Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-90

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

Technical Memorandum - 1998 - 207907 June 1998

DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-90

17 April 1998

Contributions By:

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

Approved:

Gregory N. Katnik
Shuttle Ice/Debris Systems
NASA - KSC
Mail Code: PK-H

Philip J. Weber
Chief, ET/SRB Mech/TPS Systems
NASA - KSC
Mail Code: PK-H

TABLE OF CONTENTS

TABLE OF PHOTOS

Photo 1: Launch of Shuttle Mission STS-90

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 15 April 1998. The detailed walkdown of Pad 39B and MLP-2 also included the primary flight elements OV-102 Columbia (25th flight), ET-91 (LWT 84), and BI-094 SRB's. There were no significant vehicle anomalies.

As a result of tile damage on the STS-86, -87, and -89 Orbiters and subsequent investigation of foam loss from the ET thrust panels, the ET-91 intertank was modified to remove even more foam than ET-90 (STS-89). Foam on both -Y and +Y thrust panels was machined/sanded to minimum drawing requirements to improve the stress/strain capability without the rind, eliminate a denser material layer, reduce the amount of potential debris material, and reduce the foam height above the panel ribs to decrease the cross-flow air loading on the foam. All of these measures were designed to eliminate or reduce the amount of TPS loss from the thrust panels, and in turn reduce the amount of damage to Orbiter tiles.

The Final Inspection of the cryoloaded vehicle was performed on 17 April 1998 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. Three debris items were found on the MLP deck directly below the External Tank. A ¾-inch diameter personnel safety life line was tied between two sound suppression water pipes adjacent to holddown posts #5 and #7. A white, plastic, heavy duty tie-wrap was on the 8-inch sound suppression water pipe adjacent to holddown post #1. And a broken drill bit 1-inch long by ¼-inch diameter lay on the MLP deck.

After the 2:19 p.m. (local) launch on 17 April 1998, a debris walk down of Pad 39B was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Both left and right SRB aft skirt GN2 purge lines were intact after liftoff although the first layer of protective aluminum tape had eroded away. The remaining two layers probably kept the steel braid and internal tube from melting, a common failure mode on previous launches.

A 4-foot by 4-foot by 0.25-inch thick steel ventilation hatch from the hammerhead crane machine room was recovered on the FSS 275 foot level. The hatch, which was observed in high speed launch films, had shaken loose by the SRB exhaust plume vibration/acoustics. The hatches on both launch pads have since been welded in place to prevent a reoccurrence. However, the broader concern for "abandoned in place" equipment is being addressed.

A total of 112 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission.

No stud hang-ups were observed on any of the eight holddown posts. No ordnance debris or frangible nut pieces fell from the DCS/stud holes.

Some of the lacing was loose, or untied, on two adjacent SRB thermal curtains near HDP #4. An opening in the curtain outer layer appeared momentarily as the curtains deflected from the initial SRB ignition pressure wave. Immediately afterwards, the curtains resumed the normal hanging curved shape. No detrimental effect to the inner thermal curtain was detected.

A white object appeared to originate from an area between SSME #2/#3 and fell aft at 18:19:47.730 UTC. Post flight inspection of the Orbiter showed the object was a portion of an SSME Dome Mounted Heat Shield (DMHS) closeout blanket

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 15 April 1998 at 1400 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC	Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC	Shuttle Ice/Debris Systems
R. Speece	NASA - KSC	Thermal Protection Systems
B. Bowen	NASA - KSC	Infrared Scanning Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
R. Page	NASA - KSC	SSP Integration
K. Revay	USA - SFOC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC	ET Mechanical Systems
R. Seale	USA - SFOC	ET Mechanical Systems
W. Richards	USA - SFOC	ET Mechanical Systems
M. Wollam	USA - SFOC	ET Mechanical Systems
G. Fales	USA - SFOC	ET Mechanical Systems
T. Ford	USA - SFOC	ET Mechanical Systems
F. Foster	BNA - LSS	Systems Integration
C. Hill	BNA - LSS	Systems Integration
M. Eastwood	THIO - LSS	SRM Processing
S. Otto	MMMSS - LSS	ET Processing
J. Ramirez	MMMSS - LSS	ET Processing

The Final Inspection Team observed no ice, frost, or condensate on the LO2 tank acreage. TPS surface temperatures averaged 65 degrees F.

The intertank acreage exhibited no TPS anomalies, including the sanded thrust panels. Ice/frost accumulation on the base of the GUCP appeared typical.

The Final Inspection Team detected no ice, frost, or condensate on the LH2 tank acreage. TPS surface temperatures averaged 67 degrees F on the +Z side and 63 degrees F on the -Z side. The difference between the two sides was attributed to the "thick/thin" TPS configuration.

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

A 10-inch long by 3/8-inch wide stress relief crack had formed, as expected, on the -Y vertical strut forward facing TPS.

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 less than usual.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate. A 2-inch by 2-inch frost spot had formed at the LH2 feedline-to-ET interface.

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

3.2.4 FACILITY

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

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

Three debris items were found on the MLP deck directly below the External Tank. A ¾-inch diameter personnel safety life line was tied between two sound suppression water pipes adjacent to holddown posts #5 and #7. A white, plastic, heavy duty tie-wrap was on the 8-inch sound suppression water pipe adjacent to holddown post #1. And a broken drill bit 1-inch long by ¼-inch diameter lay on the MLP deck.

3.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing did not increase noticeably. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. No ice was detected in the "no ice" zone.

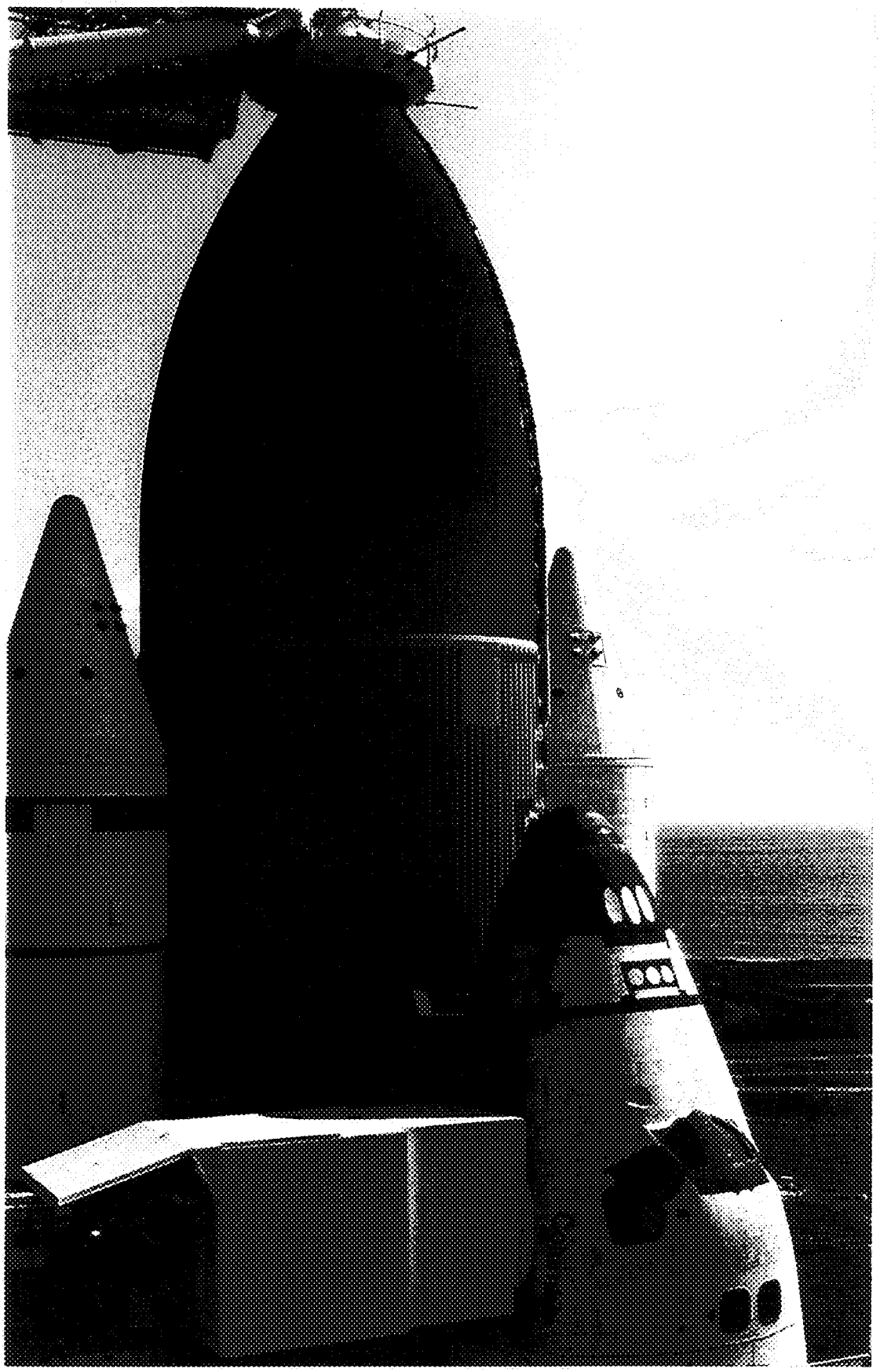


Photo 2: STS-90 Ready for Launch

OV-102 Columbia (25th flight), ET-91 (LWT 84), and BI-094 SRB's. The Final Inspection Team observed no ice, frost, or condensate on the LO2 tank acreage. TPS surface temperatures averaged 65 degrees F.

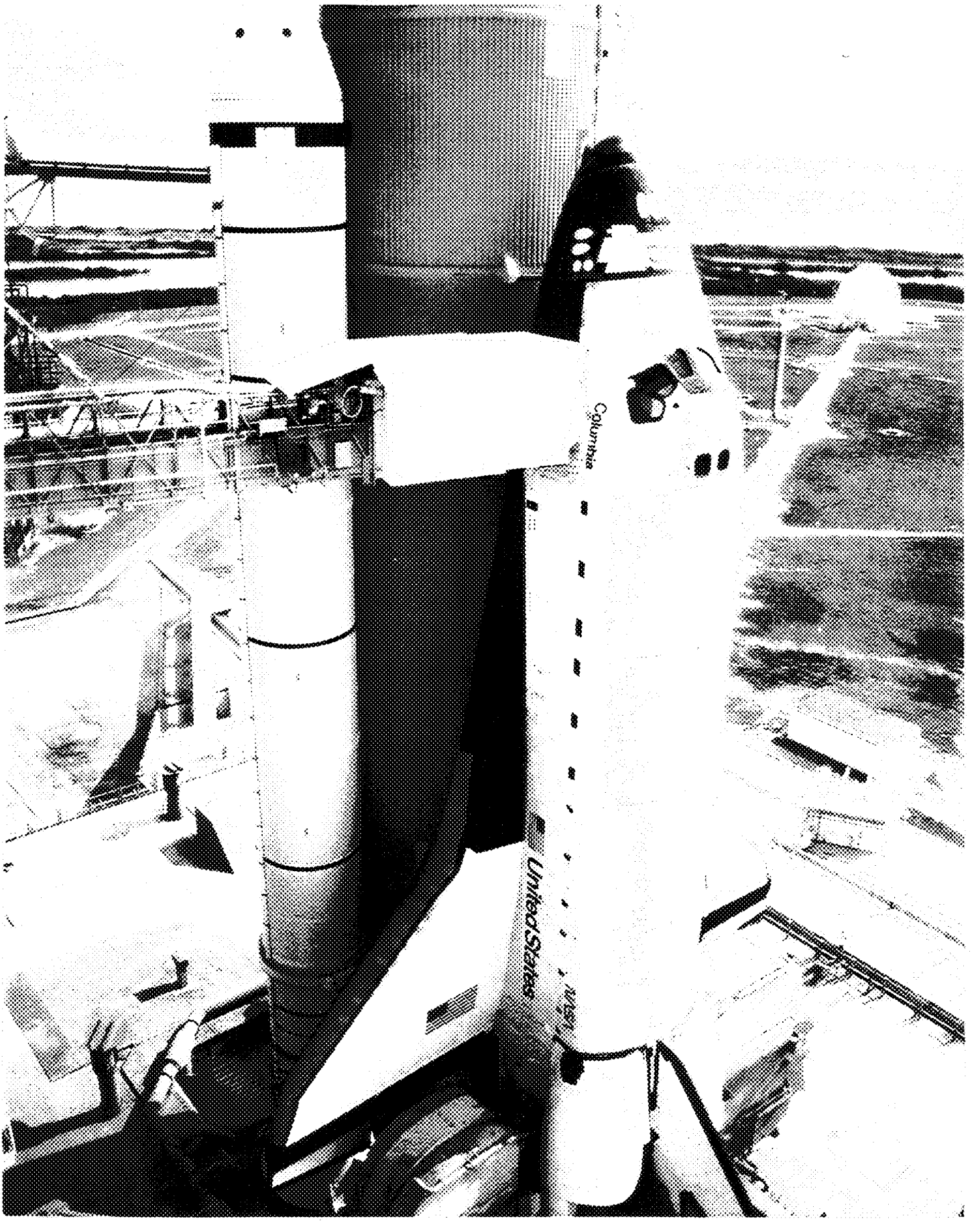


Photo 3: LH2 Tank After Cryoload

The Final Inspection Team detected no ice, frost, or condensate on the LH2 tank acreage. TPS surface temperatures averaged 67 degrees F on the +Z side and 63 degrees F on the -Z side. Note configuration change to the intertank, which had been machined/sanded.

Photo 4: Machined Intertank

Close-up view of the machined foam on intertank stringers. The forward and aft ends of the stringers retained thicker foam due to the cryogenic interface with the LO2 and LH2 tank flanges.

