Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-96

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DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-96

27 May 1999

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1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-96 consisted of OV-103 (26th flight), ET-100 and BI-098 SRB's on MLP-2 and Pad 39B. Discovery was launched at 147:10:49:42.021 UTC (6:50 a.m. local) on 27 May 1999. Landing was at 2:02 a.m. local/eastern time landing on 6 June 1999.

ET LO2 Tank Hail Damage

Approximately two weeks before launch, a thunderstorm with ¼-inch hail swept through the Complex 39 area and damaged the LO2 tank TPS causing a rollback to the VAB for repairs. A total of 728 damage sites were identified by close hands-on inspection. Although the size and depth of some damage sites were acceptable for flight, well over 200 sites were blended with adjacent foam while more than 200 other sites were repaired with PDL. All damaged areas in the LO2 tank "no ice zone" were correctly repaired according to certified design repair criteria. Environmental parameters and TPS integrity precluded ice formation on the foam insulation surfaces during cryoload through launch.

ET Thrust Panels

An 8mm video camera was flown in each SRB forward skirt for the purpose of documenting any TPS loss from the ET-100 thrust panels from launch through SRB separation. A new test for this flight incorporated thousands of pin-size vent holes with 0.3-inch spacing and 0.032-inch diameter holes to substrate in the intertank thrust panel machined foam. On the –Y thrust panel, the vent holes were placed near the EB fitting in the high heating area. However, the +Y thrust panel was configured just the opposite with no vent holes in the high heating area near the EB fitting. Instead, the vent holes were placed farther away from the EB fitting.

In terms of general observations, there were significantly less divots in the vented areas compared to the non-vented areas. Divots in the vented areas were generally smaller than divots in the non-vented areas. Divots in both vented and non-vented areas appeared shallow - no primed substrate was visible. Most divots occurred near the rib side walls and top edges. Valley divots were smaller in size than divots in the rib side walls/top edges. Divots were greater in number and larger in size in the high heating areas. Unexpectedly, a significant number of divots occurred outside the thrust panel in the +Z stringer section.

Post landing inspection revealed the Orbiter lower surface sustained 160 total hits, of which 66 had a major dimension of 1-inch or larger. Most of this damage was concentrated from the nose gear to the main landing gear wheel wells on both left and right chines. The outboard damage sites on the chines followed a similar location damage pattern documented on STS-86, -87, -89, -90, -91, -95, and -88.

With data from the last 8 flights showing out-of-family damage to Orbiter tiles, control limit analysis shows a marked change starting with STS-86 (reference Figures 6-7). Data from STS-72 through STS-85 consistently illustrate a relatively low average and reasonable upper control limit. These data represent an environment where the significant debris issues affecting the vehicle had been identified and corrected. However, a few earlier missions were also included to show the downward trend in debris damage representing corrective action still in progress. With the loss of TPS from the External Tank beginning on STS-86, the analysis clearly documents the increase in Orbiter tile damage as an out-of-family condition. Both the average and the upper control limit are significantly higher, and outside the 3-sigma value, for the previous flights.

The External Tank Project continues to work IFA STS-87-T-01 to prevent loss of foam from the External Tank and preclude further damage to Orbiter tiles.

3.0 LAUNCH

STS-96 was launched at 147:10:49:42.021 UTC (6:50 a.m. local) on 27 May 1999.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 26 May 1999. The detailed walkdown of Pad 39B and MLP-2 included the primary flight elements OV-103 Discovery (26th flight), ET-100, and BI-098 SRB's. There were no significant vehicle or launch pad anomalies. However, two pieces of scale or rust flakes approximately one inch square with minor thickness were detected on the LH SRB ETA ring. The resulting IPR (#IV-1-009141) with MRB rationale was accepted for flight based on the location and negligible threat to the Orbiter.

Approximately two weeks before launch, a thunderstorm with ¼-inch hail sweeping through the Complex 39 area damaged the LO2 tank TPS and caused a rollback to the VAB for repairs. A total of 728 damage sites were identified by close hands-on inspection. All damaged areas in the LO2 tank "no ice zone" were correctly repaired with PDL according to certified design repair criteria. (Environmental parameters and TPS integrity precluded ice formation on the foam insulation surfaces during cryoload through launch).

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 27 May 1999 from 0135 to 0305 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. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established database.

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. All RCS thruster covers were dry and intact. Ice/frost had formed on SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was wet with condensate. 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 75 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 Thermal Protection Systems performed nominally during cryoload. The Final Inspection Team observed wet TPS on the LO2 tank acreage due to condensate and a recent rain, but no ice or frost accumulations. Surface temperatures averaged 60 degrees Fahrenheit. All repairs from the hail damage were intact and exhibited no thermal shorts.

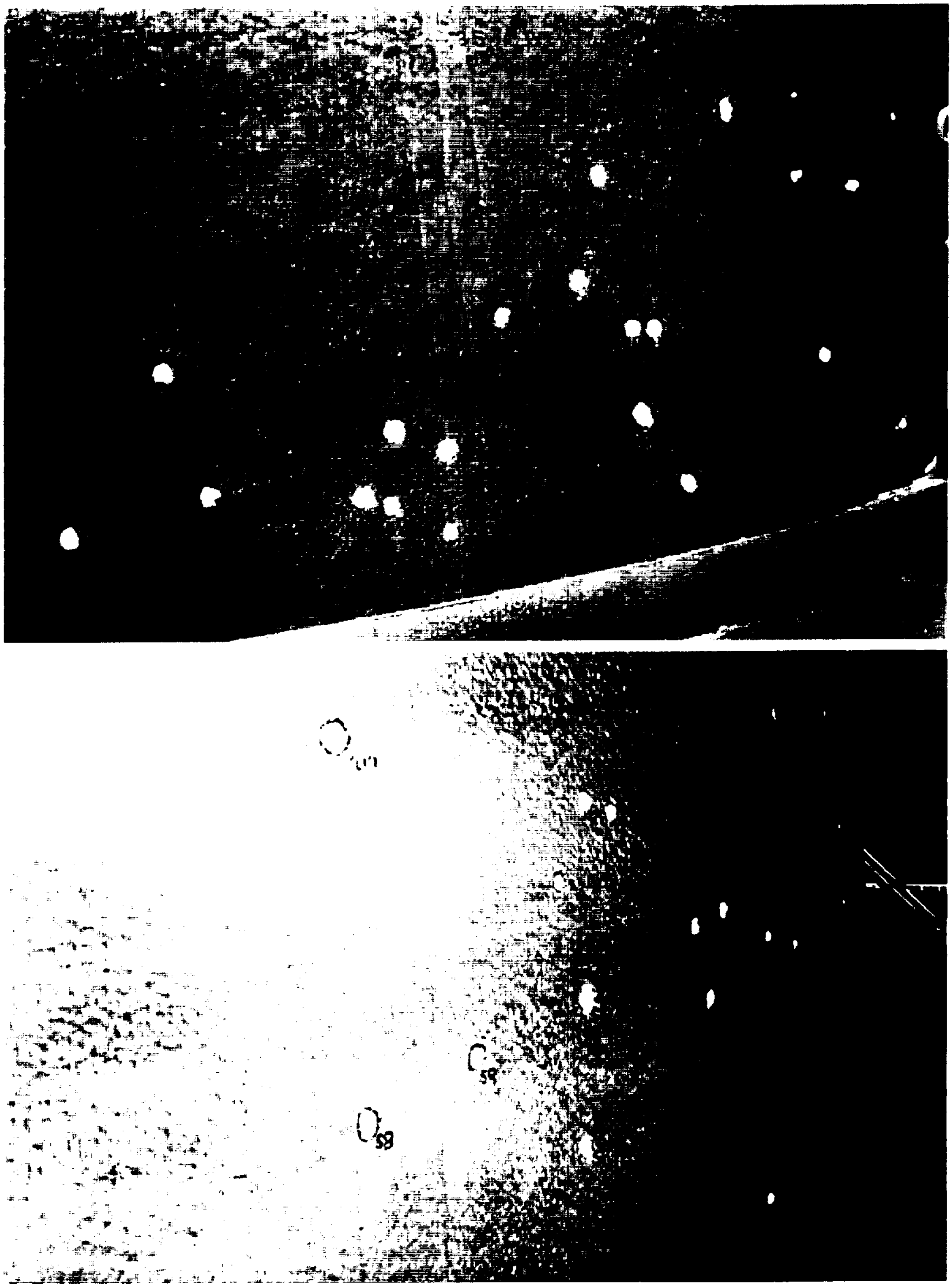


Photo 2: Hail Damage Repairs

A total of 728 hail damage sites were identified after rollback to the VAB. Although the size and depth of some damage sites were acceptable for flight per certified design criteria, well over 200 sites were blended with adjacent foam while more than 200 other sites were repaired with PDL.

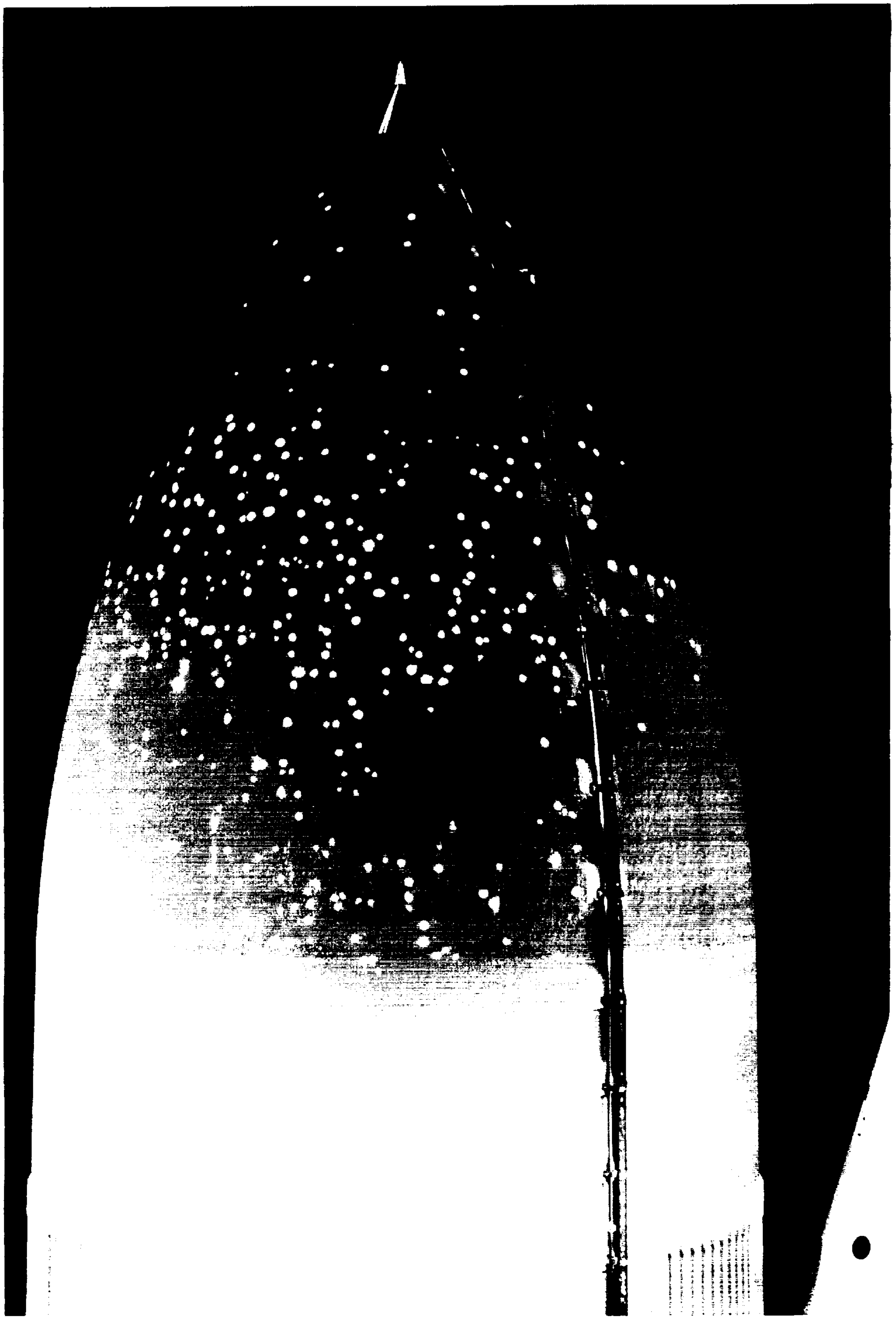


Photo 3: Hail Damage Repaired in VAB

Most of the hail damage occurred in the –Y+Z quadrant. The barrel section of the LO2 tank had been protected by the presence of the Rotating Service Structure.

Photo 4: Pre-Launch View of Hail Damage Repairs

On-pad view from the RSS roof of hail damage sites in the –Y+Z quadrant of the LO2 tank. All damaged areas in the LO2 tank "no ice zone" were correctly repaired according to certified design repair criteria.

Photo 5: Hail Damage Repairs After Cryoload

After tanking and cold soak, no anomalies or thermal shorts were detected on any of the hail damage repairs. Environmental parameters and TPS integrity during cryoload precluded ice formation on the SOFI surfaces during the countdown through launch.

Photo 6: ET/ORB Umbilicals

Ice/frost accumulations on the ET/ORB umbilicals, plate gap purge vents, pyro canister purge vents, LH2 feedline bellows, and LH2 recirculation line bellows were typical

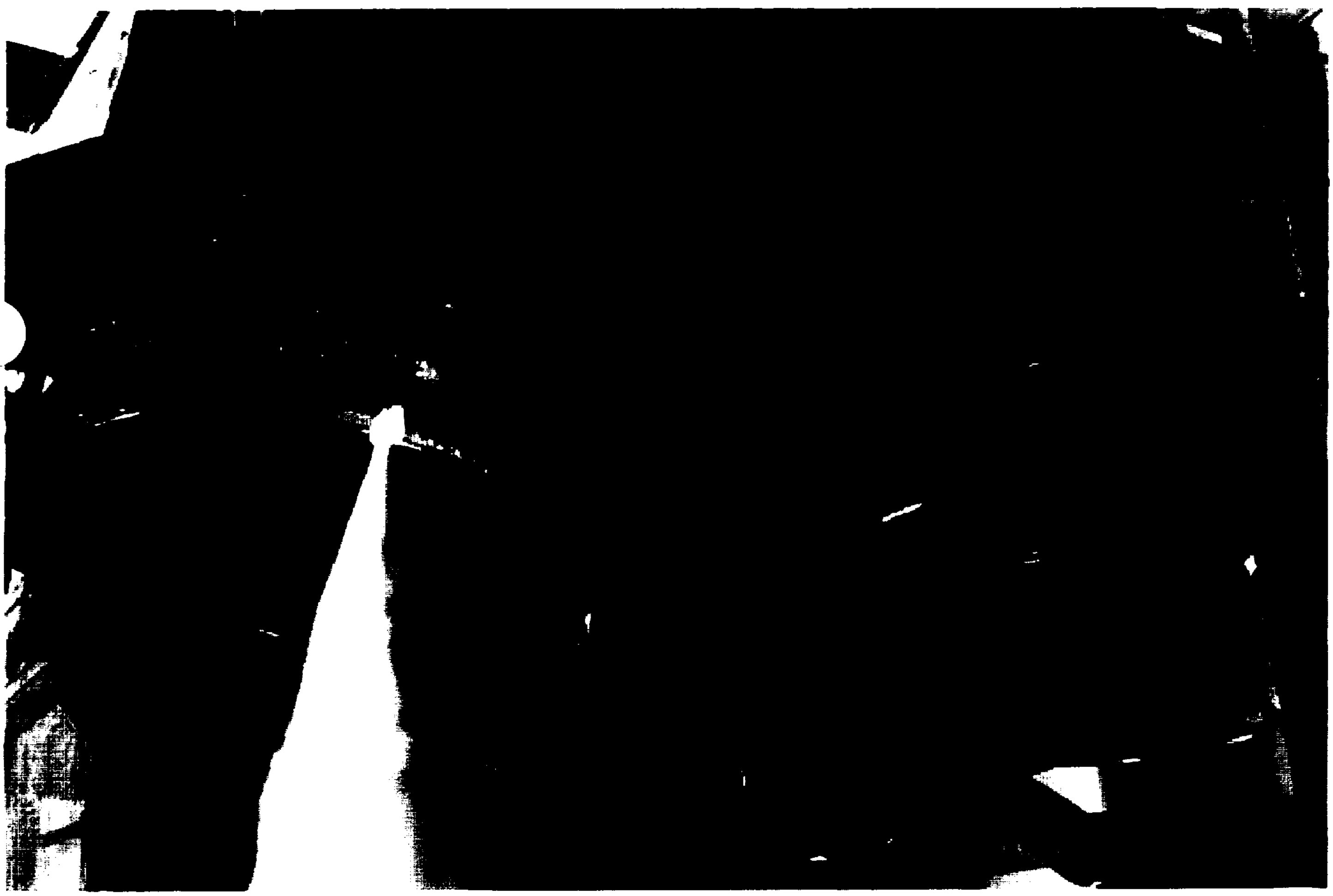


Photo 7: Overall View of SSME's

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 2, Pad B FSS and RSS was conducted on 27 May 1999 from Launch + 2 to 4 hours. No flight hardware was found.

No stud hang-ups occurred on this launch. Boeing - Downey reported an Orbiter liftoff lateral acceleration of 0.11 g's, which is below the threshold (0.14 g's) for stud hang-ups. SRB south holddown post erosion was typical. North holddown post blast covers and T-0 umbilicals exhibited typical exhaust plume damage. Test coating of RTV on the HDP #8 blast cover had ablated and performed as expected. The right SRB aft skirt GN2 purge line was intact, though the protective tape was eroded away and the braided line was damaged. The left GN2 purge flex line was also intact though the protective tape was missing.

The Tail Service Masts (TSM's) appeared undamaged and the bonnets were closed properly. Likewise, the Orbiter Access Arm (OAA) seemed to be undamaged.

The GH2 vent line was latched in the third of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited no damage. All observations indicated a nominal retraction and latchback, though the SRB exhaust plume had scorched the flex line aluminized blanket.

The GOX vent seals were in excellent shape with no indications of plume damage.

Debris findings on the FSS included cable tray covers, structural steel pieces, evacuation signs, access arm man-loading signs, and a variety of facility nuts and bolts.

Material covering the SRB flame deflector was missing from an area near the flame trench wall. The area was a 12-foot long arc by 12-18 inches wide by 4-6 inches thick. The pieces were scattered north of the flame trench throughout the pad acreage.

Overall, damage to the pad appeared to be minimal.

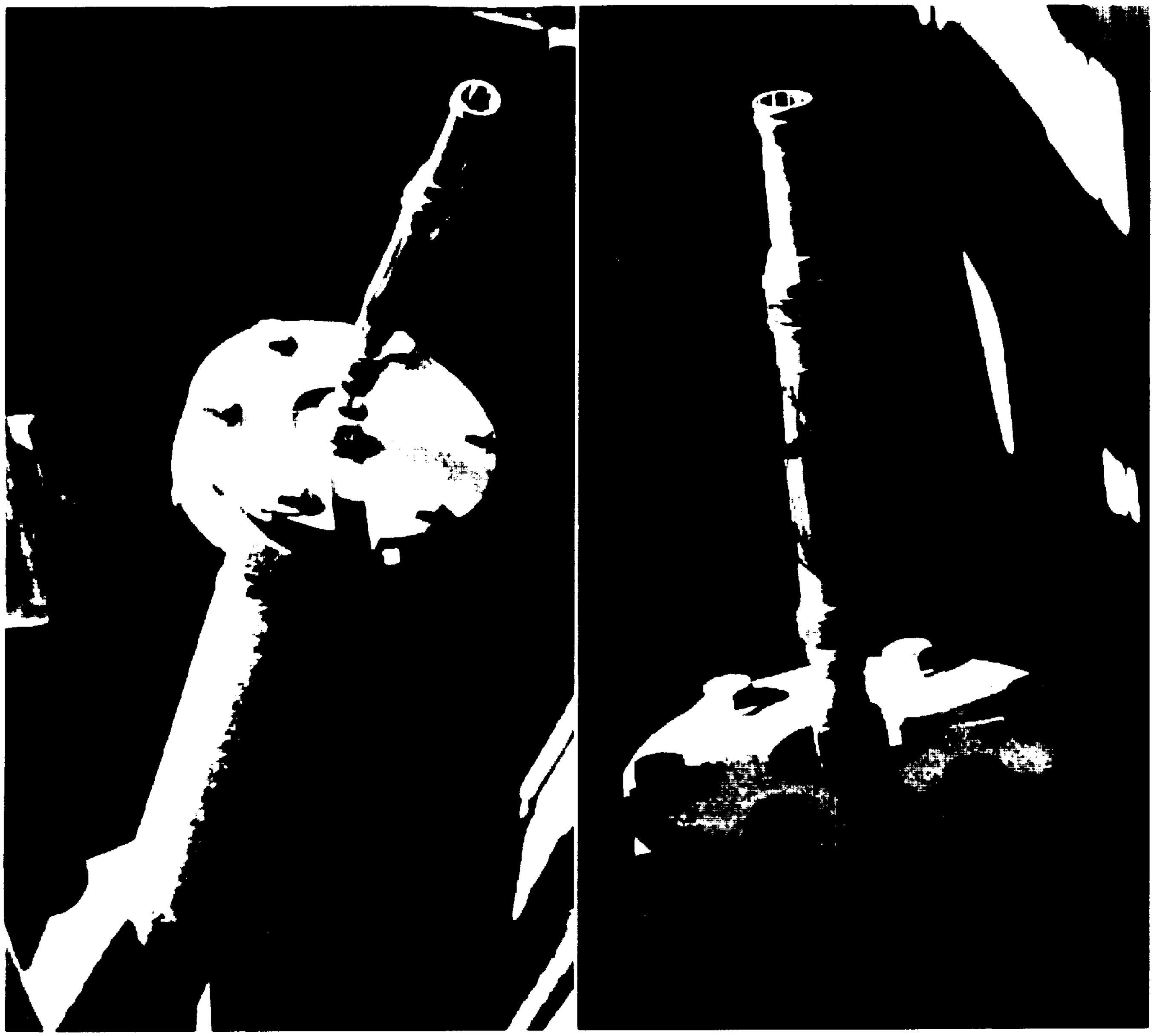


Photo 8: Aft Skirt GN2 Purge Lines

The right SRB aft skirt GN2 purge line was intact, though the protective tape was eroded away and the braided line was damaged (left photo). The left GN2 purge flex line was also intact though the protective tape was missing

Photo 9: RTV-Coated Blast Cover Prior to Launch

RTV coating on the HDP #8 blast cover was designed to minimize the repair, or replacement, of the steel covers from erosion/melting sustained in the SRB exhaust plume launch environment.

