Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-94

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DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-94

1 July 1997

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FOREWORD

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

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

Photo 1: Launch of Shuttle Mission STS-94

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 30 June 1997. The detailed walkdown of Pad 39A and MLP-1 also included the primary flight elements OV-102 Columbia (23rd flight), ET-86 (LWT 79), and BI-088 SRB's. There were no significant vehicle or launch pad anomalies.

The Final Inspection of the cryoloaded vehicle was performed on 1 July 1997 from 0910 to 1100 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Due to the warm weather conditions, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

After the 2:02 p.m. (local) launch on 1 July 1997, a debris walk down of Pad 39A was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal. The GOX vent seals were evaluated from the GVA hood access platform; no damage or topcoat residue was noted on the seals.

A total of 111 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.

OV-102 was equipped to carry ET/ORB umbilical cameras. SRB separation from the External Tank appeared nominal.

Seven very small TPS divots were detected on intertank stringer heads forward of the bipods. No divots were observed in the LH2 tank-to-intertank flange closeout. A 6-inch by 6-inch area of foam was missing from the -Y bipod jack pad closeout with some primer showing in the deep part of the divot.

TPS erosion on LO2 feedline flanges and support brackets, pressurization line ramps, and both thrust strut flange closeouts was somewhat more than usual, but still acceptable. Likewise, small and shallow "popcorn" type divots were somewhat greater in quantity on the LH2 tank with most of the divots, including as many as twenty-two 2-3 inch diameter divots, concentrated forward of the crossbeam.

Several divots were detected in and around pressurization line and LO2 feedline supports: a shallow 16-inch long by 10-inch wide divot in the LH2 acreage between the pressurization line and the LO2 feedline at station XT-1528; a 14-inch long by at least 2-inch wide divot outboard of the XT-1593 pressurization line ramp; a 5-inch diameter divot (possibly with primer showing) adjacent to the XT-1623 LO2 feedline inboard support; a 4-inch by 2-inch divot at the leading edge of the XT-1657 pressurization line ramp; and a shallow, 6-inch by 4-inch divot in the LH2 tank acreage between the pressurization line and the LO2 feedline at station XT-1722.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. Both frustums were in excellent condition. No TPS was missing and no debonds were detected over fasteners All four Booster Separation Motor (BSM) aero heat shield covers on the right frustum were locked in the fully opened position. The lower right BSM aero heat shield cover on the left frustum was locked in the fully opened position; the remaining covers were bent. The BSM aero heat shield cover attach rings had been bent by parachute riser entanglement after splashdown. The forward skirts exhibited no debonds or missing TPS. 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. One area of forward edge damage was noted on the right hand center joint at about the 200 degree position. This damage was most probably caused by ice from the ET LO2 feedline forward bellows. Seven of the holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have

functioned normally. The HDP #6 DCS plunger was obstructed by pyro debris.

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

A post landing inspection of OV-102 Columbia was conducted 17 July 1997 at the Kennedy Space Center on SLF runway 33. The Orbiter TPS sustained a total of 90 hits, of which 12 had a major dimension of 1-inch or larger. A comparison of these numbers to statistics from 69 previous missions of similar configuration indicates both the total number of hits, and the number of hits 1-inch or larger, were less than average.

The Orbiter lower surface sustained a total of 34 hits, of which 11 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the right chine. The site measured 3.75 inches long by 1.75-inches wide by 0.125-inches deep.

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size with the exception of a 7.5-inch long by 1.8-inch wide by 0.2-inch deep impact just forward of window #3. This damage site spanned the 391020-453 white tile and two unidentified adjacent black tiles. These damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the FRCS thrusters. In fact, a 2-inch long scorched piece of FRCS thruster paper cover was wedged between the window #2 glass and perimeter tiles adjacent to three tile damage sites.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 30 June 1997 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
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J. Rivera	NASA - KSC	ET Mechanisms/Structures
B. Davis	NASA - KSC	Digital Imaging Systems
R. Page	NASA - KSC	SSP Integration
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J. Blue	USA - SPC	ET Mechanical Systems
W. Richards	USA - SPC	ET Mechanical Systems
M. Wollam	USA - SPC	ET Mechanical Systems
G. Fales	USA - SPC	ET Mechanical Systems
F. Foster	BNA - LSS	Systems Integration
G. J. McClymonds	BNA - DNY	Aerodynamics
R. Harmon	THIO - LSS	SRM Processing
S. Otto	LMSO - LSS	ET Processing
J. Ramirez	LMSO - LSS	ET Processing
M. Barber	USA - Safety	

3.0 LAUNCH

STS-94 was launched at 18:02:00:010 GMT (2:02 p.m. local) on 1 July 1997.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 30 June 1997. The detailed walkdown of Pad 39A and MLP-1 also included the primary flight elements OV-102 Columbia (23rd flight), ET-86 (LWT 79), and BI-088 SRB's. There were no significant vehicle or launch pad anomalies.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 1 July 1997 from 0910 to 1100 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Due to the warm weather conditions, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

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

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. RCS thruster covers were intact, but the F4R cover was tinted green indicating small internal vapor leakage. Ice/frost and condensate had formed on the SSME #2 heat shield-to-nozzle interface. The SSME #1 and #3 heat shields had condensate only. 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 80 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted condensate, but no ice or frost, on the ET acreage TPS.

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 70 degrees F.

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

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures averaged 68 degrees F. All TPS repairs on the +Z side of the LH2 tank were intact and in nominal condition.

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

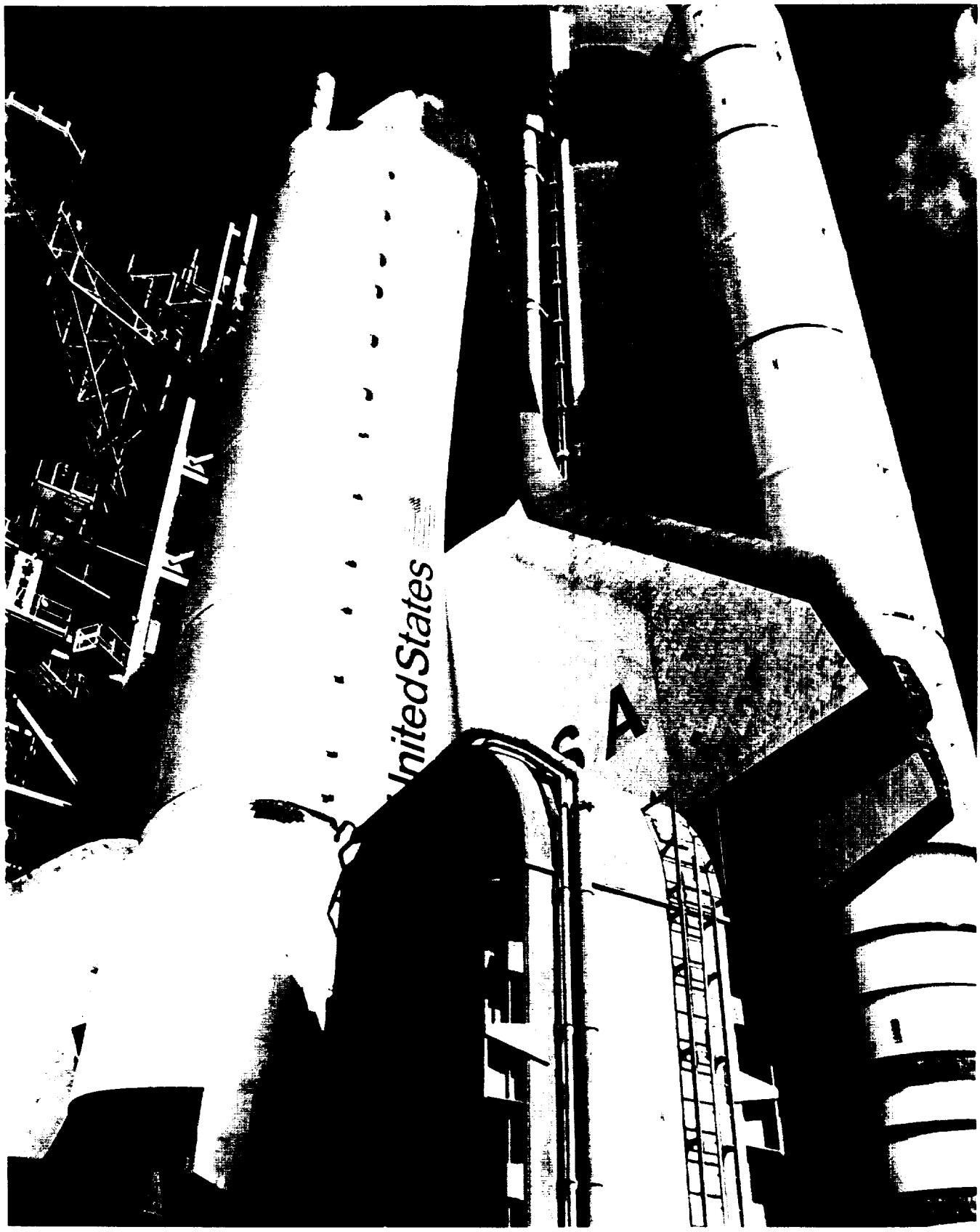


Photo 2: STS-94 Ready for Launch

OV-102 (23rd flight), ET-86 (LWT79), BI-088 SRB's

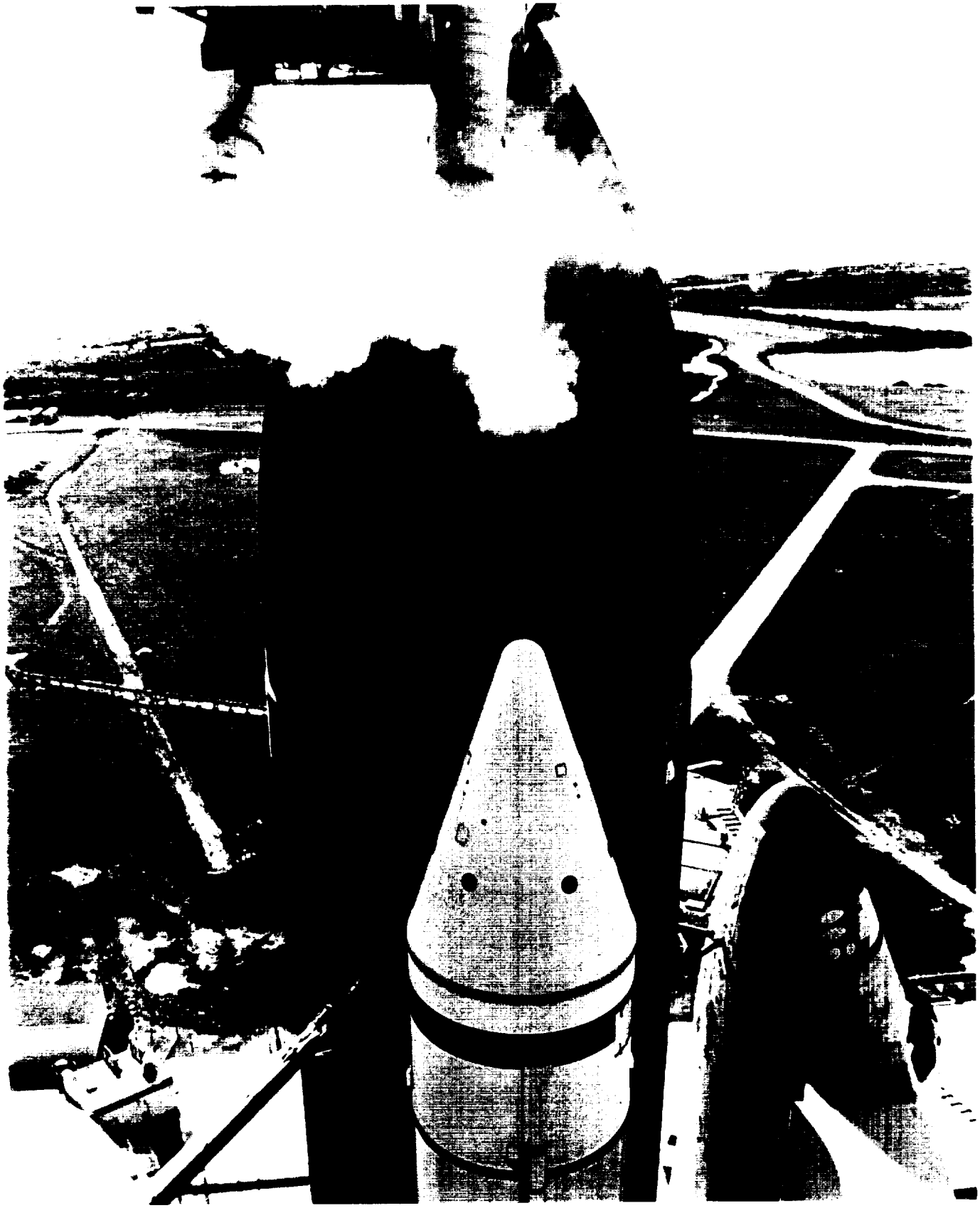


Photo 3: LO2 Tank and Intertank After Cryoload

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 70 degrees F.