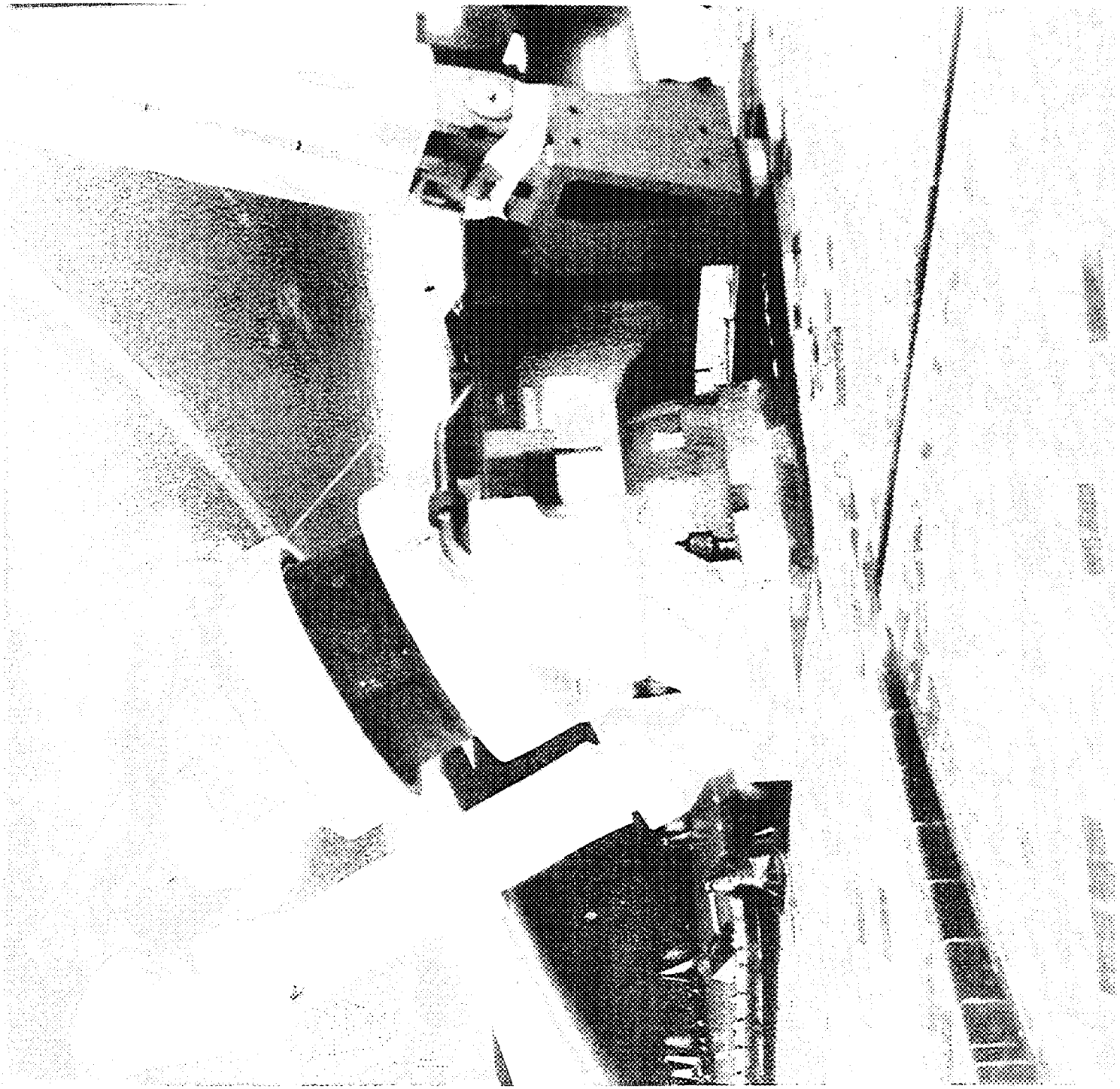


Photo 5: LH2 ET/ORB Umbilical

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

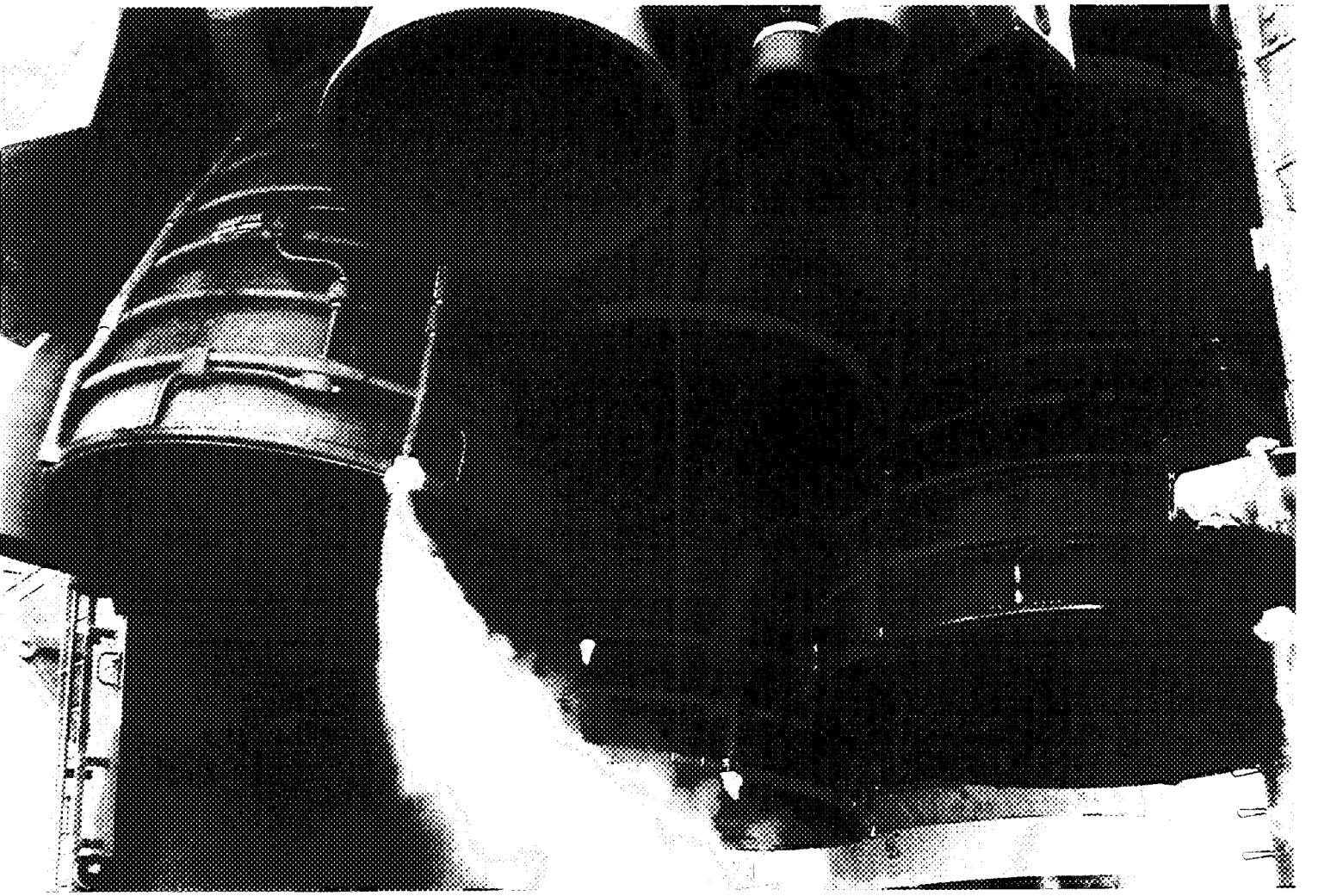


Photo 6: Overall View of SSME's

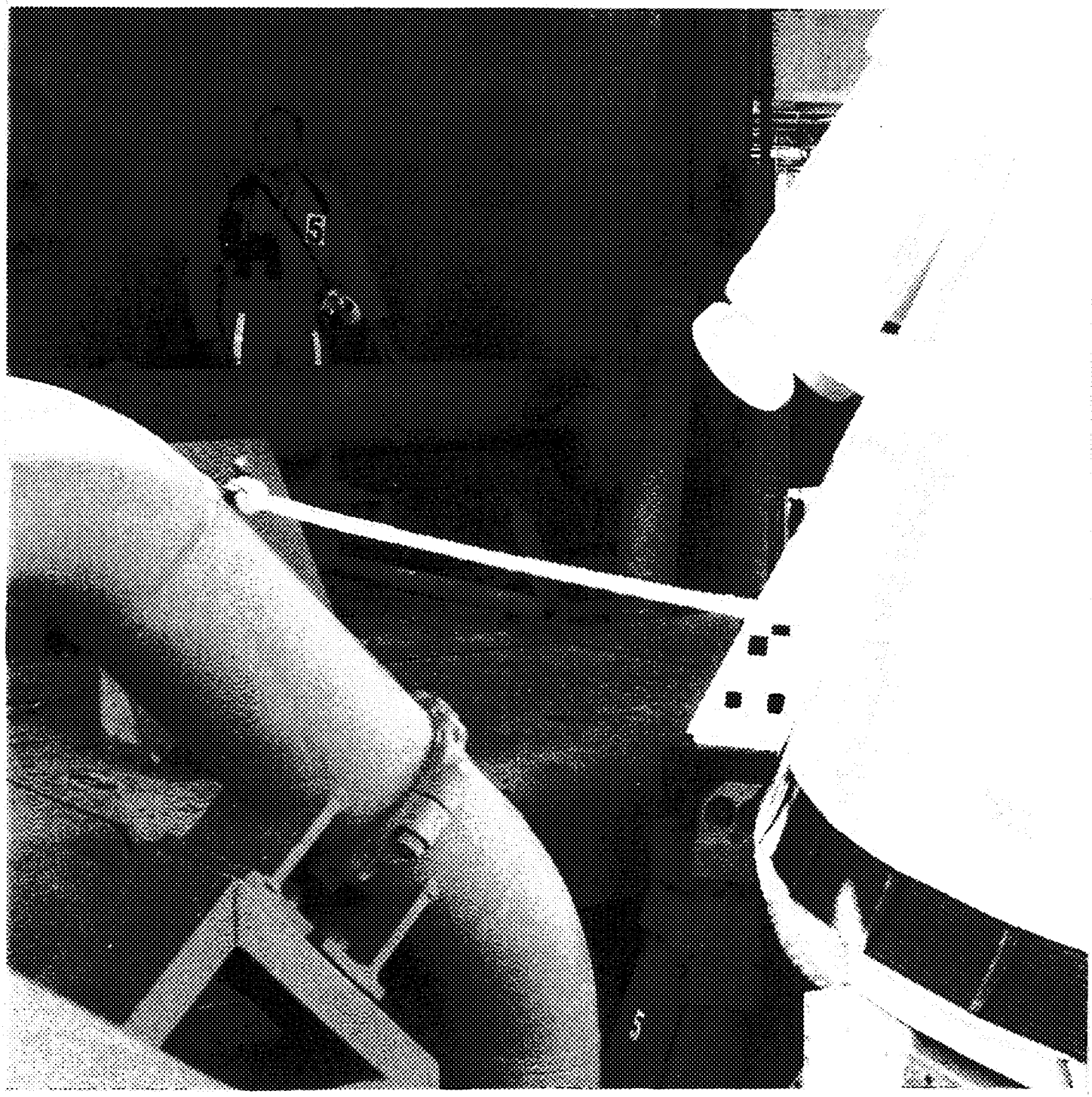


Photo 7: Debris Items on MLP Deck

Three debris items were found on the MLP deck directly below the External Tank. A ¾-inch diameter personnel safety life line was tied between two sound suppression water pipes adjacent to holddown posts #5 and #7 (above). A white, plastic, heavy duty tie-wrap was on the 8-inch sound suppression water pipe adjacent to holddown post #1. And a broken drill bit 1-inch long by ¼-inch diameter lay on the MLP deck.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 2, Pad B FSS, RSS, and pad apron was conducted on 17 April 1998 from Launch + 1 to 3 hours. No flight hardware was found.

No stud hang-ups occurred on this launch. Boeing - Downey reported an Orbiter liftoff lateral acceleration of 0.12 g's, which is below the threshold (0.14 g's) for stud hang-ups. SRB hold down post erosion was less than usual. North holddown post blast covers and T-0 umbilicals exhibited typical exhaust plume damage. Both left and right SRB aft skirt GN2 purge lines were intact after liftoff. The first layer of protective aluminum tape had eroded away. The remaining two layers probably kept the steel braid and internal tube from melting, a common failure mode on previous launches.

The Tail Service Masts (TSM's) appeared undamaged and the bonnets were closed properly. There was no unusual erosion at the bases of the TSMs where excess grout had been removed. Likewise, the Orbiter Access Arm (OAA) seemed to be undamaged.

The GH2 vent line was latched in the fourth of eight teeth of the latching mechanism. The GUCP 7-inch QD surface exhibited no scuff marks. All observations indicated a nominal retraction and latchback, though the GH2 vent line exhibited heat effects/damage from the SRB exhaust plume. The new haunch lanyard protective "lip" showed no significant damage.

The GOX vent seals were in excellent shape with no indications of plume damage. No topcoat from the External Tank nose cone adhered to the seals. The east (in the retracted position) flex duct was disconnected from the hood though the clamp had evidently been relocated by the initial safing team as it had been placed between the elevator doors.

A 4-foot by 4-foot by 0.25-inch thick steel ventilation hatch from the hammerhead crane machine room was recovered on the FSS 275 foot level. The hatch, which was observed in high speed launch films, had shaken loose by the SRB exhaust plume vibration/acoustics. The hatches on both launch pads have since been welded in place to prevent a reoccurrence. However, the broader concern for "abandoned in place" equipment is being addressed.

Other post launch debris findings on the MLP were few this launch probably due to the south winds at T-0. On the FSS, debris was typical and included fasteners, cable trays, signs, and the lower FIREX paddle from the 195 foot level. Pad apron debris was also minimal and included fasteners, small pieces of sheet metal from the RSS and a large light fixture on the southwest corner of the apron.

Overall, damage to the pad appeared to be minimal.

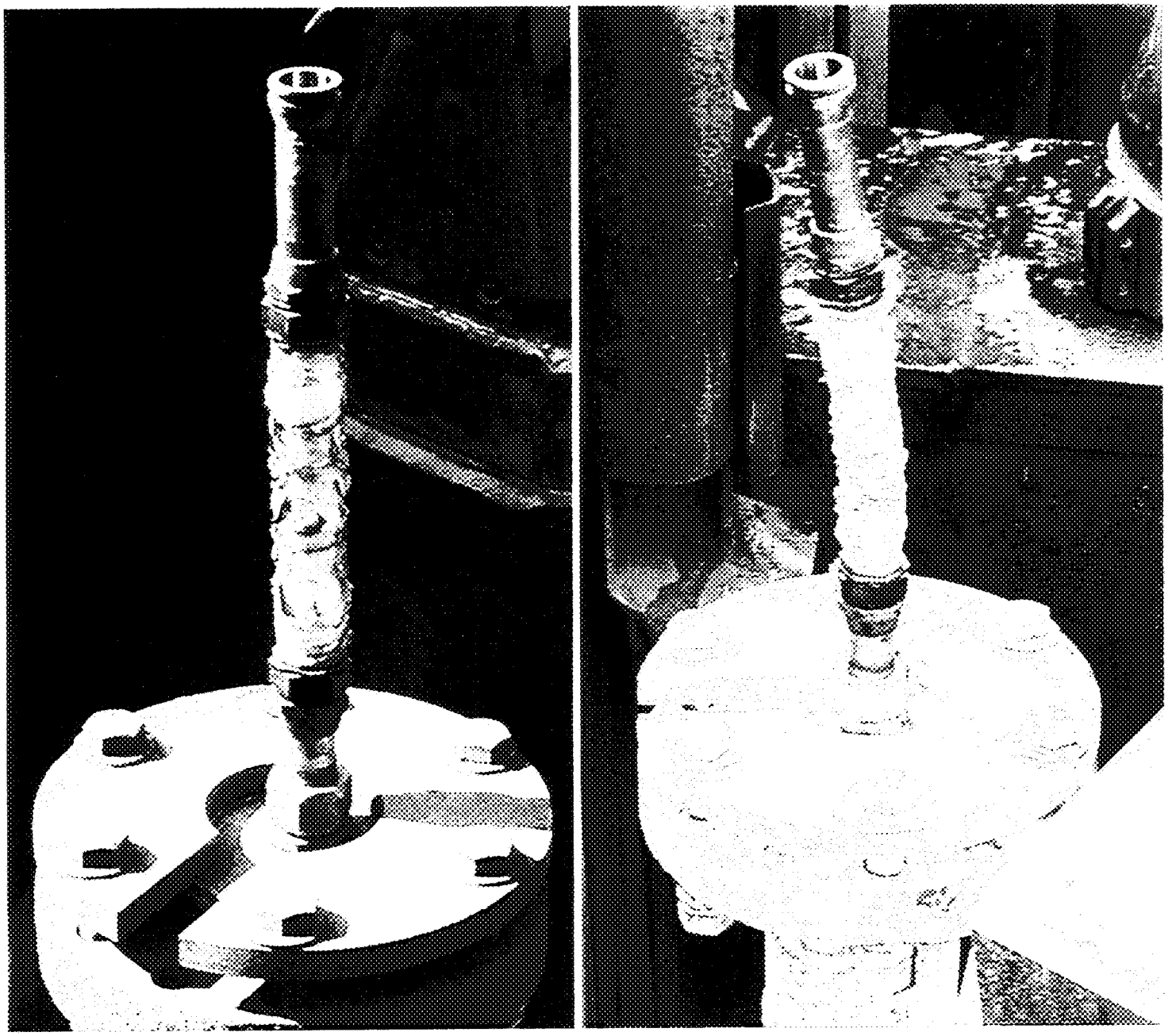


Photo 8: SRB Aft Skirt GN2 Purge Lines

Both right and left SRB aft skirt GN2 purge lines were intact after liftoff. The first layer of protective aluminum tape had eroded away. The remaining two layers probably kept the steel braid and internal tube from melting, a common failure mode on previous launches.

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 85 films and videos, which included twenty-eight 16mm films, eighteen 35mm films, and thirty-nine videos, were reviewed starting on launch day.

SSME ignition appeared normal. Noticeable amounts of free burning hydrogen were blown under the body flap by the strong southerly winds. One debris-induced streak occurred in the SSME #1 exhaust plume just after the Mach diamond formed (E-2, -3, -19, -20).

SSME ignition caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft along side the body flap. Two rectangular-appearing, silhouetted objects, most likely pieces of ice from the LH2 feedline bellows, also fell aft during SSME startup (OTV-109, 163).

Tile surface coating material was lost during ignition from three places on the RH OMS engine heat shield, two places on the base heat shield outboard of SSME #2, one place on the SSME #2 engine mounted heat shield, one place on the SSME #3 engine mounted heat shield, and one place on the base heat shield between the SSME cluster (E-17, -18, -19, -20, -76, OTV-150).

There were no stud hang-ups. No ordnance debris or frangible nut pieces fell from the DCS/stud holes. The north HDP blast covers closed normally. A 7-inch by 3-inch by 1-inch piece of instafoam broke away from the RH SRB aft skirt aft ring near HDP #1 at liftoff (E-8, -9, -20).

Some of the lacing was loose, or untied, on two adjacent SRB thermal curtains near HDP #4. An opening in the curtain outer layer appeared momentarily as the curtains deflected from the initial SRB ignition pressure wave. Immediately afterwards, the curtains resumed the normal hanging curved shape. No detrimental effect to the inner thermal curtain was detected (E-7).

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 and flame (E-8, -13).

Water leaked from the sound suppression water pipe joint near holddown post #4 (E-7, -10, -15).

Several cameras viewed more than usual amounts of MLP paint flakes/deck scale lifted and moved by aspiration. No contact with flight hardware was detected.

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

No anomalies were detected on the External Tank nose cone. No ice was present in the louvers or "no ice" zone (OTV 113, 160, 162).

Vibration from the SRB exhaust plume caused a white, 4-foot by 4-foot by ¼-inch thick metal ventilation hatch to dislodge from the top of the hammerhead crane machine room (19:18:11.431 UTC), slide down the curved wall, land on the top level of the FSS, fall still farther into the microwave antenna area (FSS south side), before being obscured from view by smoke. The vehicle was well clear of the tower and the loose hatch was not a threat to flight hardware (E-62).

Numerous light-colored particles falling along side the SRB exhaust plumes starting at the roll maneuver (including one large cluster of particles from the RH SRB aft skirt at 15.1 seconds MET) are believed to be pieces of SRB aft skirt aft ring instafoam (E-57).

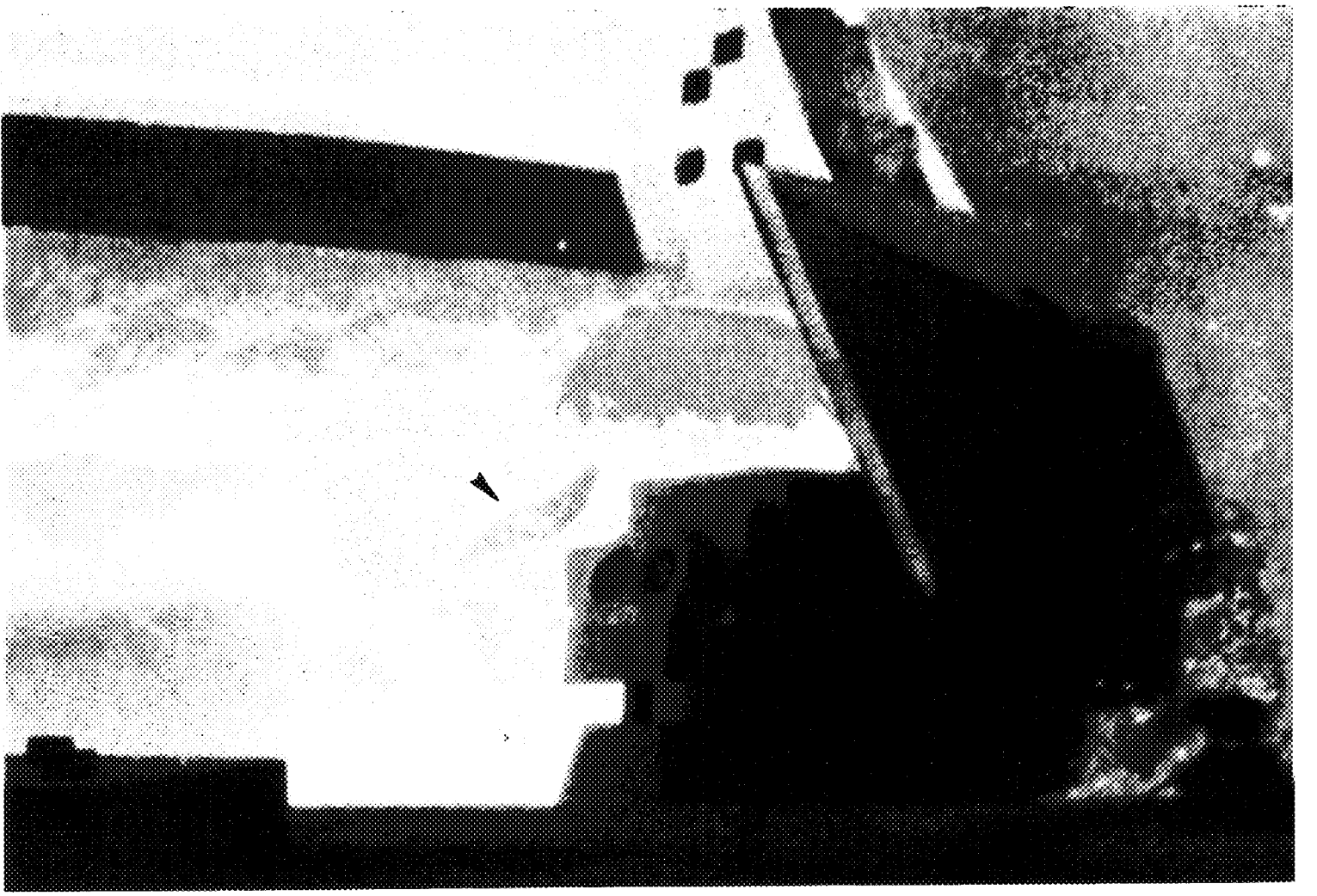


Photo 9: Right SRB Thermal Curtain

Some of the lacing was loose, or untied, on two adjacent SRB thermal curtains near HDP #4. An opening in the curtain outer layer appeared momentarily as the curtains deflected from the initial SRB ignition pressure wave. Immediately afterwards, the curtains resumed the normal curved shape. No detrimental effect to the inner thermal curtain was detected.

