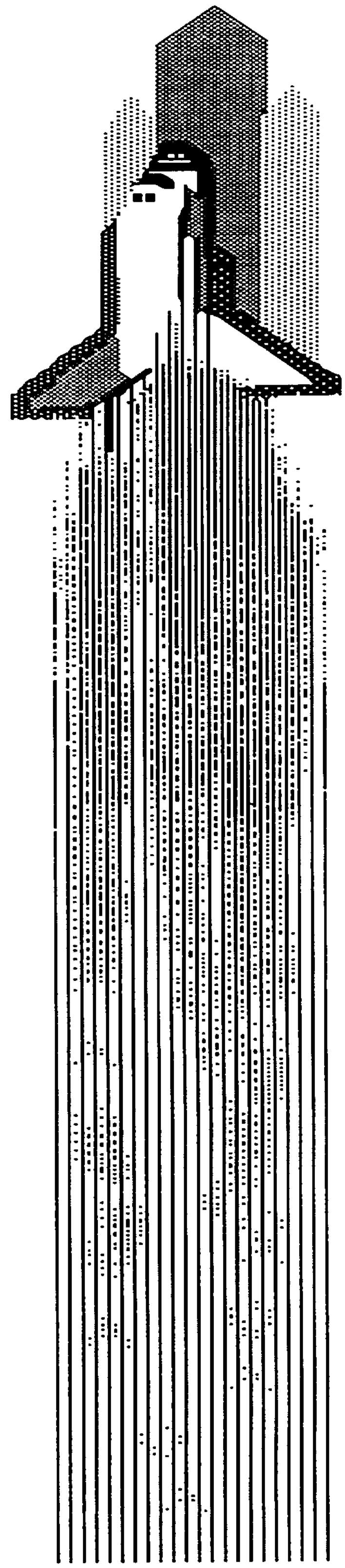
Space Shuttle

Earth Science Branch

Image Science and Analysis Group

STS-84 Summary of Significant Events

June 24, 1997



Space Shuttle
Image Science and
Analysis Group

STS-84 Summary of Significant Events

Project Work Order - SN-5LA

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1. STS-84 (OV-104): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-84 night-time launch of Atlantis (OV-104) from pad A occurred on Thursday, May 15, 1997 (day 135) at 08:07:48.009 Coordinated Universal Time (UTC), as seen on camera E9. Solid Rocket Booster (SRB) separation occurred at 08:09:51.954 UTC, as seen on camera KTV13.

On launch day, 24 of the 24 expected videos were received and screened. Following launch day, twenty-one films were screened. Nineteen additional films were received for contingency support and anomaly resolution, but were not screened since there were no major launch/ascent issues. No anomalies that could threaten vehicle safety were seen on the launch imagery.

Detailed Test Objective 312 was performed using umbilical well film (Method 1) and handheld still photography (Method 4). Handheld videos of the external tank following separation were also acquired.

1.1.2 On-Orbit

No on-orbit analysis support was requested.

1.1.3 Landing

Atlantis made an early-morning landing on runway 33 at the KSC Shuttle Landing Facility on May 24, 1997. Twelve videos were received and screened. Following landing, eleven films were screened.

Contrails were seen trailing from the Orbiter wing tips prior to landing (Camera KTV12L).

Although not considered anomalous, APU venting was seen during the approach through roll-out and wheel stop. Flames were seen coming from the APU vent after wheel stop until APU shutdown.

The Orbiter appeared to touch down to the left of the runway centerline on the SLF-South camera view.

The drag chute deployment appeared normal.

1.1.4 Post Landing

The following items were seen on the post landing walk-around video: erosion/chipping of the surface area of the base heat shield tiles between SSME #2 and SSME #3, minor tile damage on the base of the right RCS stinger, tile damage on the upper surface of the body flap, tile damage on the upper perimeter tiles of Orbiter forward window number three, and small marks (ply undercutting) on the main landing gear tires. Several small marks were seen on the leading edge of the right wing and on the chin panel forward of the nose gear doors. Several retainer springs on the ET/Orbiter EO-2 and EO-3 separation devices did not appear correctly positioned. A smudge was seen on the glass in front of the 35mm TPS camera lens in the LO2 ET/Orbiter umbilical.

Unconnected wires were visible on both the left and right main landing gear struts. These wires may be associated with the tire pressure monitor system, which are designed to break when the landing gear is deployed. Several previous mission post landing views were examined for similarly disconnected wires. Disconnected wires were not found on the previous mission views examined.