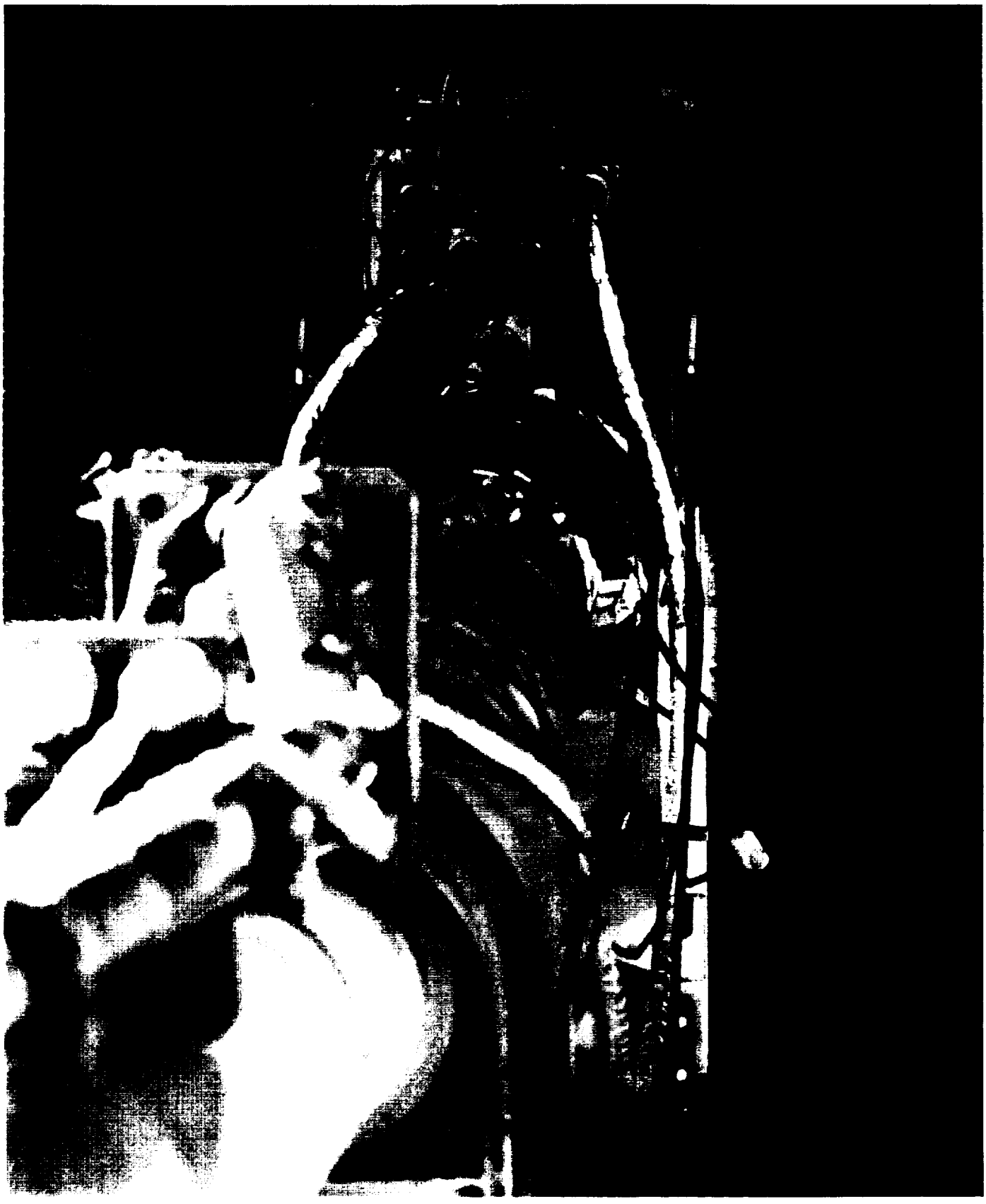


Photo 4: GUCP

Ice/frost accumulation on the GUCP appeared typical.

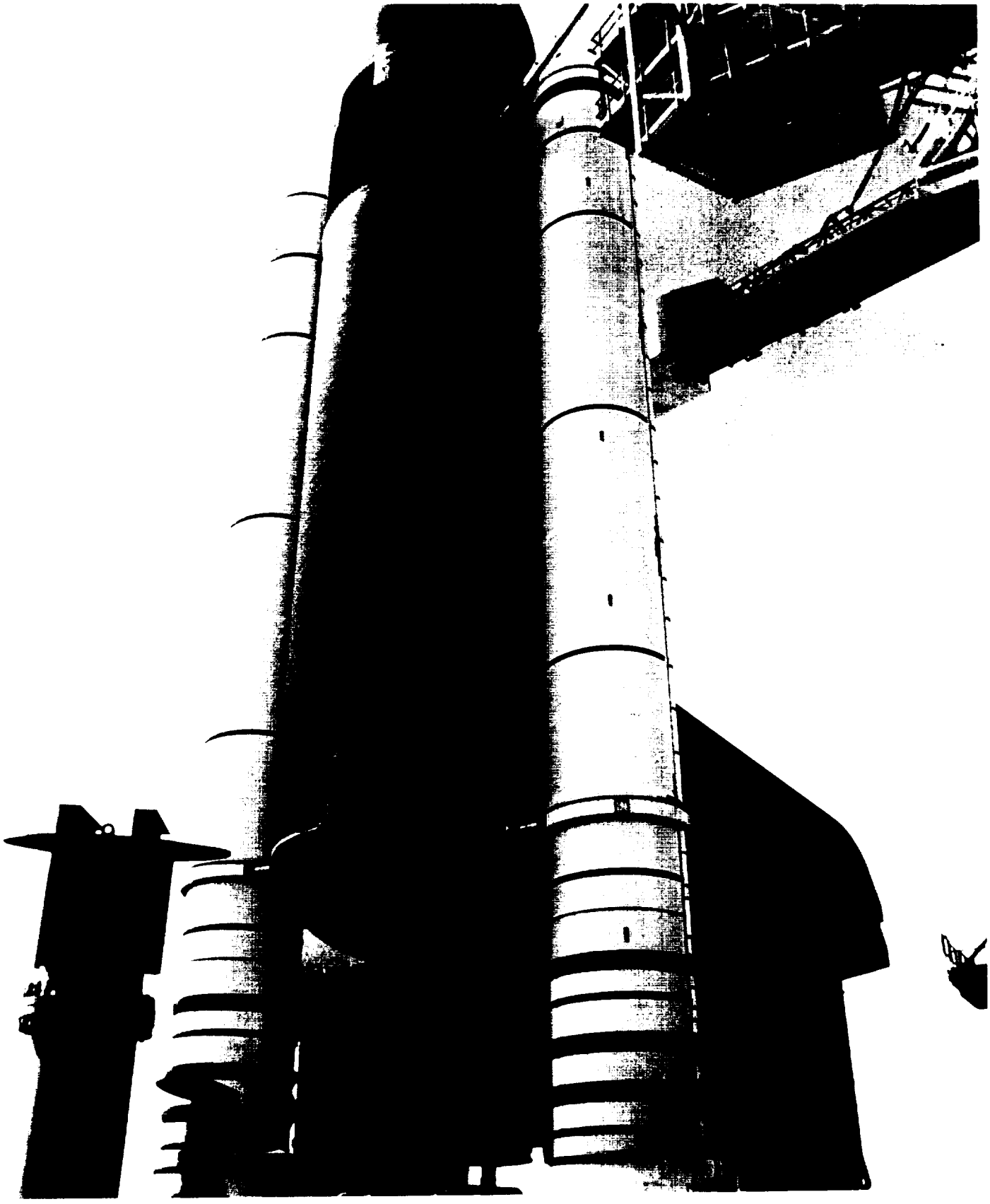


Photo 5: ET LH2 Tank Acreage

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures averaged 68 degrees F.

No stress relief crack had formed on the -Y vertical strut forward facing TPS. The presence of a crack is expected and acceptable for flight per the NSTS-08383 criteria.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice/frost accumulations were limited to small patches on the aft and inboard sides. Ice/frost fingers on the separation bolt pyrotechnic canister purge vents were typical.

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

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

3.2.4 FACILITY

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

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

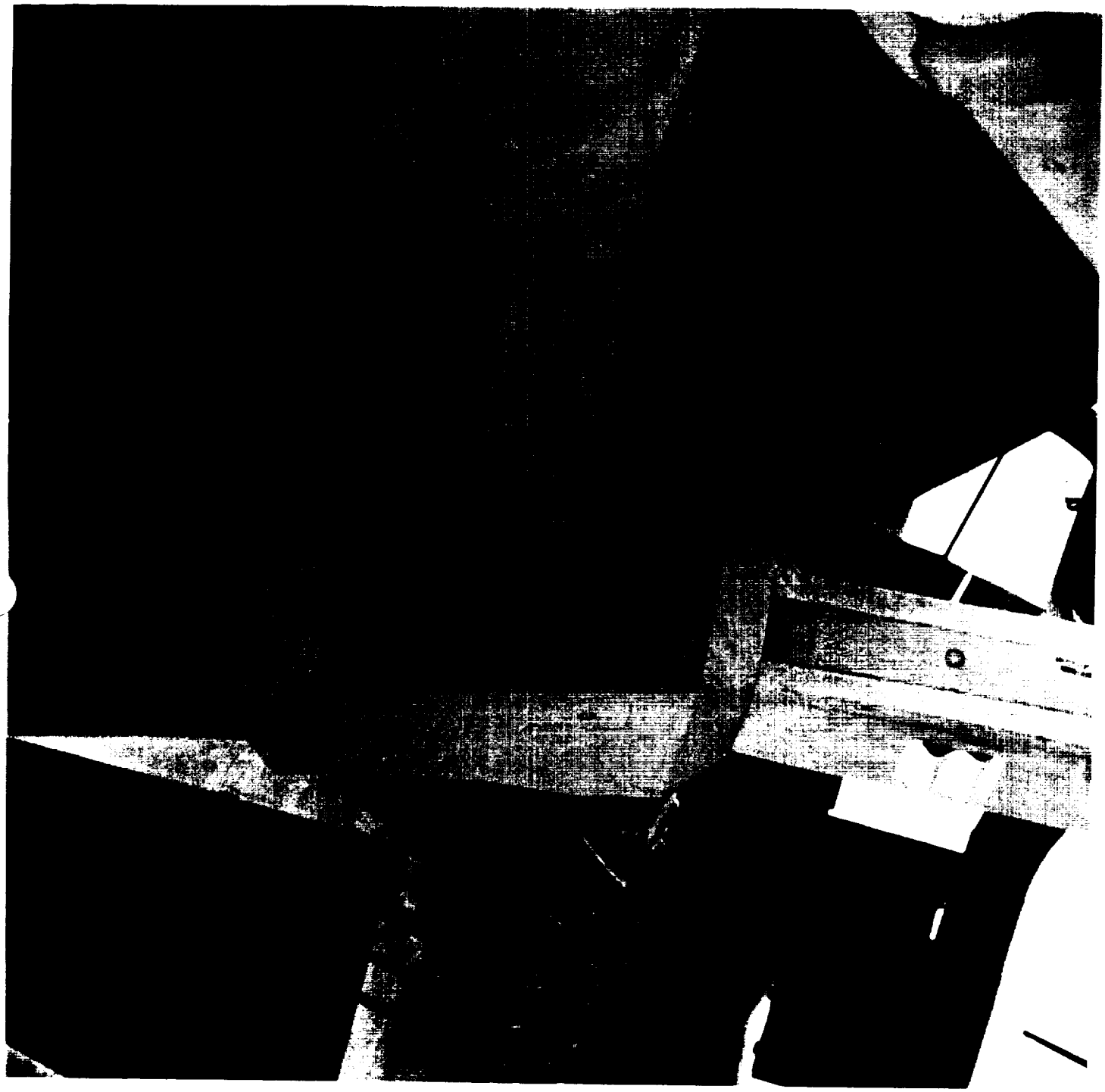


Photo 6: -Y Vertical Strut

No stress relief crack had formed on the -Y vertical strut forward facing TPS. The presence of a crack is expected and acceptable for flight per the NSTS-08383 criteria.

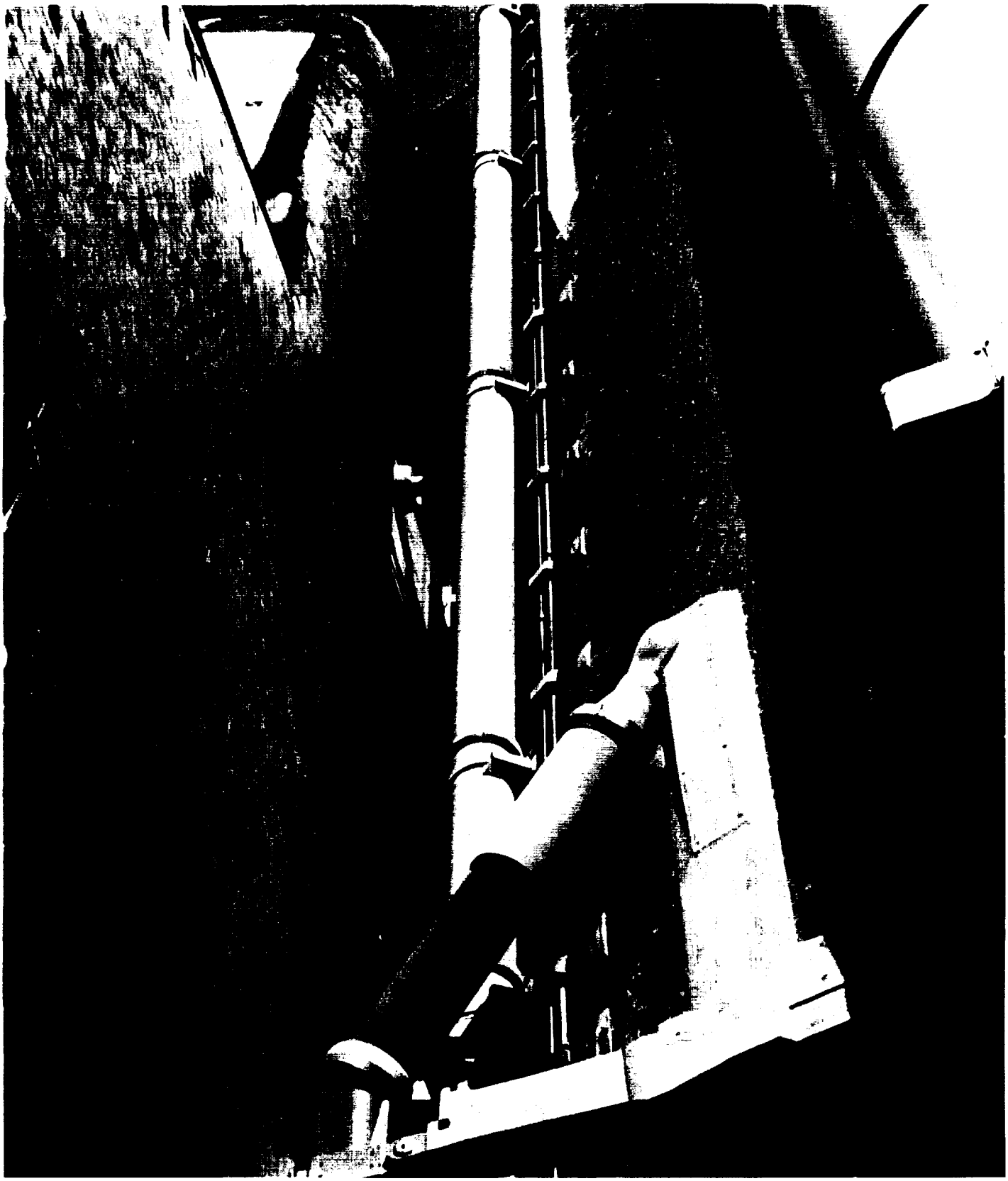


Photo 7: LH2 Feedline and +Z Side Repairs

The LH2 feedline bellows were wet with condensate. All TPS repairs on the +Z side of the LH2 tank were intact and in nominal condition.