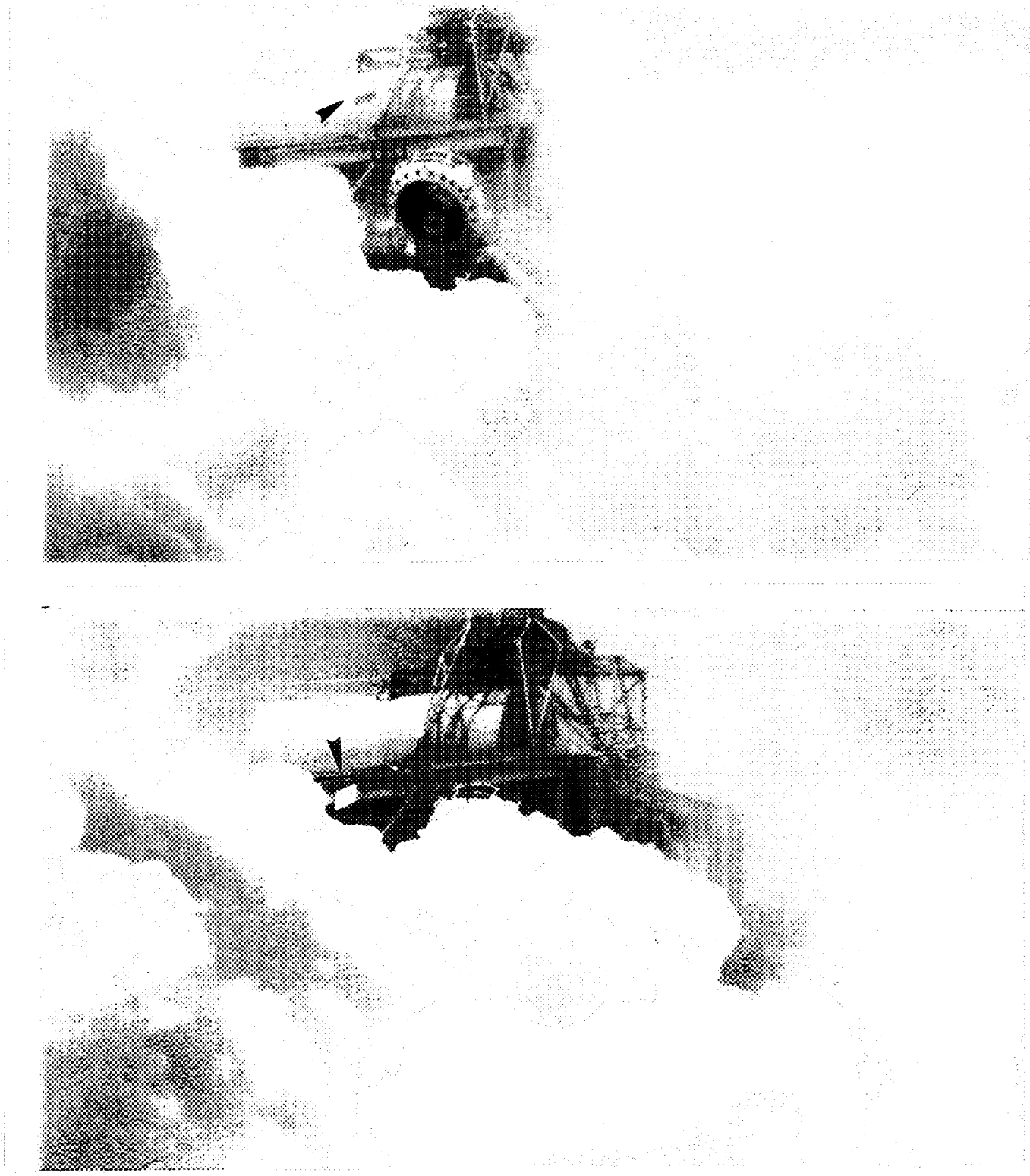


Photo 10: Hammerhead Crane Hatch

Vibration from the SRB exhaust plume caused a 4-foot by 4-foot by ¼-inch thick metal ventilation hatch to dislodge from the top of the hammerhead crane machine room, slide down the curved wall, land on the top level of the FSS, fall still farther into the microwave antenna area (FSS south side), before being obscured from view by smoke. The vehicle was well clear of the tower at this point and the loose hatch was not a threat to flight hardware.

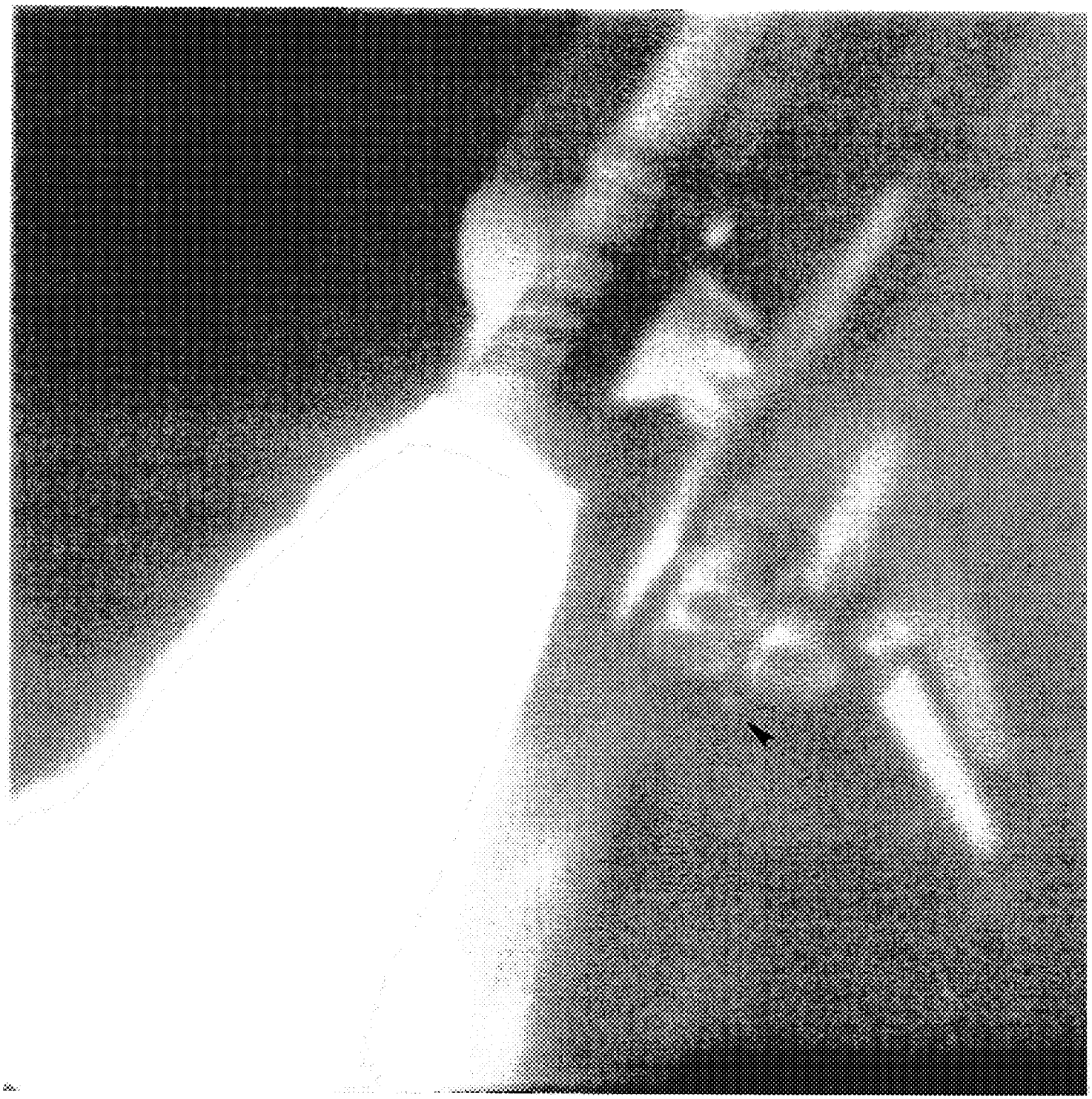


Photo 11: SSME DMHS Blanket Panel

A white object appeared to originate from an area between SSME #2/#3 and fell aft at 18:19:47.730 UTC. Post flight inspection of the Orbiter showed the object had been a portion of an SSME Dome Mounted Heat Shield (DMHS) closeout blanket from SSME #1.

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-102 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. In addition, the flight crew provided hand-held still images and video.

LH2 ET/ORB umbilical 16mm cameras

Focus on the 16mm film with 5mm lens was somewhat soft.

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

Sun illumination of the ET after separation was very good when the Orbiter shadow passed by. ET-91 separation from the Orbiter was normal. No venting from the GUCP/intertank area was observed in the two 16mm motion picture films. No divots were detected in the LO2 and LH2 tank acreage.

Three light, circular areas in the -Y thrust panel adjacent to the intertank stringer splice may be possible divots. The view of the -Y thrust panel is not very good from this angle (the +Y thrust panel is not visible at all since the 16mm cameras are located in the LH2 ET/ORB umbilical) making confirmation of divots difficult.

The +Z side of the intertank appeared to be in good condition. Heating from the shock waves off both forward EB fittings left black marks on the intertank acreage in a line from the EB fittings to the bipod spindle housings. These marks have not been so pronounced on previous tanks and may be more visible due to the sanded foam acreage.

The jack pad standoff closeouts appeared to be intact. A 6-inch diameter divot was centered between the bipods in the LH2 tank-to-intertank flange closeout. Three divots (two 4-6 inches in diameter and one approximately 10-inches in diameter) were visible in the flange closeout -Y+Z quadrant along with one 3-inch diameter divot in the +Y+Z quadrant. None of the divots were deep enough to show primed substrate.

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

A divot 4-inches in diameter on the aft surface of the -Y vertical strut revealed the underlying SLA.

No damage was observed on either LH2 or LO2 ET/ORB umbilical.

Crew Hand-held Still Images

One positive transparency roll of thirty-eight images taken by the flight crew after ET separation from the Orbiter was analyzed with the following results:

One divot, approximately 6-8 inches in diameter, was detected in the LH2 tank-to-intertank flange closeout centered between the bipods. The bipod jack pad standoff closeouts appeared to be intact.

Three divots, approximately 6-8 inches in diameter, were detected in the -Y+Z quadrant LH2 tank-to-intertank flange closeout between the -Y thrust panel and the -Y bipod.

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 main landing gear contacted the runway almost simultaneously with the left side touching down first. Touchdown of the nose landing gear was smooth.

Drag chute operation appeared nominal. Rollout and wheel stop were uneventful.

TPS damage on the lower surface of both right and left glove area was visible in some of the films.

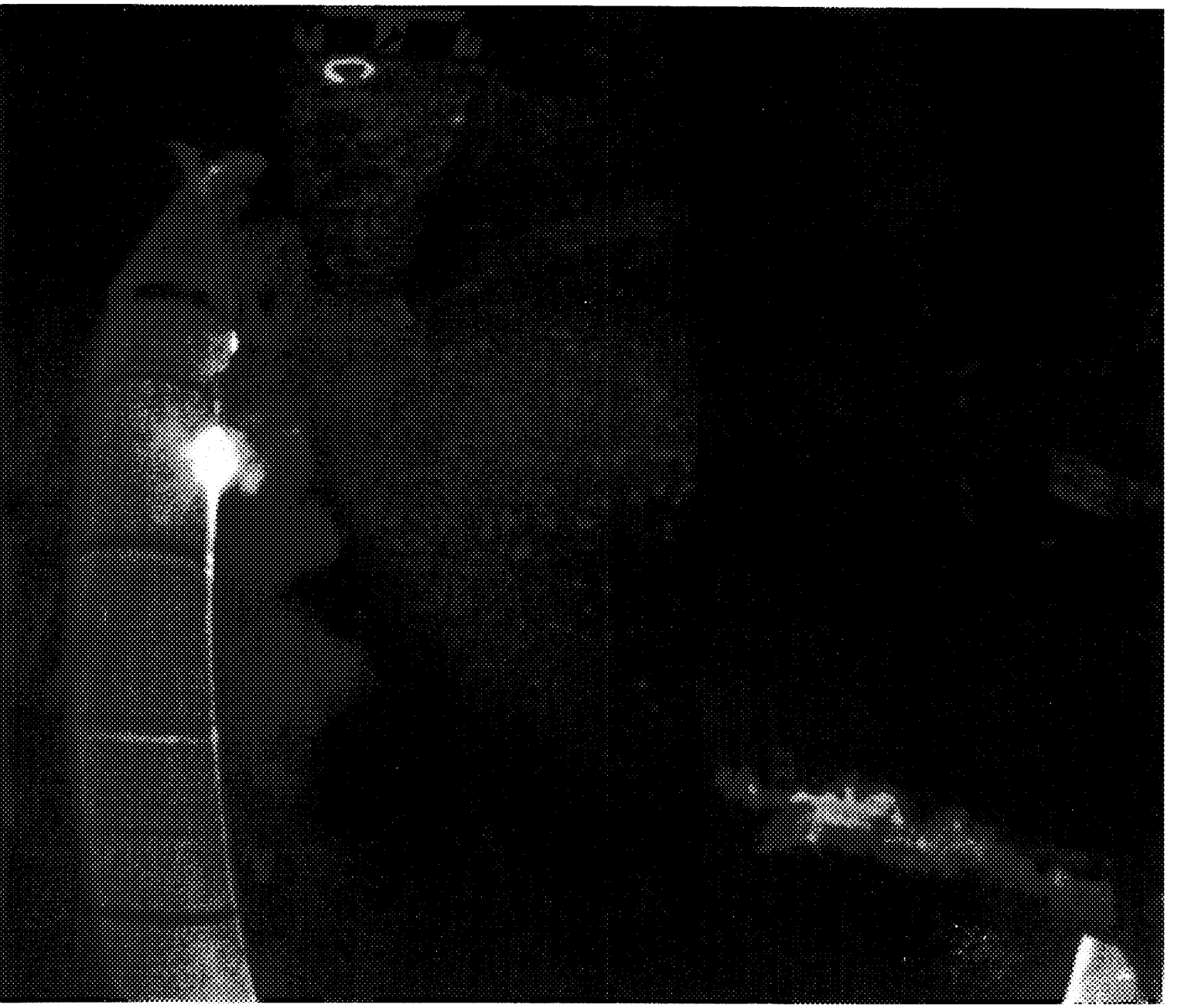


Photo 12: SRB Separation From External Tank

SRB separation from the External Tank appeared nominal. The wide angle ET/ORB LH2 umbilical camera provided a view of both SRB forward skirts/frustums/nose caps during separation. The nose caps, which are not recovered for post flight inspection, appeared to be intact and in good condition. Erosion of foam from the LH2 cable tray was typical. A divot 4-inches in diameter on the aft surface of the -Y vertical strut revealed the underlying SLA.