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	144:13:27:22.667	KTV12L
Right Main Wheel Touchdown	144:13:27:42.839	EL9
Left Main Wheel Touchdown	144:13:27:43.439	EL9
Drag Chute Initiation	144:13:27:46.861	KTV11L
Pilot Chute at Full Inflation	144:13:27:47.786	EL9
Bag Release	144:13:27:48.403	KTV15L
Drag Chute Inflation in Reefed Configuration	144:13:27:49.571	KTV15L
Nose Wheel Touchdown	144:13:27:51.375	KTV33L
Drag Chute Inflation in Disreefed Configuration	144:13:27:52.810	KTV33L
Drag Chute Release	144:13:28:17.232	KTV15L
Wheel Stop	144:13:28:35.345	EL10

Table 1.2 Landing Events Timing

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION TO LIFTOFF

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition to liftoff (umbilical ice debris, RCS paper, SRB flame duct debris). No damage to the vehicle was noted. No follow-up action was requested.

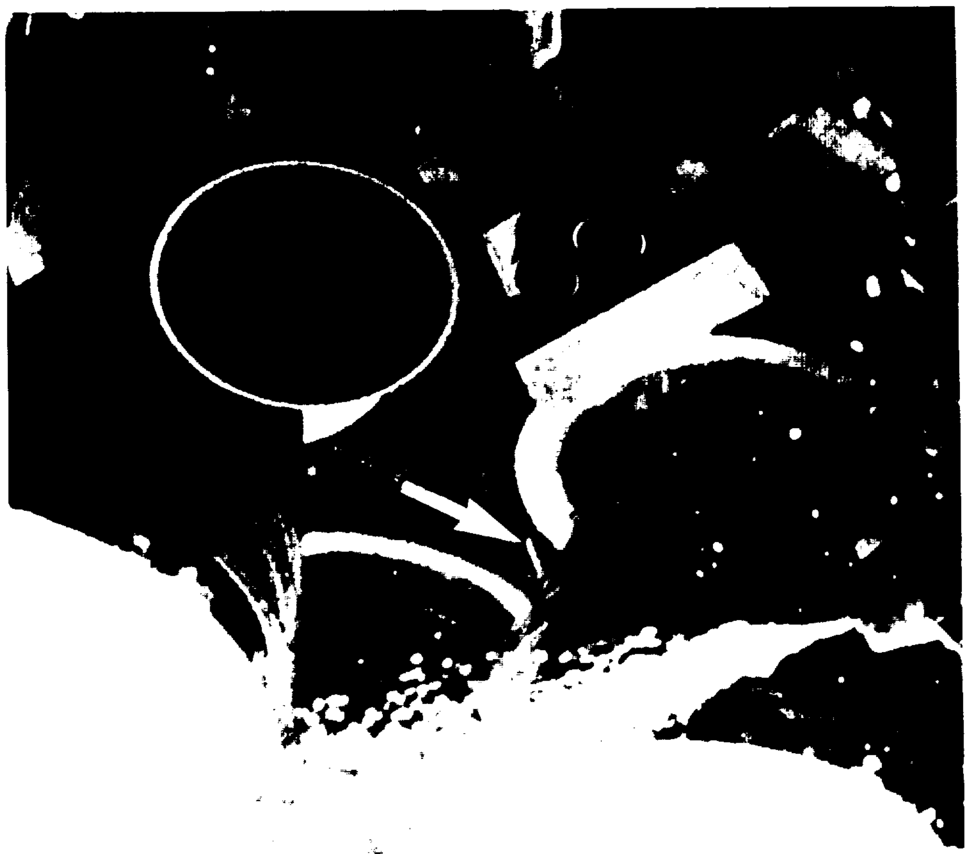

Figure 2.1 (A) Possible Tile Shim Debris Between SSMEs

A single, long, thin, light-colored, rectangular-shaped piece of debris (possibly a tile shim) was seen between SSME #2 and SSME #3 during ignition (08:07:44.667 UTC) (Cameras E19, E20).

Figure 2.1 (B) Ice Debris Strike to Umbilical Well Door Sill

Multiple pieces of ice debris from the LH2 ET/Orbiter umbilical were seen falling during SSME ignition. Several pieces of ice debris were seen to strike the LH2 umbilical well door sill (08:07:45.191 UTC). Also, a single piece of ice debris was seen to strike the LH2 four-inch recirculation line at 08:07:48.261 UTC. No damage to the Shuttle launch vehicle was noted (Camera OTV009).

A single piece of debris (probably paper) was seen falling from the LO2 TSM umbilical disconnect prior to liftoff (08:07:45.425 UTC) (Camera OTV049).