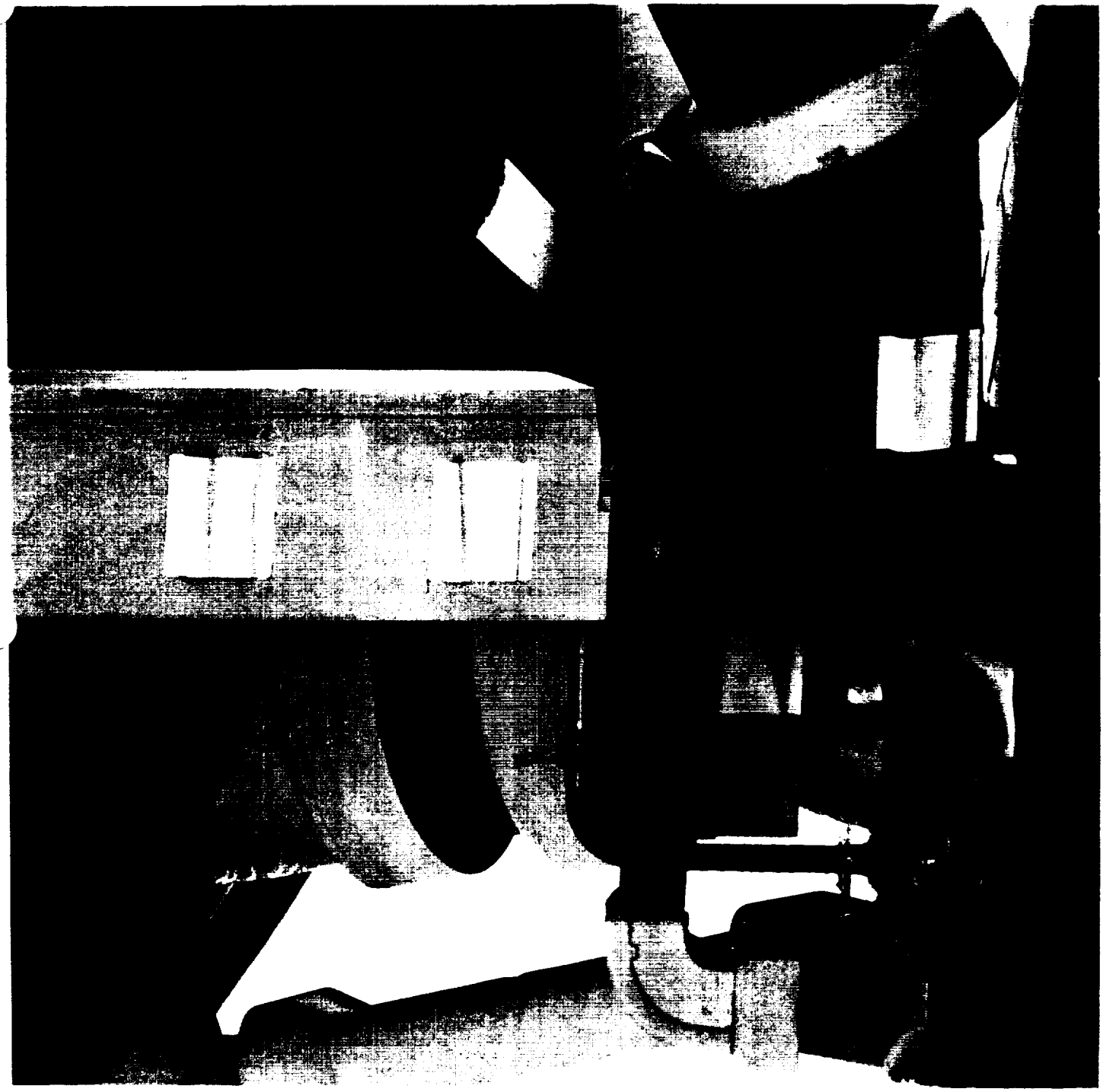


Photo 8: ET/Orbiter LH2 Umbilical

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

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 1, Pad A FSS/RSS was conducted on 1 July 1997 from Launch + 1.5 to 4 hours.

SRB Hold Down Post (HDP) erosion was typical. Boeing-Downey reported a lateral acceleration of 0.07 g's, which was well below the previously established stud hangup threshold of 0.14 g's. Aft skirt purge lines and T-0 umbilicals exhibited typical exhaust plume damage. Pad safety reported material loss and damage to the firewall in the south flame trench with pieces of ablative material scattered down the crawlerway to the pad gate.

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

The GOX vent seals were evaluated from the GVA hood access platform. No damage or ET topcoat residue was noted on the seals.

The GH2 vent line was latched in the fourth of eight teeth of the latching mechanism. The ET GUCP had been struck by the retract lanyard, damaging the 7-inch probe at the 11 o'clock position.

Overall, pad damage was minimal.

Photo 9: Holddown Post # 7 and #8

SRB Hold Down Post (HDP) erosion was typical.

5.0 FILM REVIEW

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

5.1 LAUNCH FILM AND VIDEO SUMMARY

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

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

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals. Several pieces of ice were pulled toward the LH2 umbilical cavity sill, but did not appear to contact the vehicle. No tile damage was visible (OTV-009).

A dark colored object was visible on the -Z side of the LO2 TSM at 18:01:55.872 UTC. The object first appeared outboard of the right hand SRB and fell toward the base of the TSM. The object did not impact the vehicle. (E-17, OTV-63)

Tile surface coating material was lost during ignition from one place outboard of SSME #3 and one place on the aft surface of the LH RCS stinger (E-18, -20).

The LO2 TSM door rebounded substantially after initial closure (E-3, -20

No hold down post (HDP) stud hangups occurred. Hold down post shoe rock was visible on HDP's 2, 3, 5, and 6. No ordnance debris or frangible nut pieces fell from the DCS/stud holes. (E-8, -10, -12, -13)

GUCP disconnect from the ET and GH2 vent line retraction was nominal. Residual GH2 vapors were present in the flight QD. (E-33, OTV-4, -63).

Several debris-induced streaks occurred in the SSME exhaust plume during ascent (E-212, -217, -222, -223).

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

Several particles, most likely pieces of Instafoam from the SRB aft skirt rings, fell along side the SRB exhaust plume during ascent (E-224).

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

SRB separation appeared normal (E-207, -208, -212).

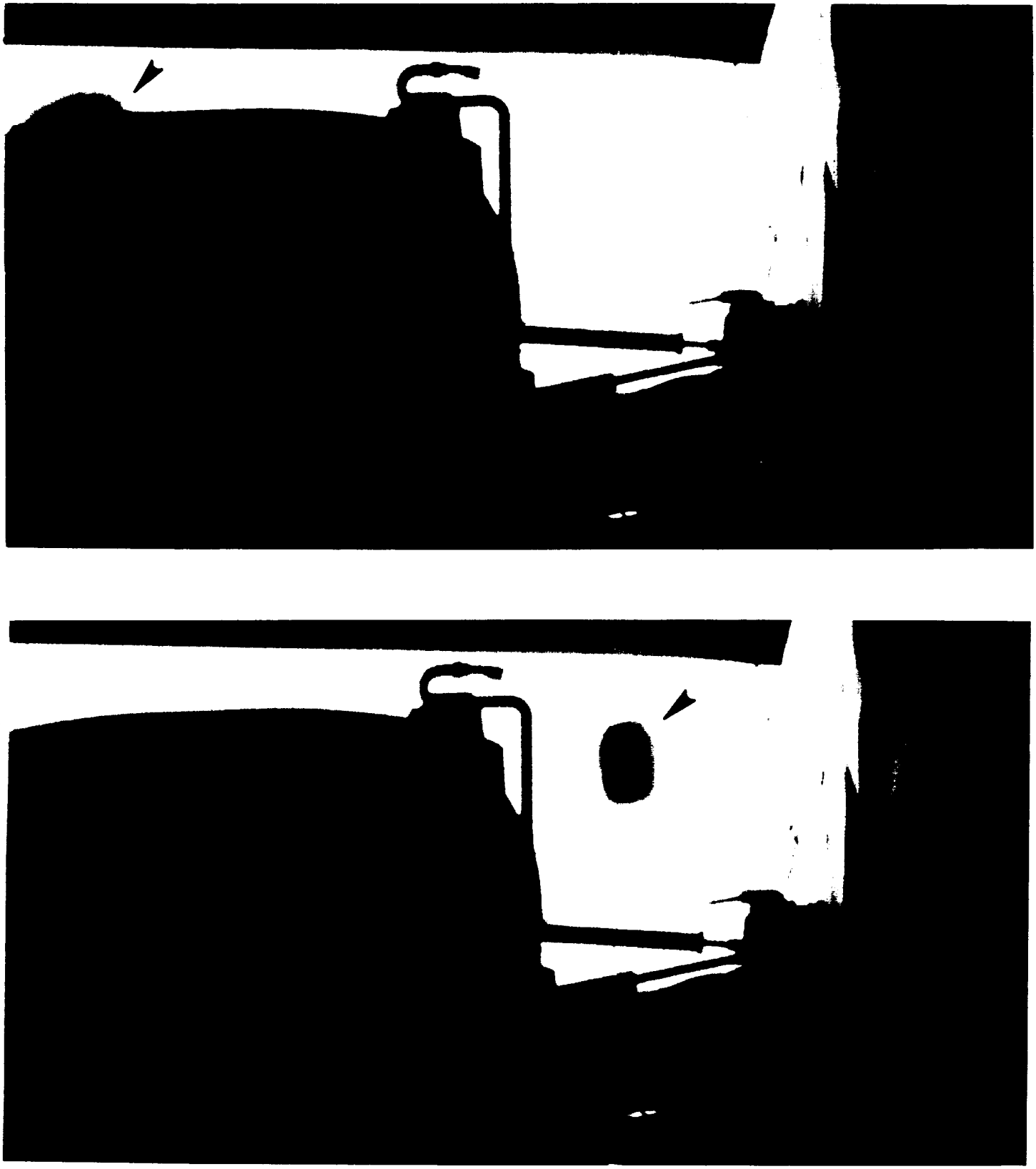


Photo 10: Debris Visible on -Z side of LO2 TSM

A dark colored object was visible on the -Z side of the LO2 TSM at 18:01:55.872 UTC. The object first appeared outboard of the right hand SRB and fell toward the base of the TSM. The object appeared to be close to the camera lens. The object did not impact the vehicle.

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. The +X translation was performed on this flight. Handheld photography by the flight crew consisted of thirty-seven still 35mm images.

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

ET-86 separation from the Orbiter also appeared normal. The nose cone appeared to be in nominal condition. A bright spot, either at the leading edge of the XT-593 pressurization line ramp, or in the acreage between ramps, may be a small, shallow divot that could not be confirmed with the available photography.

Seven very small TPS divots were detected on intertank stringer heads forward of the bipods. No divots were observed in the LH2 tank-to-intertank flange closeout. A 6-inch by 6-inch area of foam was missing from the -Y bipod jack pad closeout with some primer showing in the deep part of the divot.

TPS erosion on LO2 feedline flanges and support brackets, pressurization line ramps, and both thrust strut flange closeouts was somewhat more than usual, but still acceptable. Likewise, small and shallow "popcorn" type divots were somewhat greater in quantity on the LH2 tank with most of the divots, including as many as twenty-two 2-3 inch diameter divots, concentrated forward of the crossbeam.

Several divots were detected in and around pressurization line and LO2 feedline supports: a shallow 16-inch long by 10-inch wide divot in the LH2 acreage between the pressurization line and the LO2 feedline at station XT-1528; a 14-inch long by at least 2-inch wide divot outboard of the XT-1593 pressurization line ramp; a 5-inch diameter divot (possibly with primer showing) adjacent to the XT-1623 LO2 feedline inboard support; a 4-inch by 2-inch divot at the leading edge of the XT-1657 pressurization line ramp; and a shallow, 6-inch by 4-inch divot in the LH2 tank acreage between the pressurization line and the LO2 feedline at station XT-1722.

The ET/SRB upper strut fairing splice plate closeouts were intact but exhibited shallow "new foam" colored areas as thin layers of charred TPS flaked off during ascent.

The LH2 ET/ORB umbilical appeared to be in good condition after separation with no TPS damage. Frozen hydrogen adhered to the 17-inch disconnect and parts of the separation interface. Typically, foam had eroded from the horizontal (clamshell) section of the cable tray and the LH2 feedline support arm.

The LO2 ET/ORB umbilical sustained no visible TPS damage during separation. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. The red barrier around the EO-3 fitting was dislodged.

Aft dome NCFI 24-57 exhibited somewhat more than usual charring and "popcorn" divoting than previous flights.

No significant loss of foam from the upper LH2 tank/LO2 feedline area was observed that could be related to the cause of the debris impact to the RH SRB cork run. Since damage to the Orbiter lower surface tiles was less than average, no IFA's on ET TPS divots will be proposed.