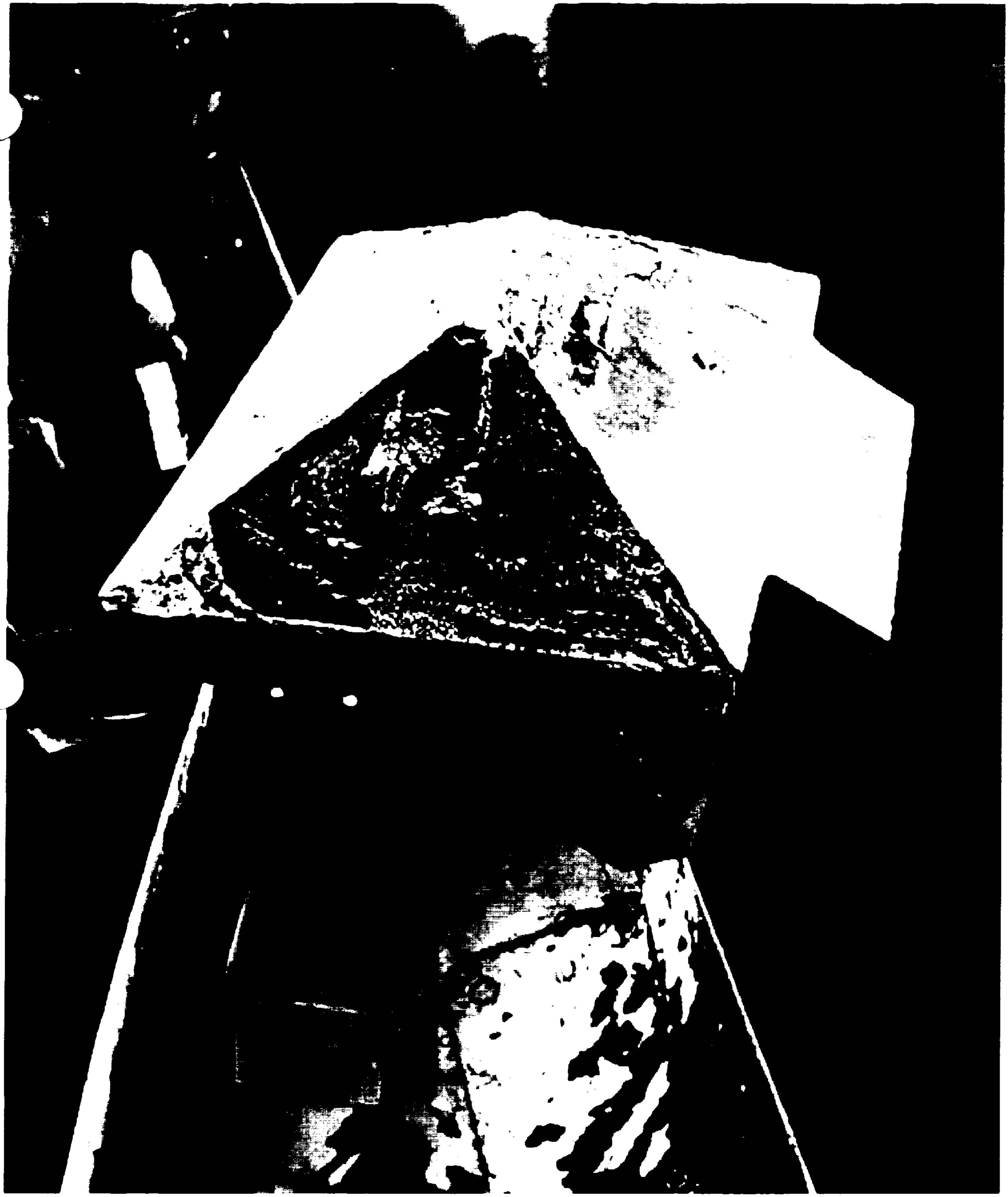


Photo 10: RTV-Coated Blast Cover After Launch

Test coating of RTV on the HDP blast cover had ablated somewhat in the SRB exhaust plume. Thickness measurements of remaining material showed the RTV performed as expected.

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.

5.1.1 LAUNCH FILM AND VIDEO SUMMARY

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

Frost formed on the ET louvers after GOX vent seal retraction. No ice was detected (OTV 160, 161).

Free burning hydrogen drifted under the body flap during SSME ignition. SSME-induced aspiration was clearly indicated by vapors drawn along the MLP deck into the SSME exhaust hole (OTV 163, TV-7).

SSME ignition appeared normal though the Mach diamonds formed in a 3-1-2 order. Two streaks occurred in the SSME #1 exhaust plume at 10:49:47.006 and 52.720 UTC (E-2, -3, -19, -20, 52, -63, -76; OTV 151, 170, 171).

SSME ignition caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft. Some pieces impacted the umbilical cavity sill, but no damage was visible (OTV-109, 163).

A light-colored, rectangular object, approximately 6 inches long by 1 inch wide and thin, appeared to originate from the base heat shield near SSME #3 or the body flap upper surface near the hinge line at 10:49:42.356 UTC. The object may be a gap filler or GSE tile shim (E-5).

Small pieces of tile surface coating material were lost during ignition from ten places on the aft surface of the left ACPS stinger (E-20). Surface coating material was missing from one tile located on the SSME #2 base mounted heat shield (OTV 150).

A 3-inch by 1-inch piece of foam came loose near the right leg/intertank stringer interface of the GUCP during disconnect. The resulting divot exposed primed substrate (E-33).

SRB shock wave was visible at T-0 due to the water vapor in the atmosphere (OTV 141, TV-7).

There were no stud hang-ups. No debris fell from the HDP stud holes. However, a considerable amount of facility debris was ejected from the HDP #7 haunch area during ignition (E-11). A small dark object, possibly a piece of shim material or putty, was visible in the HDP #8 shoe area at liftoff. The red RTV test coating on the HDP #8 blast cover was intact while in the field of view until obscured by smoke and exhaust plume impingement (E-14).

The GN2 purge lines separated cleanly from both SRB aft skirts at liftoff. The purge lines were visible for about two seconds after T-0 before being obscured from view by smoke. At that time, no anomalies were observed (E-8, -13).

Two small debris particles fell past the Orbiter left wing at 10:49:44.520 UTC. No contact with flight hardware was observed. Due to the indistinct appearance, the particles were believed to be close to the camera (E-34, -36).

Three dark, silhouetted objects were visible near the hydrogen dispersion system (stovepipe) as the vehicle cleared the TSM's. These objects are irregular in shape and were believed to be pieces of SRB throat plug material (OTV 171).

Photo 11: Loose Gap Filler or GSE Tile Shim

A light-colored, rectangular object, approximately 6 inches long by 1 inch wide and thin, appeared to originate from the base heat shield near SSME #3 or the body flap upper surface near the hinge line at 10:49:42.356 UTC. The object may be a gap filler or GSE tile shim.

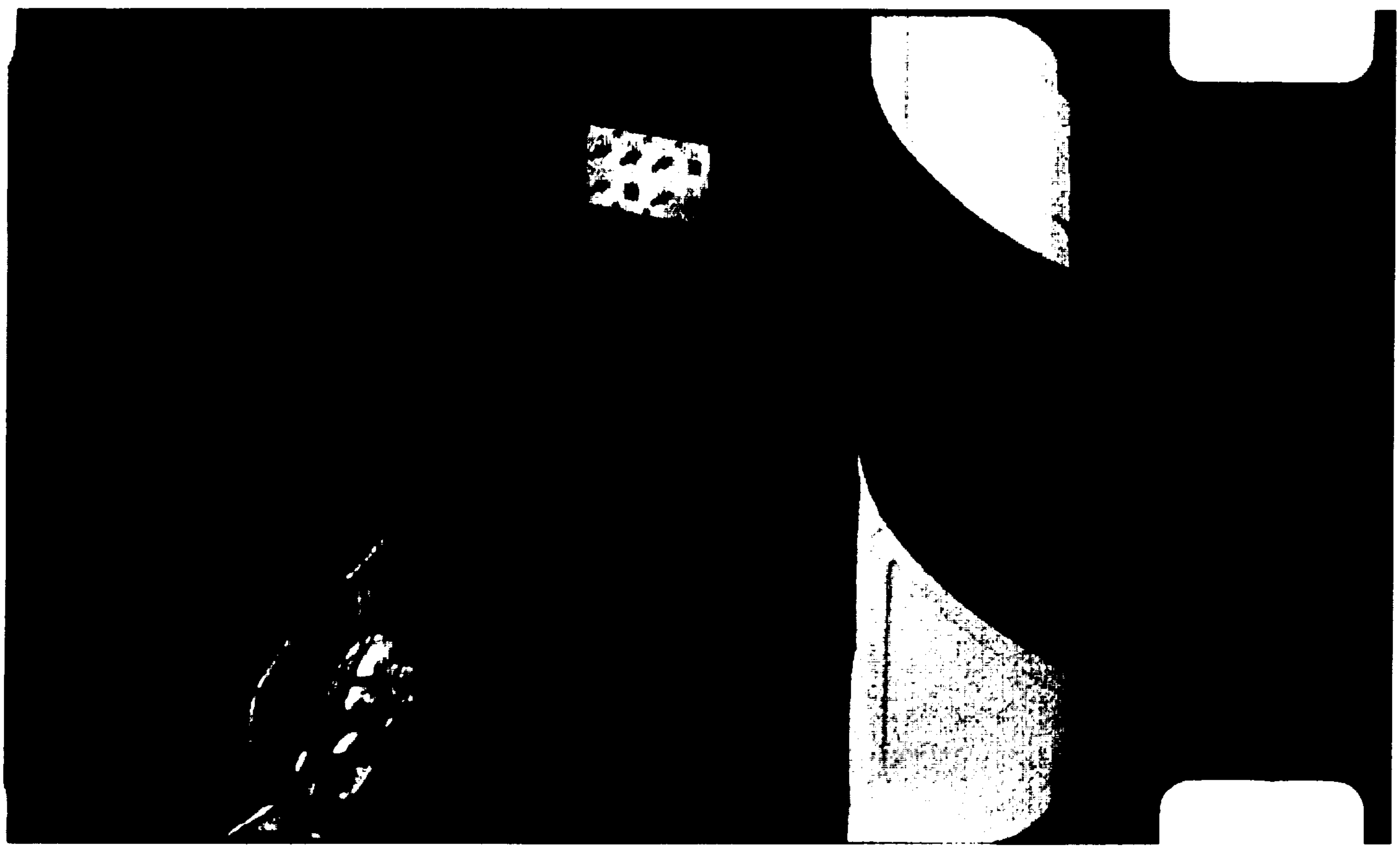


Photo 12: Foam Loss During GUCP Disconnect

A 3-inch by 1-inch piece of foam was pulled from the right leg/intertank stringer interface of the GUCP during disconnect. The resulting divot exposed primed substrate. The loose pieces of foam can been seen falling aft.

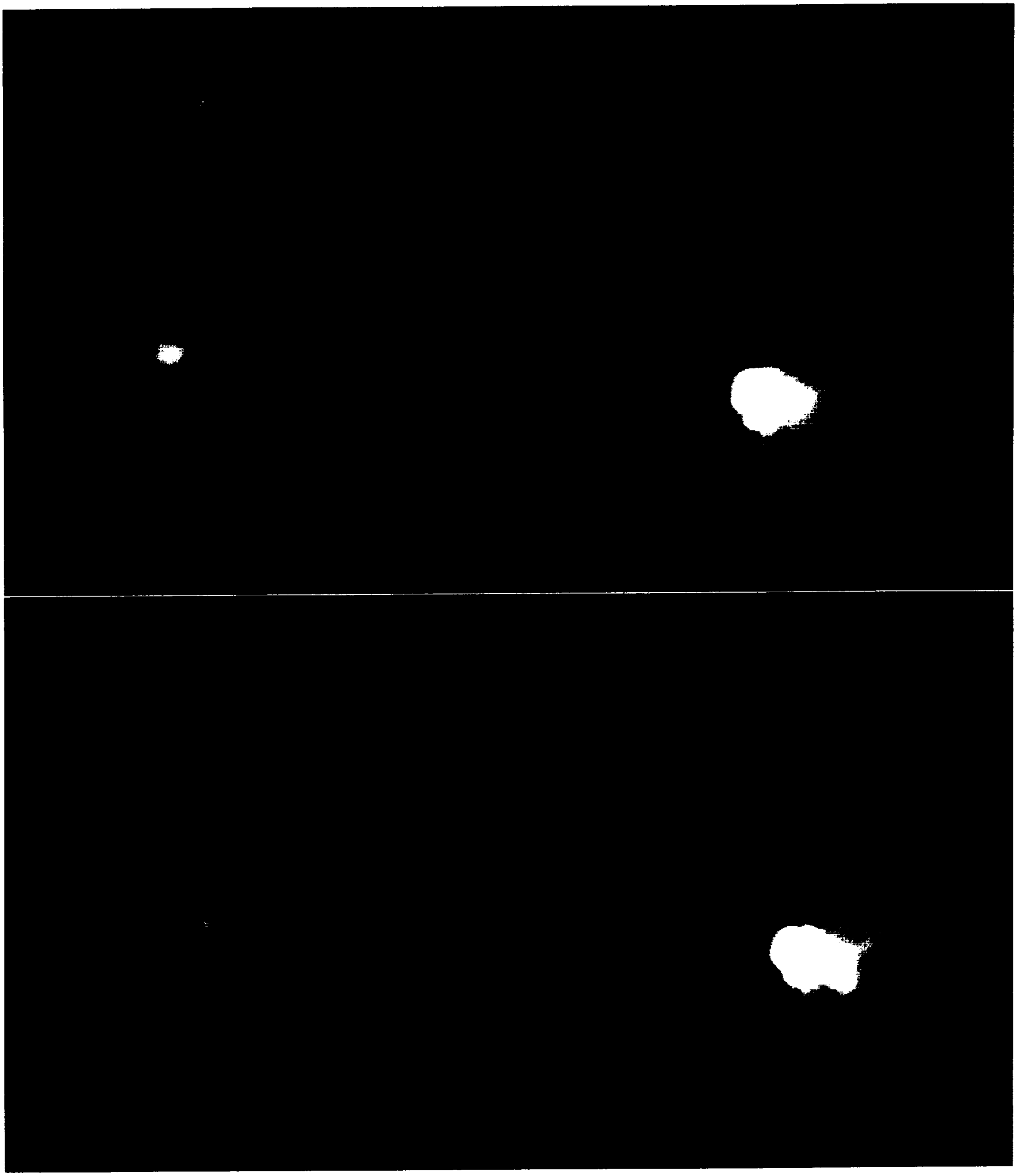


Photo 13: OMS-Assist Exhaust Plume

The OMS-assist burn occurred at 10.3 seconds after SRB separation and was visually detected by the appearance of OMS engine exhaust plumes/vapors aft of both OMS pods

5.1.2 SRB CAMERA VIDEO SUMMARY

An 8mm video camera was flown in each SRB forward skirt for the purpose of documenting any TPS loss from the ET-100 thrust panels from launch through SRB separation.

A new test for this flight incorporated thousands of pin-size vent holes with 0.3-inch spacing and 0.032-inch diameters to substrate in the intertank thrust panel machined foam. On the –Y thrust panel, the vent holes were placed near the EB fitting in the high heating area. However, the +Y thrust panel was configured just the opposite with no vent holes in the high heating area near the EB fitting.

<u>-Y Side General Observations</u>

There were significantly less divots in the vented area compared to the non-vented area. Divots in the vented area were generally smaller than divots in the non-vented area.

Divots in both vented and non-vented areas appeared shallow. No primed substrate was visible.

Most divots occurred near the rib sidewalls and top edges.

Valley divots were smaller in size than divots in the rib sidewalls/top edges.

Divots were concentrated near the EB fitting.

Several divots occurred outside the thrust panel in the stringer section.

<u>-Y Side Divot Count</u>

92 seconds MET	first divot appeared
92-95 seconds MET	2 divots
95-105 seconds MET	18 divots
105-115 seconds MET	approximately 65 divots total 20 in the vented area largest 1" x 0.25" in vented area most diameters were less than 0.25" ranged from 0.25" to 1" in non-vented area
115-125 seconds MET	approximately 100 divots total 25 in the vented area
After separation	15-20 divots between Xt-1013 to Xt-1058 circumferential ribs More divots between Xt-1058 to Xt-1102 circumferential ribs

Photo 14: Venting of Thrust Panel TPS

Thousands of pin-size holes spaced 0.3-inches apart with 0.032-inch diameterholes to substrate (in selected areas) vented External Tank intertank thrust panel TPS to aid in preventing divots and to decrease debris size and mass in the events divots did occur.

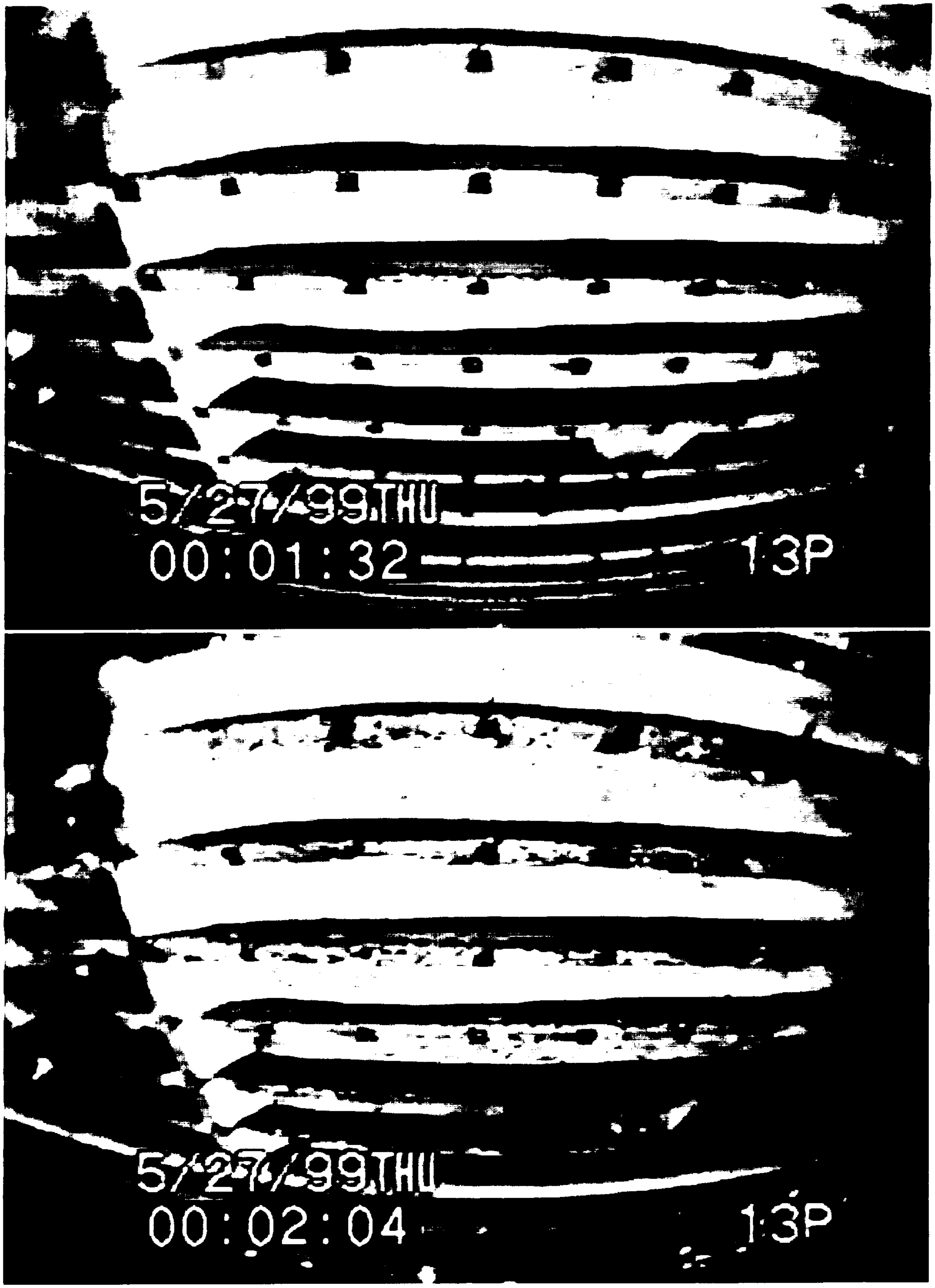


Photo 15: External Tank –Y Thrust Panel

First divots have appeared at 92 seconds MET (upper photo). Numerous divots have occurred by 124 seconds MET (lower photo) just before SRB separation. Note: significantly less divots were present in the pin-hole vented portion in this field of view (right side of photo) versus the left side, which was not vented. The vented portion was the high heating area near the EB fitting.

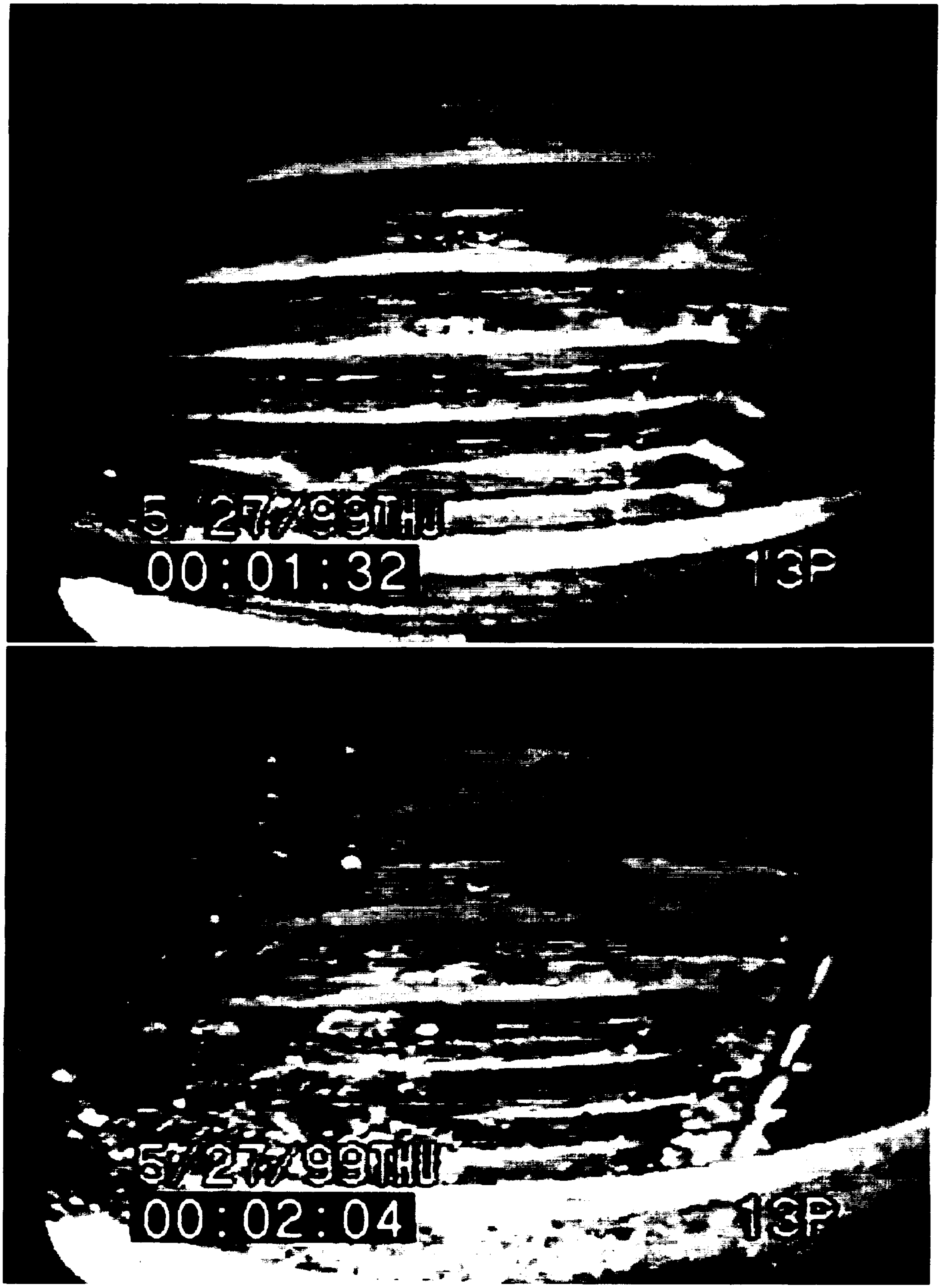


Photo 16: External Tank +Y Thrust Panel

First divots have appeared at 92 seconds MET (upper photo). Numerous divots have occurred by 124 seconds MET (lower photo) just before SRB separation. Note: significantly less divots were present in the pin-hole vented portion in this field of view (right side of photo) versus the left side, which was not vented. The non-vented portion was the high heating area near the EB fitting.