Figure 2.1 (C) Ice Debris Strike to Body Flap

A single piece of umbilical ice debris appeared to contact the lower surface of the body flap at 08:07:47.361 UTC. No damage to the body flap was noted. (Camera OTV063).

Figure 2.1 (D) Debris from SRB Flame Trench

On camera OTV 060, a single piece of debris was seen traveling from the SRB flame trench toward the FSS during liftoff (08:07:49.3 UTC). On camera E4, a long, flexable, linear-shaped piece of debris (possibly water trough material) was seen moving north from the RSRB flame trough during liftoff (08:07:49.874 UTC). On camera E224, at least two pieces of debris were seen north of the vehicle at liftoff (08:07:50.474 UTC). The debris were not seen to contact the vehicle.

2.2 DEBRIS DURING ASCENT

During ascent, multiple pieces of debris (probably umbilical ice and RCS paper) fell aft of the launch vehicle after liftoff, through the roll maneuver, and beyond. No damage to the vehicle was noted. No follow-up action was requested. (Cameras E1, E5, E31, E36, E52, E54, E207, E212, E222, E223, E224).

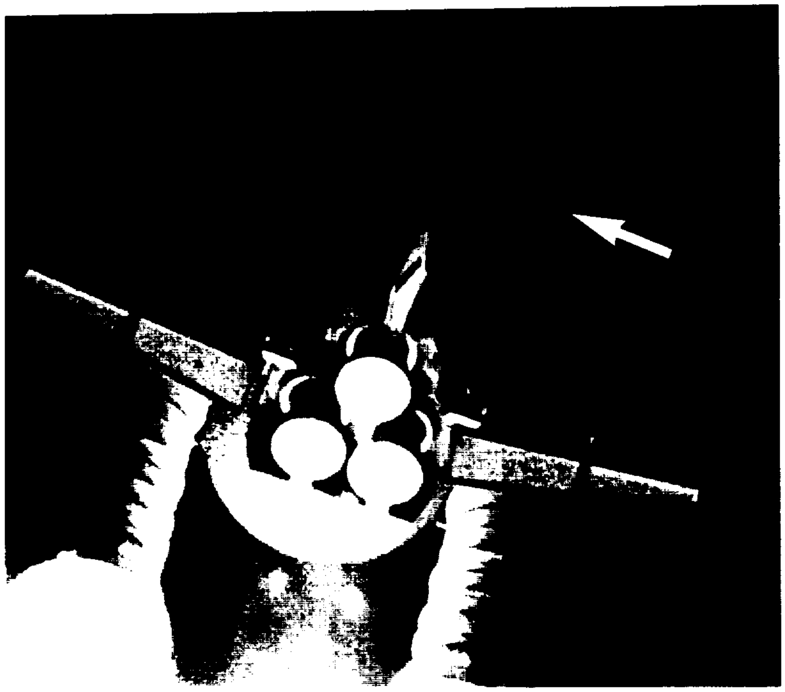

Figure 2.2 (A) RCS Paper Passing over Right Wing

A single piece of debris, probably RCS paper, was seen falling along the right side of the Orbiter fuselage and over the right wing after the roll maneuver at 08:08:02.6 UTC (Camera E52).

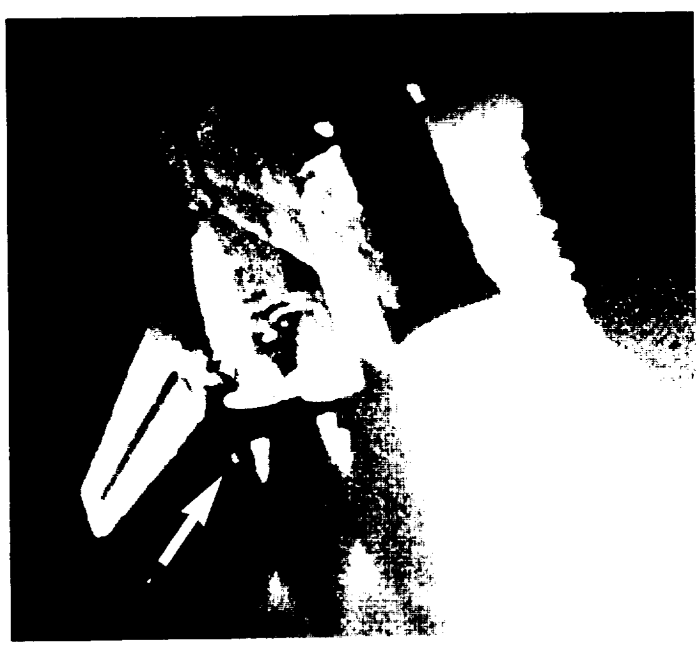

Figure 2.2 (B) Debris Near Vertical Stabilizer

A single piece of debris (probably RCS paper) was seen near the base of the vertical stabilizer at 08:08:05.906 (Camera E224).