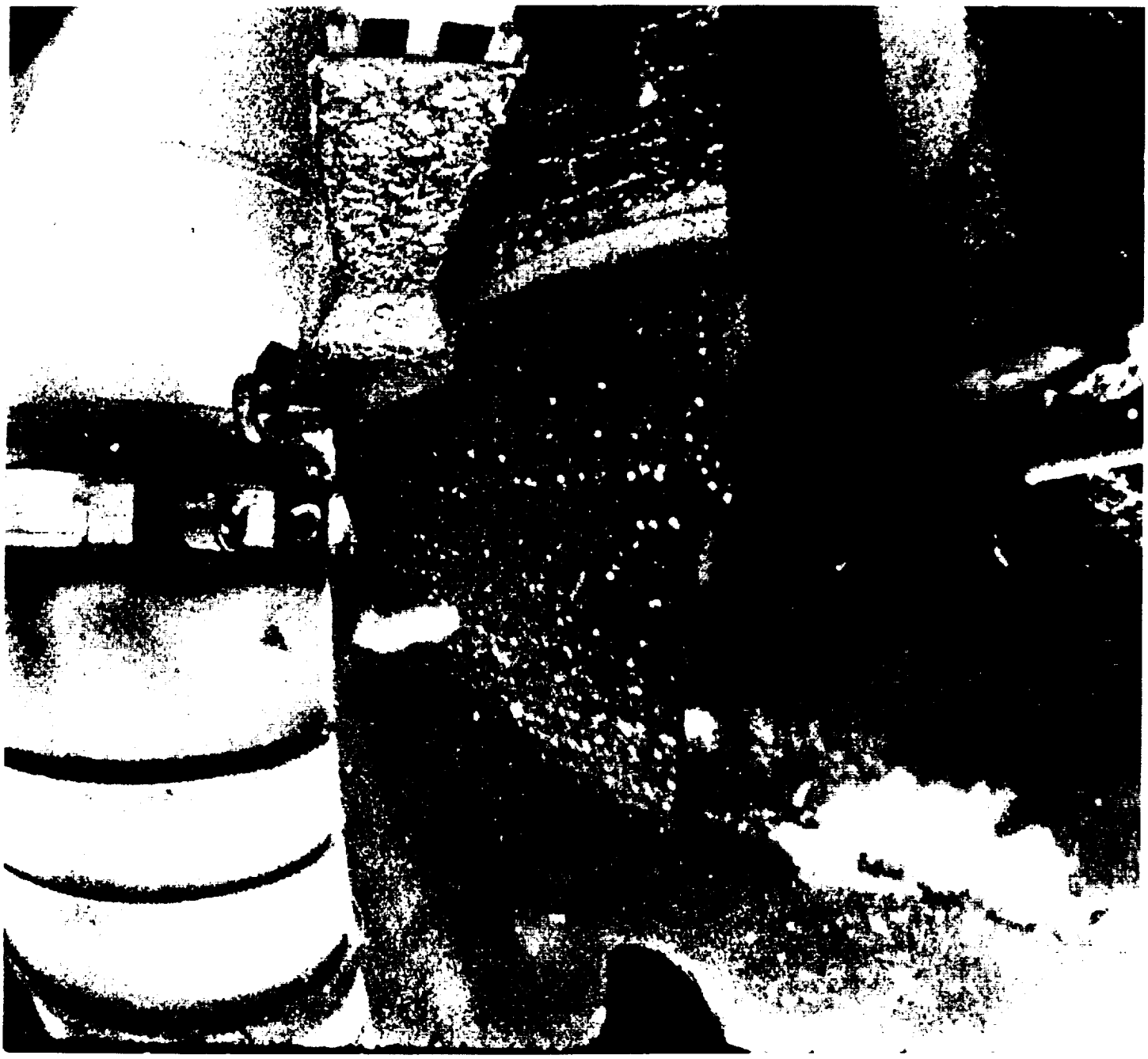


Photo 11 : SRB/ET Separation

SRB separation from the External Tank appeared nominal.

Photo 12 : ET Intertank TPS Divots

(1) Seven very small TPS divots were detected on intertank stringer heads forward of the bipods.
(2) A 6-inch by 6-inch area of foam was missing from the -Y bipod jack pad closeout with some primer showing in the deep part of the divot.

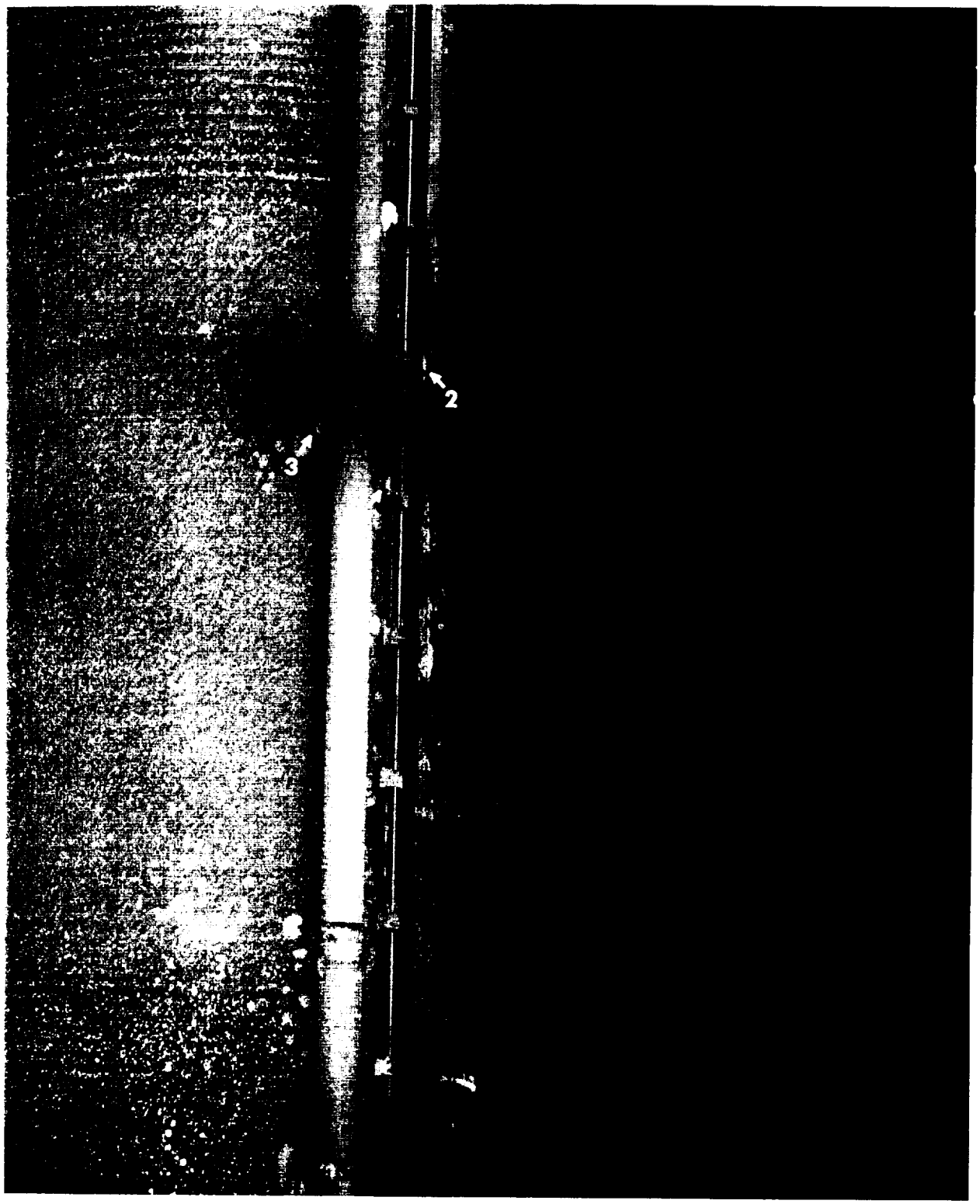


Photo 13 : ET LH2 Tank TPS Divots

Several divots were detected in and around pressurization line and LO2 feedline supports: (1) a shallow 16-inch long by 10-inch wide divot in the LH2 acreage between the pressurization line and the LO2 feedline at station XT-1528; (2) a 14-inch long by at least 2-inch wide divot outboard of the XT-1593 pressurization line ramp; (3) a 5-inch diameter divot (possibly with primer showing) adjacent to the XT-1623 LO2 feedline inboard support; (4) a 4-inch by 2-inch divot at the leading edge of the XT-1657 pressurization line ramp; (5) and a shallow, 6-inch by 4-inch divot in the LH2 tank acreage between the pressurization line and the LO2 feedline at station XT-1722.

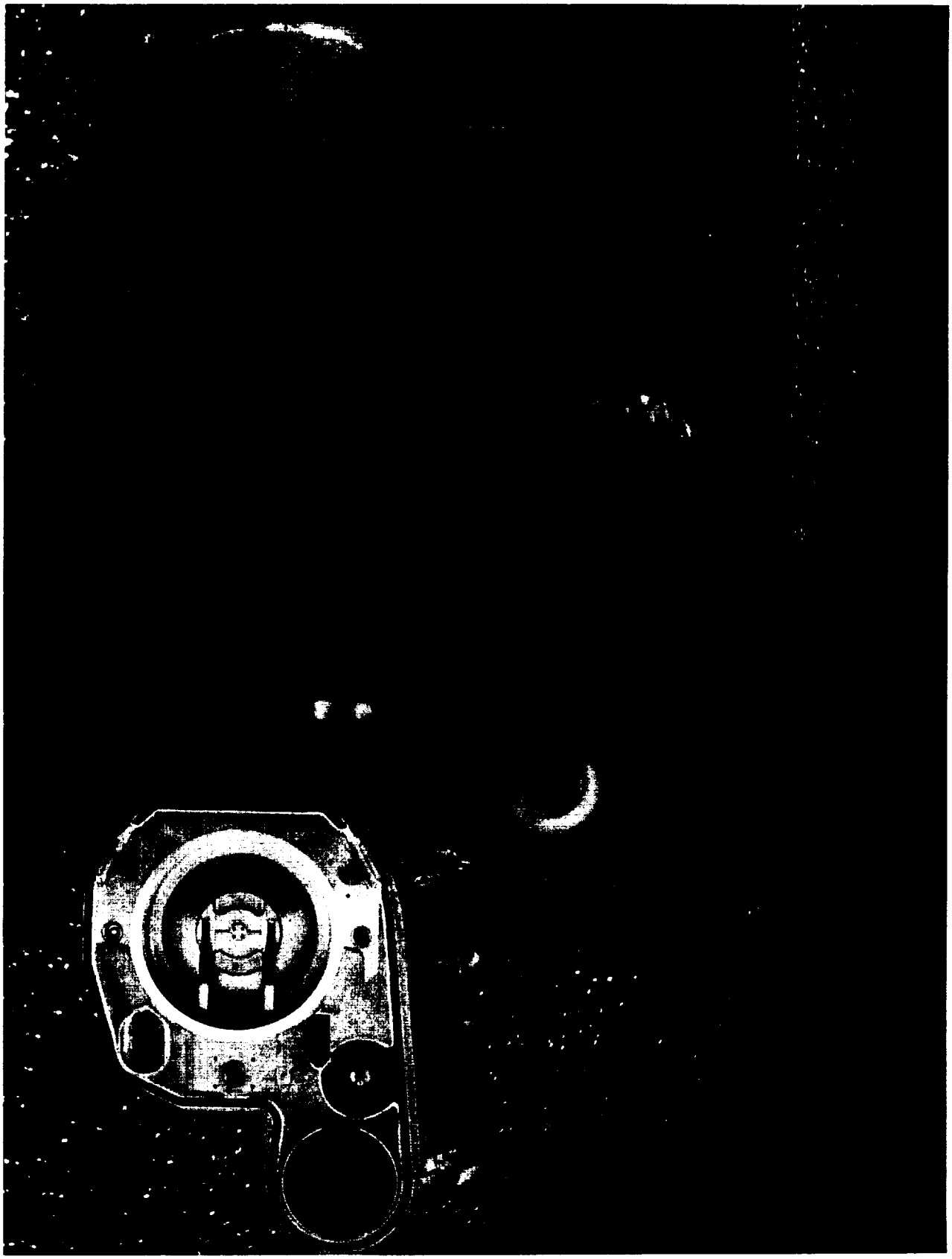


Photo 14 : ET/ORB LO2 Umbilical

The LO2 ET/ORB umbilical sustained no visible TPS damage during separation. Numerous divots and eroded areas were visible on the horizontal and vertical sections of the cable tray. The red barrier around the EO-3 fitting was dislodged.

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 left main landing gear contacted the runway first just west of the runway centerline.

Drag chute deployment appeared nominal.

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

No significant TPS damage was visible in the films.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-088 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 3-7 July 1997.

Both frustums were in excellent condition. No TPS was missing and no debonds were detected over fasteners on either frustum. None of the Hypalon paint had blistered. All four BSM aero heat shield covers on the right frustum were locked in the fully opened position. The lower right BSM aero heat shield cover on the left frustum was locked in the fully opened position; the remaining covers were bent. The BSM aero heat shield cover attach rings had been bent by parachute riser entanglement after splashdown.

The forward skirts exhibited no debonds or missing TPS. The RSS antennae covers/phenolic base plates were intact. The +Z antenna base plate on both SRB's exhibited one delaminated phenolic layer. Hypalon paint was blistered/missing over the areas where BTA closeouts had been applied. No pins were missing and no pin retainer clips were bent on either frustum severance ring.

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. One area of forward edge cork damage was noted on the right hand center joint at about the 200 degree position. This damage was most probably caused by ice from the ET LO2 feedline forward bellows.

Separation of the aft ET/SRB struts appeared normal. The ETA ring, IEA, and IEA covers appeared undamaged from splashdown

The forward stiffner ring on the left booster had been damaged by splashdown. The stiffener ring had separated from the aft booster from approximately 200 to 290 degrees.

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

Seven of the holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally. The HDP #6 DCS plunger was obstructed by pyro debris.