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-103 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. The flight crew provided 36 hand held still images and approximately 15 minutes of video from the camcorder. The +X translation and a manual pitch maneuver from the heads-up position were performed to bring the tank into view through the overhead windows.

5.2.1 ET/ORB Umbilical Films

OV-103 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Lighting of the ET after separation was poor due to sun angle. Sunlight illuminated the far +Y side of the tank, but all areas to the –Y side of the LO2 feedline were in shadow.

SRB separation from the External Tank appeared nominal. The wide angle ET/ORB LH2 umbilical camera provided a view of the left SRB forward skirt/frustum/nose cap during separation. The nose cap, which was not recovered for post flight inspection, was intact and appeared to be in good condition.

ET separation from the Orbiter was normal. The seal around the EO-2 fitting was properly positioned. The seal around the EO-3 fitting had come loose, but was still attached. No anomalies were detected on the composite nose cone. The TPS repairs to the hail-damaged areas that were visible in the sunlit section of the LO2 tank were intact and in good condition.

Due to the graininess of the film, any small divots in the +Y thrust panel could not be discerned.

The divots in the LH2 tank-to-intertank flange closeout between the bipods observed in the crew hand held photographs could not be verified in the umbilical films.

Both +Y and -Y thrust struts exhibited typical ascent erosion and very small divoting.

No damage was observed on the LO2 feedline or either ET/ORB umbilical.

Charring and "popcorn" divoting of the aft dome was typical.

5.2.2 Crew Hand Held Still Images/Video

The flight crew obtained 38 images of the External Tank after separation using the Nikon camera with 400mm lens and six minutes of footage using the camcorder. In all of the views, the External Tank was well illuminated by sunlight. Photography of the ET began at a separation distance of 1.6 kilometers approximately 6 minutes after separation from the Orbiter.

The +Y thrust panel (+Z side) was really only visible in the first few frames. No large divots in the TPS were detected. Divots less than 3-inches in size, which were expected based on the LH SRB camera data, could not be discerned due to subject distance and image resolution.

For the same reasons, confirmation of divots in the –Y thrust panel was difficult. Light spots just forward and aft of the XT-917 circumferential rib and on both +Z/-Z sides of the EB fitting are believed to be small divots.

Light spots, possibly small divots, were visible in the intertank +Z stringers in the area of the SRB shock wave scorch marks and in an area forward of the bipods.

Photo 17: SRB Separation from External Tank

SRB separation from the External Tank appeared nominal. The wide angle ET/ORB LH2 umbilical camera provided a view of the left SRB forward skirt/frustum/nose cap during separation. The nose cap, which was not recovered for post flight inspection, was intact and appeared to be in good condition. TPS erosion/ablation from the aft surfaces of the cable tray and –Y vertical strut was typical.

Photo 18: ET Separation from Orbiter

ET separation from the Orbiter was normal. The seal around the EO-2 fitting was properly positioned. No TPS damage on the LH2 ET/ORB umbilical was detected. Note frozen hydrogen in the 17-inch flapper valve. Charring and "popcorn" divoting of the aft dome was typical.

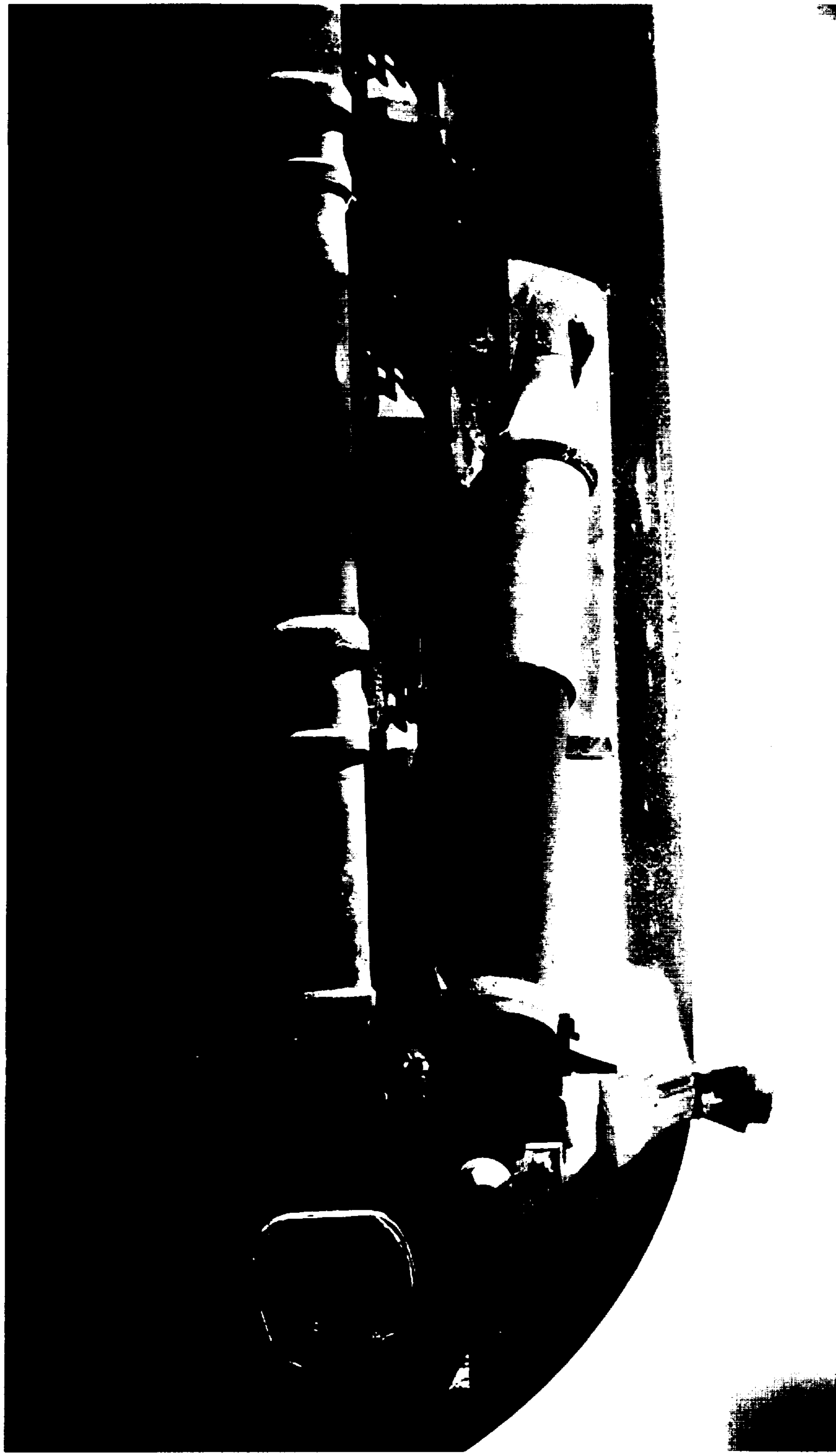


Photo 19: View from LO2 ET/ORB Umbilical Camera

The seal around the EO-3 fitting had come loose, but was still attached. No anomalies were detected on the composite nose cone. The +Y thrust strut exhibited typical ascent erosion and very small divoting. Note: large gouge from ice or debris impact on the thrust strut "knuckle". No damage was observed on the LO2 feedline or LO2 ET/ORB umbilical.

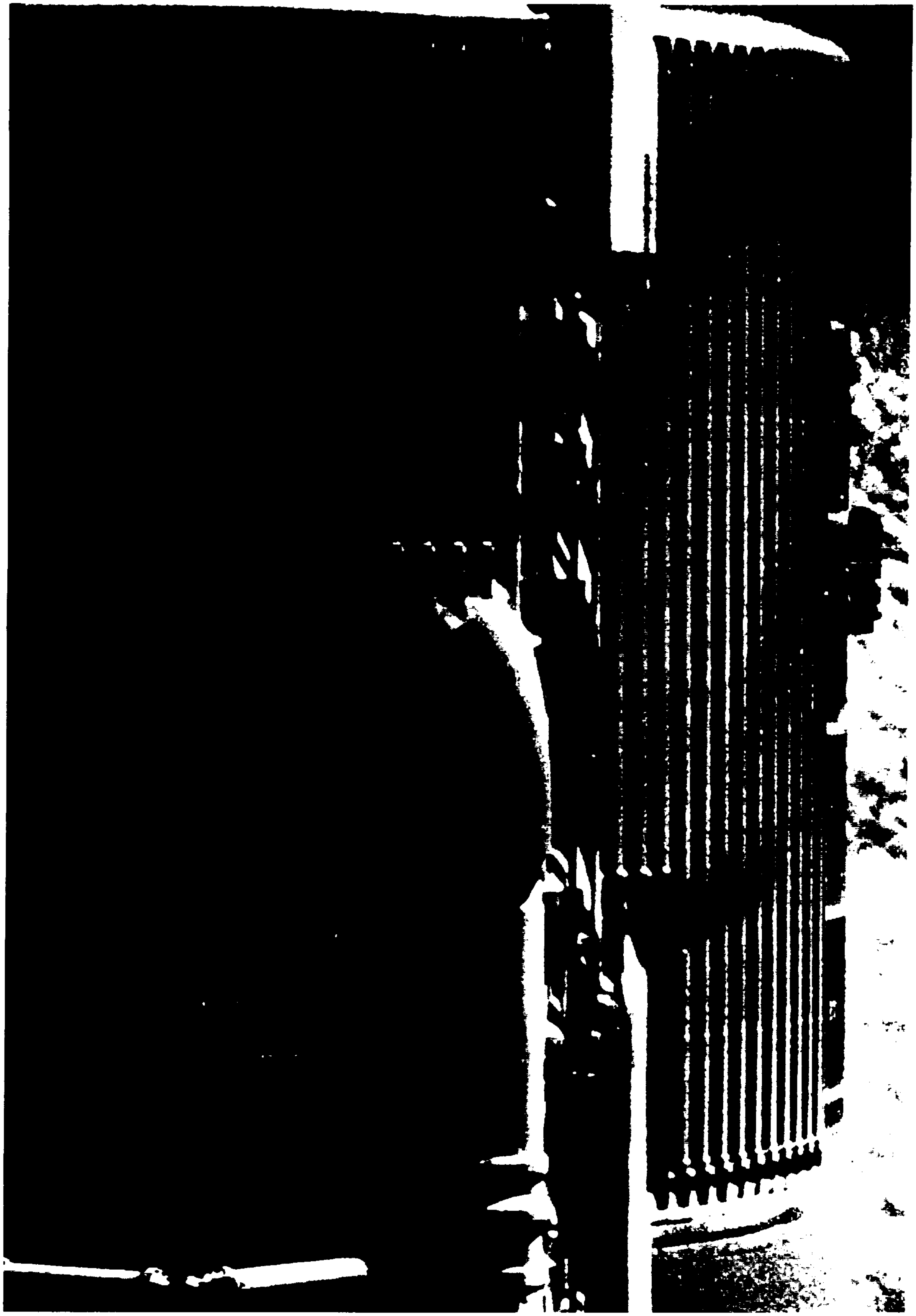


Photo 20: ET Intertank TPS

In this view of the ET intertank, no large divots on stringer heads/valleys were visible. The presence of divots in the LH2 tank-to-intertank flange closeout between the bipods could not be verified in the umbilical films. Due to the graininess of the film, any small divots in the +Y thrust panel could not be discerned.

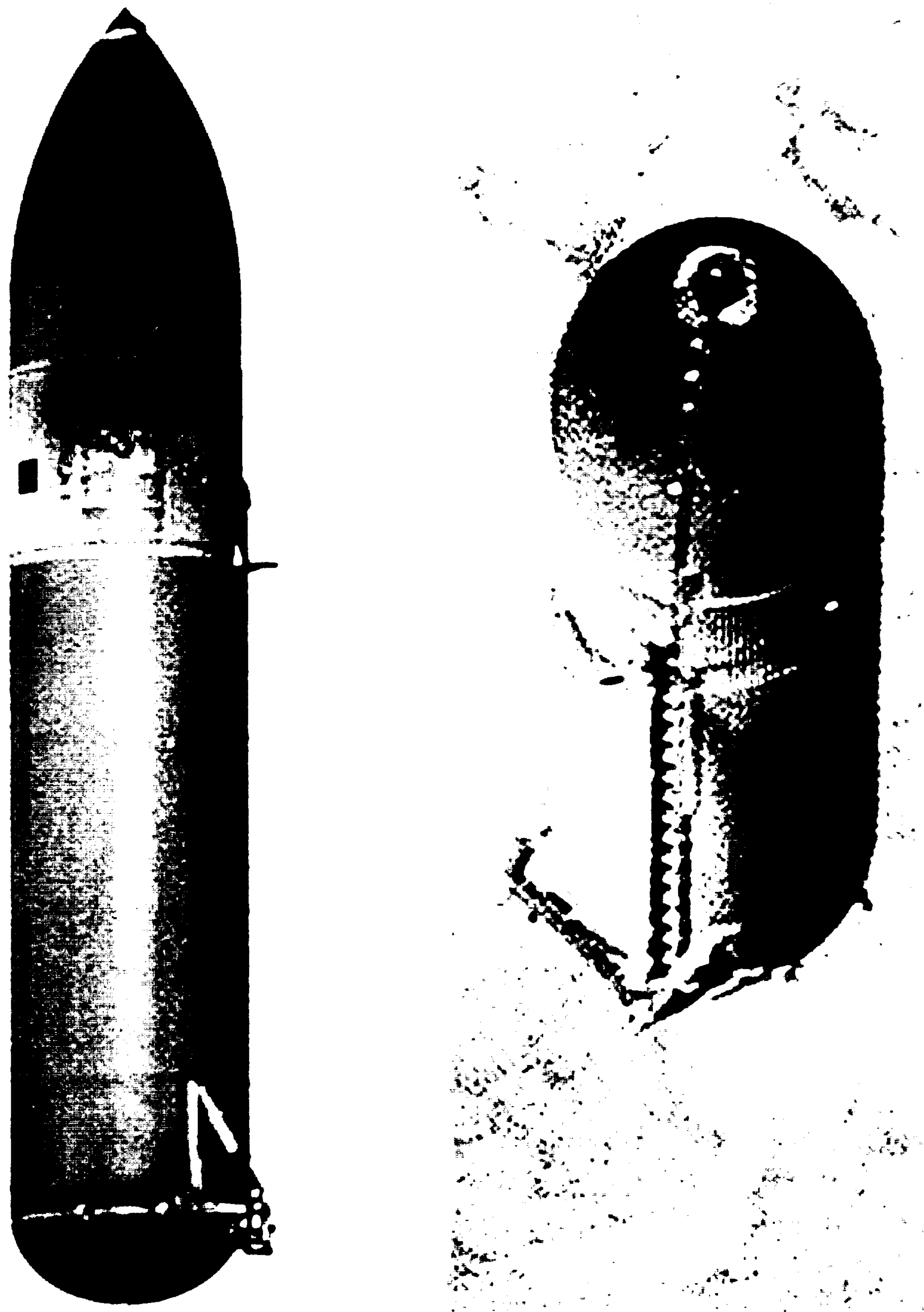


Photo 21: ET -Y and +Y Thrust Panels

Due to distance and graininess of the film, small divots and "popcorning" could not be discerned. Note rough texture of upper ogive TPS near nose cone due to foam erosion though the presence of divots could not be confirmed.

Photo 22: Pre- and Post-Launch Views of Hail Damage Repairs

Before and after (pre-rollout and on-orbit) views of the ET LO2 tank showing integrity of the hail damage repairs after flight. Some of the repairs exhibit shadow lines indicating depth. Over 200 of the damage sites were sanded and blended with adjacent foam resulting in a slight, localized depression relative to the outer mold line. Also, note change to upper ogive TPS near nose cone.

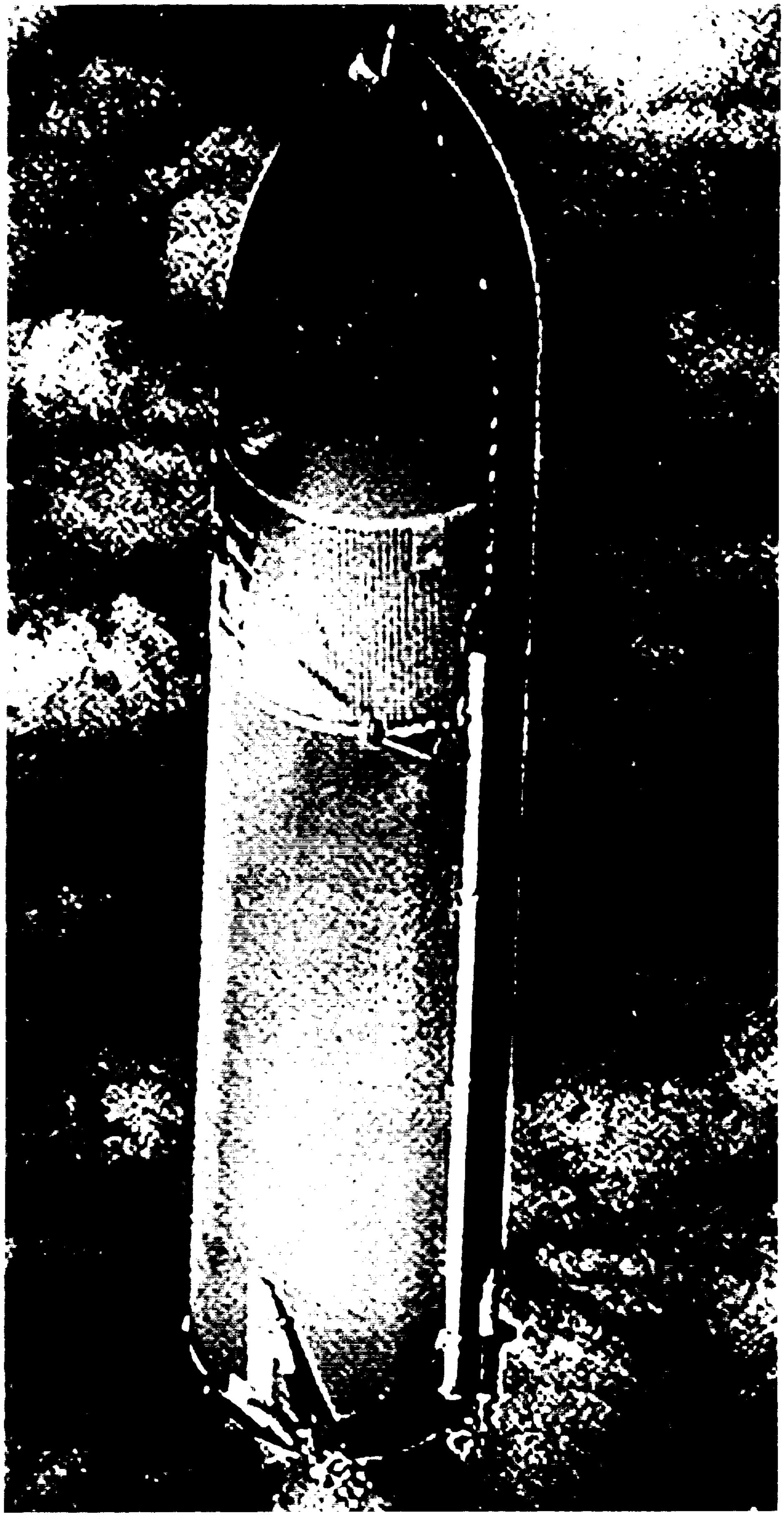


Photo 23: Upper Ogive TPS Near Nose Cone

Rough texture of TPS just aft of the nose cone indicates erosion and possible loss of foam

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 17 films and videos, which included six 35mm large format films and eleven videos, were reviewed. There was not much engineering detail due to the dark conditions of a night landing.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. The right main gear tires contacted the runway first followed by several skips before true weight on wheels was achieved.

Drag chute deployment and jettison appeared normal. No anomalies were detected from touch down through rollout.

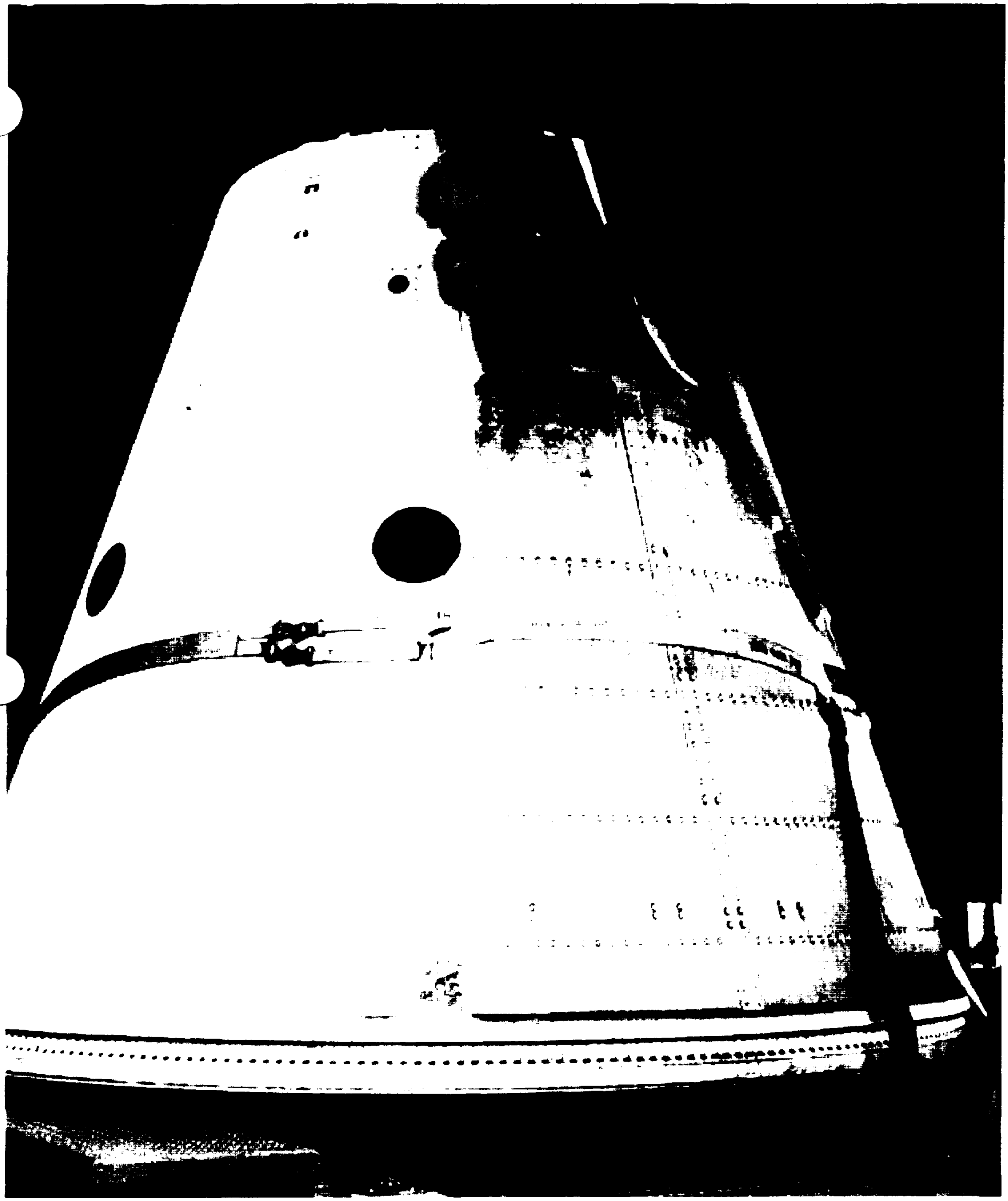


Photo 24: Frustum Post Flight Condition

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners or acreage. All BSM aero heat shield covers had locked in the fully opened position.