Figure 2.2 (C) Debris Along SRB Exhaust Plume During Ascent

Multiple pieces of debris (possible SRB aft skirt insta-foam or slag debris) were seen falling along the SRB exhaust plume during ascent.

On camera E52, three pieces of debris were seen falling along the exhaust plume during ascent at 08:08:07.4 UTC. On camera E54, debris along the SRB exhaust plume was seen between 08:08:14.9 and 08:08:17.1 UTC. On camera E222, debris was seen along the SRB exhaust plume between 08:08:15.6 and 08:08:23.6 UTC.

On KTV4A, multiple pieces of debris were seen near the SRB exhaust plume between 08:08:53.7 and 08:09:02.633 UTC.

Figure 2.2 (D) Debris Forward of RSRB Aft Skirt

On Camera E223, a piece of debris was seen on the -Z side of the ET forward of the RSRB aft skirt at 08:08.14.739 UTC.

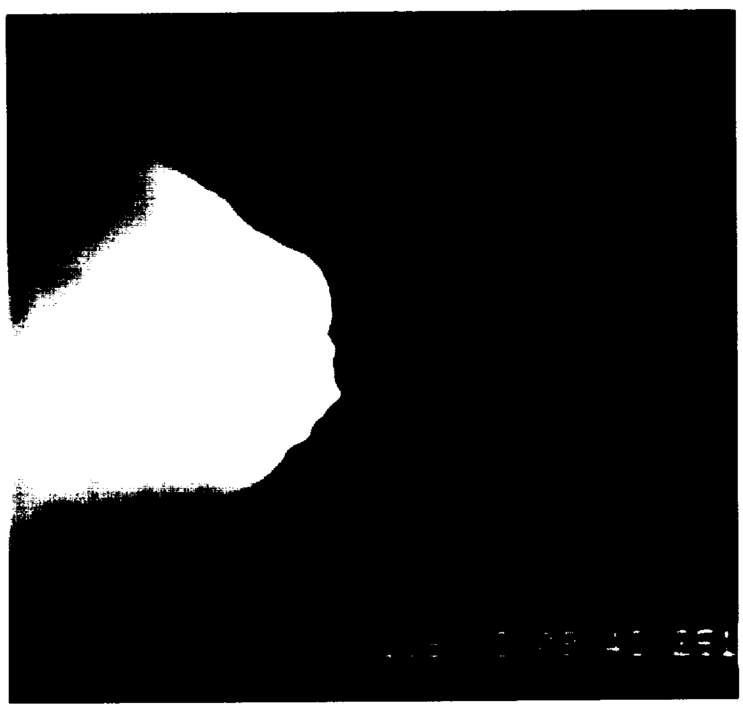

Figure 2.2 (E) Debris Prior to SRB Separation

Seven pieces of debris were seen near the SRB exhaust plume just prior to SRB separation between 08:09:48.5 and 08:09:51.3 UTC (Cameras KTV4A, KTV13, ET207 and ET208).

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

The SSME Mach diamond formation appeared to occur normally as seen on Camera E19. No follow-up action was requested. The times of the Mach diamond formation are provided in Table 2.3.