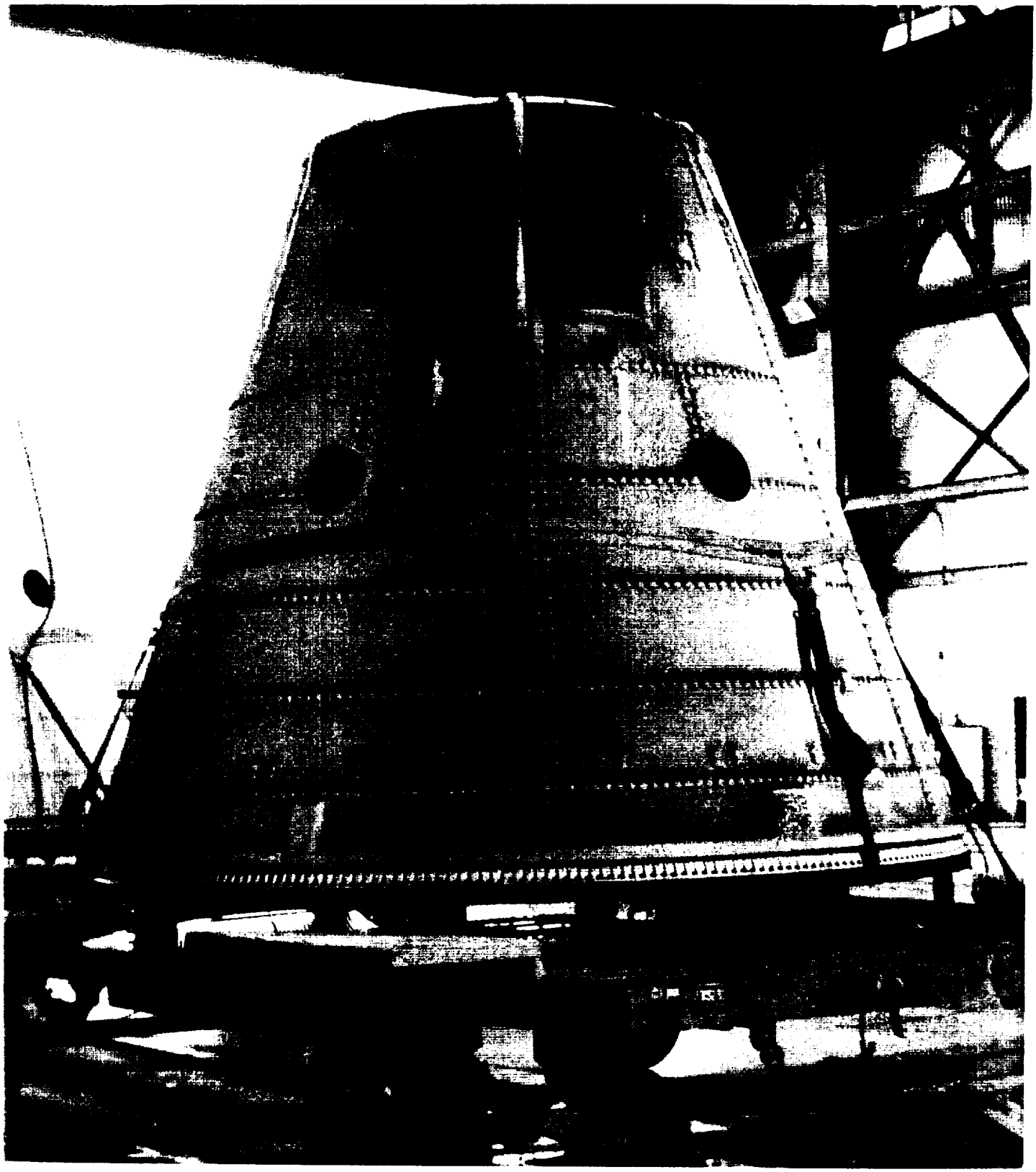


Photo 15: Right Frustum

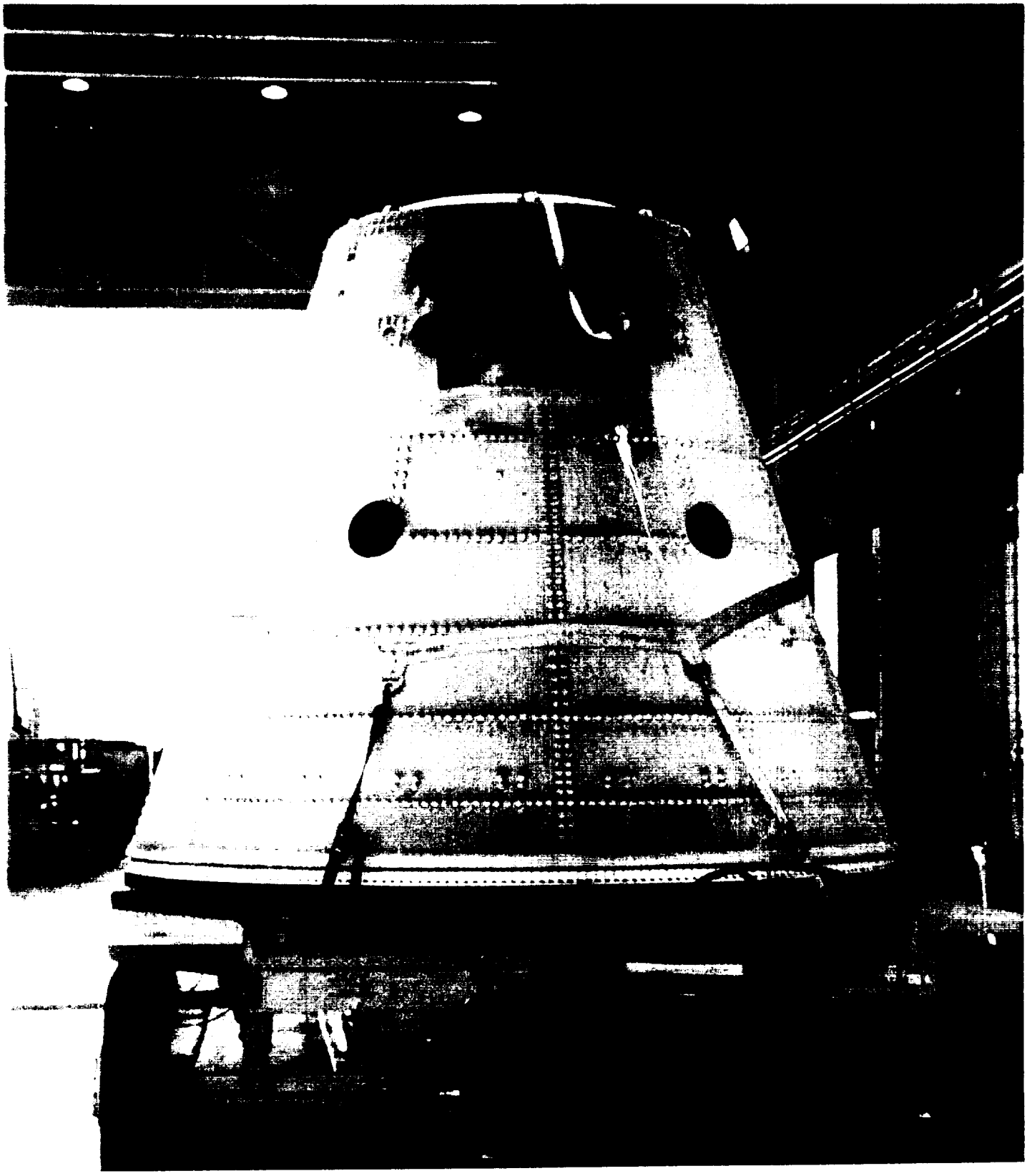


Photo 16: Left Frustum

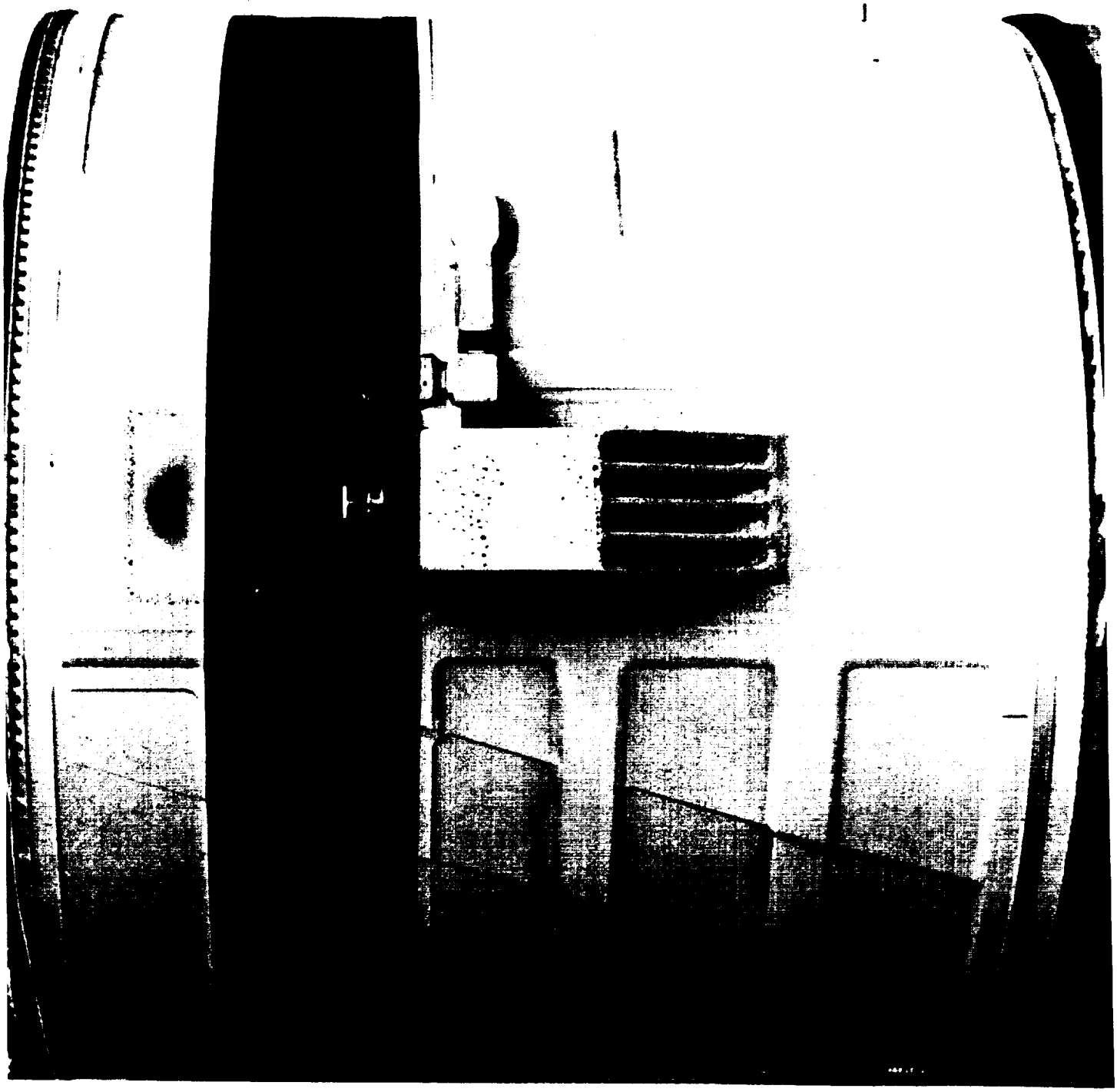


Photo 17: Left Forward Skirt

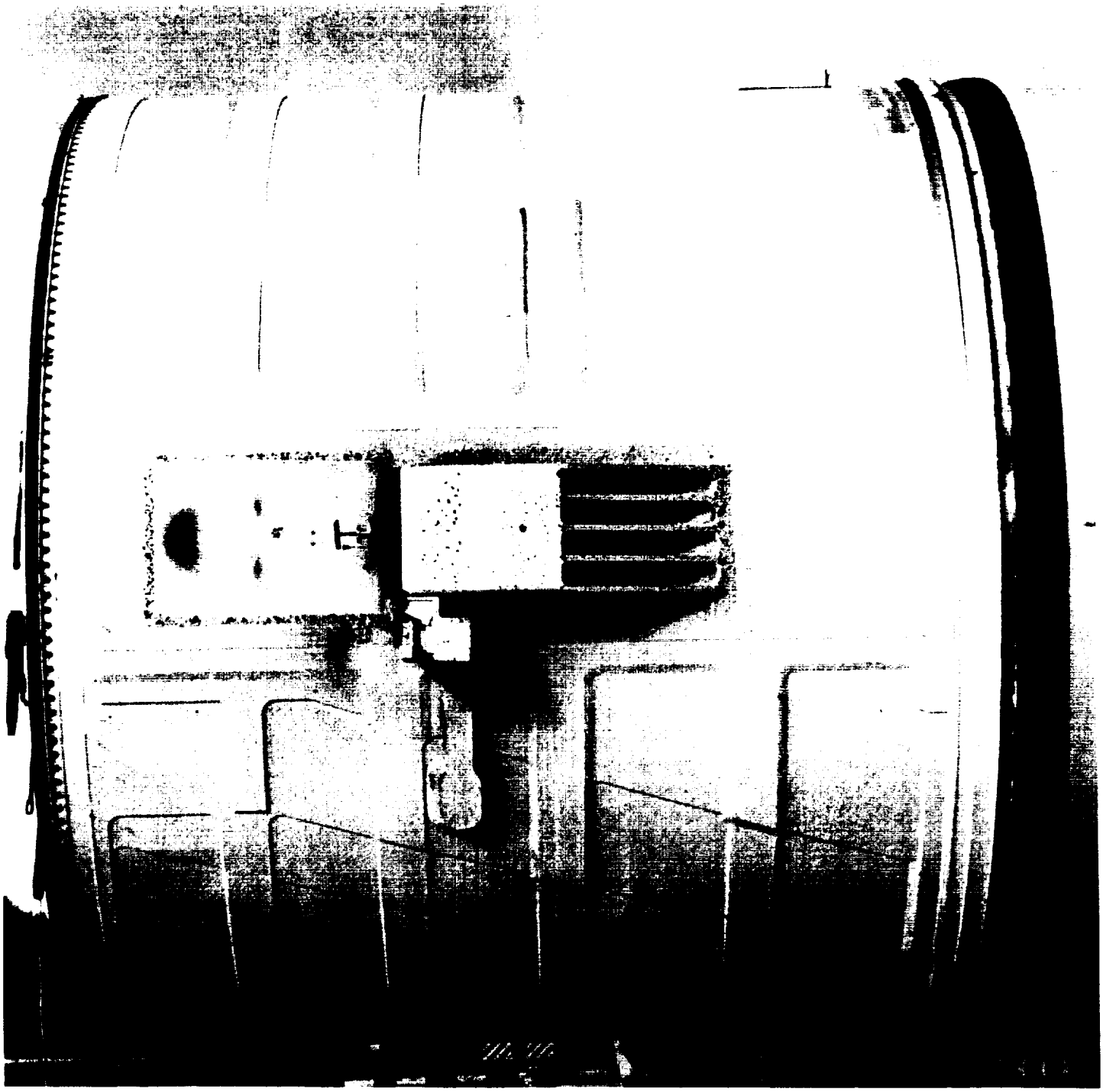


Photo 18: Right Forward Skirt

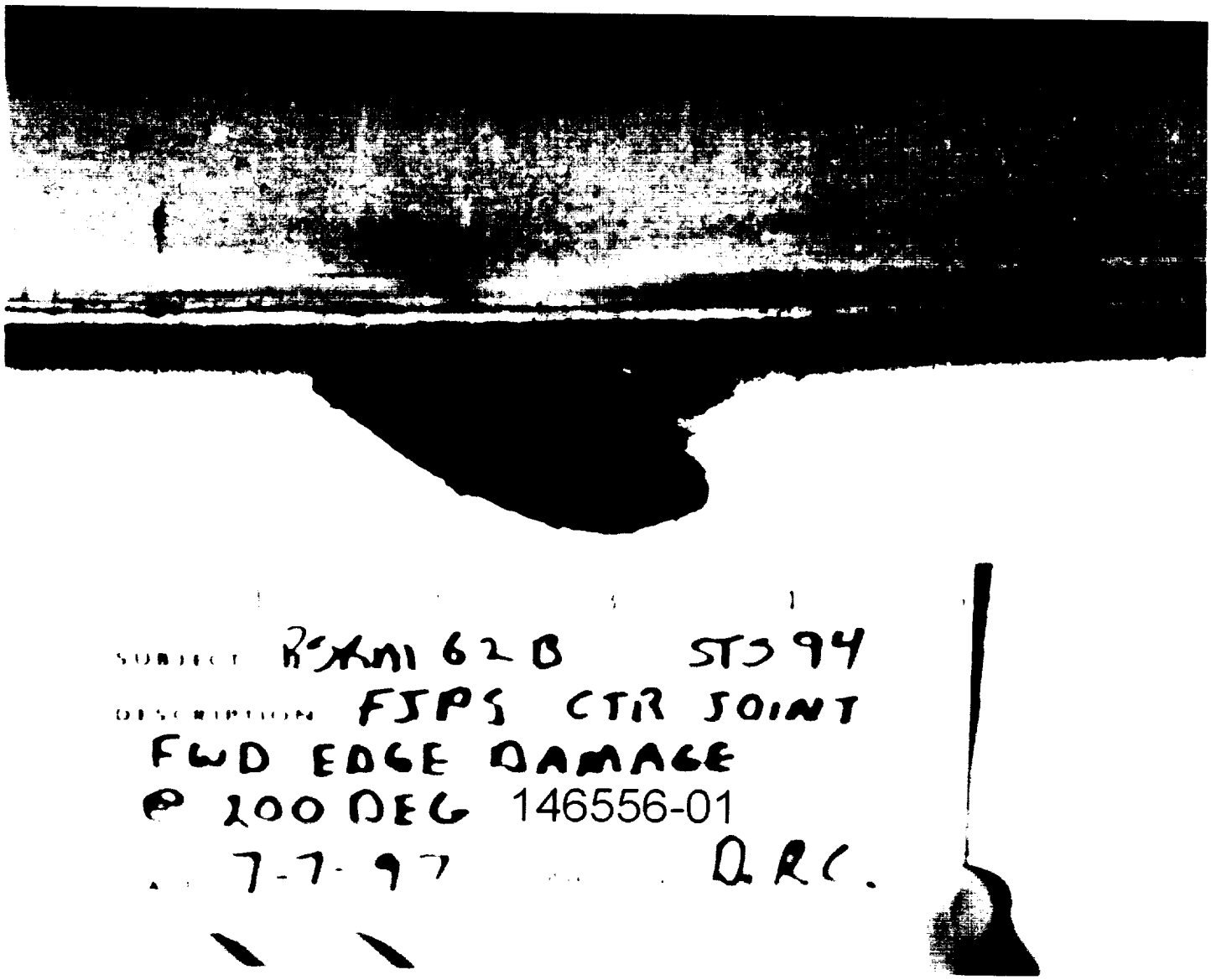


Photo 19: Right Center Joint FJPS Damage

Damage was found on the right hand SRB center joint leading edge at about the 200 degree position. This damage was most probably caused by ice from the ET LO2 feedline forward bellows.

Photo 20: LH SRB Stiffener Ring Damage

The lefthand SRB forward stiffener ring had separated from the aft booster from approximately 200 to 290 degrees. Damage was most likely caused by splashdown.

Photo 21: Lefthand SRB/ET Struts

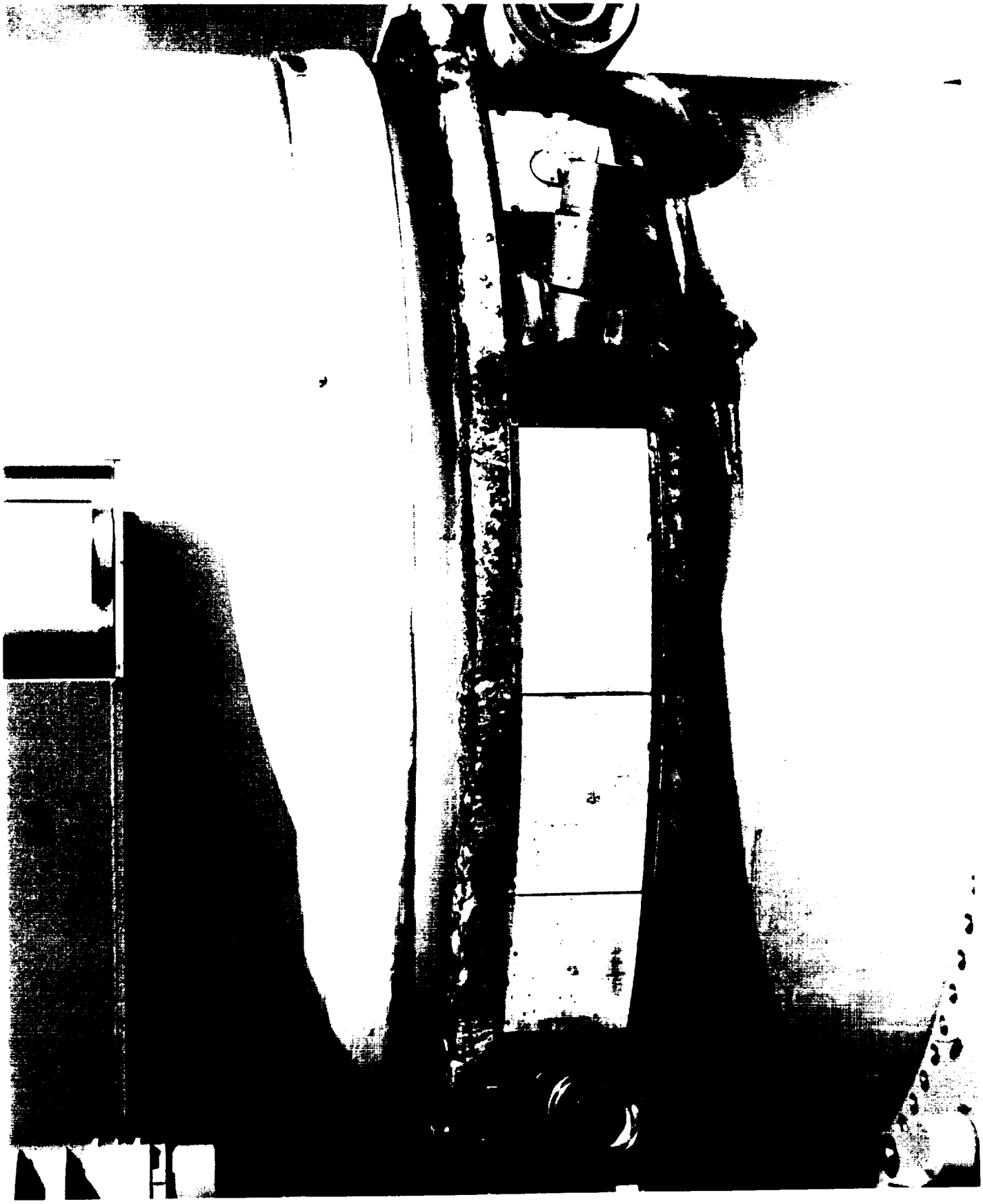


Photo 22: Righthand SRB/ET Struts

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-102 Columbia was conducted 17-18 July 1997 at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #2. This inspection was performed to identify debris impact damage and, if possible, debris sources. The Orbiter TPS sustained a total of 90 hits, of which 12 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 69 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits, and the number of hits 1-inch or larger, were less than average (Reference attached Figure 3. Note: no debris hits were recorded on both left and right sides of the Orbiter. Accordingly, those two figures have been omitted).

The following table breaks down the STS-94 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	11	34
Upper surface	1	50
Right side	0	0
Left side	0	0
Right OMS Pod	0	3
Left OMS Pod	0	3
TOTALS	12	90

The Orbiter lower surface sustained a total of 34 hits, of which 11 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the right chine and measured 3.75-inches long by 1.75-inches wide by 0.125-inch deep. The shallow damage site most likely was caused by an impact from a low density object, such as ET foam.

Tile damage sites around the LH2 and LO2 ET/ORB umbilicals were less than usual in number and size.

Two tile damage sites forward of the right MLG wheel well (tiles 191003-041 and 191003-177) were originally thought to be candidates for micrometeorite impacts due to the 0.75-inch diameter surface openings with larger, deep internal cavities. However, closer inspection in the OPF revealed glazing and erosion, which suggested the impacts occurred during ascent.