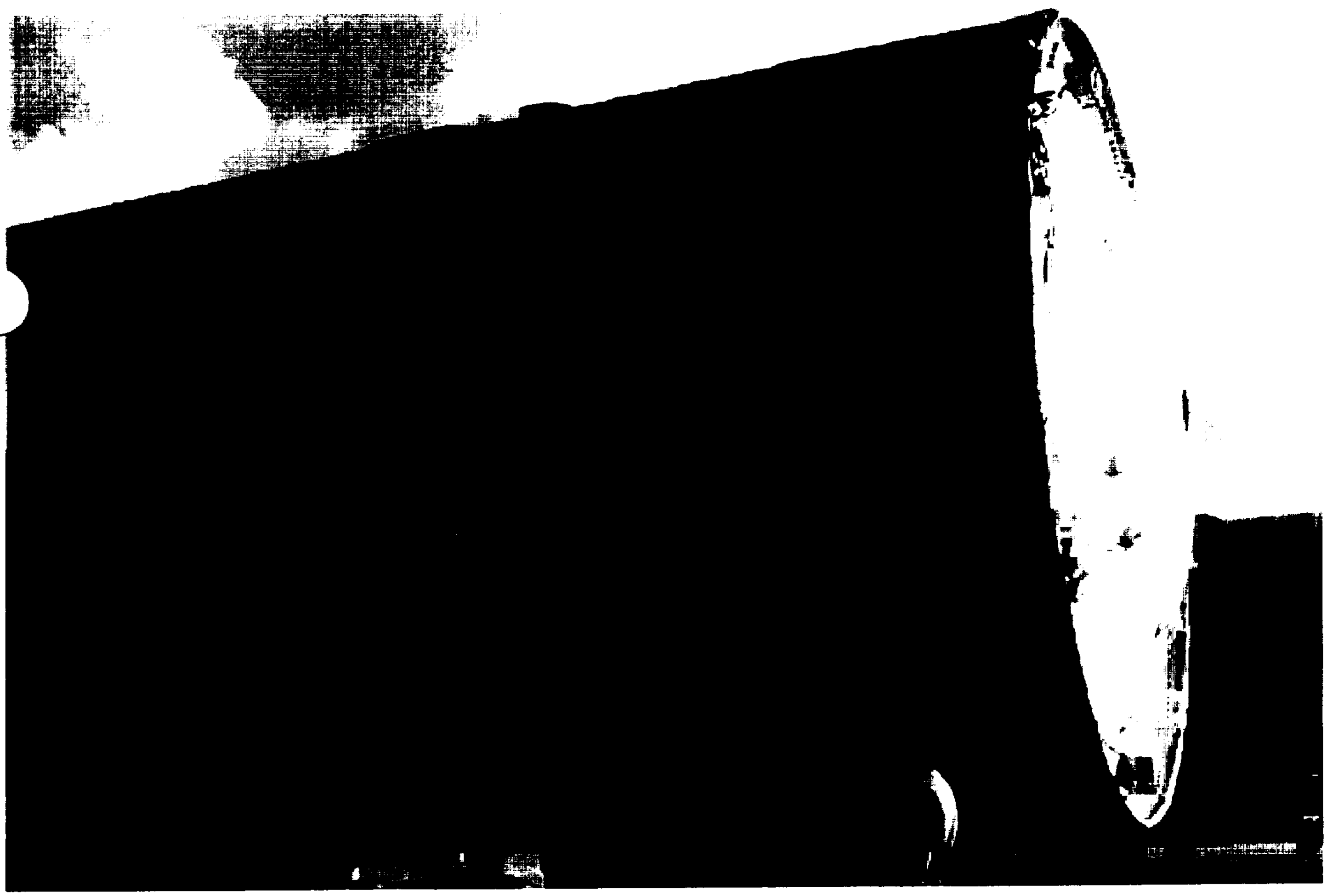


Photo 25: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact though one layer of phenolic had delaminated on the right SRB +Z side. All primary frustum severance ring pins and retainer clips were intact.

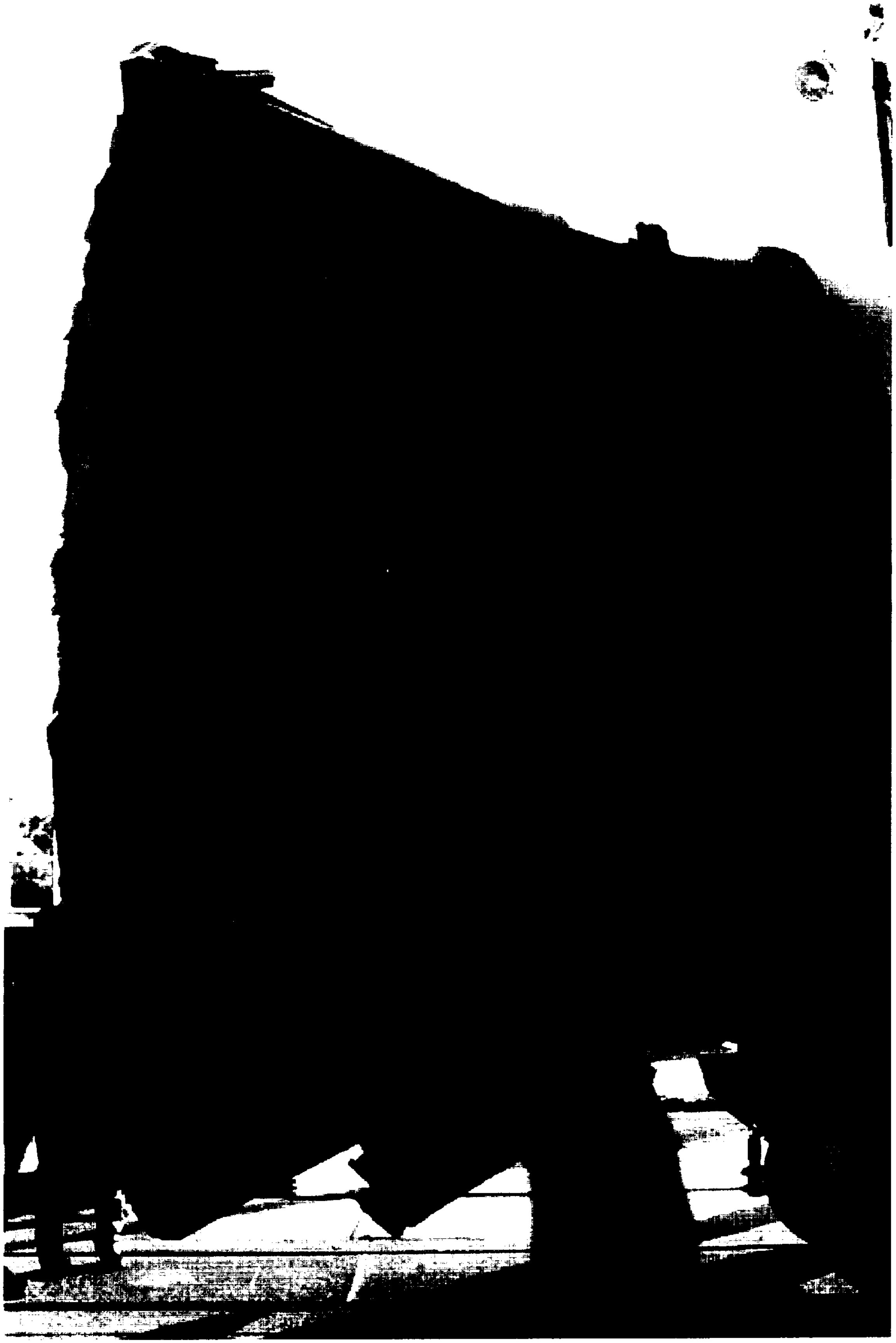


Photo 26: Aft Skirt Post Flight Condition

TPS on the external surface of both aft skirts was intact and in good condition

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 2:02 a.m. local/eastern time landing on 6 June 1999, a post landing inspection of OV-103 Discovery was conducted at the Kennedy Space Center on SLF runway 15 and in the Orbiter Processing Facility bay #1. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 199 hits, of which 72 had a major dimension of 1-inch or larger (reference Figures 1-5). This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation.

The following table breaks down the STS-96 Orbiter debris damage hits by area:

	HITS > 1"	TOTAL HITS
Lower surface	66	160
Upper surface	0	0
Window Area	4	24
Right side	0	4
Left side	0	3
Right OMS Pod	0	4
Left OMS Pod	2	4
TOTALS	72	199

The Orbiter lower surface sustained 160 total hits, of which 66 had a major dimension of 1-inch or larger. Most of this damage was concentrated from the nose gear to the main landing gear wheel wells on both left and right chines. The outboard damage sites on the chines followed a similar location/damage pattern documented on STS-86, -87, -89, -90, -91, -95, and -88.

Orbiter lower surface tile damage statistics since STS-86:

	STS-86	STS-87	STS-89	STS-90	STS-91	STS-95	STS-88	STS-96
Lower Surface (total hits)	100	244	95	76	145	139	80	160
Lower Surface (hits >1-inch)	27	109	38	11	45	42	21	66
Longest damage site (inches)	7	15	2.8	3.0	3.0	4.0	4.5	4.0
Deepest damage site (inches)	0.4	1.5	0.2	0.25	0.5	0.4	0.5	0.5

The largest lower surface tile damage site, located on the left inboard elevon, measured 6-inches long by 2-inches wide by 0.5-inches deep. The deepest lower surface tile damage site measured 0.75-inches and was located near the LO2 ET/ORB umbilical.

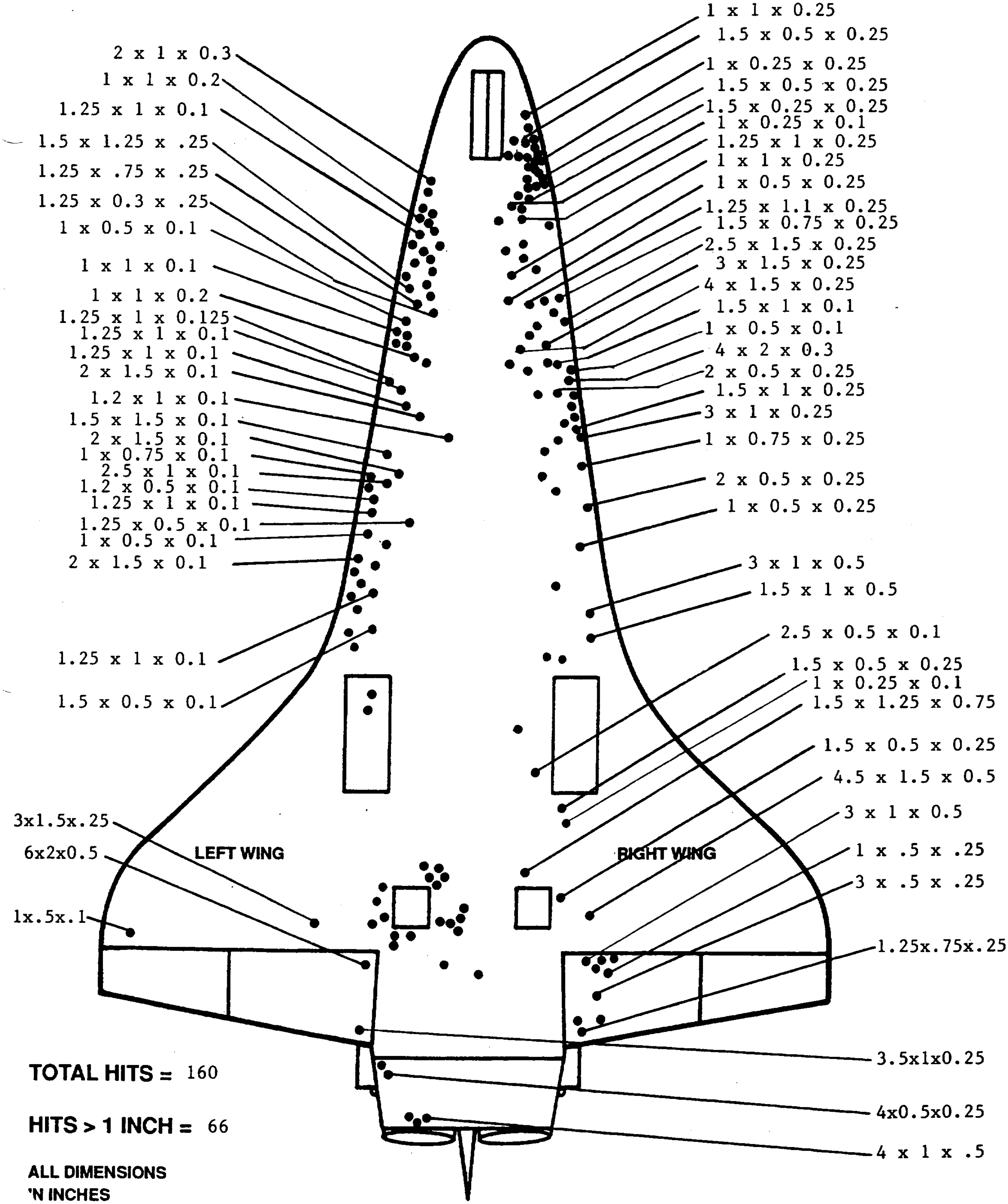


Figure 1: Orbiter Lower Surface Debris Damage Map

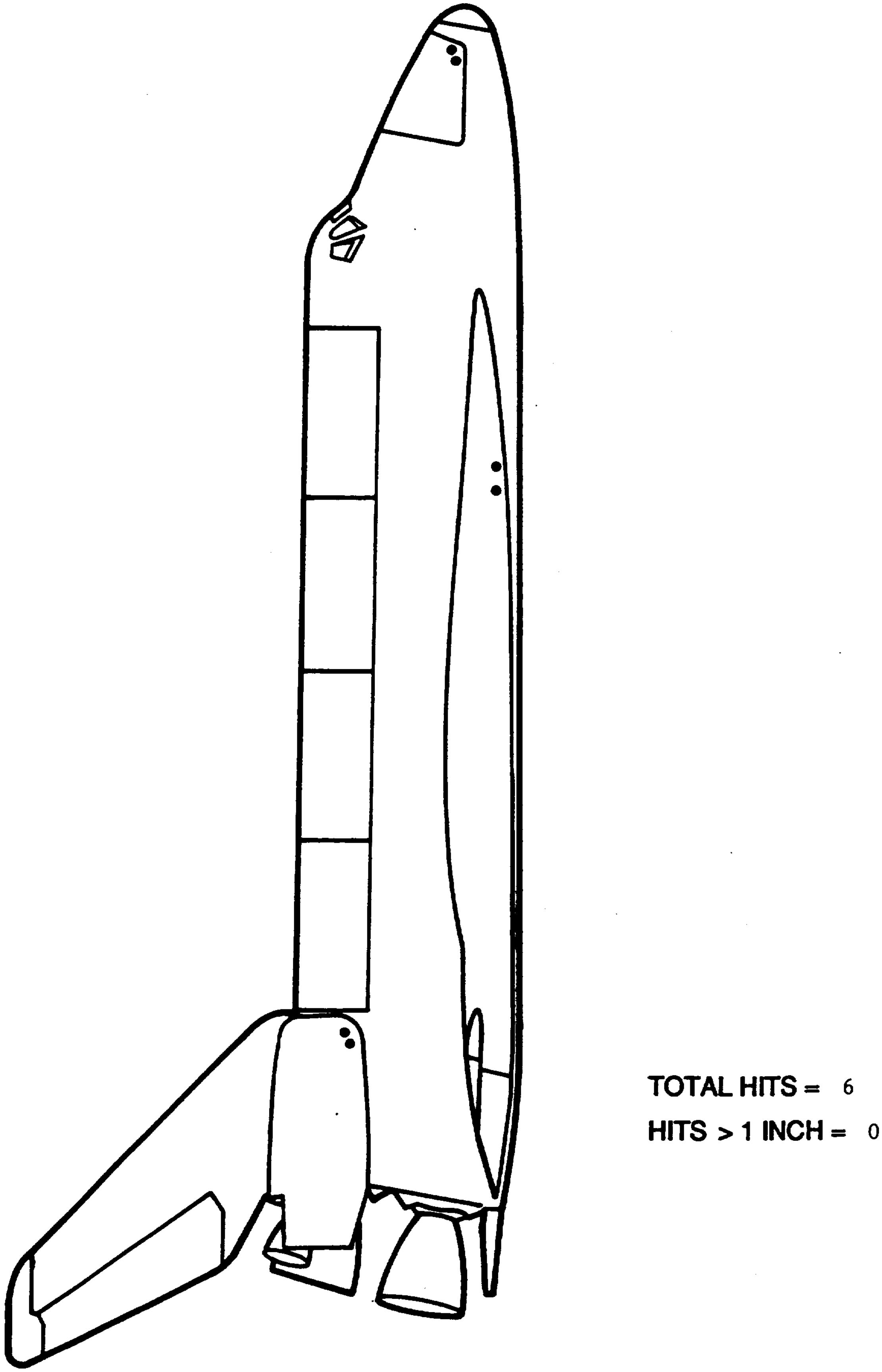


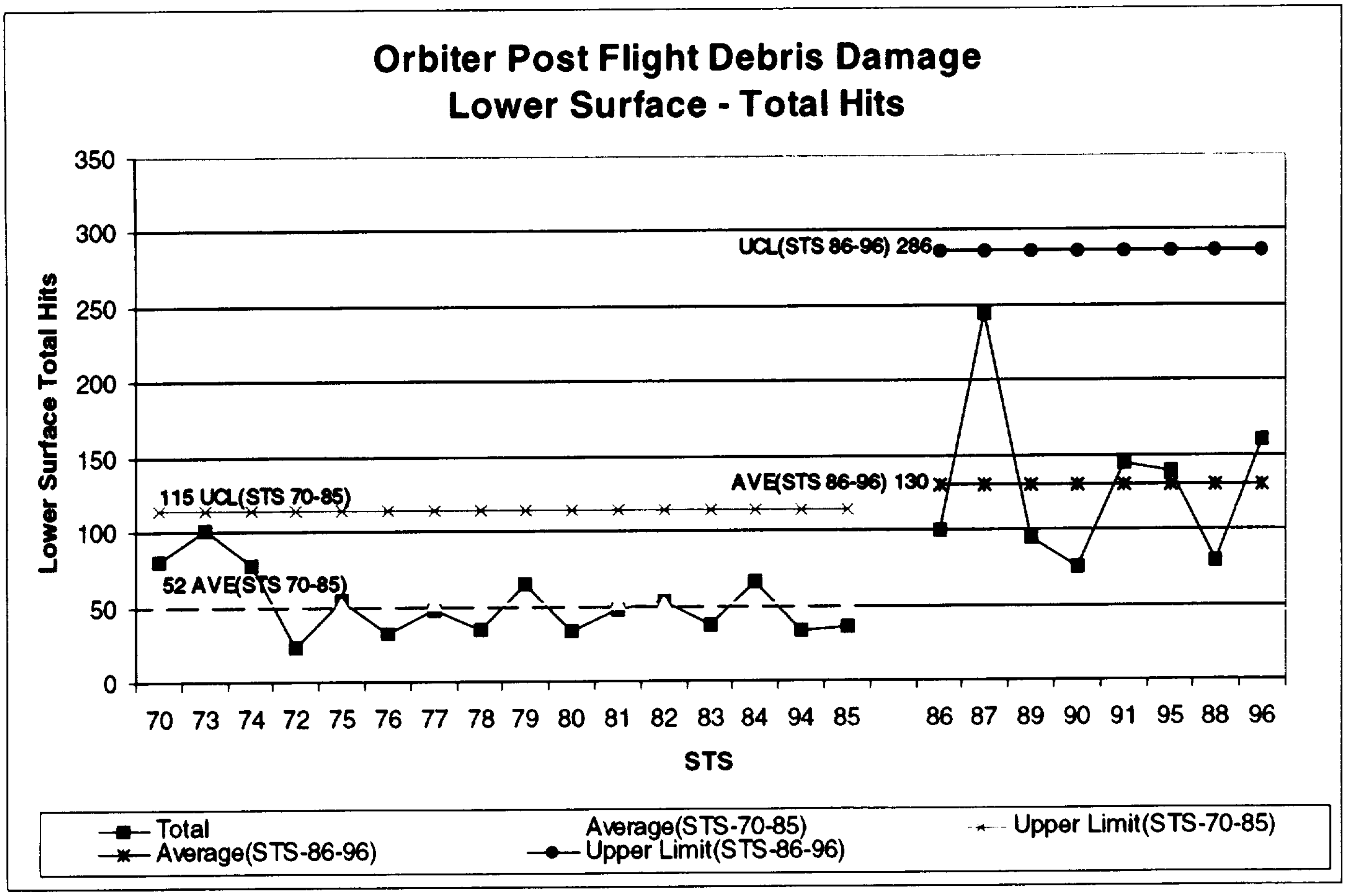
Figure 3: Orbiter Right Side Debris Damage Map

	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
STS-84	10	67	13	103
STS-94	11	34	12	90
STS-85	6	37	13	102
AVERAGE	13.3	83.2	19.6	124.3
SIGMA	7.1	43.9	9.5	51.9
STS-96	66	160	72	199

MISSIONS STS-23,24,25,26,26R,27R,30R,42,86,87,89, 90, 91, 95, & 88 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