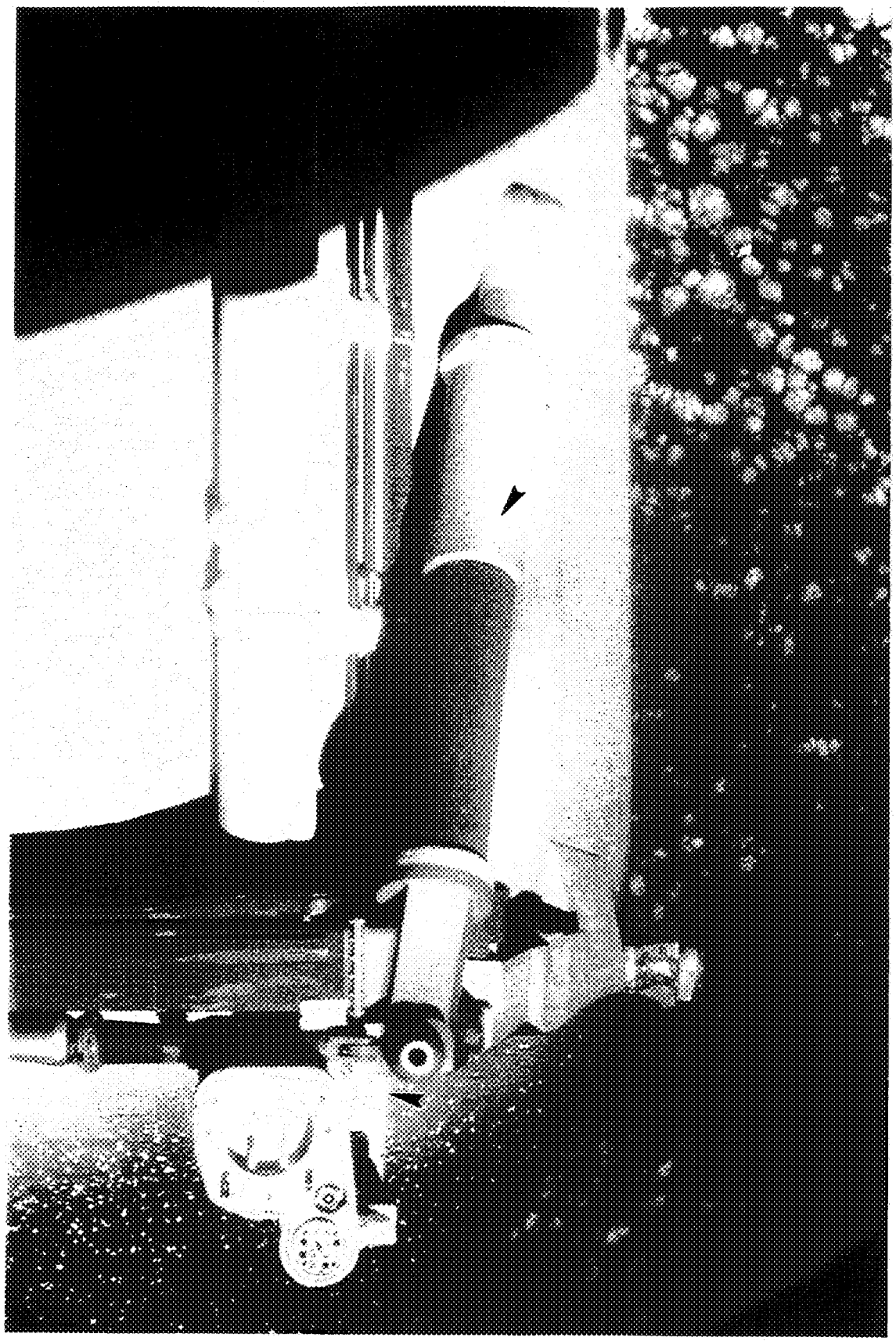


Photo 13: LO2 ET/ORB Umbilical

The LO2 ET/ORB umbilical cable tray exhibited typical erosion and divoting. The umbilical itself was undamaged. A long gash in the +Y thrust strut TPS was most likely caused by a debris impact. Note small, shallow "popcorn" type divots on the aft dome and LH2 tank acreage - a typical occurrence. Also note the charring and flaking off of a thin layer of foam from the +Y upper strut fairing closeout.

Photo 14: LH2 Tank Flange Divots

A divot in the -Y+Z quadrant of the LH2 tank-to-intertank flange closeout was deep enough to expose substrate. However, the divot on centerline between the bipod struts was shallow. A small portion of the +Y thrust panel was visible in this field of view. Very small, shallow areas of TPS were missing from stringer heads forward of the EB fitting along the thrust panel-to-intertank splice. The charring and flaking off of thin layers of foam just aft of the nose cone is the same (acceptable) phenomenon affecting other areas of the tank, such as the aft surface of the vertical struts.

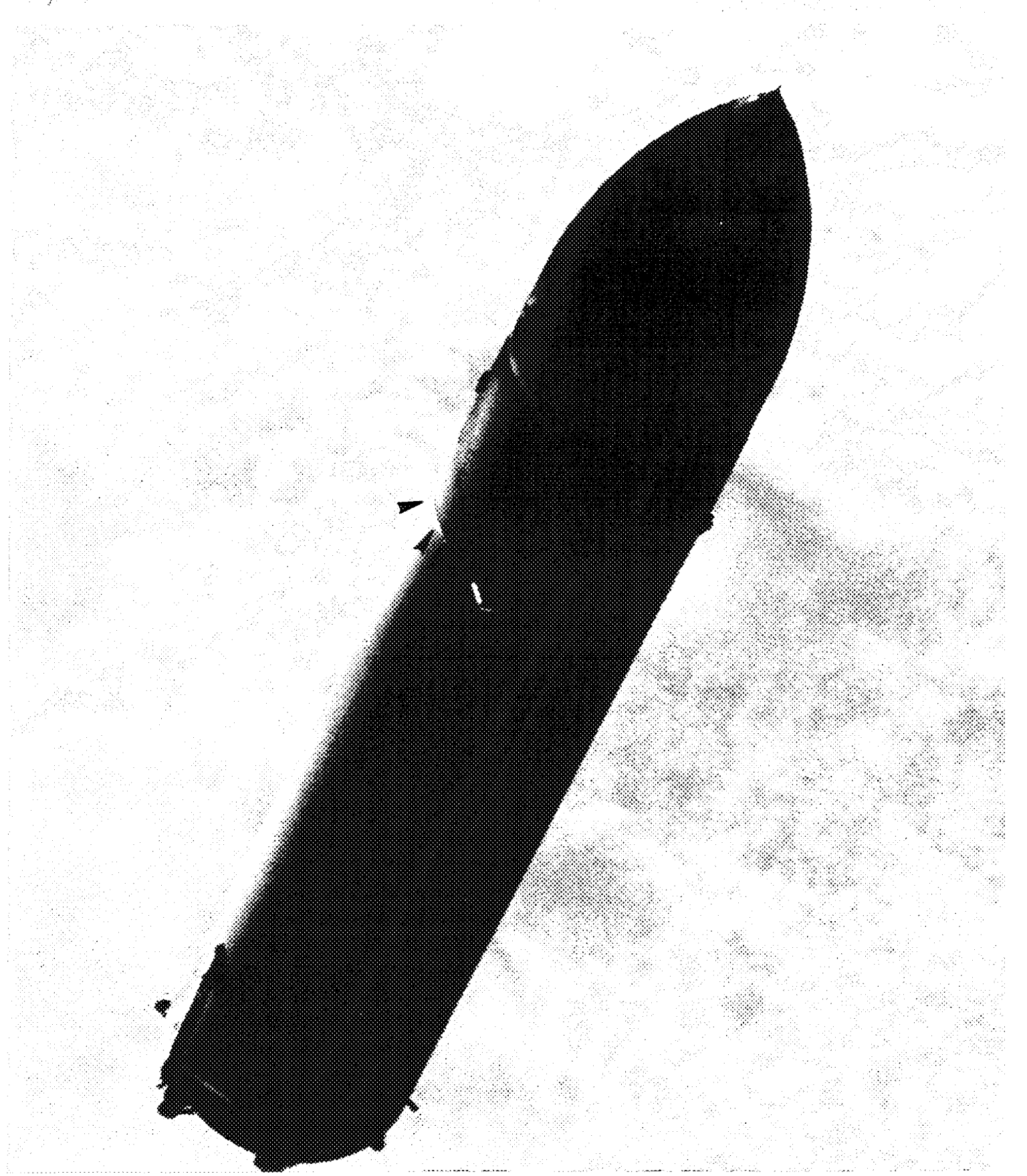


Photo 15: Intertank

The +Z side of the intertank appeared to be in good condition. Heating from the shock waves off both forward EB fittings left black marks on the intertank acreage in a line from the EB fittings to the bipod spindle housings. These marks have not been so pronounced on previous tanks and may be more visible due to the sanded foam acreage. Three divots (two 4-6 inches in diameter and one approximately 10-inches in diameter) were visible in the flange closeout -Y+Z quadrant.

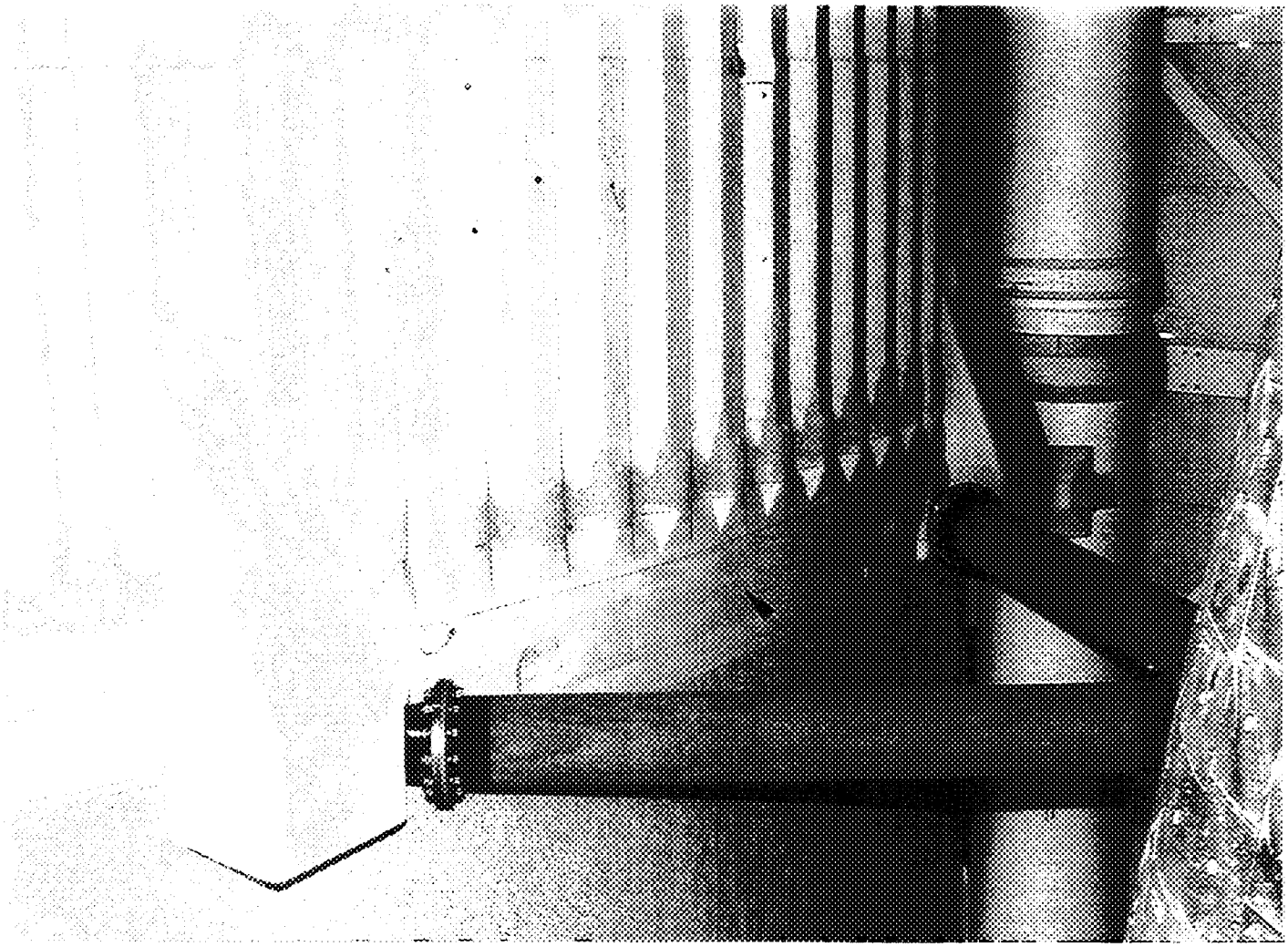


Photo 16: Pre-Launch View of Flange Closeout

A previously repaired area on the flange closeout near the ET centerline between the two bipods may have been associated with the divot detected in the on-orbit photography.

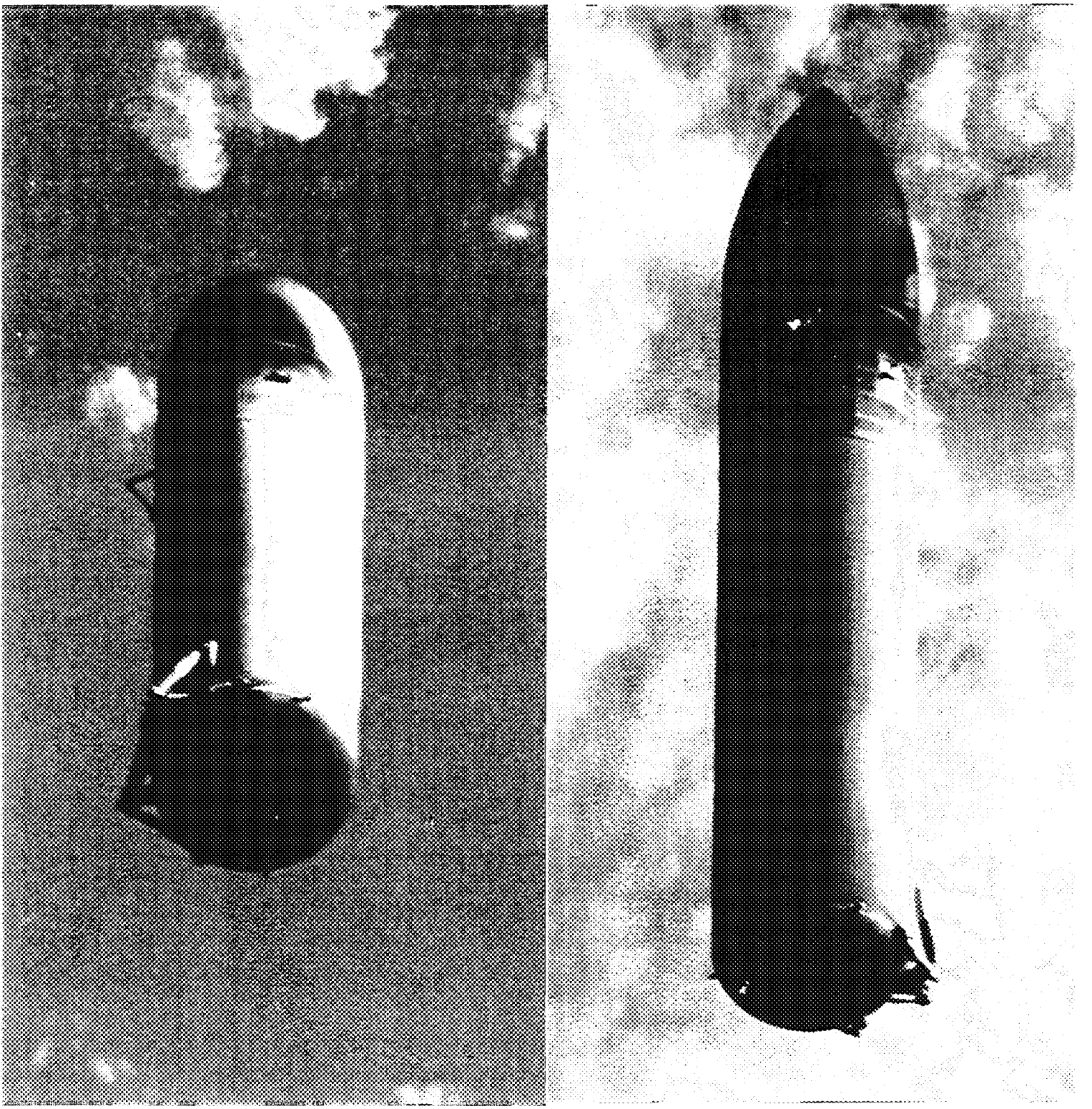


Photo 17: Thrust Panels

Loss of foam from both thrust panels that caused damage to Orbiter tiles is not readily apparent in this on-orbit photography. Small, circular, light-colored areas around the EB fittings and along the thrust panel-to-intertank splices may be divots. The BSM burn scars are typical.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-094 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 20 April 1998.

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners or acreage. Virtually none of the Hypalon paint had blistered or peeled. 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 although one phenolic layer on both +Z side base plates had delaminated. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. All frustum severance ring pins and retainer clips were intact.

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

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally. However, the HDP #3 DCS plunger was completely obstructed by a frangible nut half and may have been the result of water impact. There was no stud hang-up on this launch. A bolt shank on the HDP #1 DCS cover was broken.

Overall, the external condition of the SRB's was excellent.

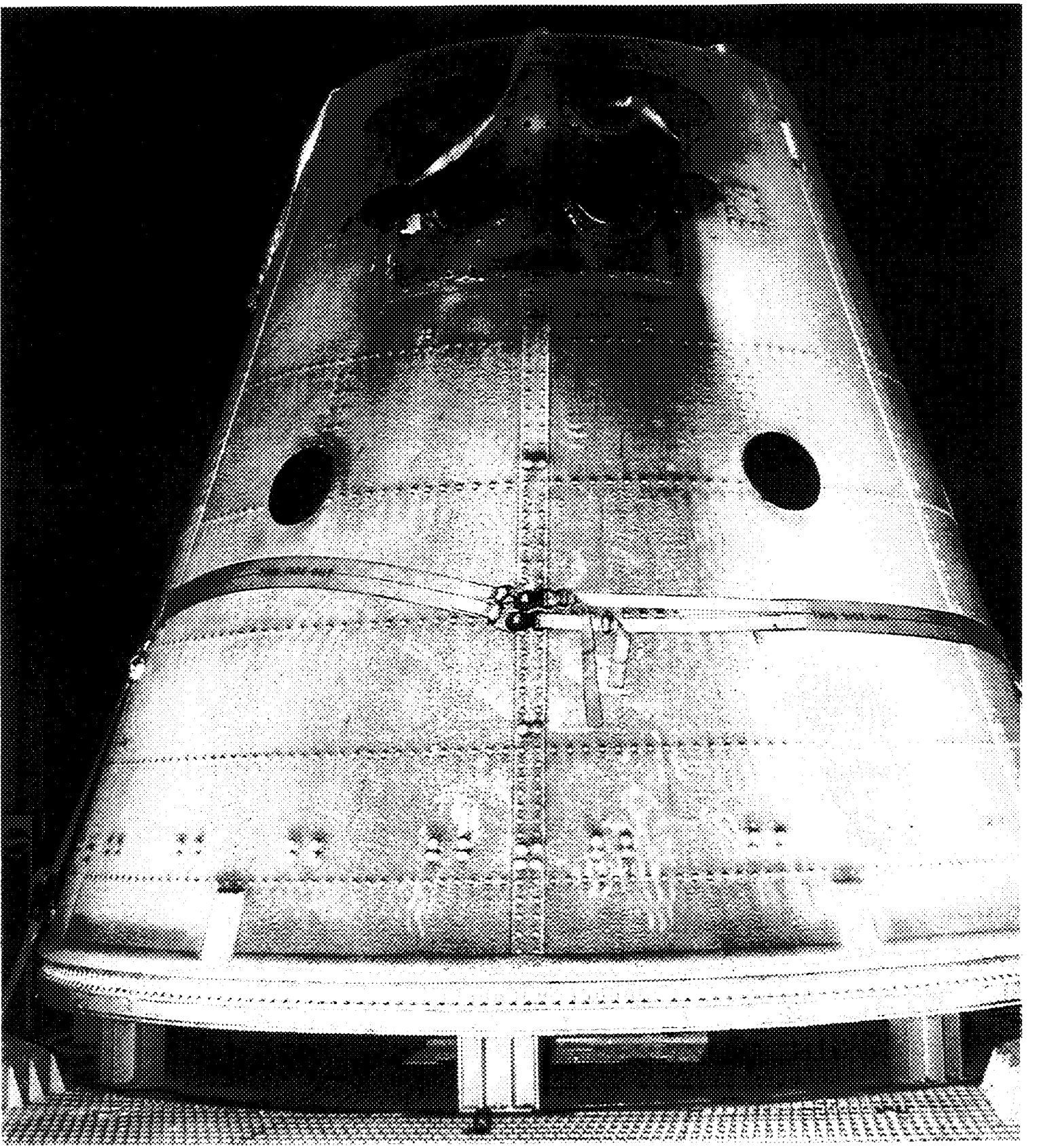


Photo 18: Frustum Post Flight Condition

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners or acreage. Virtually none of the Hypalon paint had blistered or peeled. All eight BSM aero heat shield covers had locked in the fully opened position.