No other tile damage from micrometeorites or on-orbit debris was identified during this inspection with the exception of the on-orbit impact to overhead window #7. The impact crater was approximately 0.25-inch in diameter.

The tires were reported to be in average condition for a landing on the KSC concrete runway. Some ply undercutting occurred on the MLG left inboard and right outboard tires.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilical cavities. Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect. The EO-2 and EO-3 retainer springs were dislodged. This condition has been observed on previous flights. One clip from the EO-2 and two clips from the EO-3 salad bowls were missing. A black deposit adhered to the inside of the LO2 ET door.

Damage to base heat shield tiles appeared to be less than usual. The SSME Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition, though some fraying was noted on the SSME #2 blanket at the 3-4:00 position.

Tiles on the vertical stabilizer "stinger" were intact and undamaged.

No ice adhered to the payload bay door. No unusual tile damage was observed on the leading edge of the vertical stabilizer. Although no significant tile damage was visible on the OMS pods, a 2-inch long by 1-inch wide piece of burned cloth tape was detected on the left OMS pod. Nearby, a 5-inch diameter RTV repair area had outgassed and charred, but was not the subject of a debris hit.

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size with the exception of a 7.5-inch long by 1.8-inch wide by 0.2-inch deep impact just forward of window #3. This damage site spanned the 391020-453 white tile and two unidentified adjacent black tiles. These damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the FRCS thrusters. A 2-inch long scorched piece of FRCS thruster paper cover was wedged between the window #2 glass and perimeter tiles adjacent to three tile damage sites.

The post landing walkdown of Runway 33 was performed immediately after landing. Three Ames tile gap fillers were found on the runway generally below the right inboard elevon at the Orbiter wheel-stop point. However, the thin gap fillers most likely originated from some place near the nose or nose landing gear doors. All drag chute hardware was recovered and appeared to have functioned normally. However, impact with the runway caused one of the TPS-covered carrier panels to be ripped off the drag chute door.