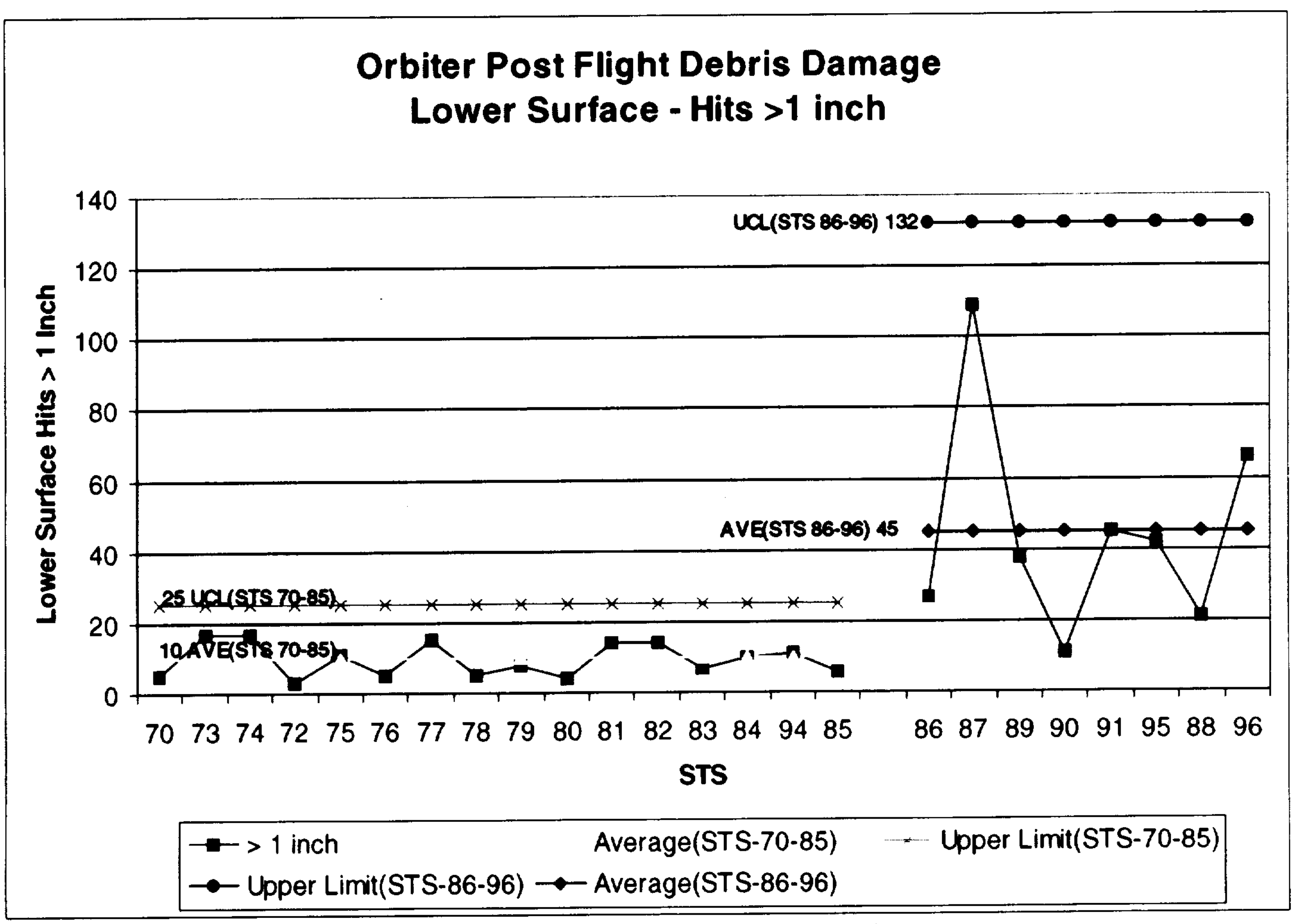
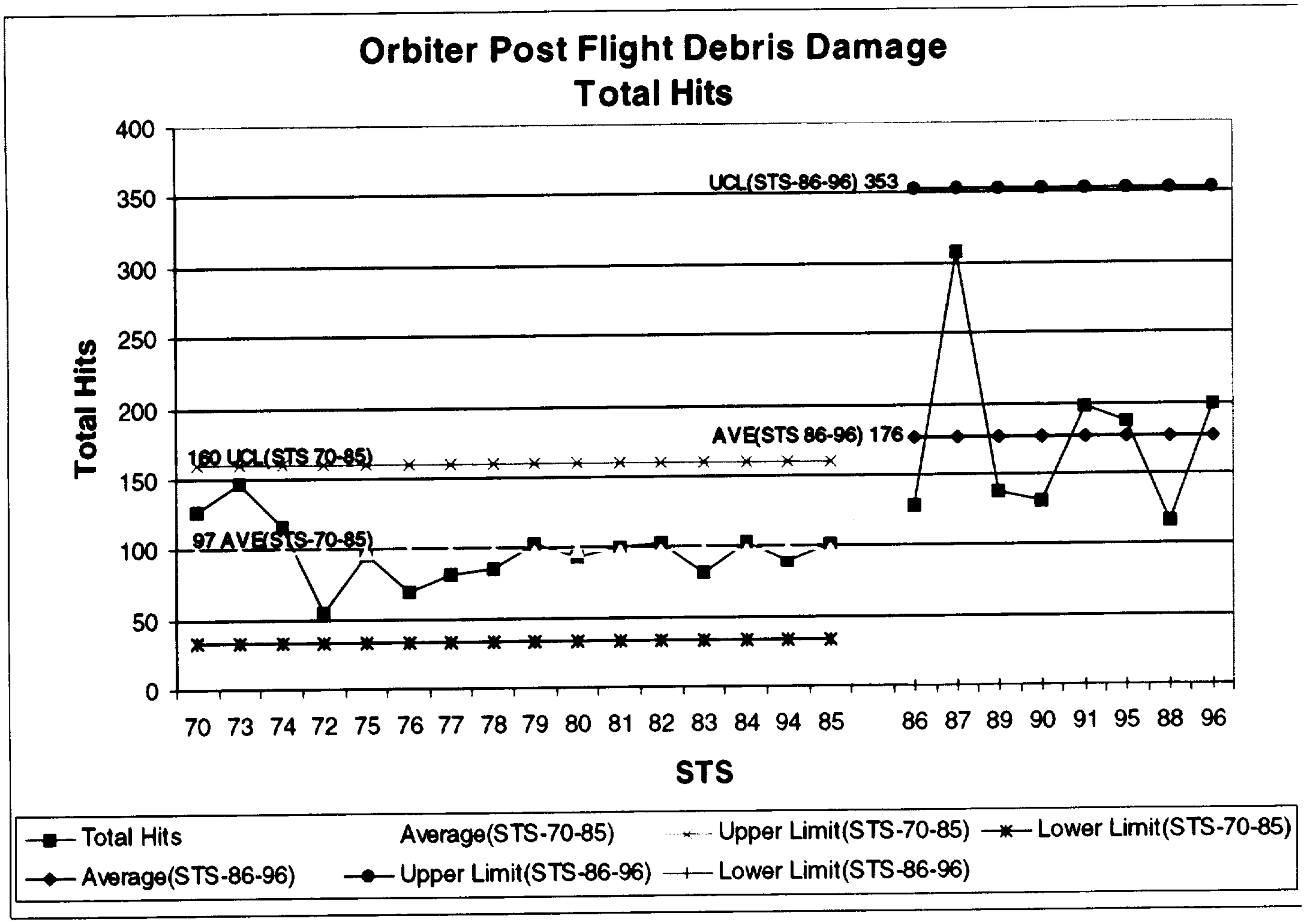


Figure 6: Control Limit Chart for Lower Surface Hits



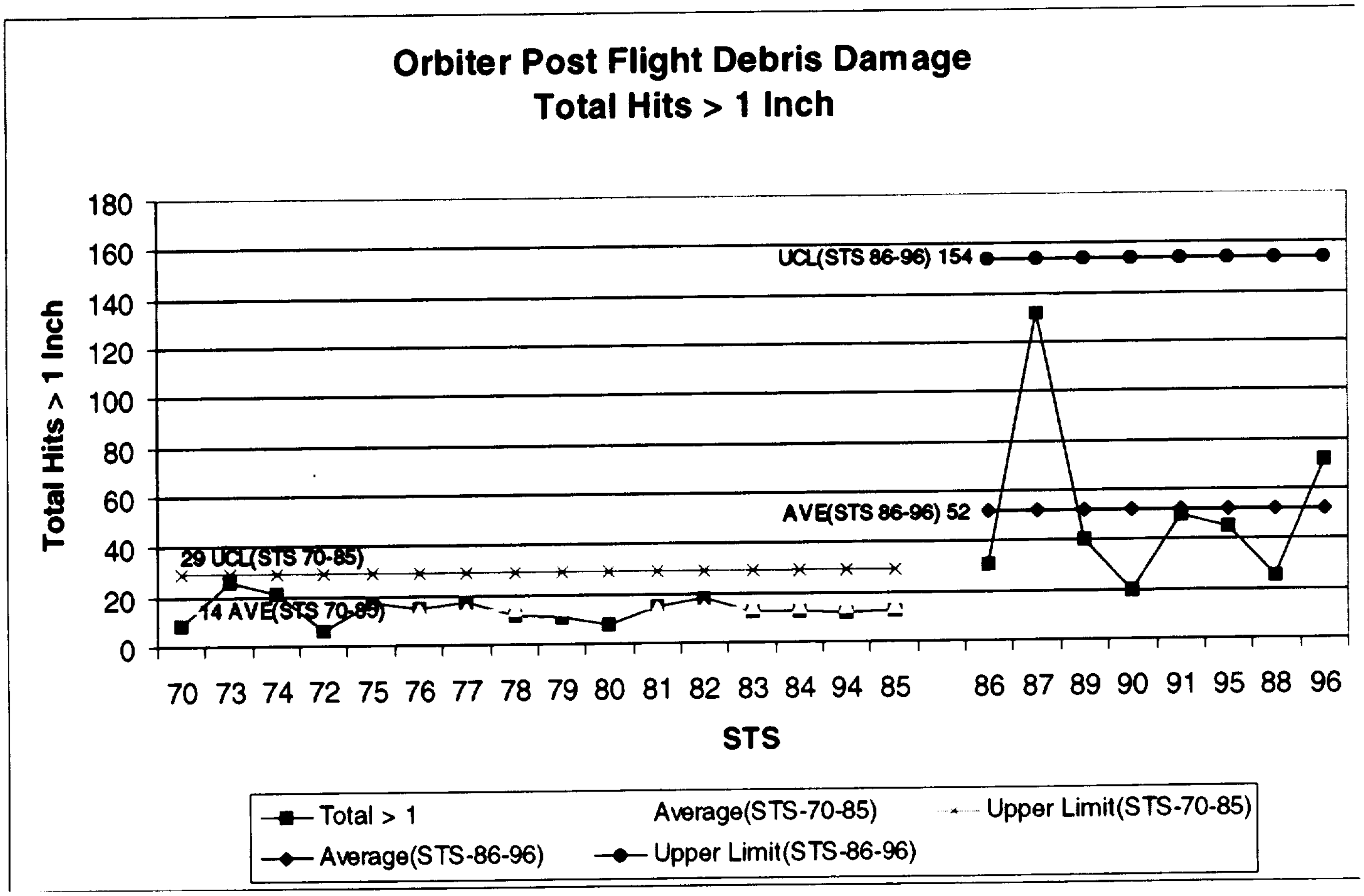


Figure 7: Control Limit Chart for Total Hits

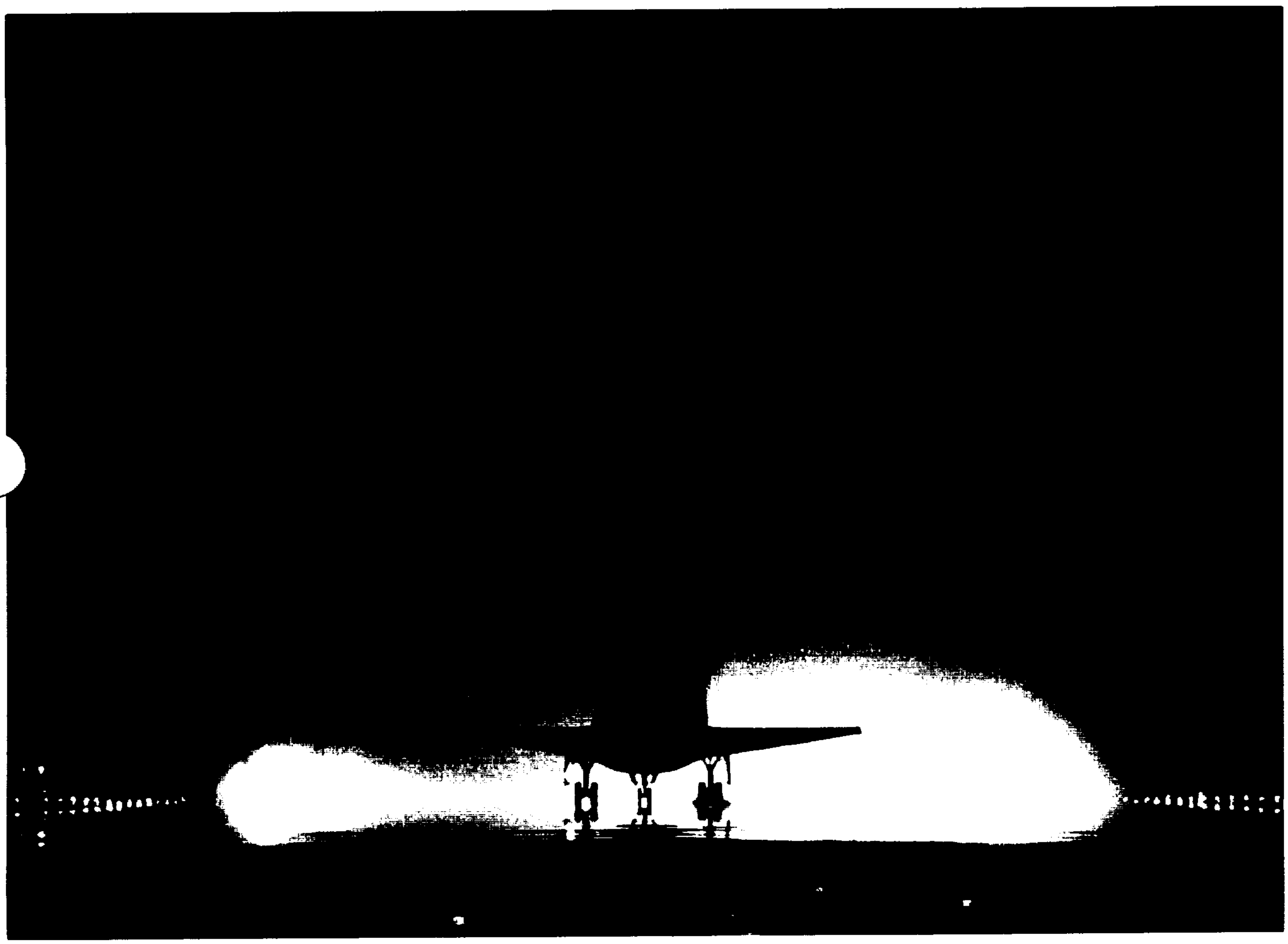
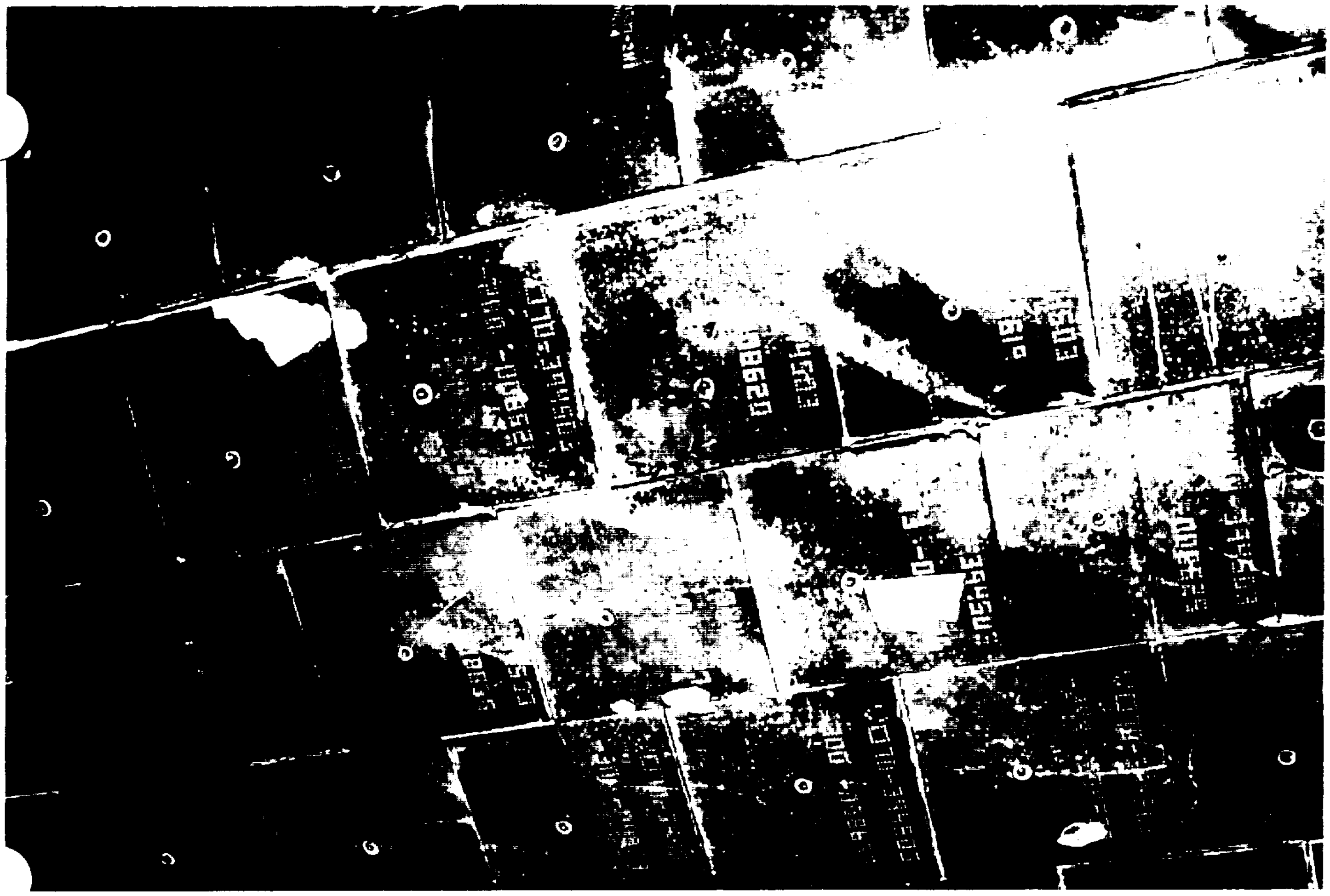


Photo 27: Night Landing of Discovery at KSC SLF

OV-103 Discovery landed at 2:02 a.m. local/eastern time 6 June 1999 on KSC SLF runway 15

Photo 28: Overall View of Orbiter Sides



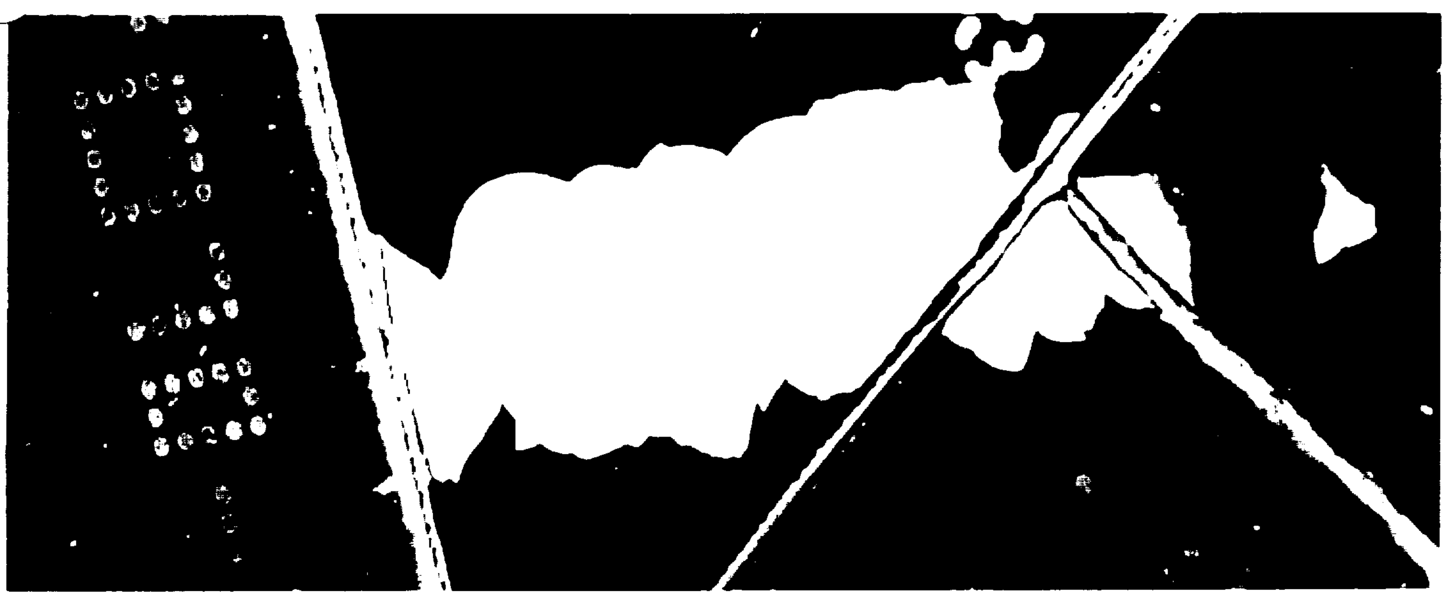


Photo 29: Lower Surface Tile Damage

The Orbiter lower surface sustained 160 total hits, of which 66 had a major dimension of 1-inch or larger. Most of this damage was concentrated from the nose gear to the main landing gear wheel wells on both left and right chines. The outboard damage sites on the chines followed a similar location/damage pattern documented on STS-86, -87, -89, -90, -91, -95, and -88.