SSME #3	08:07:44.771 UTC
SSME #2	08:07:44.875 UTC
SSME #1	08:07:44.912 UTC

Table 2.3 Mach Diamond Formation

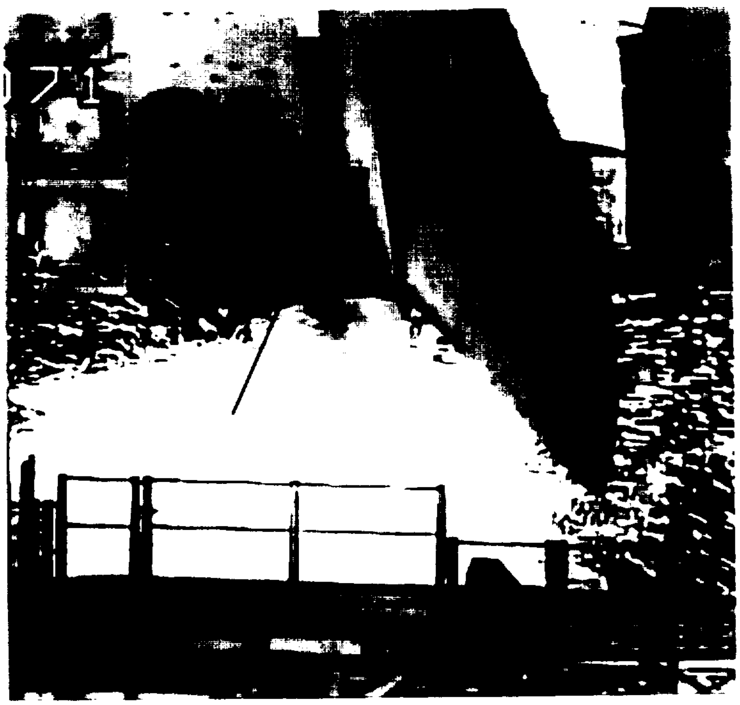

Figure 2.3 Orange Vapor During SSME Ignition

Orange vapor, probably free burning hydrogen, was seen above the SSME rims, under the body flap, and near the base of the vertical stabilizer during ignition (08:07:42.8 UTC). Orange vapors have been seen on previous missions (Camera OTV071).

A small area of TPS surface coating material erosion was seen on the tip of the right RCS stinger during SSME ignition (08:07:44.516 UTC) (Camera E17).

A thin, light-colored mark, possibly a frost line was visible at the base of SSME #2 during liftoff (08:07:48.187 UTC) (Camera E18).

2.4 ASCENT EVENTS

Figure 2.4 (A) Vapor from Vertical Speed Brake Drain Hole

Vapor was seen trailing from the vertical speed brake aft drain hole just after liftoff (08:07:52.8 UTC) (Camera E52).

Figure 2.4 (B) Orange-colored Flare in SSME Exhaust Plume

Approximately five orange-colored flares (probably debris induced) were seen in the SSME exhaust plume during ascent between 08:08:00.1 and 08:08:25.8 UTC (Camera E224). A similar flare was also seen in the SSME exhaust plume at 08:08:30.769 UTC (Camera ET207)

Linear optical effects were seen along the launch vehicle between 08:08:56.5 and 08:08:58.8 UTC, 08:09:28.030 and 08:09:29.031 UTC (Camera KTV13); and also between 08:08:43.079 UTC and 08:08:51.032 UTC (Camera E207).

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

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

Three rolls of STS-84 umbilical well camera film were acquired (DTO-312, Method 1): the 35mm film from the LO2 umbilical, the 16mm film (5mm lens) and the 16mm film (10mm lens) from the LH2 umbilical. The +X translation maneuver was performed on STS-84.

Numerous light-colored pieces of debris (insulation and frozen hydrogen), and dark debris (probably charred insulation) were seen throughout the 16mm film sequence. Two larger irregular-shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. A charred piece of TPS was seen to detach from the aft surface of the -Y upper strut fairing prior to SRB separation. 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. Normal blistering of the fire barrier material on the

outboard side of the LH2 umbilical was seen. Ablation and charring of the TPS on the aft dome was normal. The LSRB separation appeared normal.