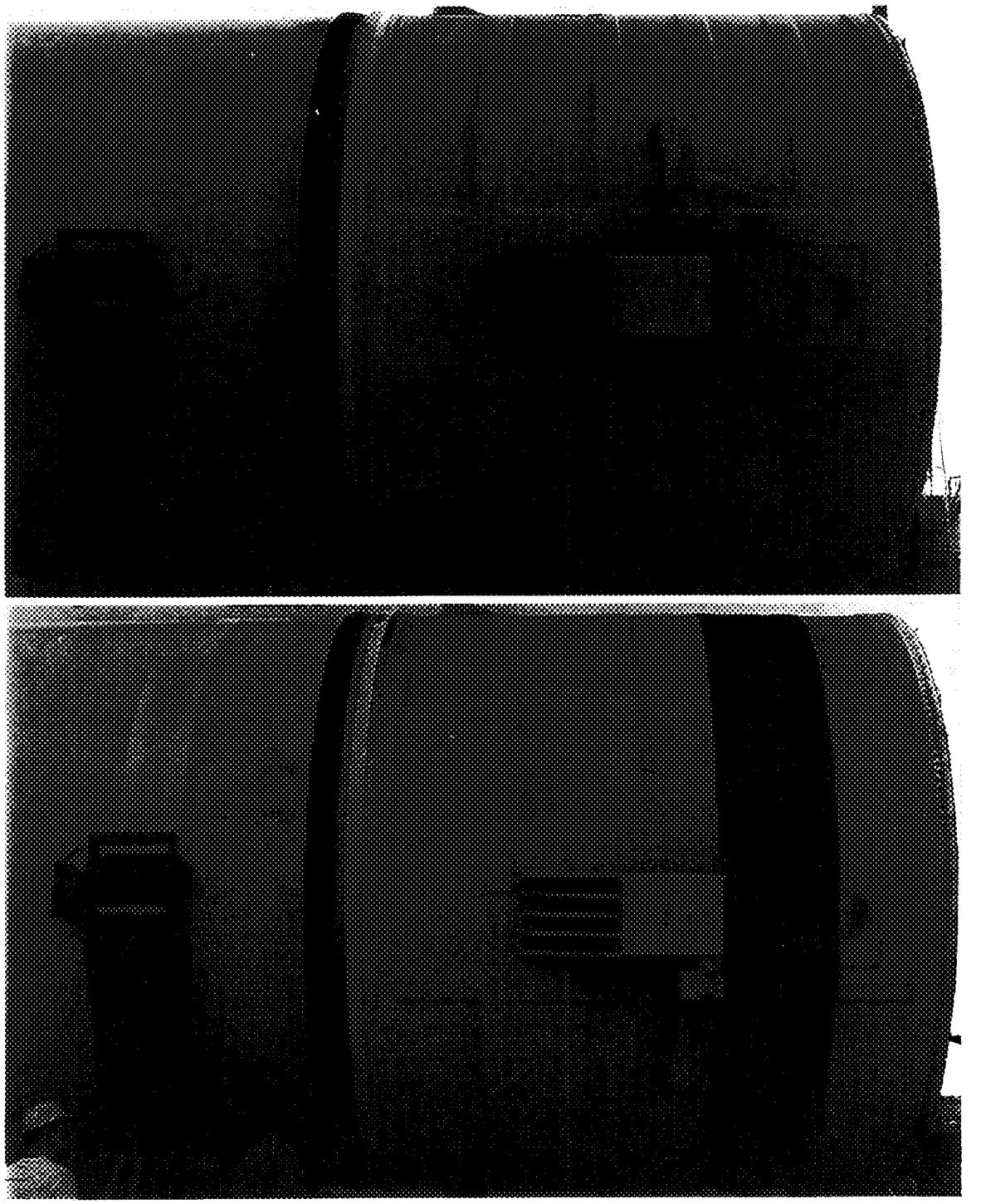


Photo 19: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact though one phenolic layer on both +Z side base plates had delaminated. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. All frustum severance ring pins and retainer clips were intact.

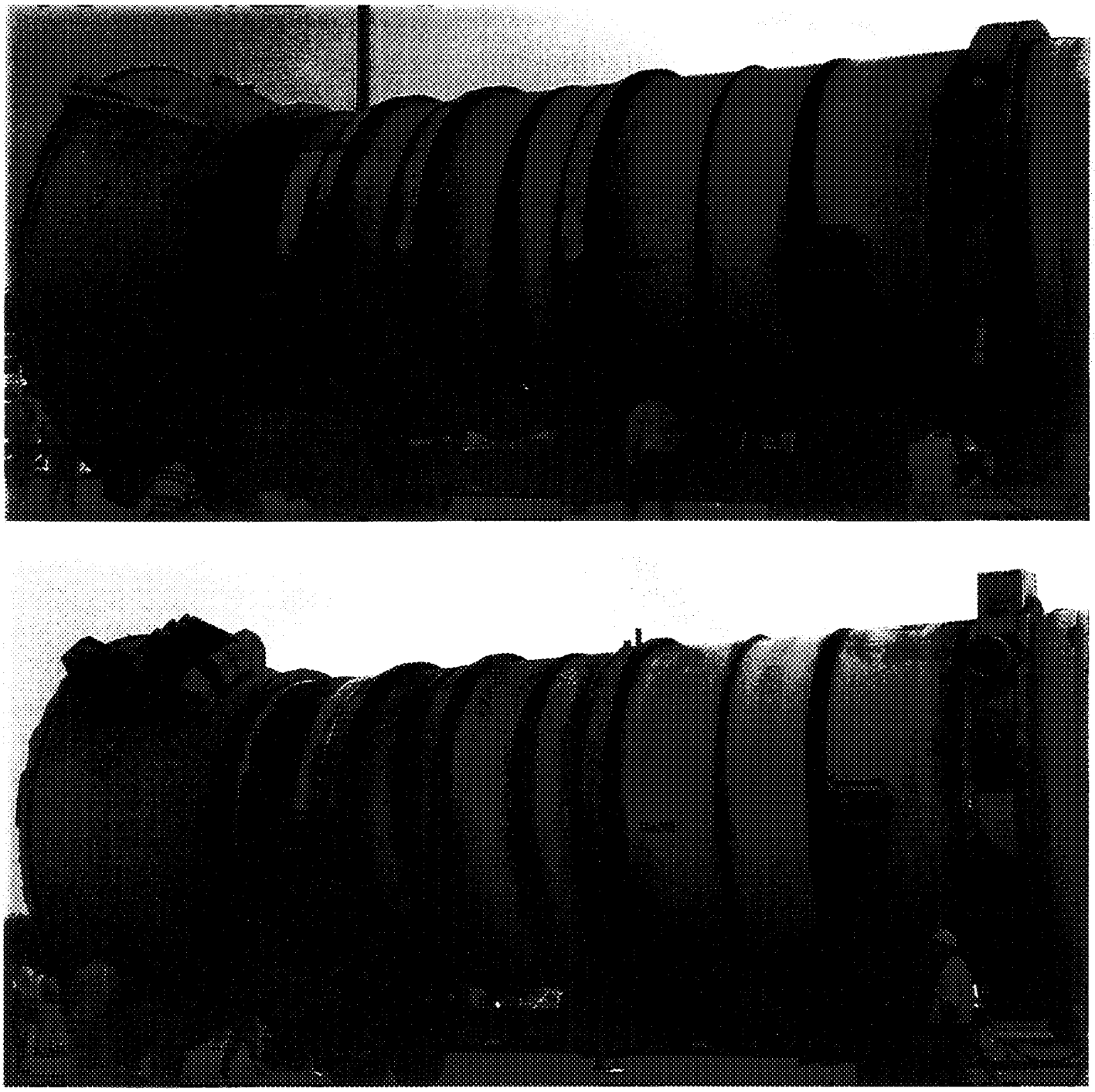


Photo 20: Aft Booster/Aft Skirt Post Flight Condition

Separation of the aft ET/SRB struts appeared normal. TPS on the external surface of both aft skirts was intact and in good condition. The holddown post Debris Containment Systems (DCS) appeared to have functioned normally.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 12:09 p.m. local/eastern time landing on 3 May 1998, a post landing inspection of OV-102 Columbia was conducted 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 131 hits, of which 20 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 71 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30, 42, 86, 87, and 89, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was close to average (reference Figures 1-4).

The following table breaks down the STS-90 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	11	76
Upper surface	3	12
Window Area	3	22
Right side	0	0
Left side	1	8
Right OMS Pod	0	5
Left OMS Pod	2	8
TOTALS	20	131

The Orbiter lower surface sustained 76 total hits, of which 11 had a major dimension of 1-inch or larger. Most of this damage was concentrated aft of the nose to the main landing gear wheel wells on both left and right chines with most of the damage occurring on the left side. Virtually no damage occurred on the Orbiter centerline. These damage sites generally follow the same location pattern documented on STS-86, STS-87, and STS-89. The numbers are slightly less than the fleet averages for the lower surface (83 total hits with 13 larger than 1-inch) and can be attributed to the External Tank intertank foam being sanded to a greater degree than the previous tanks. The sizes and depths of the damage sites were comparable to STS-89:

	STS-86	STS-87	STS-89	STS-90	Fleet Average
Lower surface total hits	100	244	95	76	83
Lower surface hits > 1-inch	27	109	38	11	13
Longest damage site	7 in.	15 in.	2.8 in.	3.0 in.	N/A
Deepest damage site	0.4 in.	1.5 in.	0.2 in.	0.25 in.	N/A

No lower surface tiles were scrapped due to debris damage. The deepest lower surface tile damage sites (0.25-inches) were located on the left chine and were most likely caused by loss of foam from the ET -Y thrust panel. The largest lower surface tile damage site was located aft of the RH main landing gear wheel well. The site measured 4-inches long by 1.25-inches wide by 0.1-inches deep and could have been caused by an impact from the umbilical purge barrier material or tape flapping in the airstream.

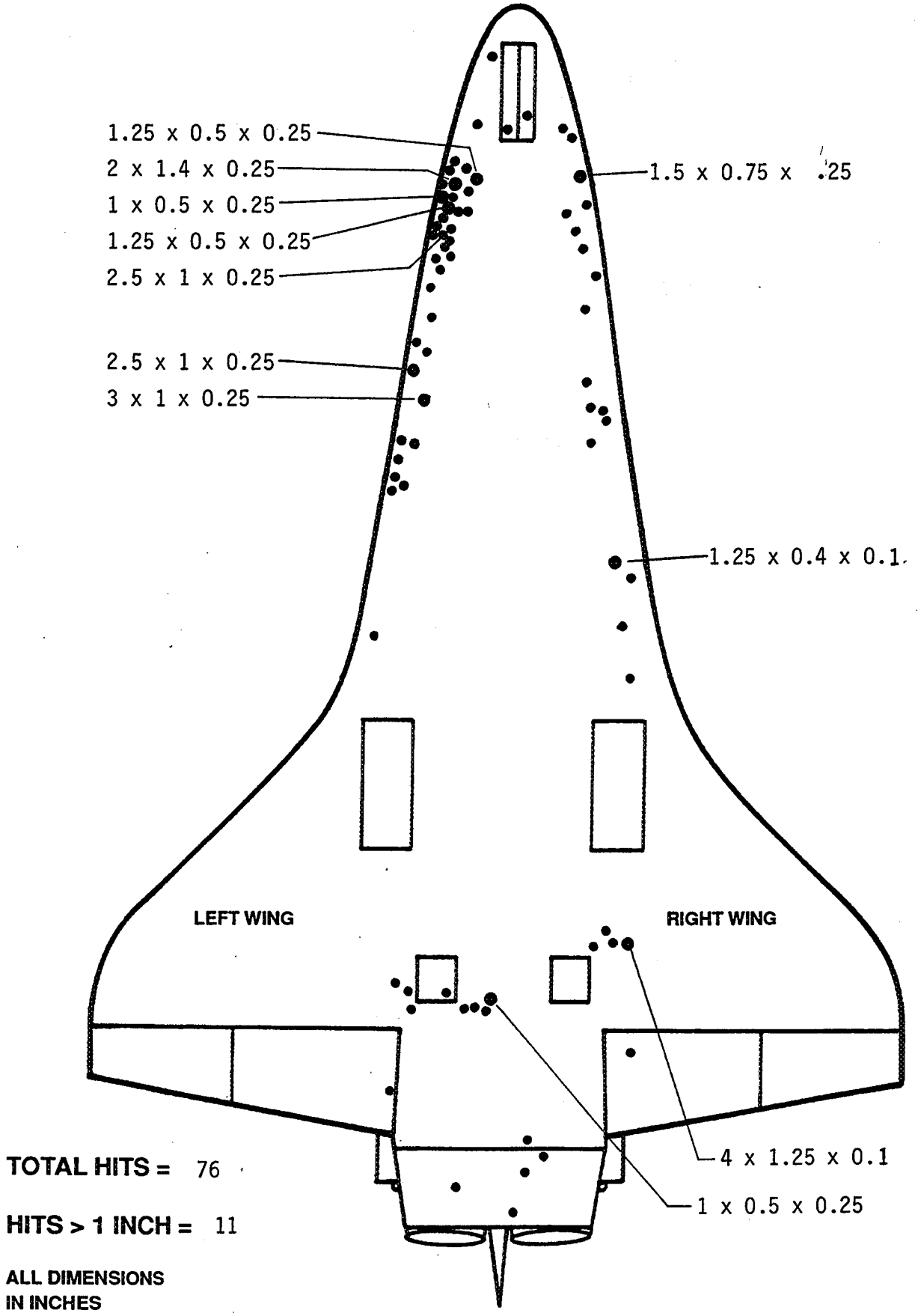


Figure 1: Orbiter Lower Surface Debris Damage Map

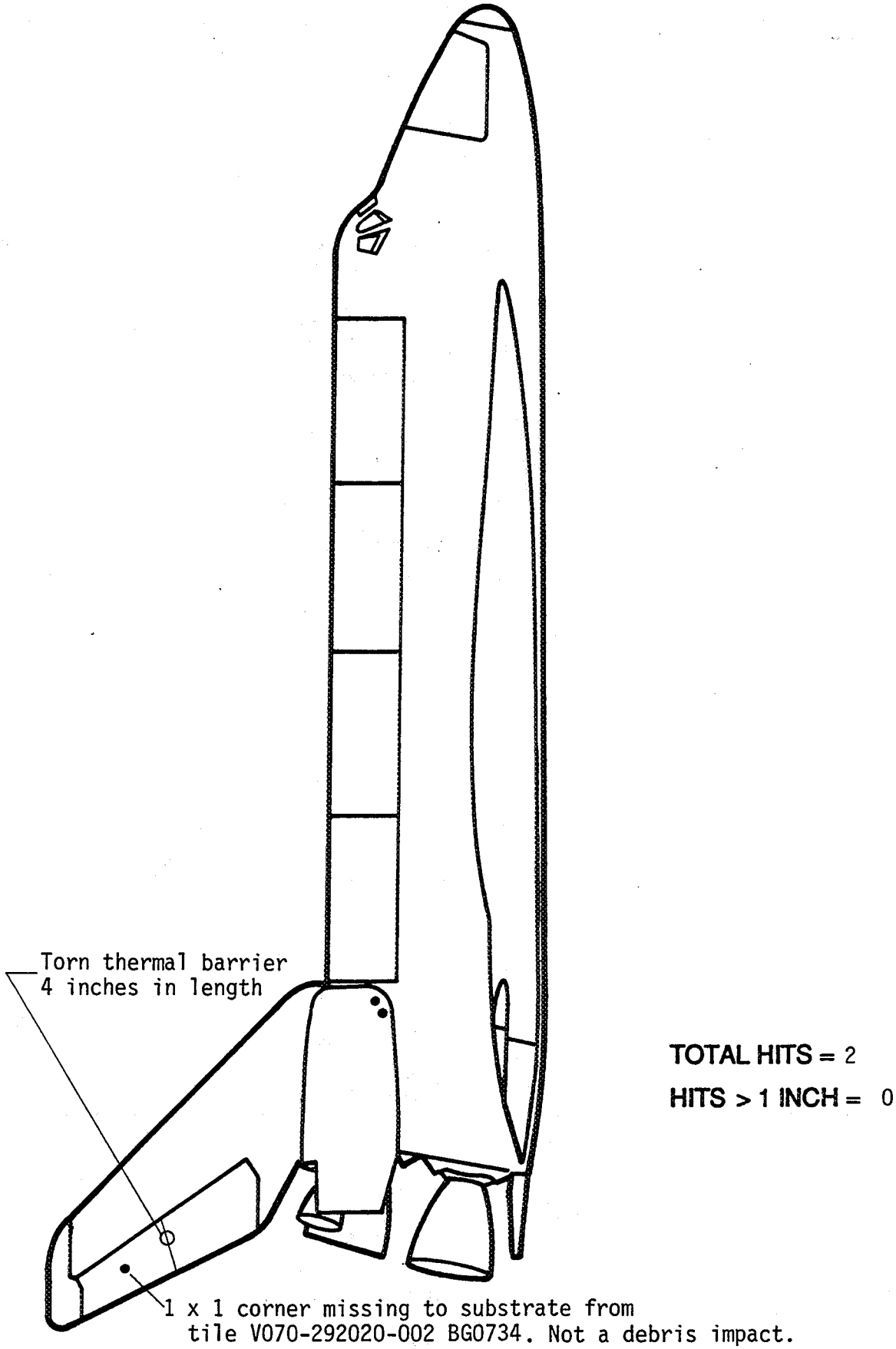


Figure 3: Orbiter Right Side Debris Damage Map

	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-90	11	76	20	131

MISSIONS STS-23,24,25,26,26R,27R,30R,42,86,87, AND 89 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