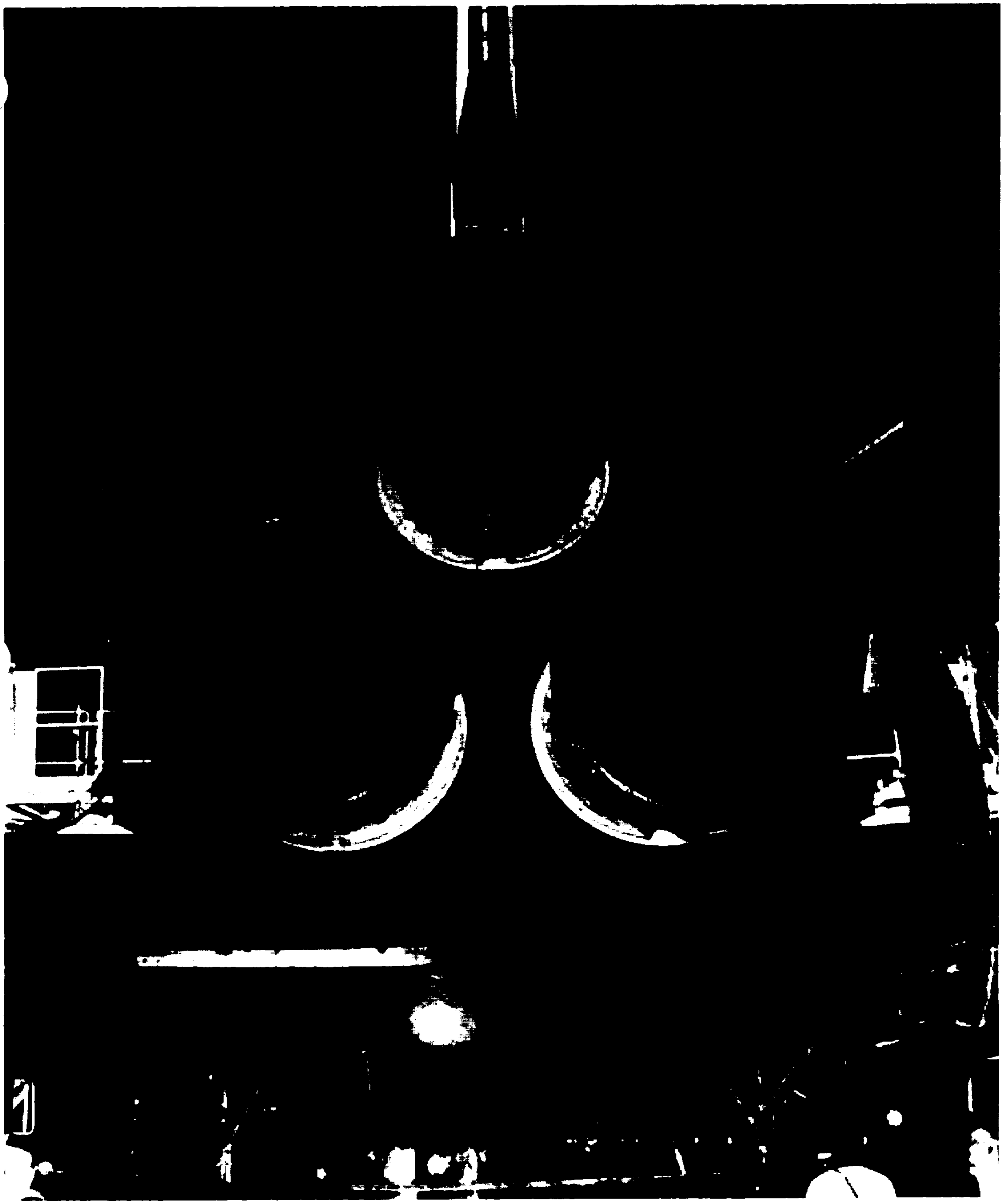


Photo 30: SSME's and Base Heat Shield

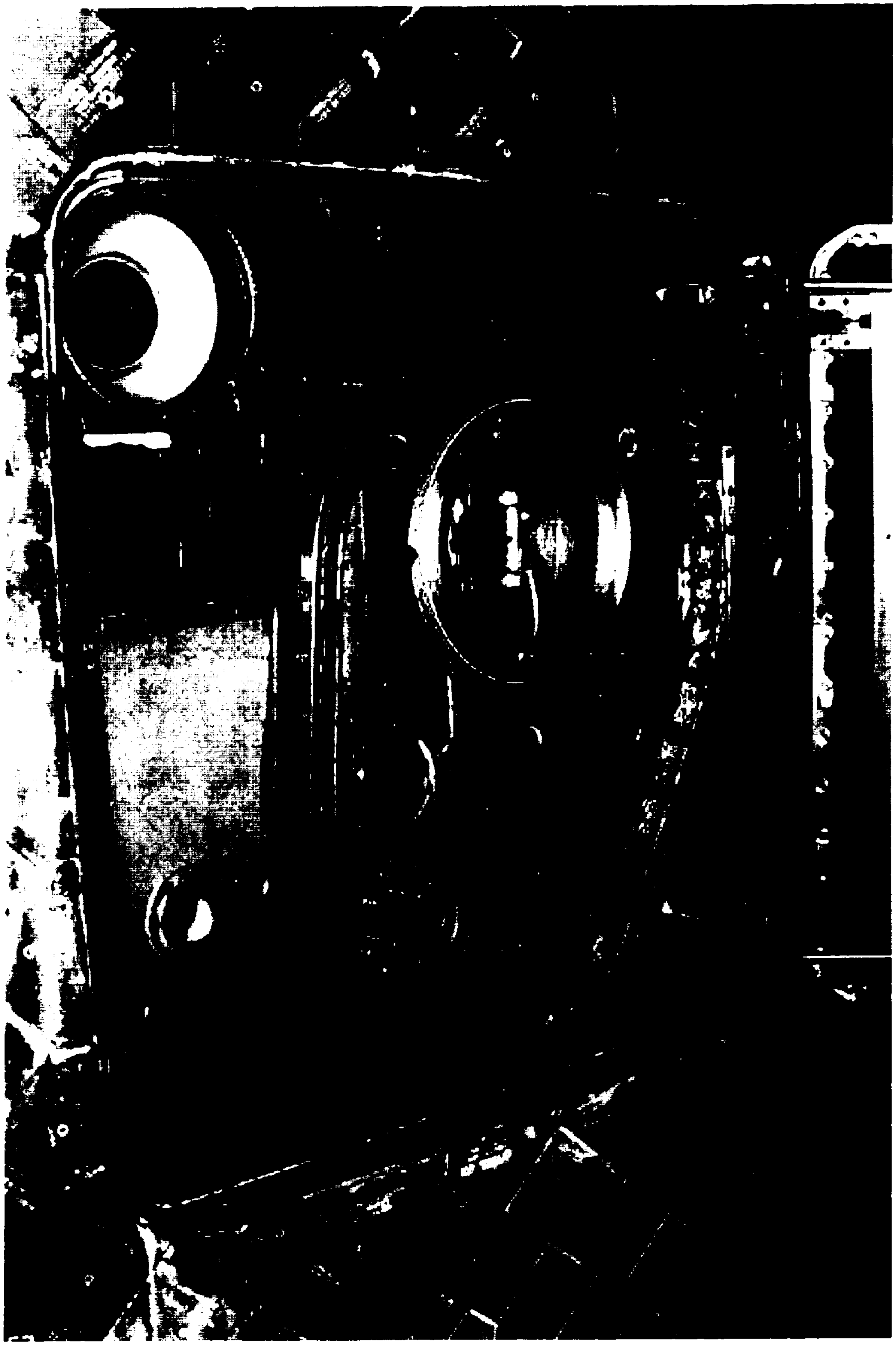


Photo 31: LO2 ET/ORB Umbilical

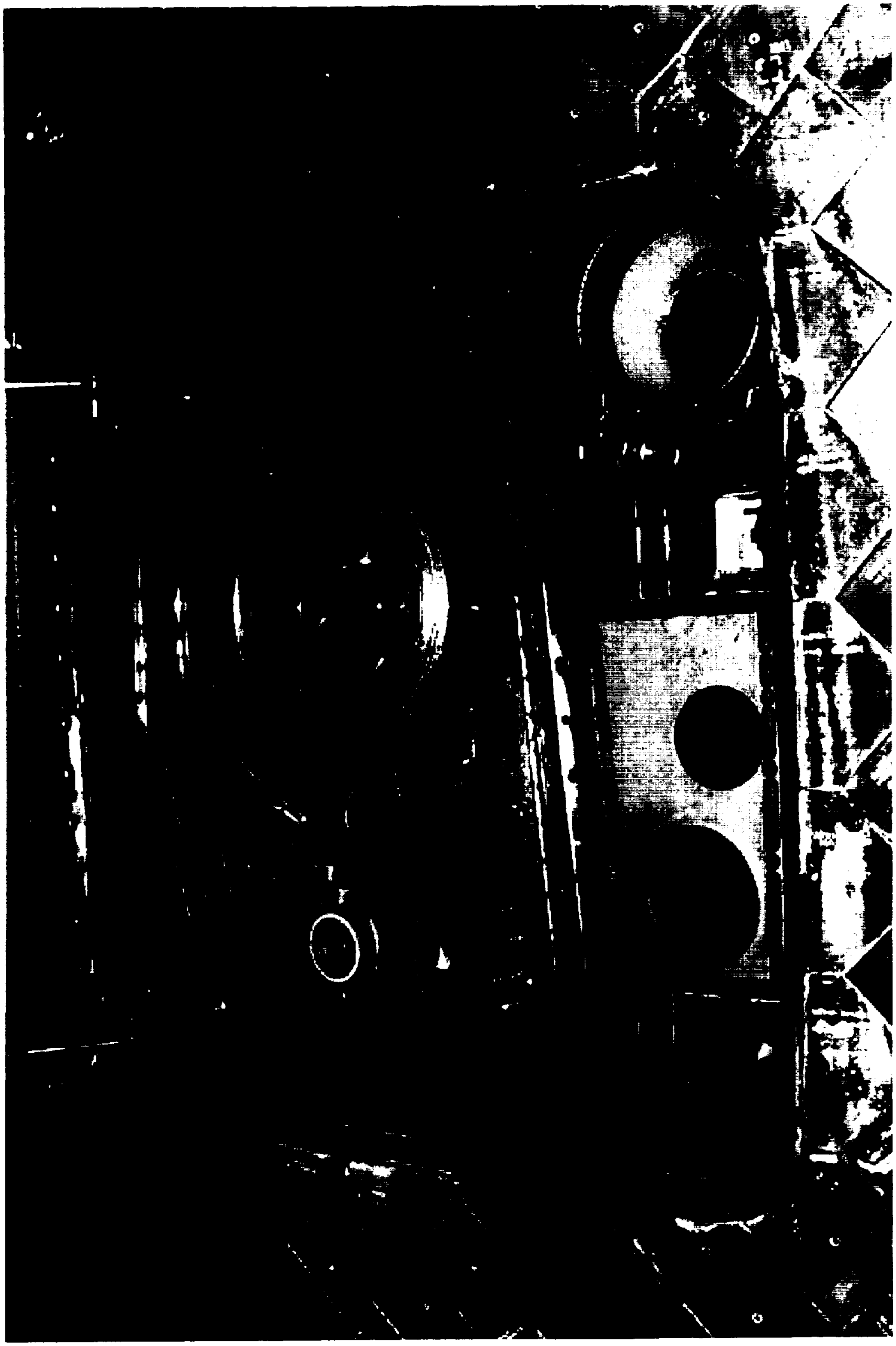


Photo 32: LH2 ET/ORB Umbilical

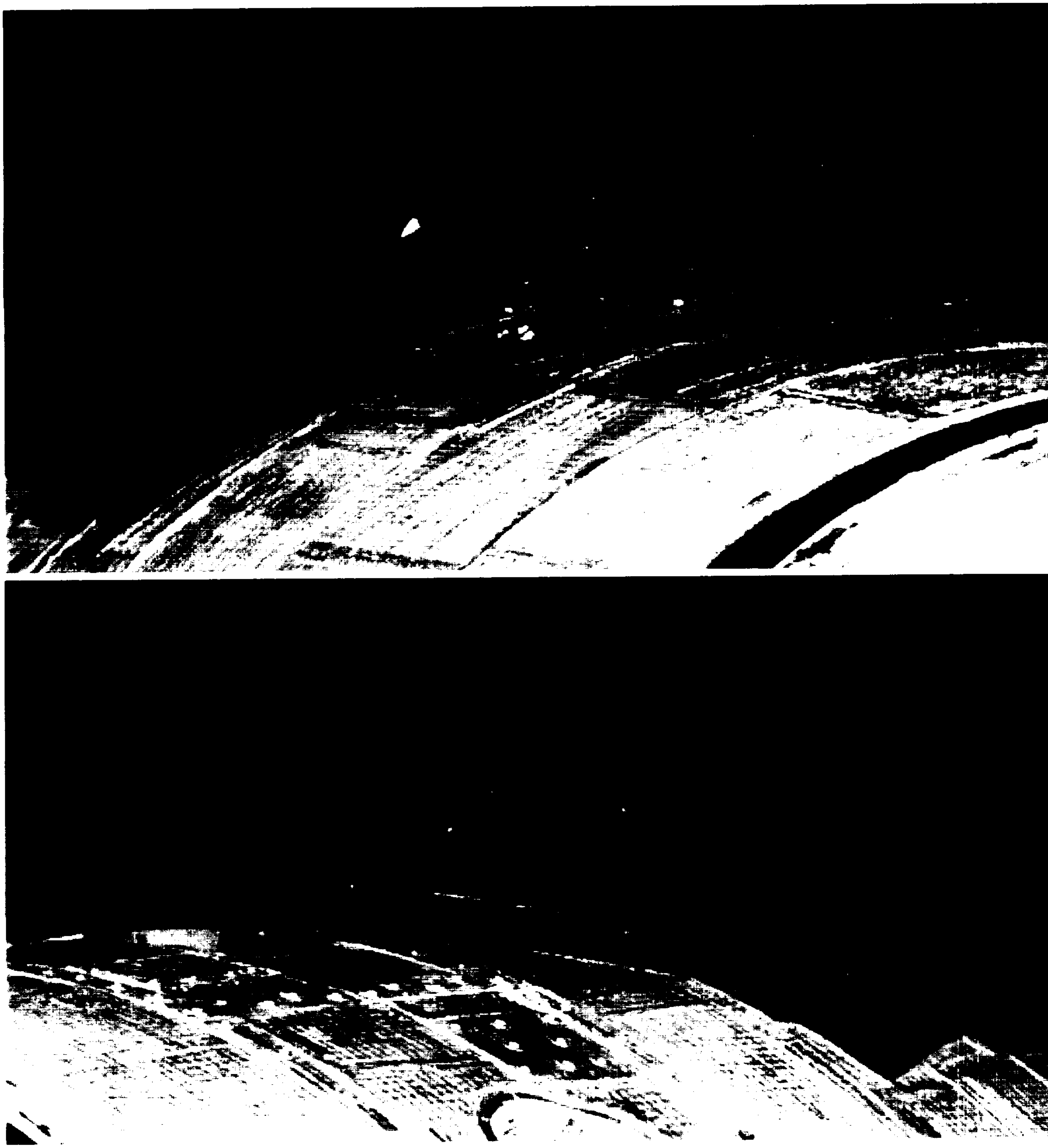


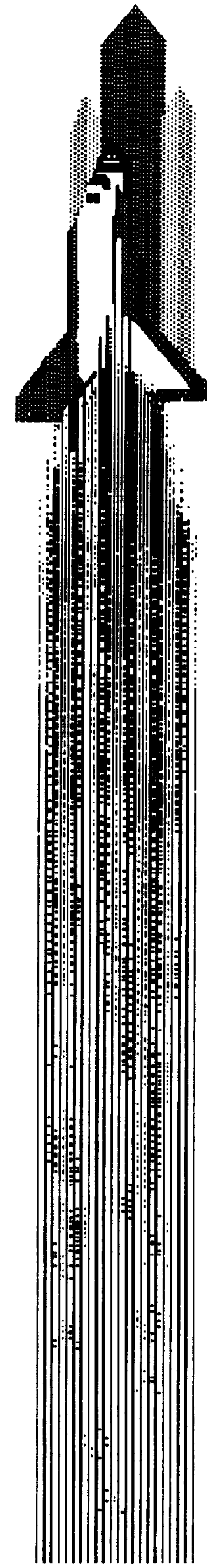
Photo 33: Windows

Hazing and streaking of forward-facing Orbiter windows was moderate.
Damage sites on the window perimeter tiles were typical in quantity and size.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

image science & analysis group
nasa-jsc

Space Science Branch



STS-96 Summary of Significant Events

July 15, 1999

image science & analysis group
nasa-jsc

Space Shuttle
STS-96 Summary of Significant Events

Project Work Order - SN3CS

Approved By

Lockheed Martin	NASA
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Earth Sciences and Solar System Exploration Division
Space and Life Sciences Directorate

Tables and Figures

1.2 LANDING EVENTS TIMING

The time codes from videos and films were used to identify specific events during the screening process. The landing event times are provided in Table 1.2.

Event Description	Time (UTC)	Camera
Main gear door opening	Noted	EL17IR
*Right main gear inboard tire touchdown	157:06:02:42.431	KTV33L
*Left main gear inboard tire touchdown	157:06:02:44.066	KTV33L
Drag chute initiation	157:06:02:51.119	KTV15L
Pilot chute at full inflation	157:06:02:51.940	KTV33L
Bag release	157:06:02:52.174	KTV33L
Drag chute inflation in reefed configuration	157:06:02:53.542	KTV33L
Nose gear tire touchdown	157:06:02:56.745	KTV33L
Drag chute inflation in disreefed configuration	157:06:02:57.546	KTV33L
Drag chute release	157:06:03:18.267	KTV33L
Wheel stop	157:06:03:32.247	KTV33L

*Note: The inboard main gear tires were seen to touchdown before the outboard main gear tires on both wheels on the EL17IR and EL18IR infrared camera views. No timing data was recorded on these infrared cameras. Assuming a video recording rate of 30 fps, the right main inboard tire touched down approximately 0.7 seconds prior to the right main outboard tire. The left main inboard tire touched down approximately 0.3 seconds prior to the left main outboard tire.

Table 1.2 Landing Events Timing

2 SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

As observed on previous missions, numerous light-colored pieces of debris (umbilical ice debris, RCS paper, SRB flame duct debris and water baffle debris) were seen aft of the launch vehicle before, during, and after the roll maneuver.

Numerous pieces of ice debris were seen falling from the ET/Orbiter umbilicals along the body flap during SSME ignition. Multiple pieces of ice debris were seen to contact the LH2 umbilical well door sill (10:49:37.6 through 10:49:40.3 UTC). No damage to the launch vehicle was noted. (Cameras OTV109, OTV154, OTV163, E4, E5, E17, E31, E34, E36, E76)

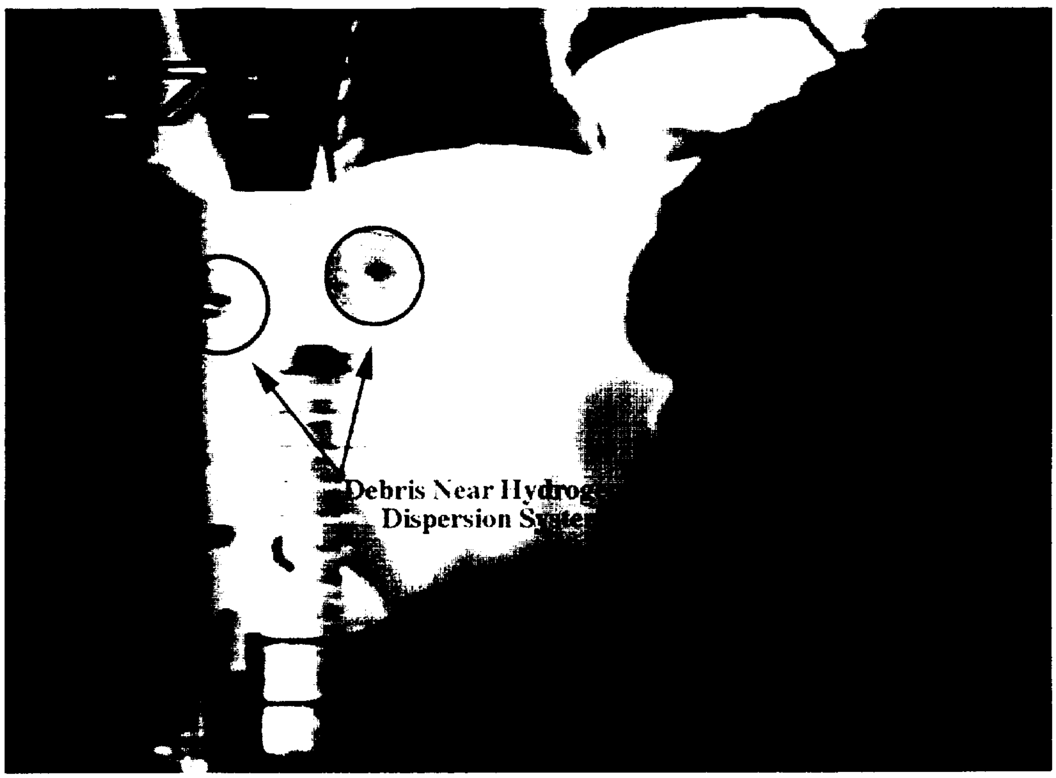


Figure 2.1 (A) Debris Near Hydrogen Dispersion System

Two large-appearing pieces of debris (possible SRB throat plug material) were seen above the MLP near the hydrogen dispersion system during liftoff (10:49:43.28 UTC). The debris was not seen to contact the vehicle. (Camera OTV171)

Figure 2.1 (B) Rectangular-shaped Debris Near Base of SSME #3

A thin, light-colored, rectangular-shaped piece of debris that appeared to originate near the base of SSME #3 after SSME ignition (10:49:42.37 UTC) was seen falling aft toward the MLP. This debris resembled a GSE tile shim/gap filler or a piece of ice debris. The origin and identification of this debris was not confirmed. (Cameras E19, E20)

Multiple pieces of light-colored debris fell between the LSRB and the –Z/-Y side of the ET during liftoff. The debris was probably ice that fell from the GUCP area during the GH2 vent arm retraction. (Camera E34)

Several pieces of light-colored debris (probably ice) fell along the –Z side of the Orbiter fuselage just after liftoff. The debris was first seen near the top of the view, indicating it originated from the forward end of the launch vehicle. None of the debris was seen to contact the vehicle. (Camera E34, E41)

A single piece of light-colored debris (probably SRB throat plug material) was seen near the aft skirt of the LSRB at liftoff (10:49:43.94 UTC). At this same time on camera E52, at least two pieces of debris were seen moving north away from the launch vehicle. This debris was not seen to contact the launch vehicle. (Camera E1, E52)

2.2 DEBRIS DURING ASCENT

Multiple pieces of ET/Orbiter umbilical ice debris and RCS paper debris (too numerous to count) were seen near the SSME rims, near the vertical stabilizer, aft of the vehicle from liftoff, through the roll maneuver and beyond.

On camera E52, a single, relatively large-appearing piece of debris (probably umbilical ice) was seen near the body flap after the roll maneuver (10:49:55.465 UTC). Debris (probably instafoam from the SRB aft skirts) was seen near the SRB exhaust plume(s). Several small orange-colored flares (probably debris induced) were seen in the SSME exhaust plume. (Cameras E52, E54, E207, E212, E223, E224)

Figure 2.2 Debris First Seen Near Body Flap

A single, large-appearing, orange-colored piece of debris (umbilical purge barrier material or umbilical ice debris) was seen falling along the body flap and aft near the LSRB aft skirt during ascent (10:50:16.96 UTC). (Camera ET207)

A single piece of light-colored debris (probably from the SRB aft skirt area) was seen exiting the SRB exhaust plume during ascent (10:51:40.91 UTC). (Camera ET208)

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.3.1 Mobile Launch Platform Events

No vibration of the drag chute door was detected during SSME ignition. STS-96 was the first flight using new inconol shear pins to hold the drag chute door in position during launch. (Cameras E19, E20)

Orange vapor (possibly free burning hydrogen) was visible forward of the SSME rims during SSME ignition. Orange vapors drifting forward from the aft end of the vehicle have been seen on previous mission imagery. (Camera OTV171, E2, E17, E18, E19, E20, E36)

Figure 2.3.1 (A) Tile Surface Coating Erosion on Base of Right RCS Stinger

Small areas of tile surface coating material erosion were seen during SSME ignition on the base of the right RCS stinger (10:49:37.144 UTC). Several small areas of tile surface coating material erosion were also seen on the +Z side of the left RCS stinger at this same time. A single, small area of tile surface coating material erosion was seen on the base heat shield near SSME #3. (Cameras E17, E19, E20)

The SSME ignition appeared normal on the high-speed engineering films. However, the SSME Mach diamonds did not form in the expected 3, 2, 1 sequence. The times for the Mach diamond formation given below are from camera film E19. (Cameras E19, E63, E76)

SSME	TIME (UTC)
SSME #3	10:49:38.773 UTC
SSME #1	10:49:38.973 UTC
SSME #2	10:49:39.074 UTC

Table 2.3.1 SSME Mach Diamond Formation Times

Figure 2.3.1 (B) Detached Surface Material on Holddown Post M7

Surface coating material on the holddown post M7 foot was seen to detach at liftoff (10:49:42.038 UTC). (Camera E11)

2.4 ASCENT EVENTS

Small flashes seen near the base of the right OMS pod during ascent appeared to be partially detached RCS paper. (Camera E207)

Body flap motion was seen during ascent (10:50:16.7 UTC). The amplitude and frequency of the body flap motion appeared similar to that seen on previous mission imagery. No follow-up action was requested. (Cameras E207, ET207, E212, ET212)

A wave-like motion was visible on the LSRB aft skirt thermal curtain during ascent. No damage to the thermal curtain was noted and the thermal curtain tape remained attached. (Camera E207)

Figure 2.4 Flashes from OMS Assist Burn

White and orange-colored flashes or pulses were seen near the aft end of the Orbiter 10.4 seconds after SRB separation (10:51:56.4 UTC). This event was not seen on previous mission imagery. The MER reported that the flashes observed on the STS-96 long-range tracking imagery coincided with an OMS assist burn that occurred at this time. The visual detection of the burn was probably due to the fuel mixture during ignition. (Cameras KTV13, ET208, E208)

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-100)

2.5.1 Analysis of the Umbilical Well Camera Films

Umbilical well cameras (one 35mm and two 16mm cameras) flew for the third time on OV-103 during STS-96. The +X translation maneuver was performed on STS-96 to facilitate the imaging of the ET with the umbilical well cameras. The film quality is very good. However, the ET limb in the -Y direction from the LO2 feedline was in shadow due to the early morning sun and is too dark for analysis. OV-103 provided timing data to the 16mm umbilical well cameras.