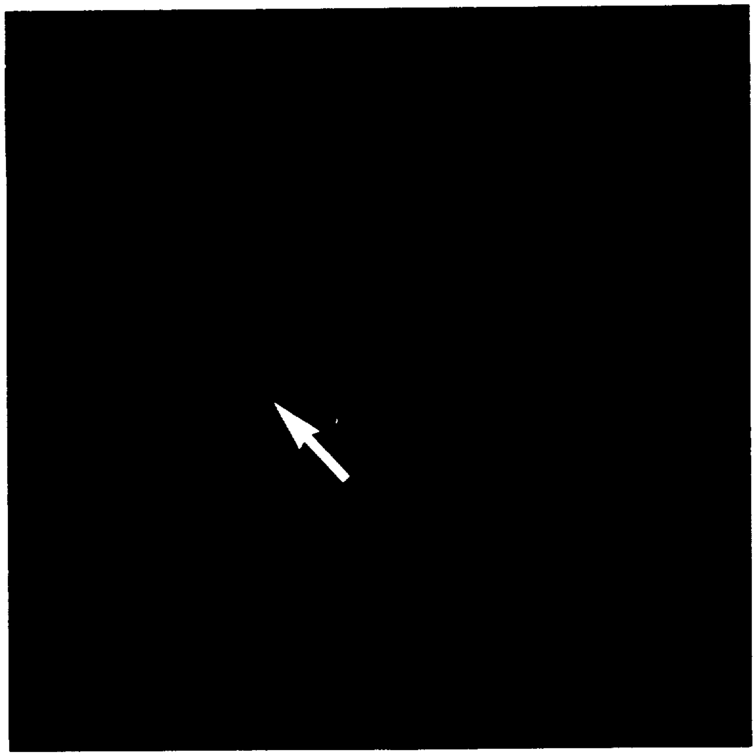

Figure 2.5.1 Divots on Forward ET

Three TPS divots, approximately six inches in size, were seen on the intertank-to-LH2 tank flange closeout between the legs of the bipod (+Z axis). Seven small shallow-appearing divots were seen on the intertank TPS forward of the ET/Orbiter bipod attach.

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

DTO-312 handheld photography (Method 4) of the STS-84 ET was acquired after ET separation. A Nikon 35mm camera with a 400mm lens and a 2X extender was used. The OMS-2 attitude pitch maneuver was performed early to assist the crew members in acquiring the ET visually.

Eight views of the external tank were acquired (roll 354). Six views of the -Z, -Y axis were acquired. Two views are of the aft dome and the +Z axis of the ET. Timing data is present on the handheld film. The first picture was taken on May 15, 1997 at 8:25:39 UTC (approximately 18 minutes after liftoff), and the last picture was taken at 08:28:36 UTC.

Two camcorder videos were also acquired of the ET after separation. The mini-cam view of the ET was too small for analysis. A second camcorder view, lasting approximately ten minutes, provided excellent post-separation views of all aspects of the ET

No anomalies were seen on the handheld photography of the ET.

STS-84 (ET-85) was the first flight of the new NCFI 24-184 liquid hydrogen tank sidewall thermal protection system. The new TPS appeared to be in good condition on the handheld photography. The new intertank access door and the new LH2 tank aft dome TPS (NCFI 24-57), first flown on STS-79 (ET-82), also appeared to be in good condition.

The normal SRB separation burn scars and aero-heating marks were noted on the ET TPS.