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

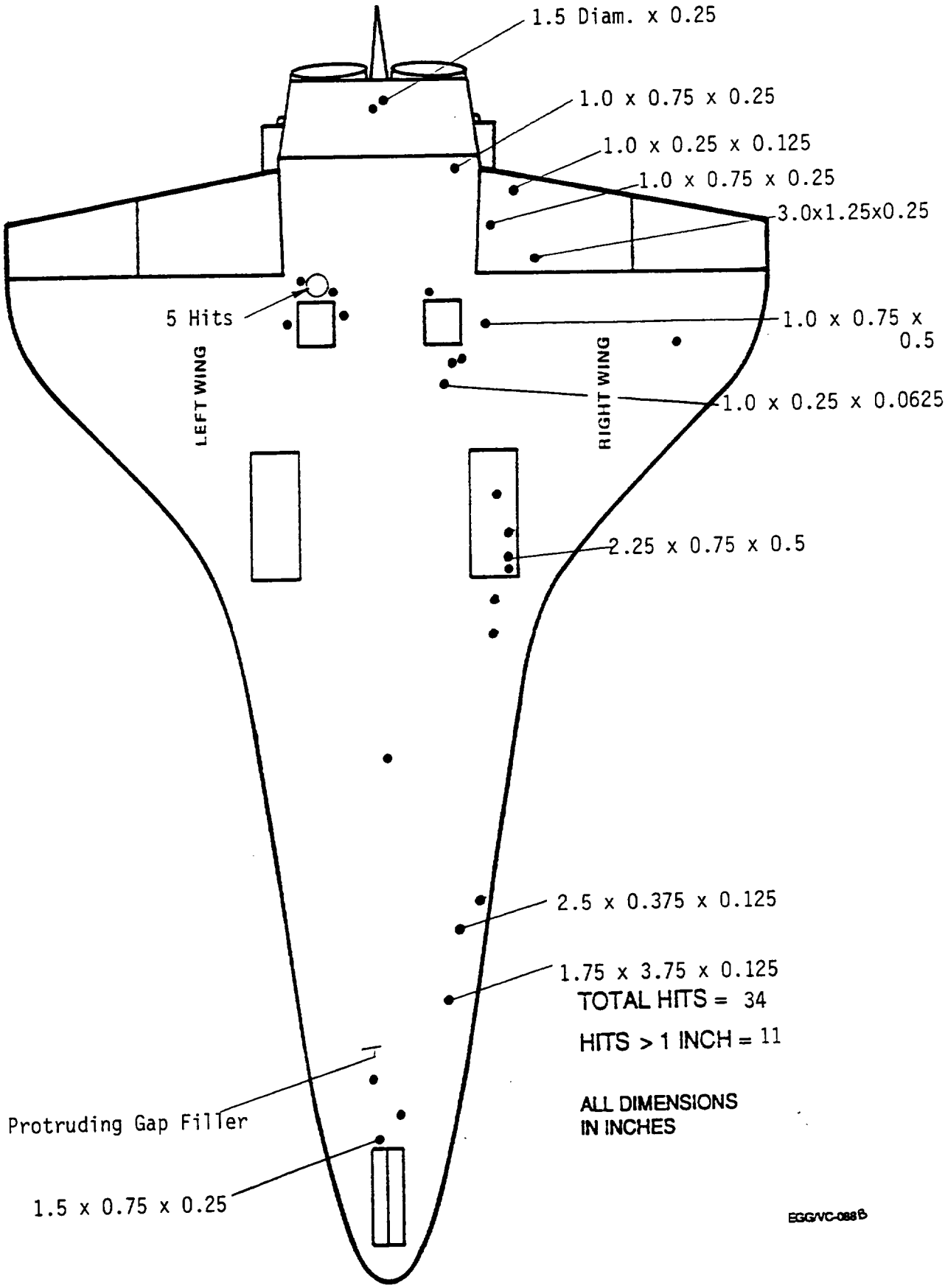


Figure 1: Orbiter Lower Surface Debris Damage Map

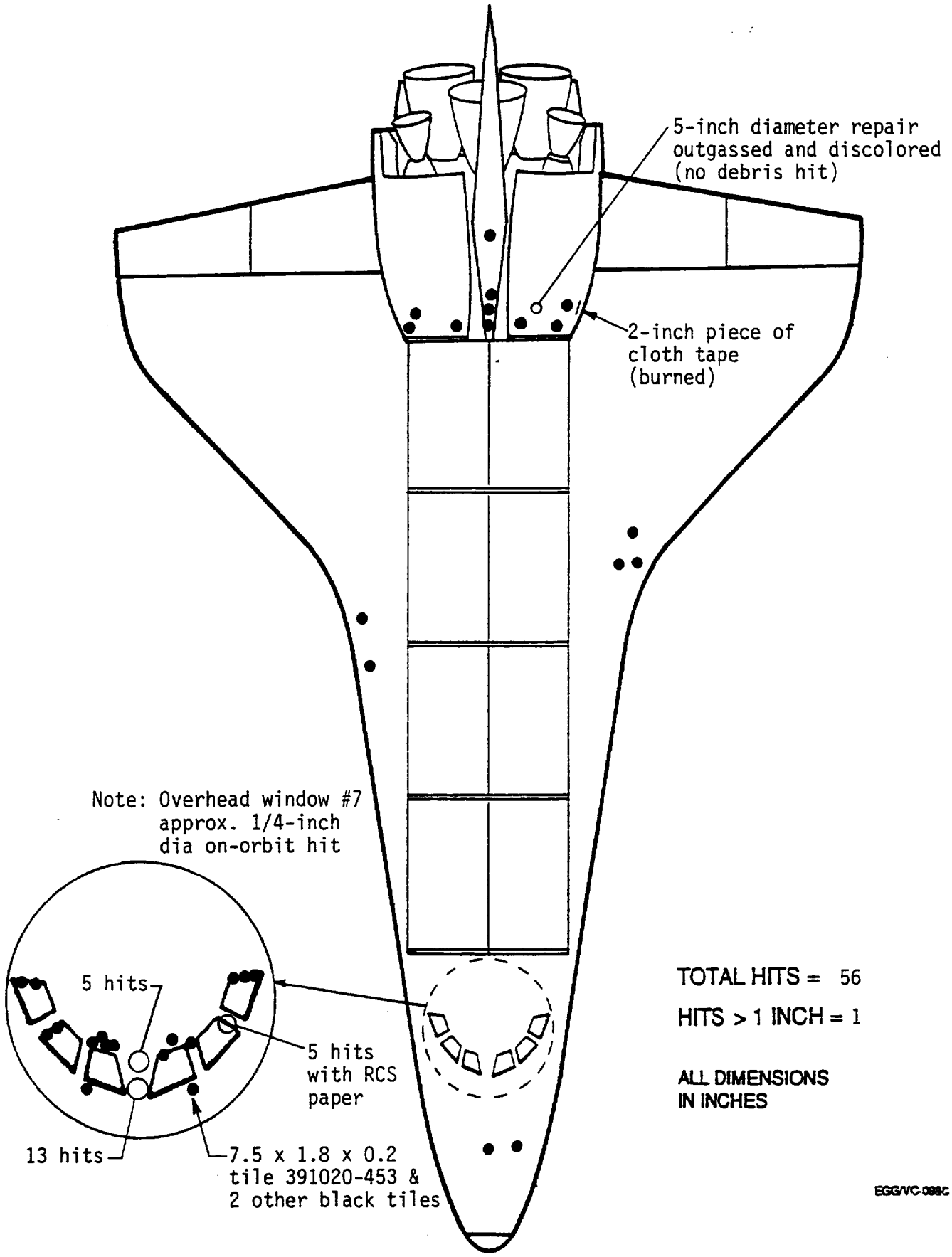


Figure 2: Orbiter Upper Surface Debris Damage Map

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-6	21	89	36	120
STS-8	3	29	7	56
STS-9 (41-A)	9	49	14	58
STS-11 (41-B)	11	19	34	63
STS-13 (41-C)	5	27	8	36
STS-14 (41-D)	10	44	30	111
STS-17 (41-G)	25	69	36	154
STS-19 (51-A)	14	66	20	87
STS-20 (51-C)	24	67	28	81
STS-27 (51-I)	21	96	33	141
STS-28 (51-J)	7	66	17	111
STS-30 (61-A)	24	129	34	183
STS-31 (61-B)	37	177	55	257
STS-32 (61-C)	20	134	39	193
STS-29	18	100	23	132
STS-28R	13	60	20	76
STS-34	17	51	18	53
STS-33R	21	107	21	118
STS-32R	13	111	15	120
STS-36	17	61	19	81
STS-31R	13	47	14	63
STS-41	13	64	16	76
STS-38	7	70	8	81
STS-35	15	132	17	147
STS-37	7	91	10	113
STS-39	14	217	16	238
STS-40	23	153	25	197
STS-43	24	122	25	131
STS-48	14	100	25	182
STS-44	6	74	9	101
STS-45	18	122	22	172
STS-49	6	55	11	114
STS-50	28	141	45	184
STS-46	11	186	22	236
STS-47	3	48	11	108
STS-52	6	152	16	290
STS-53	11	145	23	240
STS-54	14	80	14	131
STS-56	18	94	36	156

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
STS-84	10	67	13	103
AVERAGE	13.4	84.6	19.8	125.1
SIGMA	7.2	43.8	9.5	52.4
STS-94	11	34	12	90