The STS-96 35mm Umbilical and Handheld ET Digital Images can be seen at:

http://sn-isag.jsc.nasa.gov/shuttleweb/STS/missions.html

Click on "STS-96"

Then click on "External Tank • 35mm Umbilical Well Photography"

35mm Umbilical Well Camera Film Screening

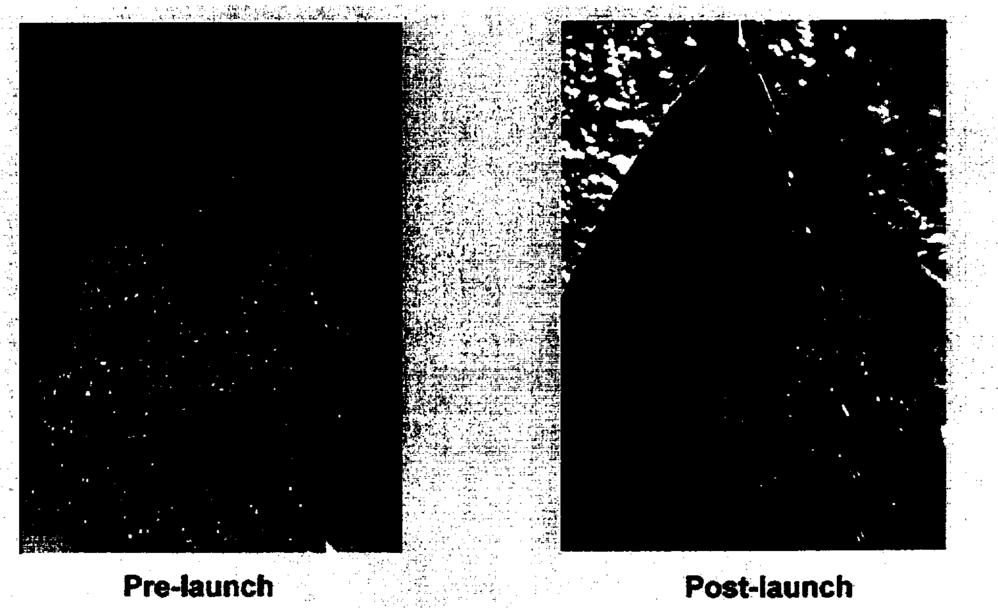


Figure 2.5.1 (A) Hail Damage Repair

Hail damage repair marks were visible on the ET nose / Ogive. The pattern of the repair marks appeared identical to the pattern present on the pre-launch repair close-out photography (Figure 2.5.1(A)). No "new foam," indicative of a subsurface material from a failed or missing repair, was identified. (An assumption is made that the foam exposed by a missing repair is lighter in color than the repair itself.) Using stereoscopic analysis, however, a dozen or more repair marks visible on the sunlit TPS in the –Y direction from the cable tray appeared to contain shadows indicating depth and possible missing TPS. The largest such repair indicating depth was measured at approximately 5 to 6 inches in the longest dimension. Other repairs with possible depth were 2 to 3 inches or smaller in size. KSC stated that not all of the repairs were flat and flush with the outer mold line, but that many repair areas were blended over a 5 or 6 inch diameter and resulted in shallow, bowl-type depressions in order to meet the waviness criteria. Therefore, repair areas with shadows and depth visible on the film do not necessarily indicate missing TPS, but may warrant further investigation.

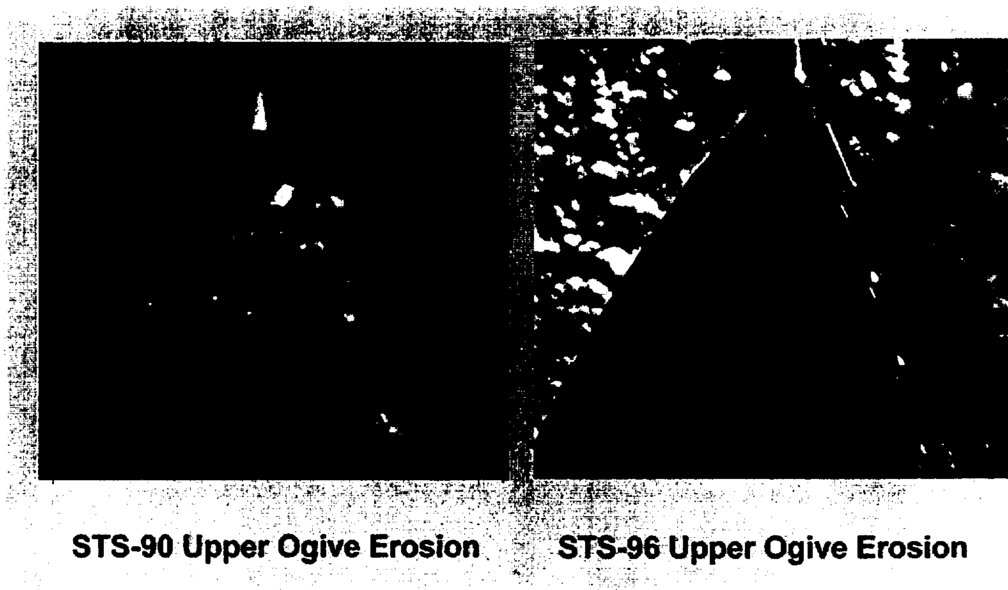


Figure 2.5.1 (B) Upper Ogive Erosion

Similar to STS-90, STS-91, STS-95 and other previous missions, a gray-colored band of pock marked or possible missing TPS is visible on the +Z ET upper Ogive just aft of the ET nose cone fairing (Figure 2.5.1 (B)). Discoloration and/or pocketing in this area are probably due to aero-friction and heating. On the ET-100 pre-launch photography, the upper ET Ogive appears orange-colored with a smooth texture.

Figure 2.5.1 (C) Thrust Panel Damage Comparison

The visible portion of the +Y thrust strut and adjacent intertank rib heads appeared relatively free of divots compared to the same view acquired on STS-87 (Figure 2.5.1 (C)). (The –Y thrust panel was not imaged on the 35mm umbilical well film.)

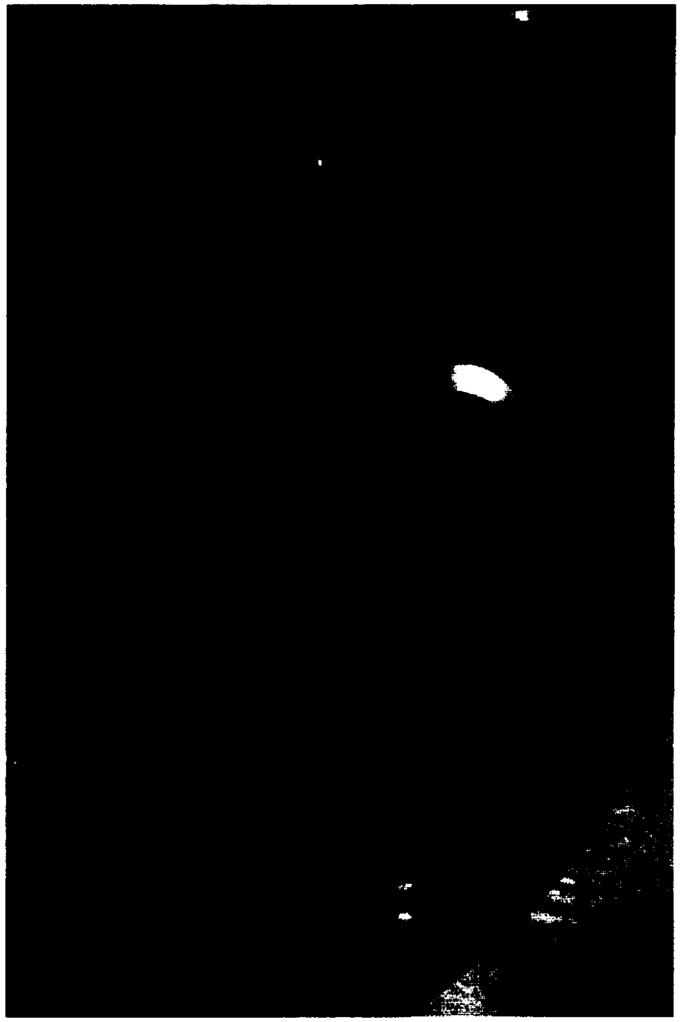


Figure 2.5.1 (D) Detached EO-3 Seal

The red band (seal) surrounding the aft right ET/Orbiter attach (EO-3 fitting) was partially detached. This event has been seen on previous missions.

The LH2 tank TPS in the +Y direction from the LO2 feedline appeared to be in excellent condition on the close-up 35mm umbilical well camera film. (The LH2 tank TPS in the –Y direction from the LO2 feedline was obscured by shadow).

The SRB separation motor burn scars appeared typical of previous missions.

Minor TPS chipping and very small divots (typical of previous missions) were seen on the LO2 feedline, feedline flanges and on the forward end of the +Y ET/Orbiter thrust strut. Ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical was visible. The face of the LO2 umbilical carrier plate was shadowed, hindering the analysis of the plate face condition and the determination of the presence of lightning contact strips.

16mm Umbilical Well Camera Films

The LSRB separation appeared normal on the 16mm umbilical well camera films. Numerous light-colored pieces of debris (insulation) and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing prior to SRB separation were seen. Numerous irregular-shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. Several small pieces of dark-colored debris were seen near the aft LSRB/ET attach at SRB separation. Normal blistering of the fire barrier material on the outboard side of the LH2 umbilical was seen. Ablation of the TPS on the aft dome was less than usual. The left SRB nose cap was visible during SRB separation.

The ET separation from the Orbiter appeared normal. Typical vapor and multiple light-colored pieces of debris were seen after the umbilical separation.

No anomalies were noted on the face of the LH2 umbilical after ET separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect. A long, angular piece of debris (possibly a piece of umbilical purge barrier tape) was seen prior to ET separation. Typical small erosion marks were visible on both the +Y and -Y thrust struts. No anomalous conditions on the ET were noted other than those seen at the higher resolution of the 35mm umbilical well film. The -Y ET thrust panel was in shadow and was too dark for analysis.

2.5.2 Analysis of the ET Handheld Photography

The STS-96 crew performed a manual pitch maneuver from the heads-up position to bring the ET into the view of the Orbiter's overhead windows for the handheld photography and video. STS-96 was the seventh flight to use the roll-to-heads-up maneuver.

The crew obtained ET photography with a 35mm handheld camera (Nikon-F4 w/400 mm lens). A total of 38 pictures of the ET were obtained (roll number 328). Timing data was present on all frames.

A description of the ET views of the handheld film is given in Table 2.5.2. Views of the nose, aftdome, +Z, -Y, -Z and +Y sides of the ET were acquired including views of the +Y and -Y thrust panel.

The STS-96 handheld pictures of the ET have excellent exposure. The ET was in full sunlight with very little shadowing. The distance of the ET from the Orbiter was calculated to be approximately 1.6 km on the first photographic frame acquired at 14:21 minutes:seconds MET.

Frame No	GMT (hh:mm:ss)	MET (mm:ss)	View	Distance in km
1	11:04:03	14:21	Nose, +Z, +Y	1.61
2	11:04:05	14:23	Nose, +Z, +Y	1.61
3	11:04:08	14:26	Nose, +Z, +Y	1.61
4	11:04:15	14:33	Nose, +Z, +Y	1.69
5	11:04:17	14:35	Nose, +Z, +Y	1.69
6	11:04:21	14:39	Nose, +Z, +Y	1.69
7	11:04:25	14:43	Nose, +Z, -Y	1.69
8	11:04:29	14:47	Nose, +Z, -Y	1.69
9	11:04:34	14:52	Nose, +Z, -Y	1.74
10	11:04:40	14:58	Nose, +Z, -Y	1.78
11	11:04:44	15:02	Nose, +Z, Y	1.88
12	11:04:48	15:06	Nose, +Z, -Y	1.88
13	11:04:53	15:11	-Y	1.88
14	11:04:55	15:13	-Y	1.93
15	11:05:02	15:20	-Y	1.93
16	11:05:07	15:25	-Y	1.99
17	11:05:10	15:28	-Y, -Z, Aft Dome	1.99
18	11:05:18	15:36	-Y, -Z, Aft Dome	2.11
19	11:05:27	15:45	-Z, Aft Dome	2.11
20	11:05:43	16:01	Aft Dome, -Z, +Y	2.26
21	11:05:48	16:06	Aft Dome, -Z, +Y	2.26
22	11:05:51	16:09	Aft Dome, -Z, +Y	2.26
23	11:05:54	16:12	Aft Dome, -Z, +Y	2.26
24	11:06:00	16:18	Aft Dome, -Z, +Y	2.42
25	11:06:02	16:20	Aft Dome, -Z, +Y	2.42
26	11:06:05	16:23	Aft Dome, -Z, +Y	2.42
27	11:06:10	16:28	Aft Dome, +Z, +Y	2.42
28	11:06:22	16:40	+Z	2.51
29	11:06:26	16:44	+Z, Aft Dome	2.51
30	11:06:30	16:48	+Z, -Y	2.60
31	11:06:33	16:51	+Z, -Y	2.60
32	11:06:39	16:57	-Y	2.60
33	11:06:53	17:11	-Y	2.71
34	11:06:55	17:13	-Y	2.71
35	11:06:58	17:16	-Y	2.71
36	11:07:01	17:19	-Y	2.82
37	11:07:05	17:23	-Y	2.82
38	11:07:09	17:27	-Y, -Z	2.82

Table 2.5.2 Description of the Handheld ET Film Views

Handheld Film Screening Summary

Two divots were noted on the LH2 tank-to-intertank close-out flange between the legs of the forward bipod. The normal SRB separation burn scars and aero-heating marks were noted on the intertank and nose TPS of the ET. The hail damage repairs were seen on the ET nose. No indication of damage to these repairs was noted. No indication of venting was seen on the ET images.

Enhancements were made to bring out detail on the +Y and −Y thrust panels. If present, divots greater than seven inches in size should have been detectable on the thrust panels. However, none were confirmed.

Light-colored marks were visible on the ET thrust panel and adjacent intertank TPS. Possible causes include the presence of TPS erosion and/or multiple divots too small to be individually resolved on the handheld film.

The following summaries are an attempt to describe the location of the light-colored marks. Station and rib number locations can be referenced from the diagram provided in Figure 2.5.2 (A).

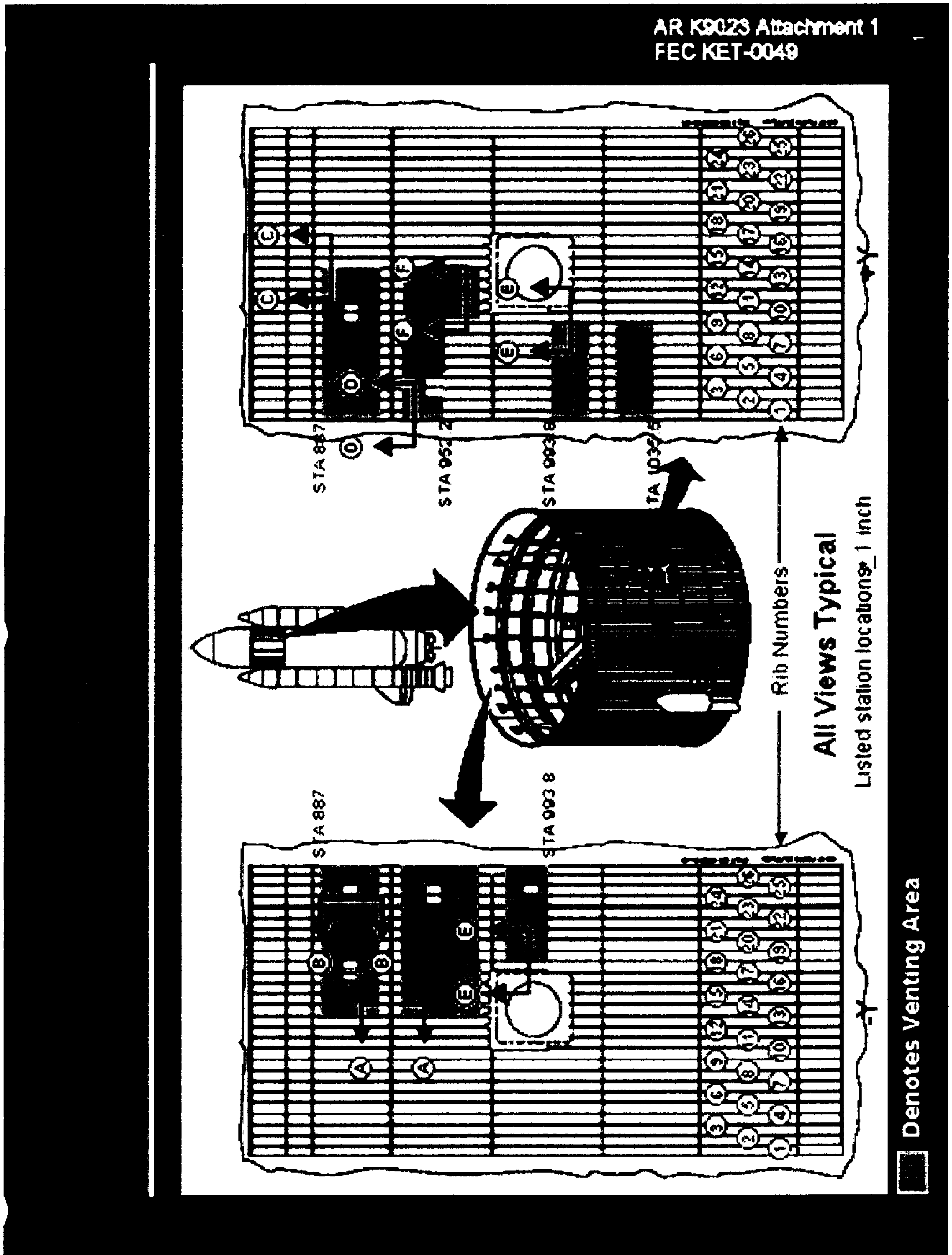


Figure 2.5.2 (A) ET Thrust Panel Location Reference

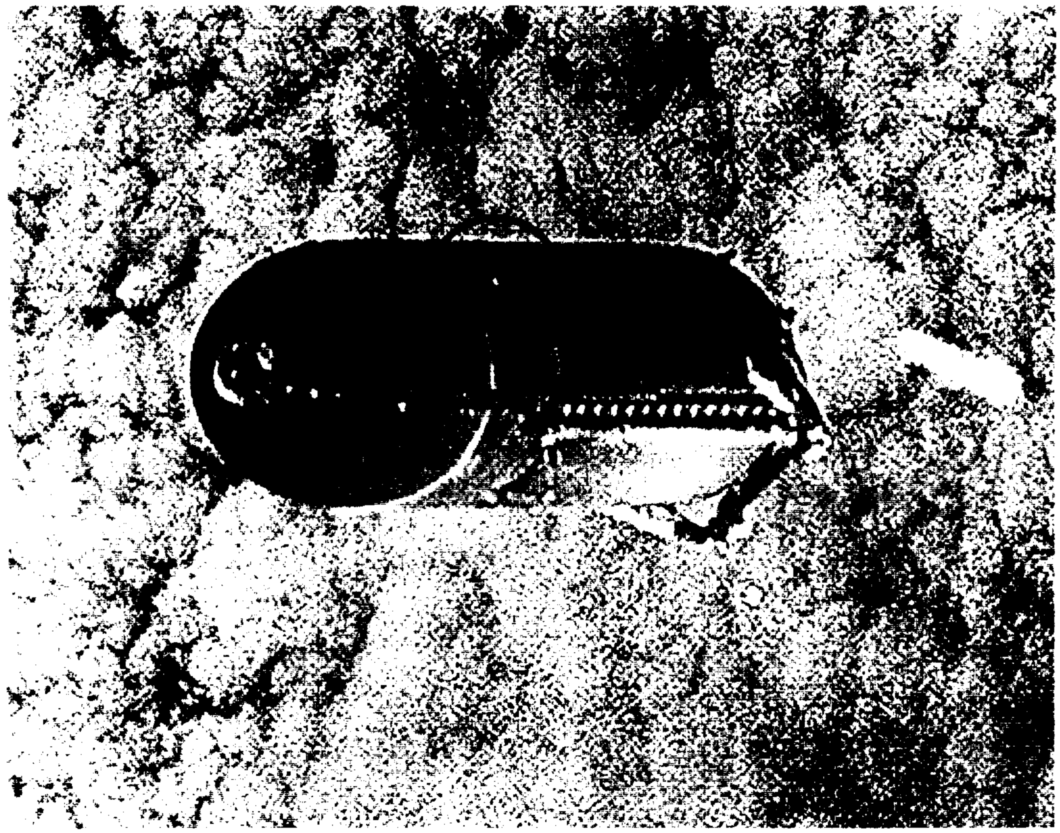


Figure 2.5.2 (B) + Y Thrust Panel (Frame 1)

Frame 1 – Several light-colored areas were observed at station 990 in the vicinity of ribs 3 through 7 on the +Y thrust panel. Directly aft of these marks, additional light-colored areas were seen near station 1060. Several light-colored areas were noted inboard from the +Y thrust panel on the intertank TPS between stations 990 and 1100.

Frame 21 – A large, light-colored area was noted on the +Y panel outboard of the RSRB forward attach point between station 890 and 990 in the vicinity of ribs 18 through 25.

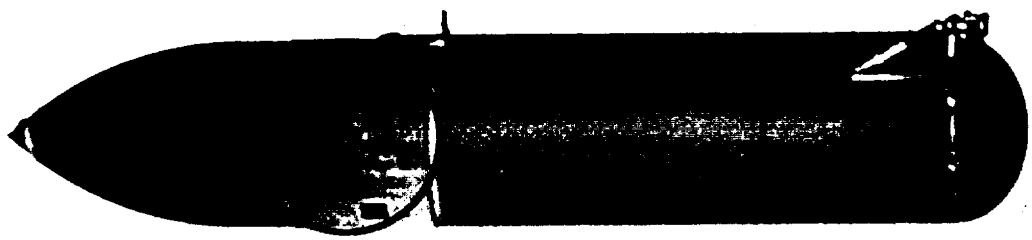


Figure 2.5.2 (C) -Y Thrust Panel (Frame 15)

Frame 8 - A significant-appearing light-colored area was seen near the station 990 level in the vicinity of ribs 21 through 26 on the -Y thrust panel. Additional light-colored areas were seen further aft along these same ribs.

Frames 10, 15 – Light-colored areas were seen between station 990 in the vicinity of ribs 1 through 10. Additional light-colored areas were visible near the LSRB forward attach point. Light-colored areas were seen extending from the LSRB forward attach point in the 4 o'clock direction relative to the nose between station 990 and 1010 in the vicinity of ribs 16 through 25.