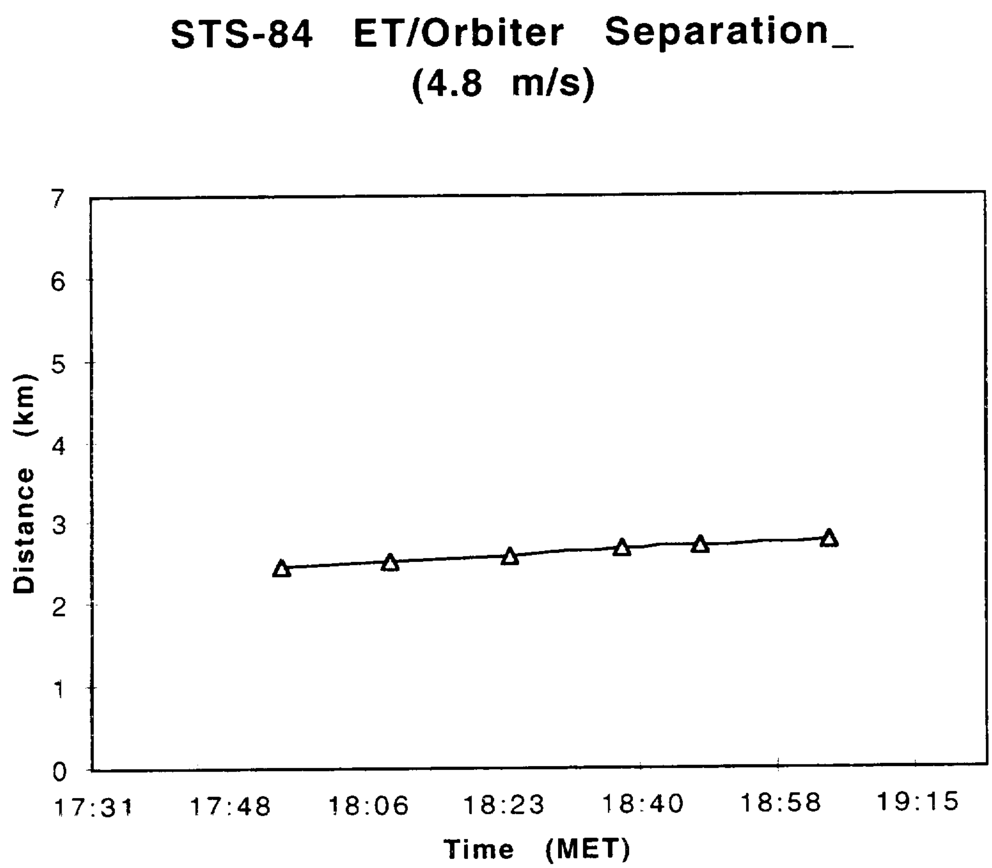

Figure 2.5.2 ET Separation Velocity

The distance of the external tank was calculated on six frames. On the first usable view, the external tank was calculated to be a distance of 2.4 kilometers away from the Orbiter at 17:55 MET. On the last view, the tank was calculated to be at a distance of 2.7 kilometers (1 minute, nine seconds after the first view). The tank separation average velocity was determined to be 4.8 meters/second (m/s), with an uncertainty of approximately 1 m/s. The tank tumble rate was approximately 0.5 degrees/second. The tank roll rate was too small to be determined.

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis (Task #1)

Film camera EL9 was used to determine the landing sink rate of the Oribter main gear and EL12 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-84 Orbiter was reported to be 216,167 lb.). The sink rate measurements for STS-84 are given in Table 2.6.1. In Figure 2.6.1(A), and 2.6.1(B), the trend of the measured data points for the image data is illustrated.

Sink Rate Prior to Touchdown (1 Second)	
Main Gear	0.4 ft/sec.
Nose Gear	4.3 ft/sec.