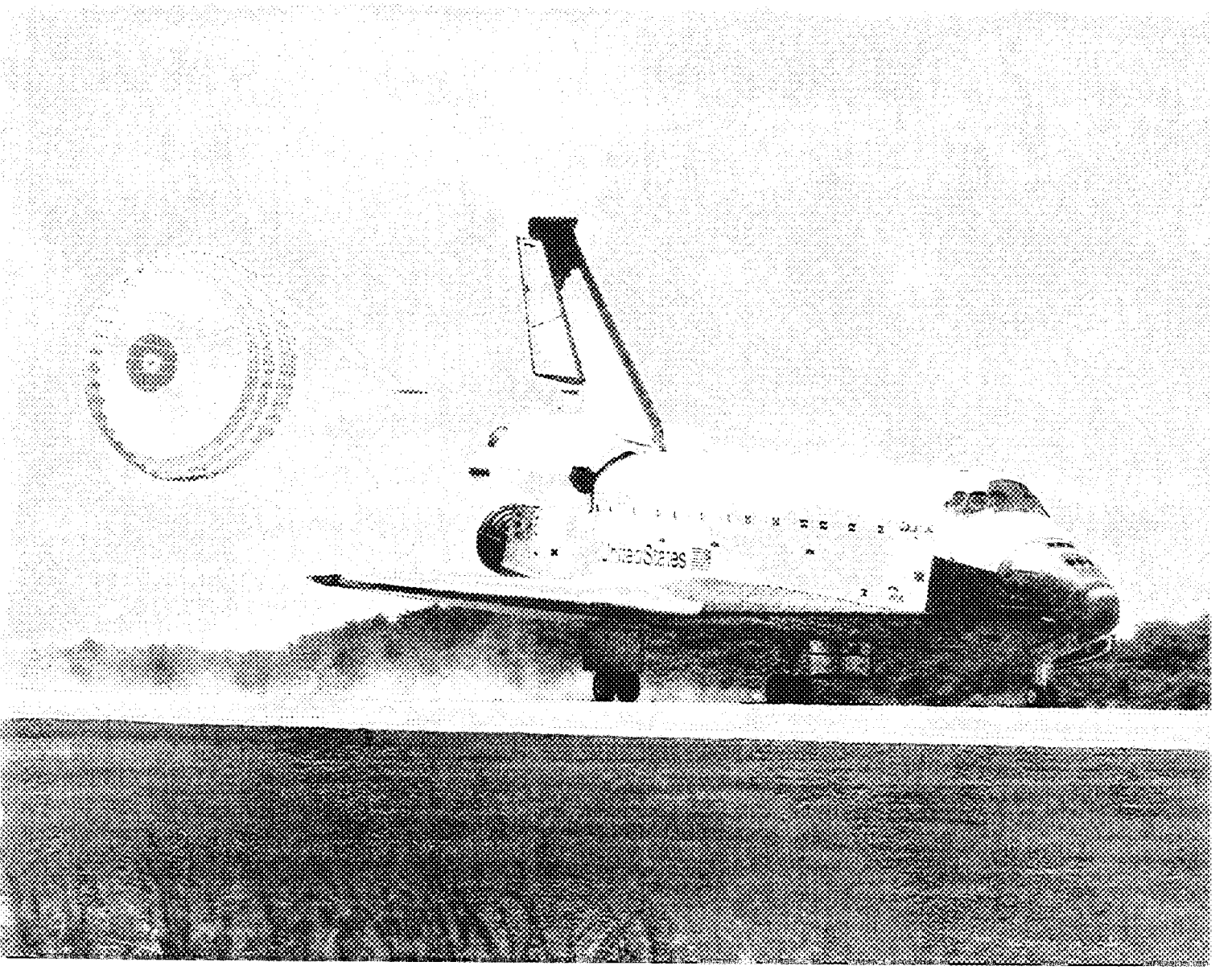


Photo 21: Landing

After the 12:09 p.m. local/eastern time landing on 3 May 1998, a post landing inspection of OV-102 Columbia was conducted at the Kennedy Space Center on SLF runway 33.

Photo 22: Overall View of Orbiter Sides

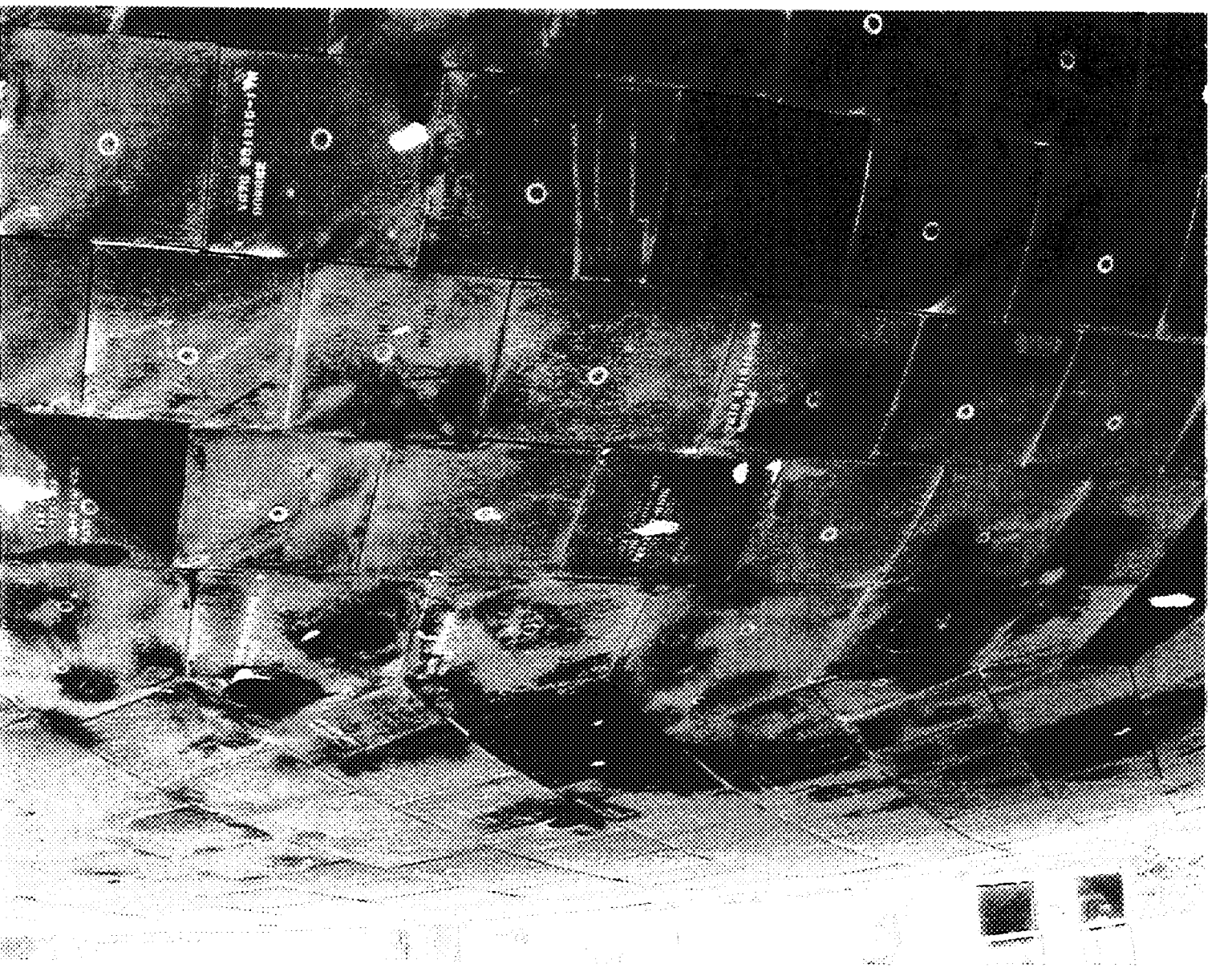


Photo 23: Lower Surface Tile Damage

The Orbiter lower surface sustained 76 total hits, of which 11 had a major dimension of 1-inch or larger. Most of this damage was concentrated aft of the nose to the main landing gear wheel wells on both left and right chines with most of the damage occurring on the left side. Virtually no damage occurred on the Orbiter centerline. These damage sites generally follow the same location pattern documented on STS-86, STS-87, and STS-89. The numbers are slightly less than the fleet averages for the lower surface (83 total hits with 13 larger than 1-inch) and can be attributed to the External Tank intertank foam being sanded to a greater degree than the previous tanks.

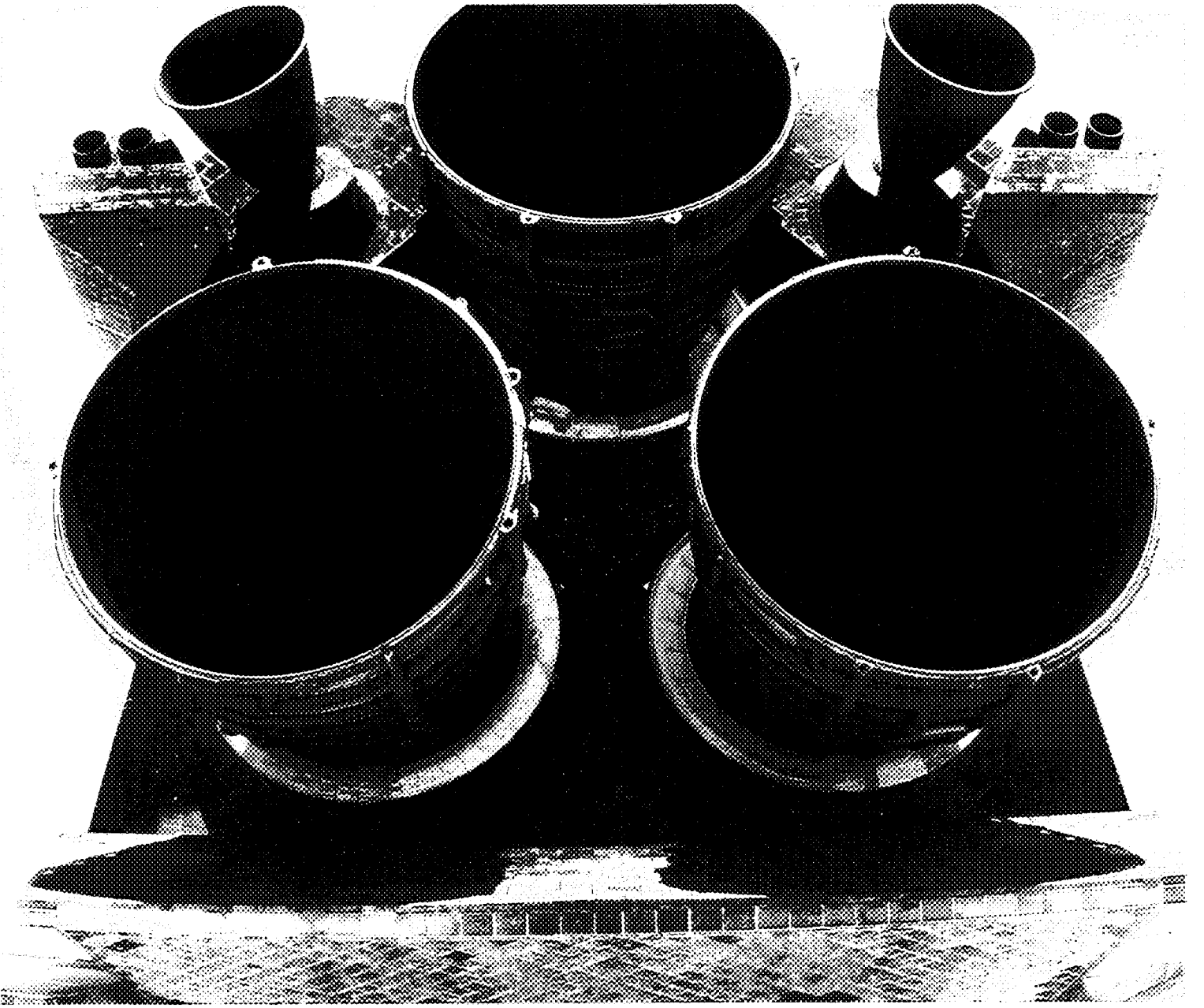


Photo 24: SSME's/Base Heat Shield

Typical amounts of tile damage occurred on the base heat shield due to exhaust plume acoustics and recirculation. Generally, the SSME Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition. However, the blanket panels on SSME #1 at the 7:00 o'clock position were torn/frayed with missing batting material. This missing material may have been the white object falling aft of the SSME area during ascent at 47 seconds MET in the launch films.

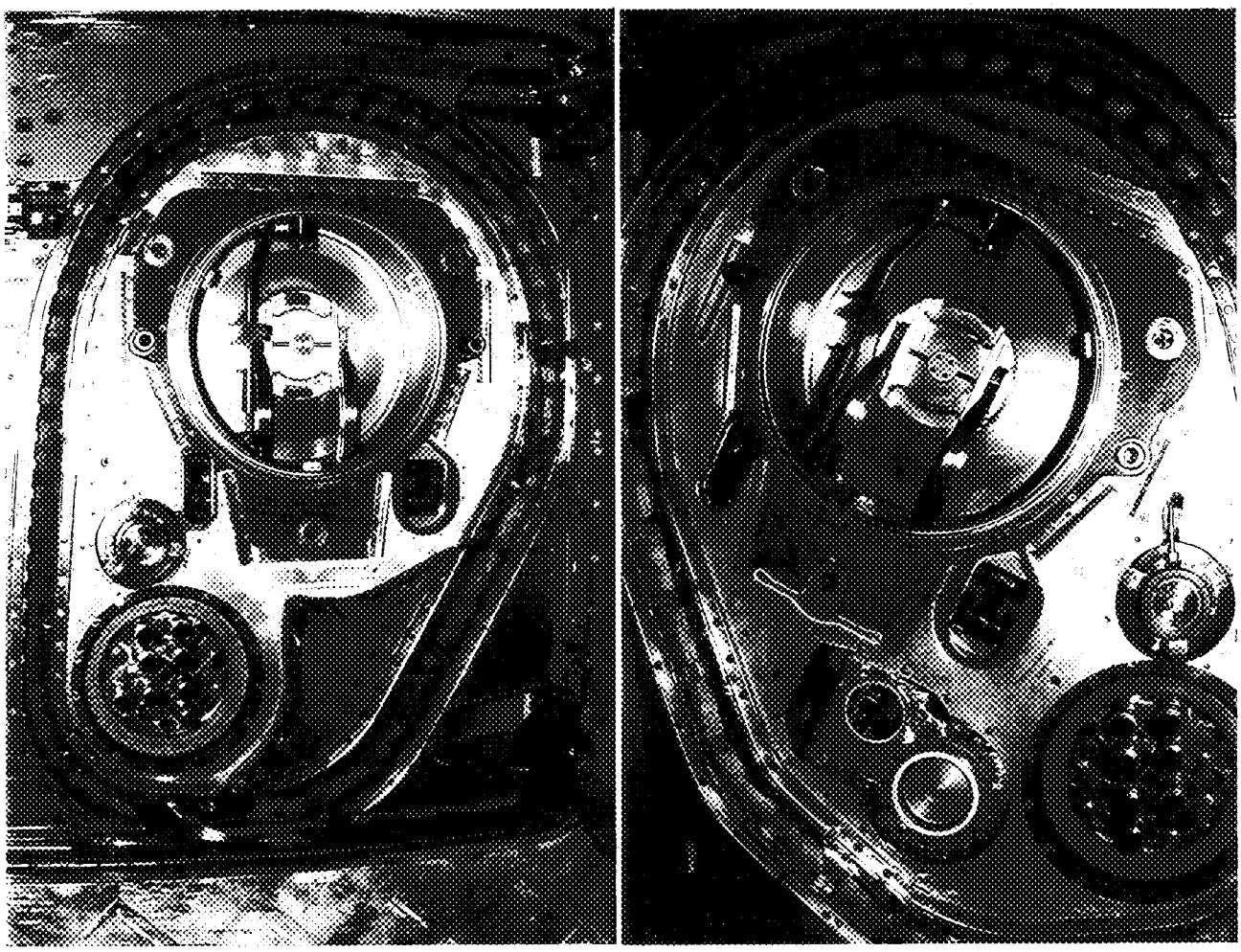


Photo 25: LO2 and LH2 ET/ORB Umbilicals

Note closeout foam and RTV along the edge of the umbilical plate aft of the 17-inch disconnect on the LO2 umbilical (left photo).

Photo 26: Excess Closeout Foam

An excessive amount of umbilical closeout foam (an "L"-shape 7-inches long by 3 inches on the perpendicular side) adhered to the umbilical plate aft of the 17-inch disconnect.