Frame 33 – Light colored areas were noted surrounding the LSRB attach point.

The normal SRB separation burn scars and aero-heating marks were noted on the +Y and -Y sides of the intertank and nose of the ET.

2.5.3 Analysis of the ET Handheld Video

The astronauts acquired over six minutes of handheld ET video. The first view was acquired at 13:26 minutes:seconds MET. The overall quality of the video is excellent. The focus and exposure is generally good. The GMT time of the video acquisition is recorded in the view.

Views of all aspects of the ET were acquired, including views of both thrust panels. No TPS damage could be confirmed at the resolution of this video because of the distance of the ET. However, bright areas surrounding the forward –Y ET/SRB attach (particularly in the +Y direction from this attach) indicated the presence of TPS erosion and/or damage too small to resolve at the resolution of the video. The normal SRB separation burn scars and aero-heating marks are visible on the intertank and nose TPS of the ET.

As on STS-88, no venting from the ET was detected. However, venting was seen on the five missions previous to STS-88. The cloud and ocean background made it very difficult to detect the STS-96 ET venting if it had occurred. No sudden increase in the tumble rate of the STS-96 ET typically associated with ET venting was noted.

The tumble rate of the ET (end-to-end rotation of the ET about its center of mass) was equivalent or less than that seen on the previous five missions. Table 2.5.3 contains a comparison of the averaged tumble rate measurements for the current and the previous six Space Shuttle missions.

MISSION	Tumble Rate (deg/sec)	Separation Rate (m/sec)	MET (mm:ss)	Venting
STS-87	11	--	17:23 - 18:08	Yes
STS-89	12	--	31:42 - 35:27	Yes
STS-90	3	--	14:30*	Yes
STS-91	11	--	16:29 - 18:46	Yes
STS-95	< 1	5.5 (prior to venting)	13:40 - 20:50	Yes
STS-88	2	6.2	15:39 - 22:44	No
STS-96	**1.3**	**6.5**	**13:21 – 18:21**	**No**

* Only the first four frames had timing data (on STS-90 photography). Relative time from video was used to determine the STS-90 tumble rate.

Table 2.5.3 ET Tumble and Separation Rates

2.6 ET THRUST PANEL VIDEO

A screening of both the left and right STS-96 (ET) thrust panel videos was conducted. The following observations were made (Figures 2.6 (A), (B) and (C)):

<u>-Y View</u>

Compared to the equivalent STS-95 mission video of the ET –Y thrust panel, fewer total divots were visible on the STS-96 –Y panel view. Similar to the STS-95 –Y view, the divots occurred on or near the rib heads. Very few divots were noted in the valleys between the ribs. The majority of the divots were near the top of the view in the direction of the SRB forward attach. Several divots were noted outside of the thrust panel on the ET intertank stringers. The divots appeared shallow with no primed substrate visible.

At 22 seconds MET, the first divot was noted (approximately 1/4 inch in size). At 90 seconds, a second divot was noted. By 93 seconds, multiple divots, discoloration and

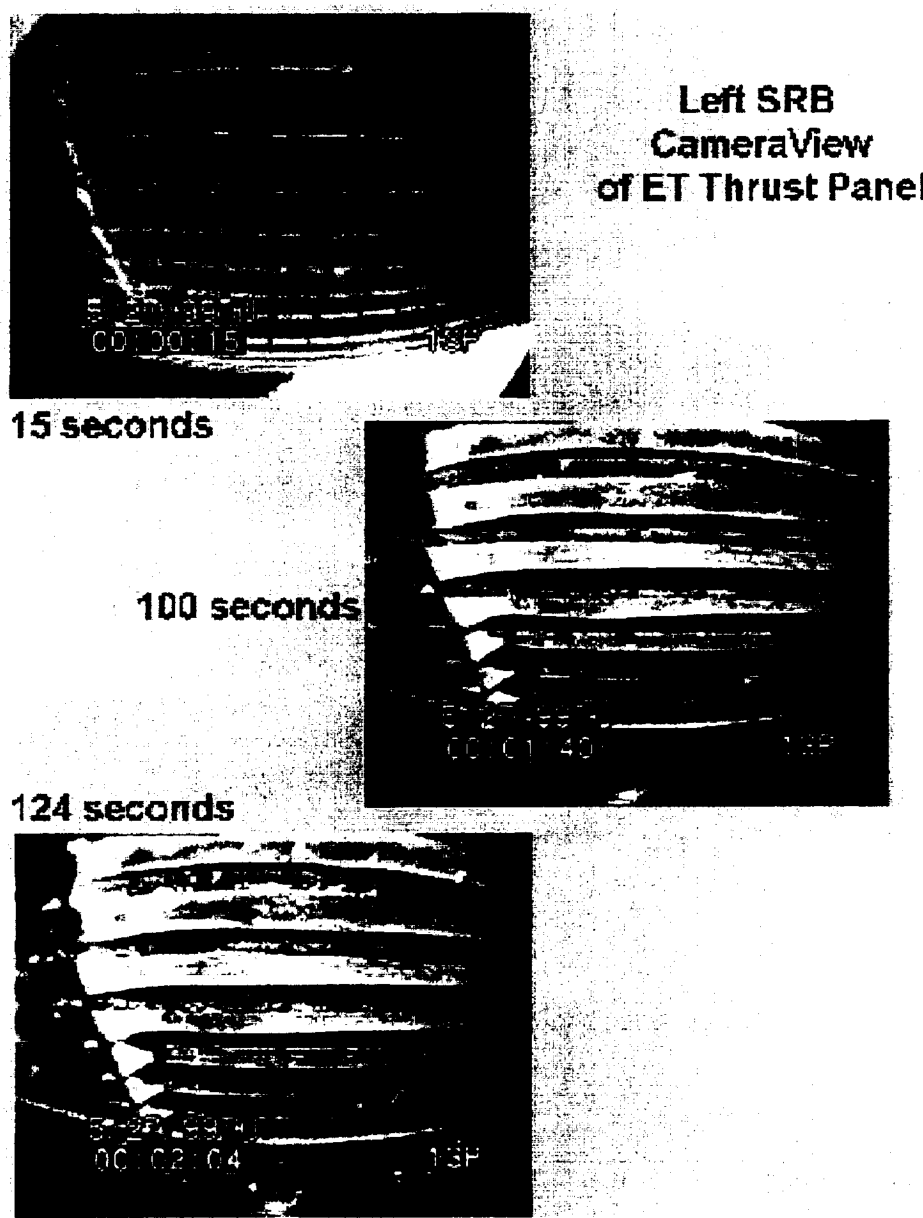


Figure 2.6 (A) LSRB Views of ET Thrust Panel

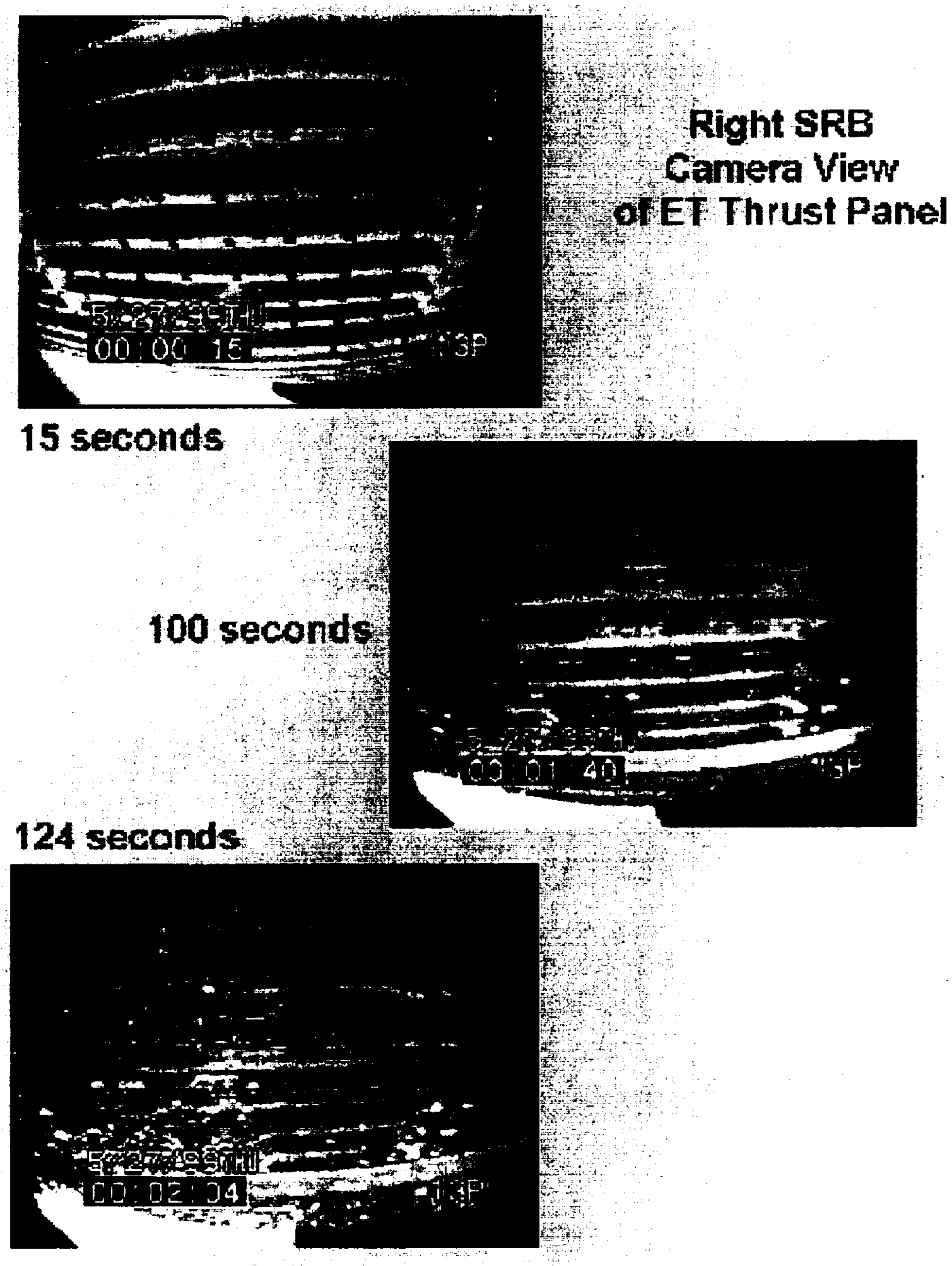


Figure 2.6 (B) RSRB Views of ET Thrust Panel

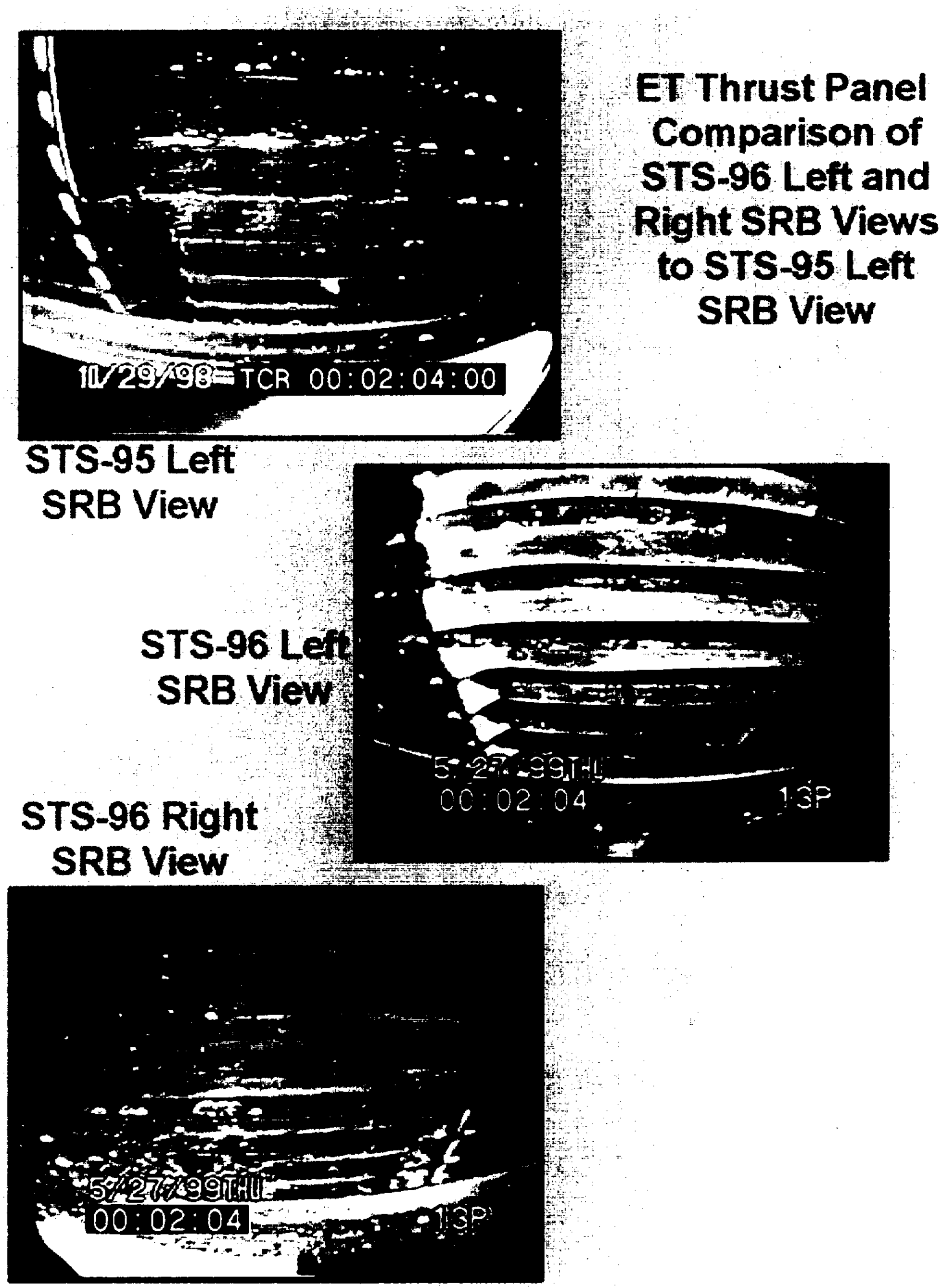


Figure 2.6 (C) Comparison of STS-96 and STS-95 SRB Views

2.7 LANDING EVENTS

2.7.1 Landing Sink Rate Analysis

Image data from film camera EL-7 North was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touchdown was considered. Data points defining the main gear struts were collected on every frame (100 frames of the data during the last second prior to touch down). An assumption was made that the line of sight of the camera was perpendicular to the Orbiter's y-axis. The distance between the main gear struts (272 in.) was used as a scaling factor. The main gear height above the runway was calculated by determining the vertical difference between the main gear struts and the reference point. A regression trend line of the heights was calculated with respect to time. The sink rate equals the slope of this regression line.

The right main gear sink rate for the STS-96 landing at one second, at 1/2 second, and at 1/4 second are provided in Table 2.7.1. A plot describing these sinkrates is provided in Figure 2.7.1.

Time Prior to Touchdown	**1.00 Sec.**	**0.50 Sec.**	**0.25 Sec.**
Right Main Gear Sink Rate	2.1 ft/sec	1.2/sec	0.8 ft/sec
Estimated Error (1σ)	± 0.1 ft/sec	± 0.1 ft/sec	± 0.2 ft/sec

Right Main Gear Touchdown = 157:06:02:42.4 (UTC)

Table 2.7.1 Main Gear Sink Rate

The maximum allowable main gear sink rate values are 9.6 ft/sec for a 212,000 lb vehicle and 6.0 ft/sec for a 240,000 lb vehicle. The landing weight of the STS-96 vehicle was estimated to be 222,128 lbs.

STS-96 Main Gear Landing Sink Rate
(Camera EL-7)

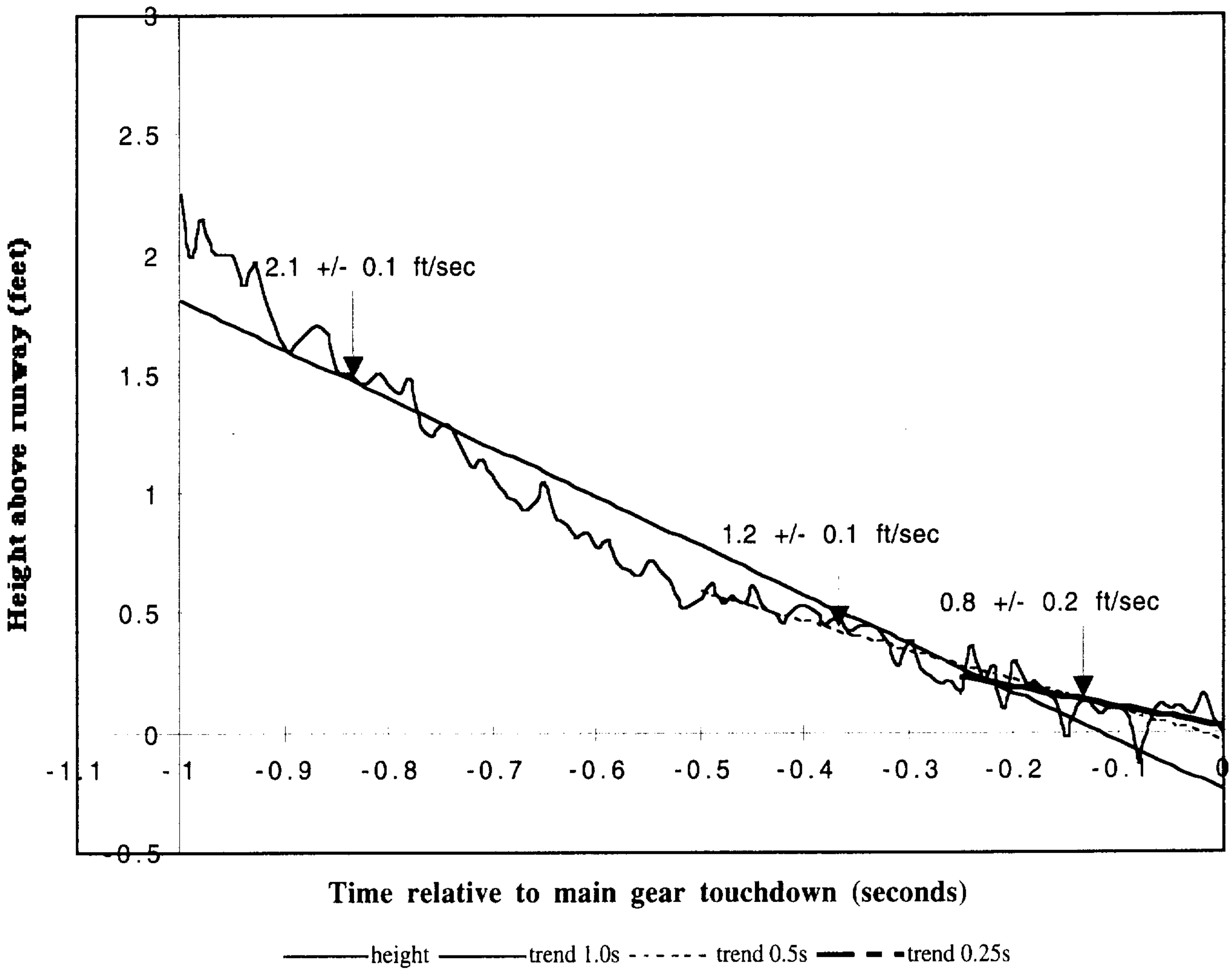


Figure 2.7.1 Main Gear Landing Sink Rate

2.8 OTHER

2.8.1 Normal Events

Normal events observed included: vapors from the ET vent louver prior to liftoff, elevon motion prior to liftoff, RCS paper debris from SSME ignition through liftoff, ET twang, ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and after disconnect, multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff, acoustic waves in the exhaust cloud during liftoff, debris in the exhaust cloud after liftoff, expansion waves after liftoff, white-colored flashes in the SSME exhaust plume after liftoff, vapor off the SRB stiffener rings, charring of the ET aft dome, ET aft dome outgassing, condensation on the Shuttle launch vehicle during ascent, linear optical effects, recirculation, SRB plume brightening, and slag debris after SRB separation.

2.8.2 Normal Pad Events

Normal pad events observed included: the hydrogen burn ignitor operation, the FSS and MLP deluge water activation, sound suppression system water operation, GH2 vent arm retraction, and the TSM T-0 umbilical operations, and TSM door closures.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

STS-96 Engineering Photographic Analysis Report

Engineering Photographic Analysis is in the process of moving from building 4666 to building 4203. Our new facility is not yet fully operational, and will continue to be limited in capability for several more weeks. We hope to achieve minimal functionality before the next launch. Please contact Tom Rieckhoff (256-544-7677) if you require updated information or assistance during this period.

Table of Contents

Introduction

The launch of space shuttle mission STS-96, the twenty-sixth flight of the Orbiter Discovery occurred May 27, 1999, at approximately 5:49AM Central Daylight Time from launch complex 39B, Kennedy Space Center (KSC), Florida. Launch time reported as 99:147:10:49:42.021 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. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Engineering Analysis Objectives

The planned engineering photographic and video analysis objectives for STS-96 include, but are not limited to the following:

- Verification of cameras, lighting and timing systems.
- Overall propulsion system coverage for anomaly detection and structural integrity.
- Determination of SRB PIC firing time and SRB separation time.
- Verification of SRB and ET Thermal Protection System (TPS) integrity.
- Correct operation of the following:
  - SSME ignition and mainstage
  - SRB debris containment system
  - LH2 and LO2 17-inch disconnects
  - Ground umbilical carrier plate
  - Free hydrogen ignitors
  - Booster separation motors

Camera Coverage Assessment

The following table illustrates the camera coverage expected at MSFC for STS-96.

	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	5
Tracking	0	9	11
Onboard	0	0	2
Totals	24	16	25

Total number of film and videos received to date: 65

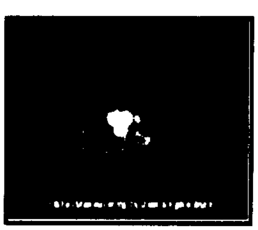
An individual motion picture camera assessment is provided as Appendix A. Appendix B contains detailed assessments of the video products received at MSFC.

Ground Camera Coverage

Anomalies

No anomalies observed to date.

Observations



Orbital Maneuvering System (OMS) engine burn. This occurred at 147:10:51:56.8 UTC. This was a planned burn and is expected to be performed on missions which rendezvous with the ISS. MPEG movie of the event.

T-Zero Times

T-Zero times are determined from cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

Holddown Post	Camera Position	Time (UTC)
M-1	E9	Exposure too dark
M-2	E8	Exposure too dark
M-5	E12	10:49:42.030
M-6	E13	10:49:42.030

SRB Separation Time

SRB separation as recorded by observations of the BSM combustion products from long-range video cameras. Both ET207 and ET208 recorded SRB separation at 147:10:51:46.4 UTC. High speed film camera E205 recorded SRB separation time as 147:10:51:46.419 UTC.

Appendix A - Individual film camera assessments

Appendix B - Individual video camera assessments

Appendix C - Definitions and acronyms

Individual film/video summary report

Return to Engineering Photographic Analysis Reports

Return to MSFC Engineering Photographic Analysis Home Page

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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-96. 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 Space Shuttle mission STS-96 and the resulting effect on the Space Shuttle Program.

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