Table 2.6.1 Sink Rate Measurements

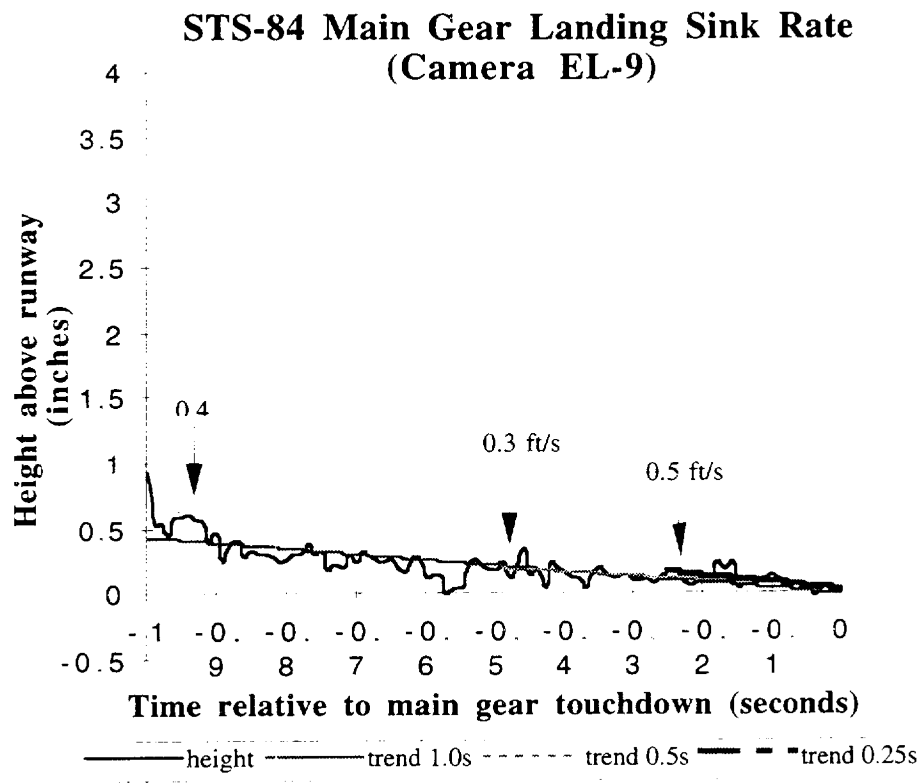

Figure 2.6.1 (A) Main Gear Height versus Time Prior to Touchdown

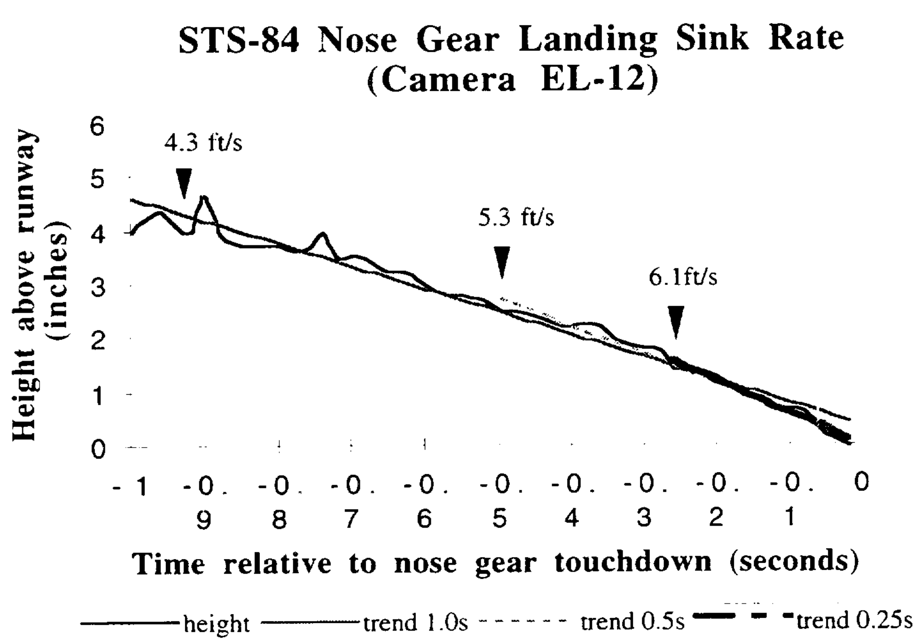

Figure 2.6.1 (B) Nose Gear Height versus Time Prior to Touchdown

2.7 OTHER

2.7.1 Normal Events

Other normal events observed included: ice and vapor from the ET/Orbiter umbilical areas during SSME ignition, elevon motion at SSME ignition, frost on the ET vent, ET twang, multiple pieces of light-colored debris falling from the LH2 and LO2 TSM T-0 umbilicals prior to and following disconnect, MLP debris at liftoff, acoustic waves during liftoff, birds in view during liftoff, debris in the exhaust cloud after liftoff, vapor off the SRB stiffener rings, condensation from the orbiter wing tips, outgassing of the ET aft dome, body flap motion, roll maneuver, ET aft dome charring, expansion waves, SRB separation, and slag debris after SRB separation.

2.7.2 Normal Pad Events

Normal Pad events observed were: Hydrogen ignitor operation, FSS deluge water operation, MLP deluge water activation, GH2 vent arm retraction, TSM T-O umbilical operations, and sound suppression system water operation.

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 (97-030)

TO: Distribution

FROM: EP42/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-84

The launch of space shuttle mission STS-84, the nineteenth flight of the Orbiter Atlantis occurred on May 15, 1997, at approximately 3:07 A.M. Central Daylight Time from launch complex 39A (LC-39A), Kennedy Space Center (KSC), Florida. Launch time was reported as 97:135:08:07:48.003 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team. Photographic and video coverage has been evaluated to determine proper operation of the flight hardware.

All ground based films and videos have been received and reviewed at MSFC. The films and videos from this launch are dark due to the night sky. This greatly reduces the amount of data recorded. Only the aft end of the vehicle is visible in the tracking films. Mobile Launch Platform (MLP) camera E11, which views Solid Rocket Booster (SRB) holddown post M7, experienced camera problems and tracking camera E220 did not run.

The astronauts provided eight photographs of the ET -Z side and aft dome using the hand-held Nikon camera. The 16mm motion picture films from the cameras located in the Orbiter's LH2 umbilical well provided coverage of the SRB separation and coverage of the External Tank (ET) after separation when lighting conditions became brighter.

No anomalies or problems were identified from the film and video review. All MSFC elements appeared to operate normally. The typical events of ice/frost falling from 17 inch disconnects during Space Shuttle Main Engine (SSME) start and liftoff, pad debris, falling debris from the vehicle during SSME start, liftoff and ascent, debris induced streaks in the SSME plumes and glowing debris particles being ejected from the Solid Rocket Motor (SRM) plumes were observed.

Post separation photography of the ET showed no major problems with the Thermal Protection System (TPS). Only the forward half of the ET was imaged by the Orbiter umbilical well cameras due to the transition from dark to daylight during the imagery sequence.

The following event times were acquired.

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	08:07:48.014	Camera E9
M-2 PIC Firing	08:07:48.012	Camera E8
M-5 PIC Firing	08:07:48.014	Camera E12
M-6 PIC Firing	08:07:48.014	Camera E13
SRB separation	08:09:51.99	Several Cameras

This report and additional information are available on the World Wide Web at URL:

http://photo4.msfc.nasa.gov/STS/sts84/sts84.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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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-84. 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 cyrogenic 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-84 and the resulting effect on the Space Shuttle Program.

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