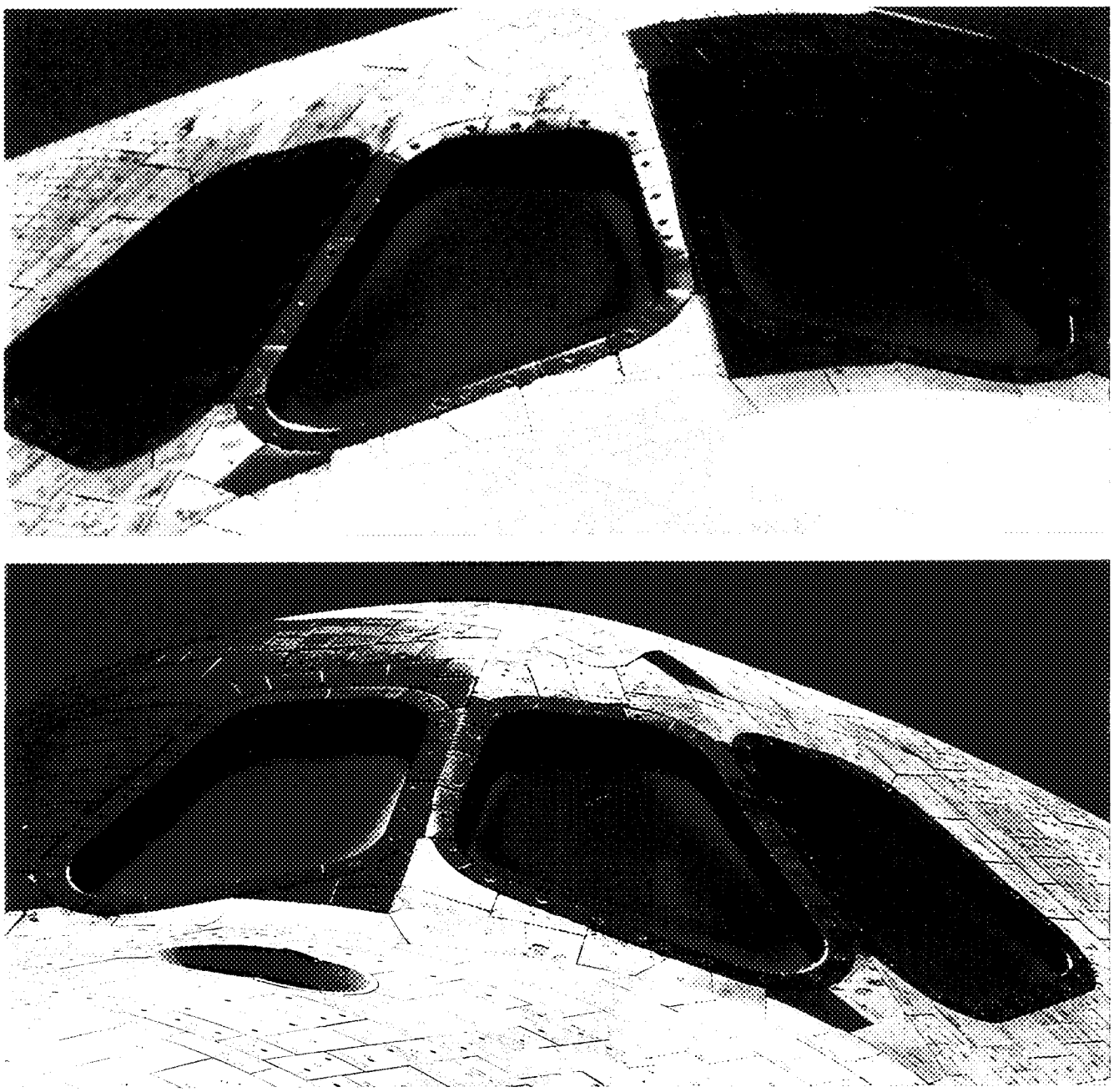
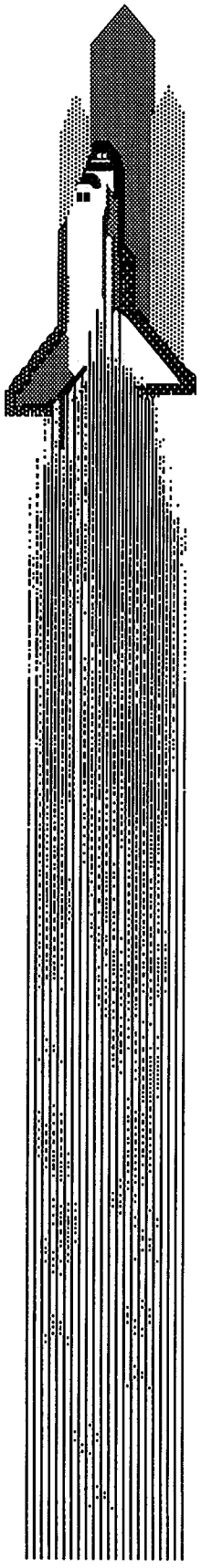


Photo 27: Windows

Hazing and streaking of forward-facing Orbiter windows was moderate to heavy. Damage sites on the window perimeter tiles was less than usual in quantity and size. The larger damage sites were attributed to old material falling out and were not included in this assessment.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Space Science Branch
Image Science and Analysis Group



STS-90 Summary of Significant Events

May 29, 1998

Space Shuttle
Image Science and Analysis Group
STS-90 Summary of Significant Events

Project Work Order - SN5CA

Approved By

Lockheed Martin

Jon Disler, Project Analyst
Image Science and Analysis Group

C. A. Sapp, Project Manager
Image Analysis Projects

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

NASA

Greg Byrne, Lead
Image Science and Analysis Group
Space Science Branch

Prepared By

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

Table of Contents

1. STS-90 (OV-102): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-90 launch of Columbia (OV-102) from Pad B occurred on Friday, April 18, 1998 at approximately 108:18:19:00.122 UTC as seen on camera OTV149. SRB separation occurred at approximately 18:21:05.08 UTC as seen on camera ET212.

On launch day, 24 of the 24 expected videos were received and screened. No anomalous events that would affect the Orbiter re-entry and landing were seen. Twenty launch films were screened on April 21, 1998.

Photography of the left SRB and the LSRB/ET aft attach and the external tank aft dome was acquired using umbilical well camera films during SRB separation. Photography of the external tank was acquired during ET separation. Handheld still photography of the ET was acquired following separation. Also, handheld video of the ET was acquired.

1.1.2 On-Orbit

No on-orbit tasks were requested.

1.1.3 Landing

Columbia made an early afternoon landing on runway 33 at the KSC Shuttle Landing Facility on May 3, 1998. Twelve videos and ten films were received.

The landing touch down appeared harder than normal. A sink rate analysis of the main landing gear was performed (see Section 2.6). The drag chute deployment appeared normal.

According to the pre-mission agreement, the STS-90 landing film and video was not screened due to budgetary constraints.

1.2 POST LANDING

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

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

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

As on previous missions, numerous light-colored pieces of debris were seen aft of the launch vehicle before, during, and after the roll maneuver (umbilical ice debris, RCS paper, SRB flame duct debris, and water baffle debris). On OTV109 and OTV163, multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals during SSME ignition. A piece of ice/frost debris fell aft and contacted the LH2 umbilical door sill at 18:18:55.764 UTC. No damage to the door sill was visible.

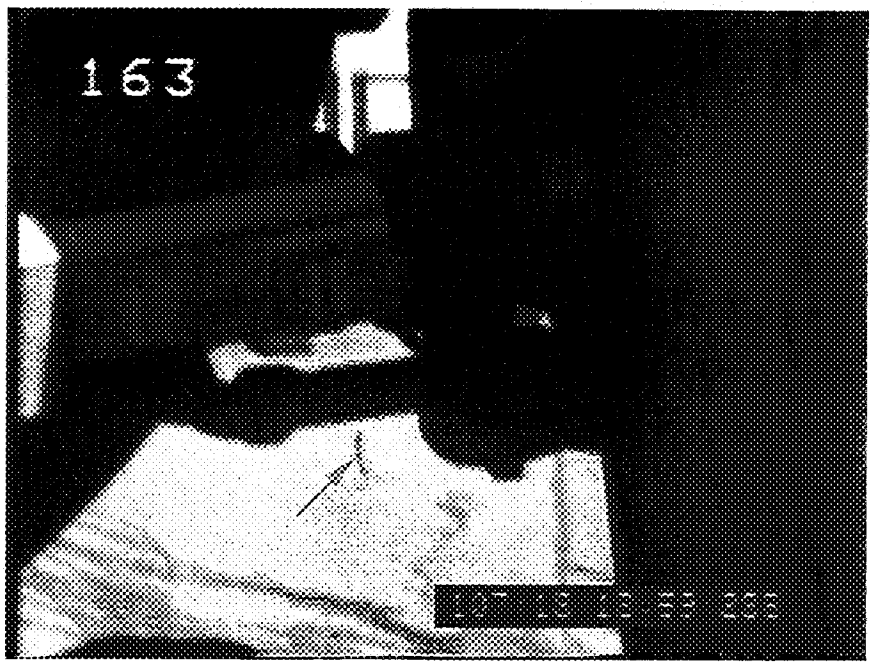


Figure 2.1 Linear-Shaped Debris

A single light-colored linear-shaped piece of debris (probably umbilical ice) was seen falling near the LH2 four inch recirculation line at 18:18:59.121 UTC. A second light-colored linear-shaped piece of debris was seen falling near the ET aft dome at the same time. On cameras E2 and E5 multiple pieces of light colored debris (probably SRB throat plug material) were seen near RSRB at SRB ignition. These debris were not seen to contact the vehicle.

2.2 DEBRIS DURING ASCENT

A light-colored piece of debris was seen between the LSRB and the aft end of the ET after liftoff on camera OTV148 (18:19:11.288 UTC). A light-colored flare (probably debris induced) was visible in the SSME exhaust plume during ascent (18:19:44.589 UTC) on camera KTV4B.

A light-colored piece of debris, first seen near the center of the three SSMEs, may have been a piece of Dome Mounted Heat Shield (DMHS) closeout blanket

(18:19:47.7 UTC). A single piece of debris near the RSRB stiffener rings (probably instafoam) fell aft along the SRB exhaust plume (approximately 18.4 seconds MET). A single piece of light-colored debris first seen near the RSRB aft skirt appeared to travel toward SSME #3 before falling aft into the SSME exhaust plume (18:19:33.3 UTC). Debris seen near the LSRB aft skirt was seen falling aft at approximately 30.8 seconds MET. (Cameras E52, E207, E222, E223, E224.)

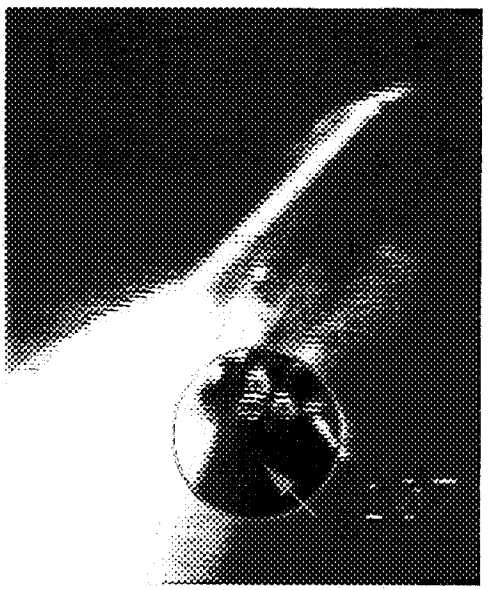


Figure 2.2 Large Light-Colored Debris

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

A thin, gray-colored vapor was visible near the inboard portion of the RSRB aft stiffener ring prior to SRB ignition on camera E4 (18:18:58.532 UTC). The vapor was probably outgassing, caused by the heat from the SSME engines.

Orange vapor, probably free burning hydrogen, was seen forward of the SSME rims, forward of the trailing edge of the body flap, and near the base of the vertical stabilizer during SSME ignition (E2, E5, E17, E18, E19, E52). Orange vapors drifting forward from the aft end of the vehicle have been observed on previous missions.

Tile surface coating material erosion was seen during SSME ignition at the base of SSME #2 and SSME #3, on the base heat shield above SSME#1, on the base heat shield near the right OMS pod, and at three areas on the base of the right RCS stinger (E2, E17, 19, E20).

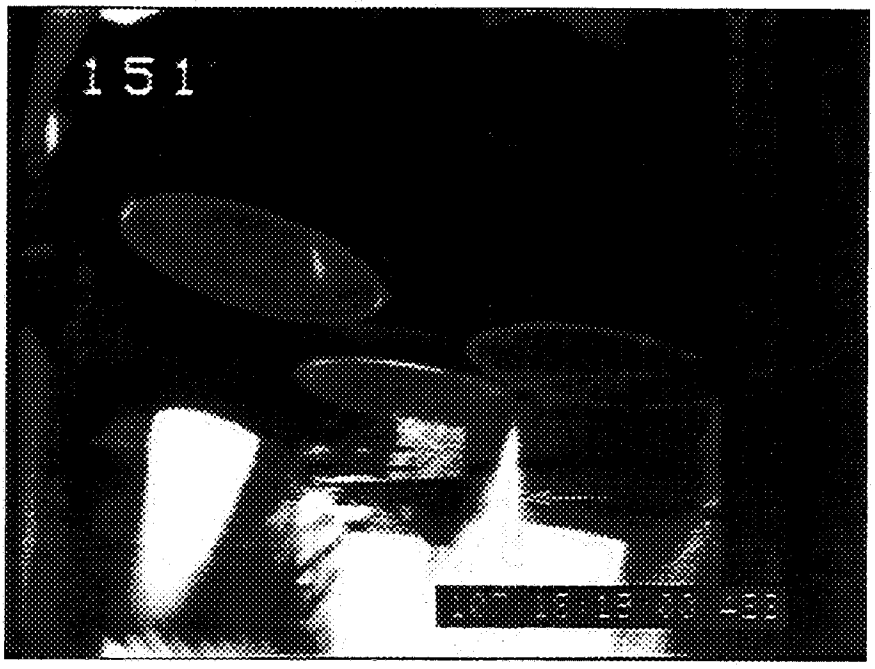


Figure 2.3 Flash in SSME #2 Exhaust Plume

A light-colored flash (probably debris induced) was seen in the SSME #2 exhaust plume at liftoff on OTV151 (18:19:00.488 UTC). The SSME Mach diamonds appeared to form in the expected sequence as seen on camera E19 and recorded in Table 2.3. No follow-up action was requested.

SSME	TIME (UTC)
SSME #3	18:18:56.738
SSME #2	18:18:56.791
SSME #1	18:18:56.967

Table 2.3 SSME Mach Diamond Formation

2.4 ASCENT EVENTS

Recirculation, or the expansion of burning exhaust gas, was seen at the aft end of the launch vehicle between 18:20:32.3 and 18:20:38.1 UTC on camera ET204. Recirculation has been seen on previous missions.

Seven orange-colored flares (probably debris induced) were seen in the SSME exhaust plume during ascent on cameras E52, E222 and E224 (18:19:07.130, 18:19:10.526, 18:19:34.013, 18:19:40.805, and 18:19:44.5 through 18:19:44.7 UTC).

Body flap motion (less than usual) was seen during ascent (E207).

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK

2.5.1 Analysis of the Umbilical Well Camera Films

Two rolls of 16mm umbilical well film and one roll of 35mm umbilical well film were received. The +X translation maneuver was performed on STS-90. OV-102 does not provided timing data to the 16mm umbilical well cameras.

35mm Umbilical Well Camera Film

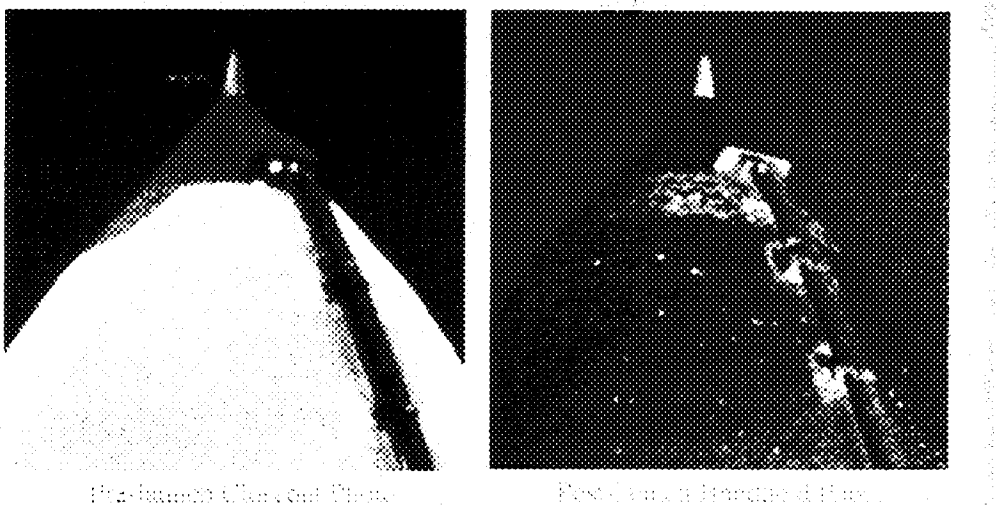


Figure 2.5.1 (A) Comparison of Pre-launch and Post-launch ET Nose Photography

On the post-launch handheld photography, a gray-colored band of pock marked or possible missing TPS is visible on the +Z ET nose just aft of the ET nose cone fairing. The low Sun angle accentuates the rough appearance of the surface texture on the photography. The gray-colored area is estimated to be approximately 15 to 18 inches in length (fore and aft) and is visible across the visible width of the ET nose. On the ET-91 pre-launch closeout photography, the same area appears orange-colored with a smooth texture. Discoloration in this area (probably due to aero heating) has been seen on several previous mission post separation umbilical films. However, the roughness of the surface texture seen on ET-91 appears unusual. Small popcorn divots from ascent are visible on the ogive aft of the nosecone.

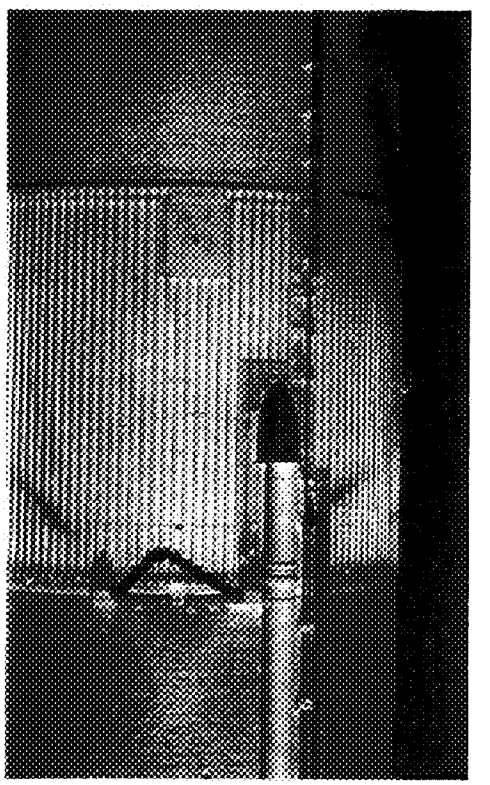


Figure 2.5.1 (B) View of +Z ET Intertank Area

No damage to the visible portion (+Z/+Y) of the right SRB thrust panel was noted on the 35mm umbilical well film (the left SRB thrust panel is not imaged). A divot, approximately four to five inches in size, is visible under the ET/Orbiter attach bipod in the LH2 tank-to-intertank closeout flange. A divot, approximately three inches in size, is visible in the -Y direction from the forward bipod on the LH2 tank-to-intertank flange closeout. A small divot is visible in an aft intertank stringer head forward of the LH2 tank-to-intertank closeout flange in the +Y direction from the LO2 feedline. A possible three inch divot is visible in the LH2 tank TPS aft of the right leg of the forward bipod next to the -Y side of the LO2 feedline. Dark-colored linear-shaped marks, possibly from shock waves off the EB fittings, were visible extending across the intertank stringer heads.

Typical TPS erosion/divots were noted on vertical section of the LO2 electric cable tray and on the aft portion of the +Z side of the LH2 tank. Chipping of the TPS on the aft two LO2 feedline flanges were noted. A divot in the TPS on the +Y ET/Orbiter aft thrust strut was noted. No anomalies were noted on the face of the LO2 umbilical carrier plate.

16mm Umbilical Well Camera Film

The LSRB separation appeared normal on the 16mm umbilical well camera films. Numerous light-colored pieces of debris (insulation and frozen hydrogen), and dark debris (probably 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 irregularly-shaped pieces of debris

(charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. A piece of TPS was seen to detach from the aft surface of the horizontal section of the -Y ET vertical strut leaving a divot with exposed substrate. 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 normal. Both the left and right SRB nose caps were visible during SRB separation.

The ET separation from the Orbiter appeared normal. Numerous light colored pieces of debris (probably insulation and frozen hydrogen) were seen throughout the ET separation sequence on the 16mm films. Vapor and multiple light colored pieces of debris were seen after the umbilical separation. White debris (frozen hydrogen) were seen striking the forward surface of the LH2 electric cable tray. No damage to the cable tray was detected.

No anomalies were noted on the face of the LH2 umbilical after ET separation (the view of the LH2 umbilical interface is very dark due to back-lighting from the Sun). As typically seen on previous missions, frozen hydrogen is visible on the orifice of the LH2 17 inch connect.

A divot is visible under the ET/Orbiter attach bipod in the LH2 tank-to-intertank closeout flange. Three divots are visible in the same flange closeout in the -Y/+Z quadrant.

2.5.2 Analysis of the Handheld Photography of the ET

Thirty-eight images of the ET were acquired using the handheld 35mm Nikon camera with a 400mm lens (roll 367). The exposure and focus of the photography is good. Views of the sides, nose, and aft dome of the ET were acquired. Venting from the ET in the vicinity of the intertank was observed. The normal SRB separation burn scars and aero-heating marks were noted on the ET TPS.

The ET was estimated to be about 1.4 km from the Orbiter on the first picture. The minimum resolvable object size on the ET was estimated to be approximately three inches on the best view. Back lighting from the Sun hindered the analysis of some views. Timing data is present on the first four frames of the film. No timing was present on the remaining frames. The first picture was taken at 14:30 (minutes:seconds) MET. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows (STS-90 was the third flight with the roll-to-heads-up maneuver).

2.5.2.1 Analysis of the Handheld Film

Damage to the external tank, including both intertank thrust panels, was not confirmed from the available hand held camera views. Damage was seen on the -Y LH2 tank-to-intertank close-out flange (frame 4). The damage appears as three small light-colored marks (divots) approximately six to nine inches in size (divots on this flange are a typical occurrence). The light-colored mark on the LH2 tank TPS aft of the +Y thrust panel is visible on the pre-launch closeout photography and is not damage. The light-colored appearance of the ET intertank access door on frame 24 was caused by reflected Sun light and is not anomalous.

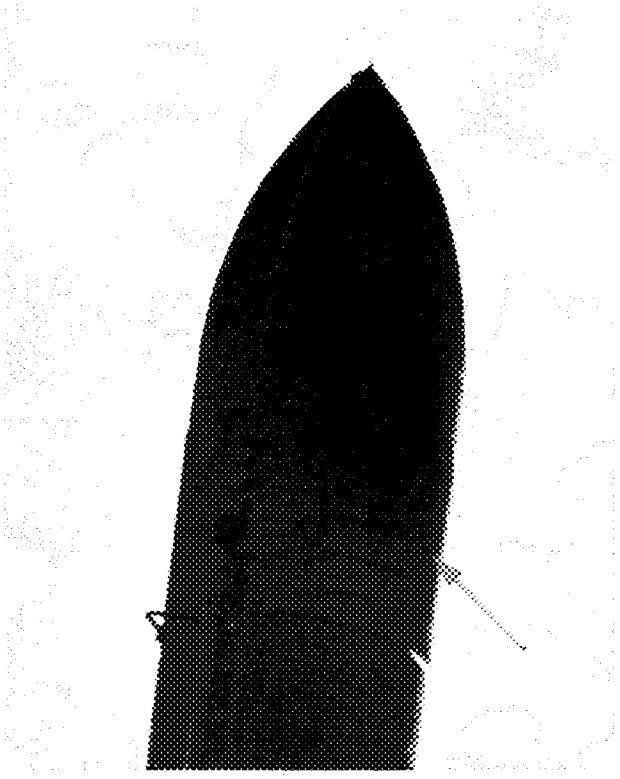


Figure 2.5.2.1 (A) ET +Y Intertank Thrust Panel

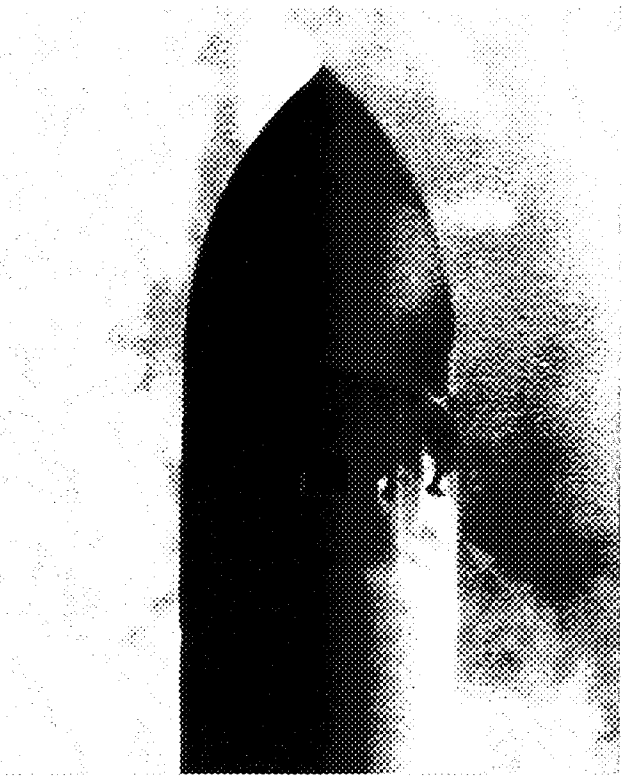


Figure 2.5.2.1 (B) ET -Y Intertank Thrust Panel

No damage was confirmed on the views of ET Thrust panels.

2.5.2.2 Analysis of the Camcorder Video of the ET

Figure 2.5.2.2 ET Intertank Venting

Approximately twelve minutes of downlink video of the STS-90 external tank (ET) was received. No anomalies to the ET were confirmed during the screening of the video. Venting was clearly visible from both the ET intertank vent area and the aft ET/Orbiter umbilical attach areas. The venting in the region of the ET intertank vent was visible for twenty seconds. Approximately six minutes later, a three second period of venting was seen coming from what appeared to be the LO2 ET/Orbiter umbilical. After three more minutes, a 170 second period of venting was visible originating from the LH2 umbilical. The tumbling motion of the ET did not appear excessive. The ET rate of tumble, i.e., the end-to-end rotation of the ET about its center of mass, at the beginning of the video sequence was estimated to be approximately three degrees/second. The rate of roll about the ET X axis appeared to increase after the intertank venting began. As noted on the two previous roll-to-heads-up flights, debris (probably ice) were visible during the video sequence.

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis

Film camera EL-9 was used to determine the landing sink rate of the STS-90 Orbiter 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 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 was used as a scaling factor. The main gear height above the runway was calculated by the vertical difference between the main gear struts and the reference point. These heights were then regressed with respect to time and the trendline was determined. Sink rate equals the slope of this regression line.

The left main gear sink rate for STS-90 landing at one second, at half a second, and at a one quarter of a second are provided in the following table. A plot describing these sinkrates is also provided.

Time Prior to Touchdown	1.00 Sec.	0.50 Sec.	0.25 Sec.
Left Main Gear Sink Rate	6.3 ft/sec	6.5 ft/sec	6.7 ft/sec
Estimated Error (1σ)	± 0.2 ft/sec	± 0.2 ft/sec	± 0.1 ft/sec

Table 2.6.1 Main Gear Landing 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-90 vehicle was estimated to be 232,965 lb.

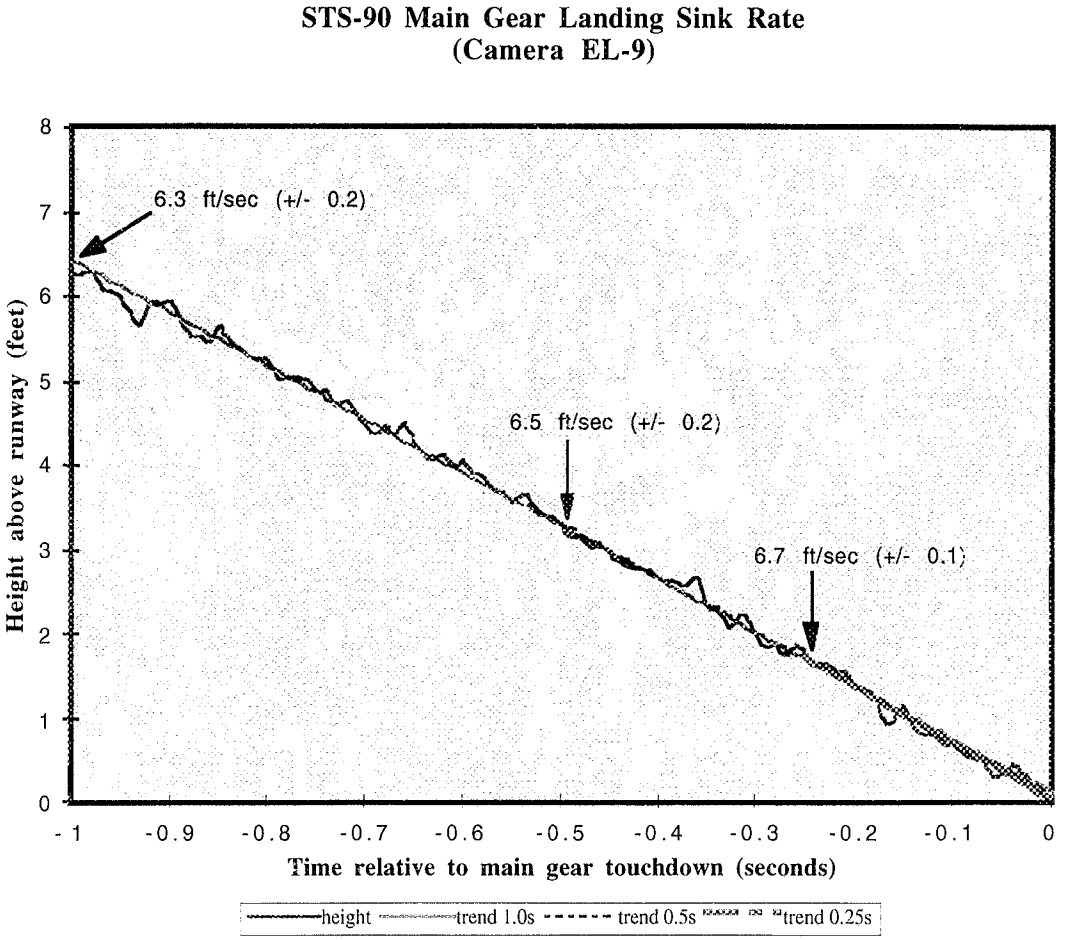


Figure 2.6.1 Main Gear Landing Sink Rate

A sink rate analysis of the nose gear was not performed on STS-90 due to budgetary constraints.

2.7 OTHER

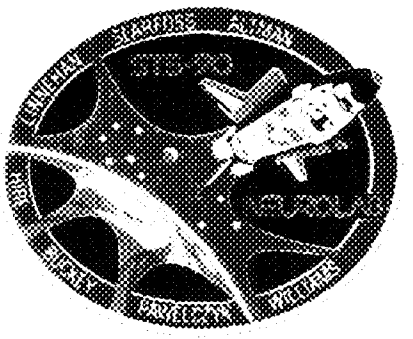
2.7.1 Normal Events

Normal events observed included inboard elevon and body flap motion prior to liftoff, RCS paper debris, ET twang, vapor from the ET vent louver at liftoff, 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 were during liftoff, expansion waves after liftoff, vapor off the SRB stiffener rings, charring of the ET aft dome, condensation around the launch vehicle, and SRB separation.

2.7.2 Normal Pad Events

Normal pad events observed included the Hydrogen burn ignitor operation; the FSS deluge water activation; the MLP deluge water activation; and the TSM T-0 umbilical operations.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY



STS-90 Engineering Photographic Analysis Report

Table of Contents

Introduction

The launch of space shuttle mission STS-90, the 25th flight of the Orbiter Columbia occurred on April 17, 1998 at approximately 1:19 P.M. Central Standard Time (CST) from Launch Complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Launch time was reported as 107:18:18:59.998 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), LC-39B perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Engineering Analysis Objectives

The planned engineering photographic and video analysis objectives for STS-90 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 (GUCP)

- Free hydrogen ignitors
- Booster separation motors (BSM)

Camera Coverage Assessment

The following table illustrates the camera coverage received at MSFC for STS-90.

	16mm	35mm	70mm	Video
MLP	19	0	0	4
FSS	5	0	0	3
Perimeter	0	3	0	6
Tracking	0	14	0	11
Onboard	2	2	0	1
Totals	26	19	0	25

Total number of film and videos received: 70

Individual camera assessments are provided in Appendix A.

Ground Camera Coverage

No problems occurred with the KSC camera systems. Clear skies and the mid-day sun provided for good photographic conditions.

Onboard Camera Coverage

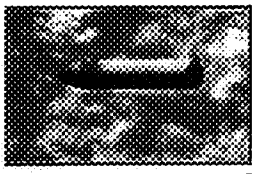
The orbiter Columbia carried two 16mm motion picture cameras and a 35mm still camera in the umbilical wells to record the SRB and ET separation events. The astronauts also photographed the ET with a hand held 35mm camera and camcorder after separation.

Anomalies

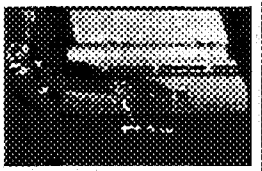
No anomalies were noted.

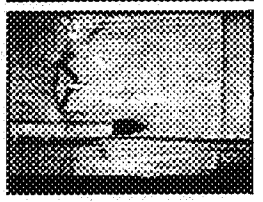
Observations

The typical observations noted on most missions were also noted during this review. The thermal curtains on both SRB's momentarily buckled inward at liftoff. The curtains do not typically buckle inward, but the outer surface has been observed to wrinkle.

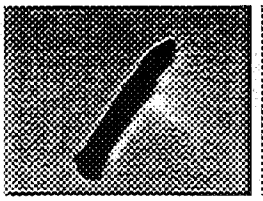


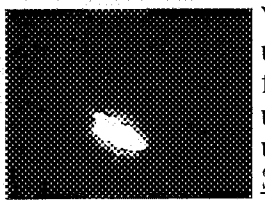
The photographic products from the astronaut photography of the ET shows that the thrust panels TPS remained in good condition during ascent. Good views of both thrust panels were made.





Typical divots where observed near the forward bipod strut, the LH2 tank/intertank interface and on the right ET/Orbiter thrust strut. These photographs were recorded with the 35mm umbilical well camera.





Venting of gasses from the ET GUCP and the LH2 and LO2 umbilicals was noted from the camcorder video. Venting was first observed from the GUCP region and later venting from the umbilicals was observed. Venting from the GUCP and LH2 umbilical has been previously observed on STS-45 and STS-87.

Engineering Data Results

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	18:18:59.995
M-2	E8	18:18:59.998
M-5	E12	18:18:59.997
M-6	E13	18:18:59.997

SRB Separation Time

SRB separation as recorded by observations of the BSM combustion products from long range film cameras E212 and E208 occurred at 107:18:21:05.09 UTC.

Appendix A - Individual camera assessments

Appendix B - Definitions and acronyms

Individual film/video summary report

Return to Engineering Photographic Analysis Reports

Return to MSFC Engineering Photographic Analysis Home Page

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	June 1998	Final April 15 - May 5, 1998

4. TITLE AND SUBTITLE

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-90

5. FUNDING NUMBERS

OMRS00U0

6. AUTHOR(S)

Gregory N. Katnik

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

John F. Kennedy Space Center, NASA
Process Engineering/ Mechanical Systems Division
ET/SRB Branch, Mail Code: PK-H7
Kennedy Space Center, Florida 32899

8. PERFORMING ORGANIZATION REPORT NUMBER

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

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA/TM-1998-207907

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Blanket Release

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-90. 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-90 and the resulting effect on the Space Shuttle Program.

14. SUBJECT TERMS

Subject Category: 15, 16
STS-90 Thermal Protection System (TPS)
Ice Debris Photographic Analysis

15. NUMBER OF PAGES

16. PRICE CODE

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

KSC DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS
REPORT DISTRIBUTION LIST 6/98

NASA - KSC

AA-C/L. J. Shriver
MK/D. McMonagle
MK-SIO/R. Page
PK-D/R. Harrison
PK-H/R. Seiffer
PK-H/G. Katnik (7)
EY-B6/A. Wilted
PK-J-C/C. Brown
SK/F. Kienitz
USK-321/R. S. Herman
USK-437/K. Revay
ZK-86/C. Hill
BICO-RVITS/R. B. Hoover
MMC-15/D. S. Otto
USBI-LSS/L. Clark

NASA - HQ

QSO/W. Comer

NASA - JSC

Johnson Space Center
Houston, Texas 77058

EP2/P. Cota
ES3/J. Kowal
MV3/D. Camp
SN3/E. Christiansen
SN5/G. Byron

NASA - MSFC

Marshall Space Flight Center
Huntsville, AL 35812

EE31/J. L. Lusaka
EE31/M. G. Harsh
EP42/T. J. Rieckhoff

Rockwell - Downey

Boeing North American
12214 Lakewood Blvd
Downey, CA 90241

AE21/J. McClymonds
FA44/R. Ramon

Lockheed Martin

P. O. Box 29304
New Orleans, Louisiana 70189

Dept. 3571/S. Copsey
MAF Technical Library