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

Figure 3: Orbiter Post Flight Debris Damage Summary

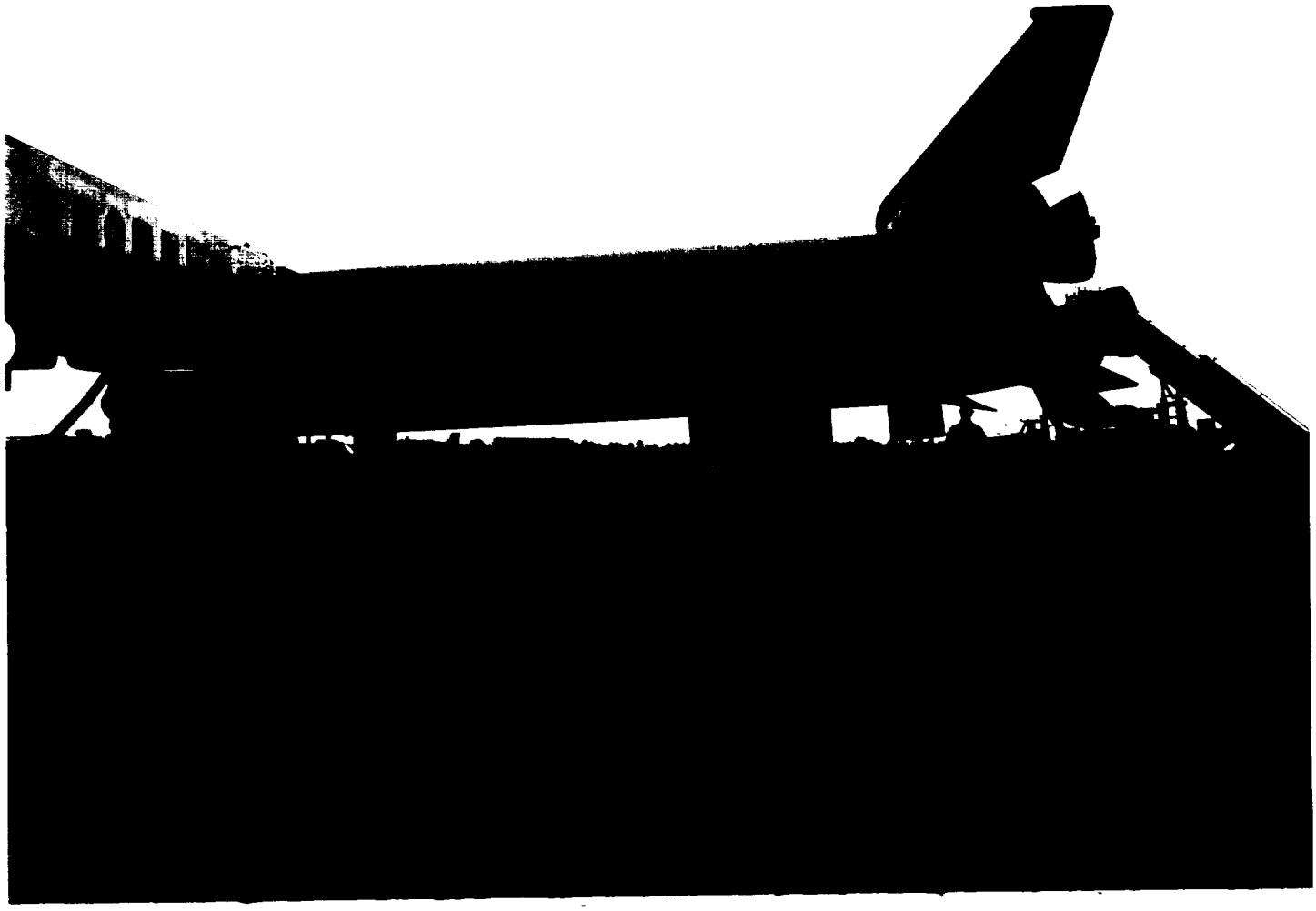


Photo 23: Overall View Orbiter Left Side

Photo 24: Overall View Orbiter Right Side

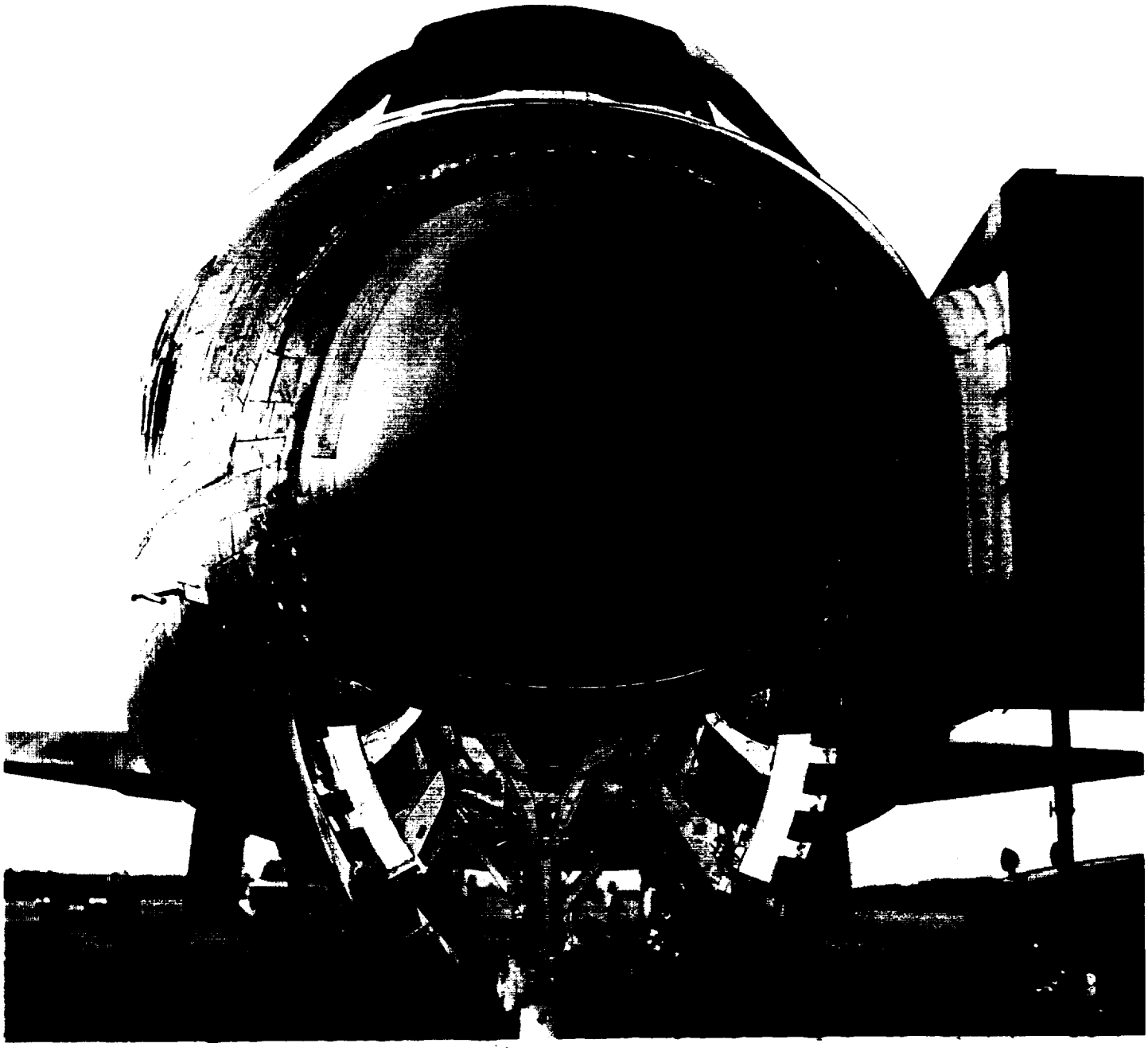


Photo 25: Overall View of Orbiter Nose

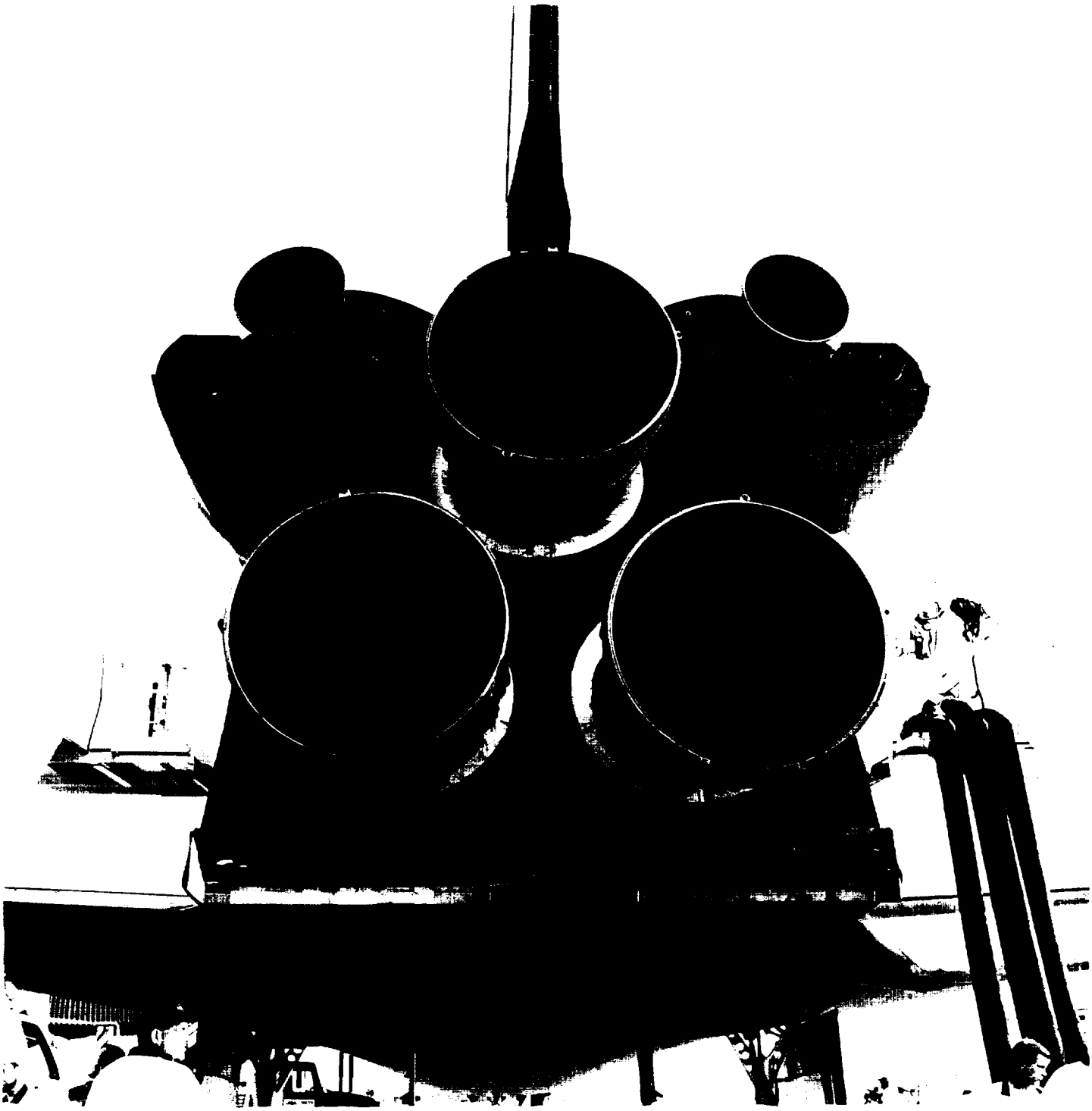


Photo 26: Overall View of Orbiter Base Heat Shield

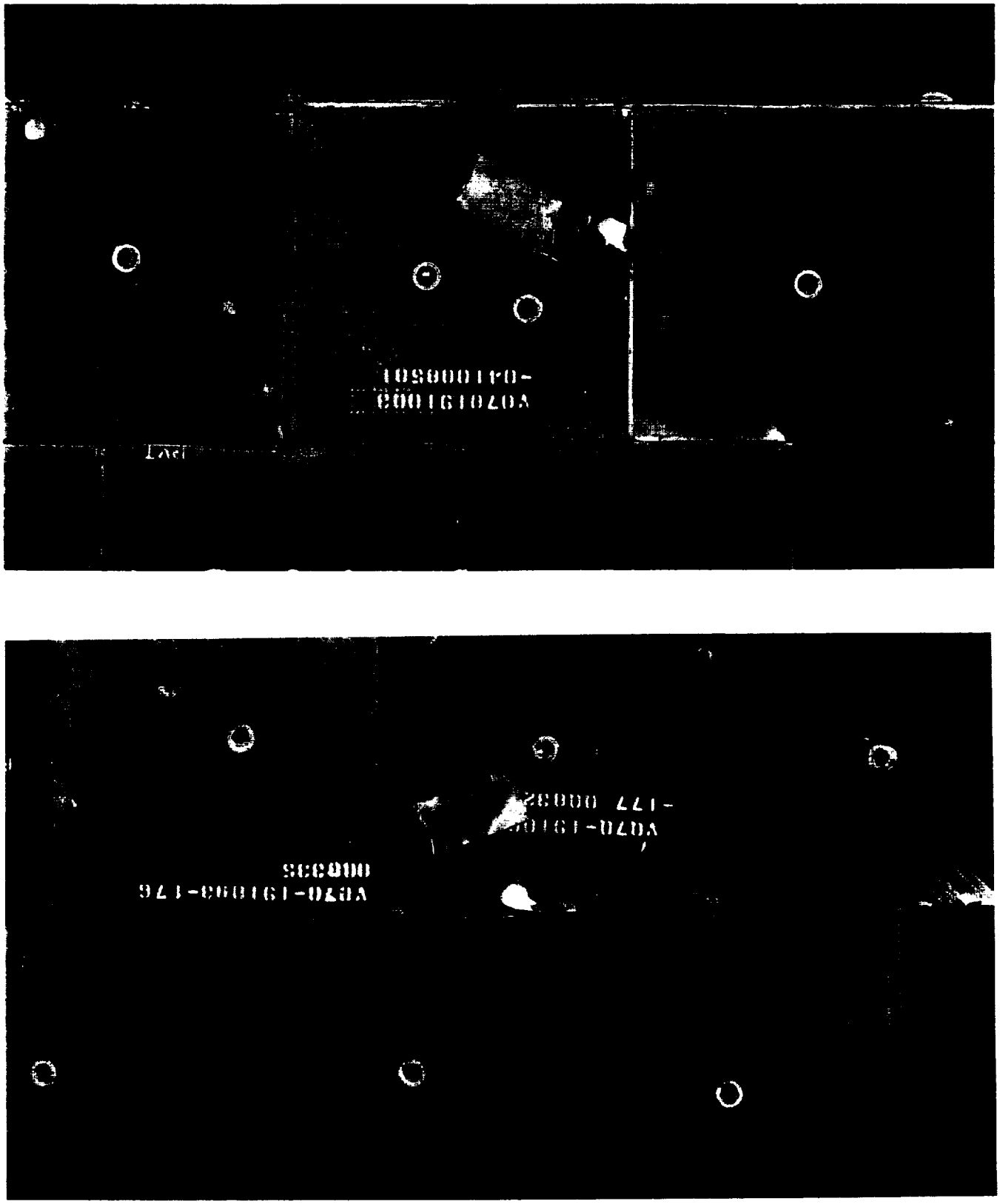


Photo 27: Tile Damage Sites Forward of Right MLG Door

Two tile damage sites forward of the right MLG wheel well (tiles 191003-041 and 191003-177) were originally thought to be candidates for micrometeorite impacts due to the ¾-inch diameter surface openings with larger, deep internal cavities. However, closer inspection in the OPF revealed glazing and erosion, which suggested the impacts occurred during ascent.

Photo 28: LO2 ET/ORB Umbilical

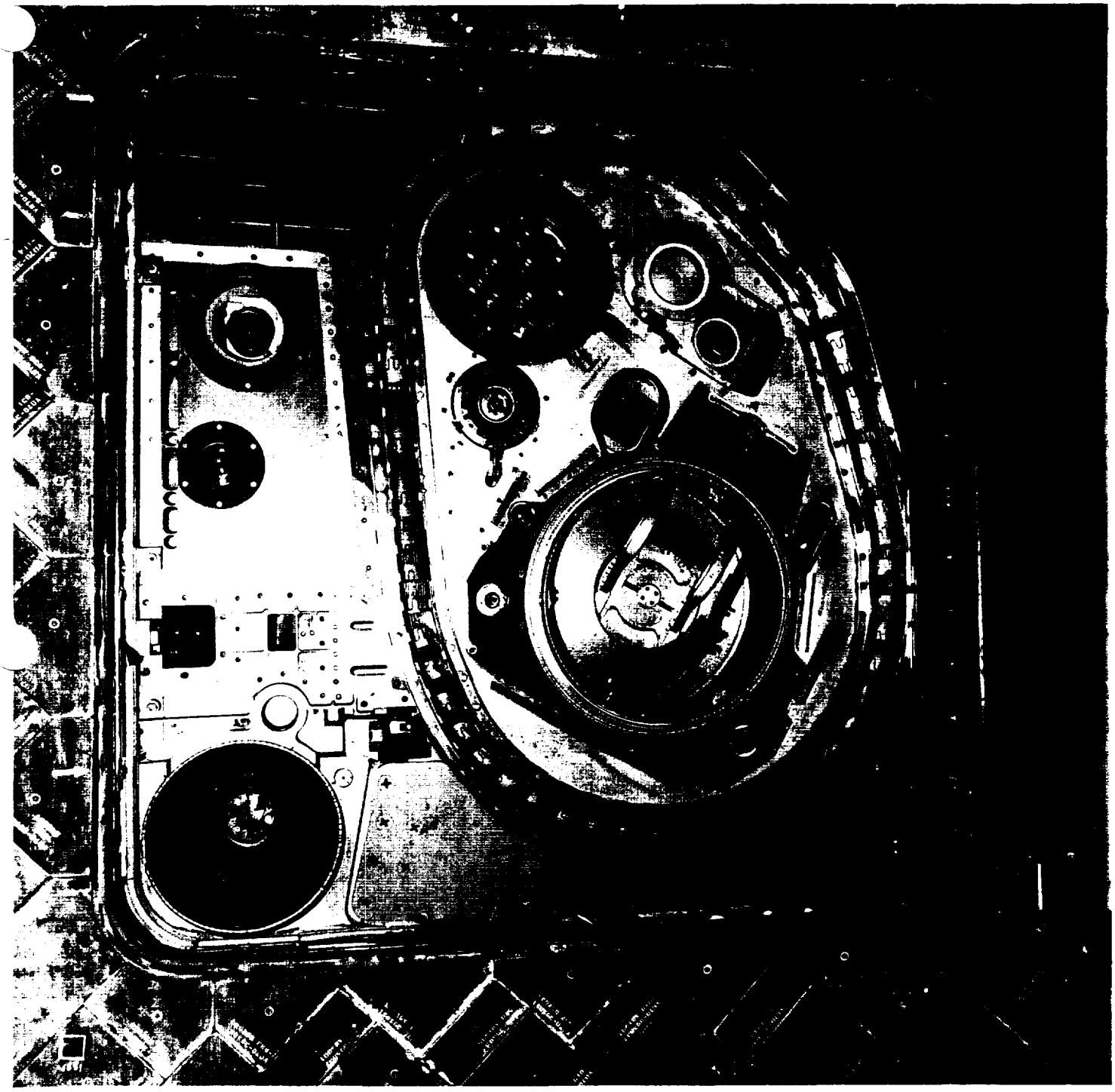


Photo 29: LH2 ET/ORB Umbilical

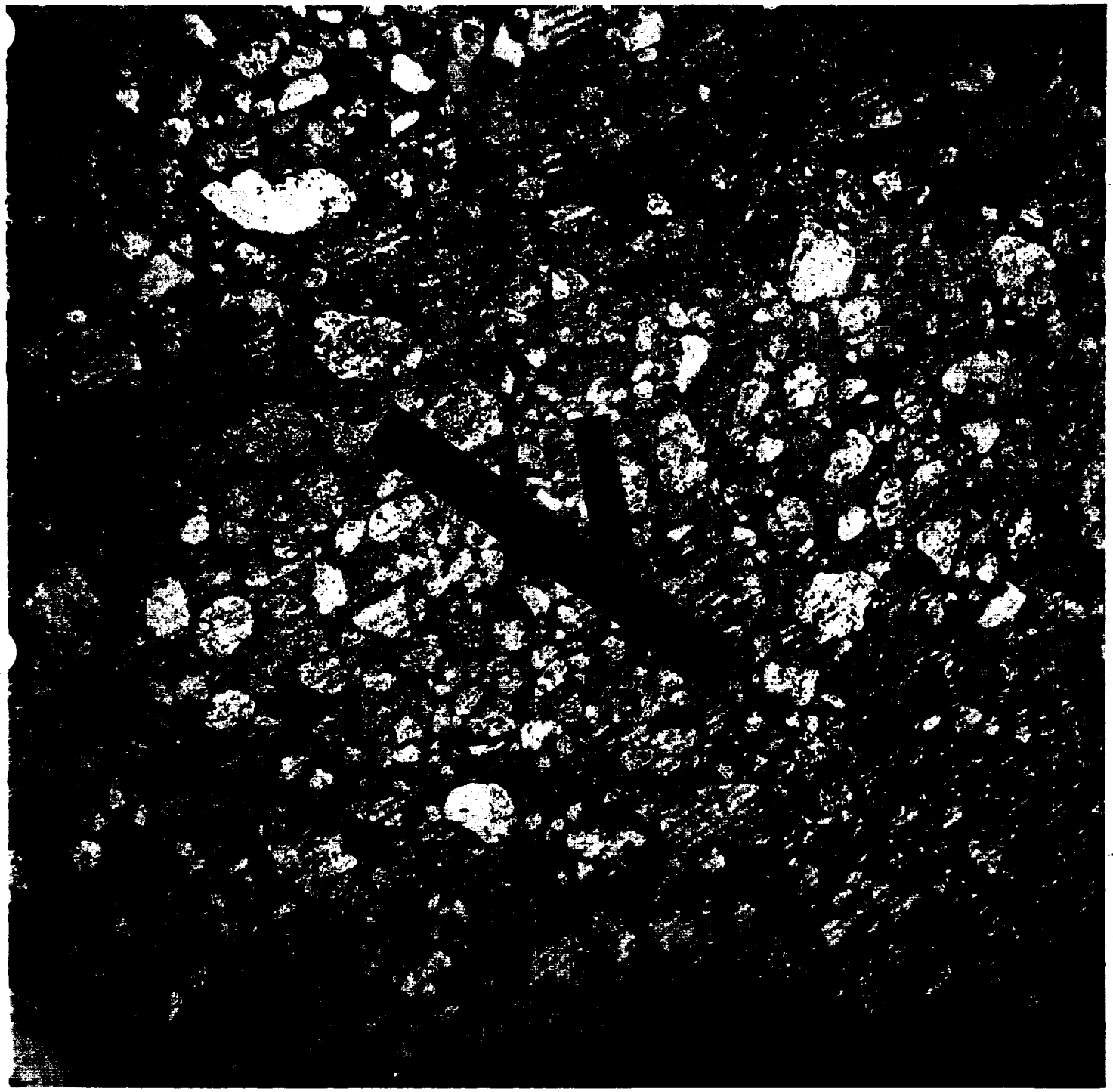


Photo 30: Ames Tile Gap Fillers Found on Runway

Three Ames tile gap fillers were found on the runway generally below the right inboard elevon at the Orbiter wheel-stop point. However, the thin gap fillers most likely originated from some place near the nose or nose landing gear doors.

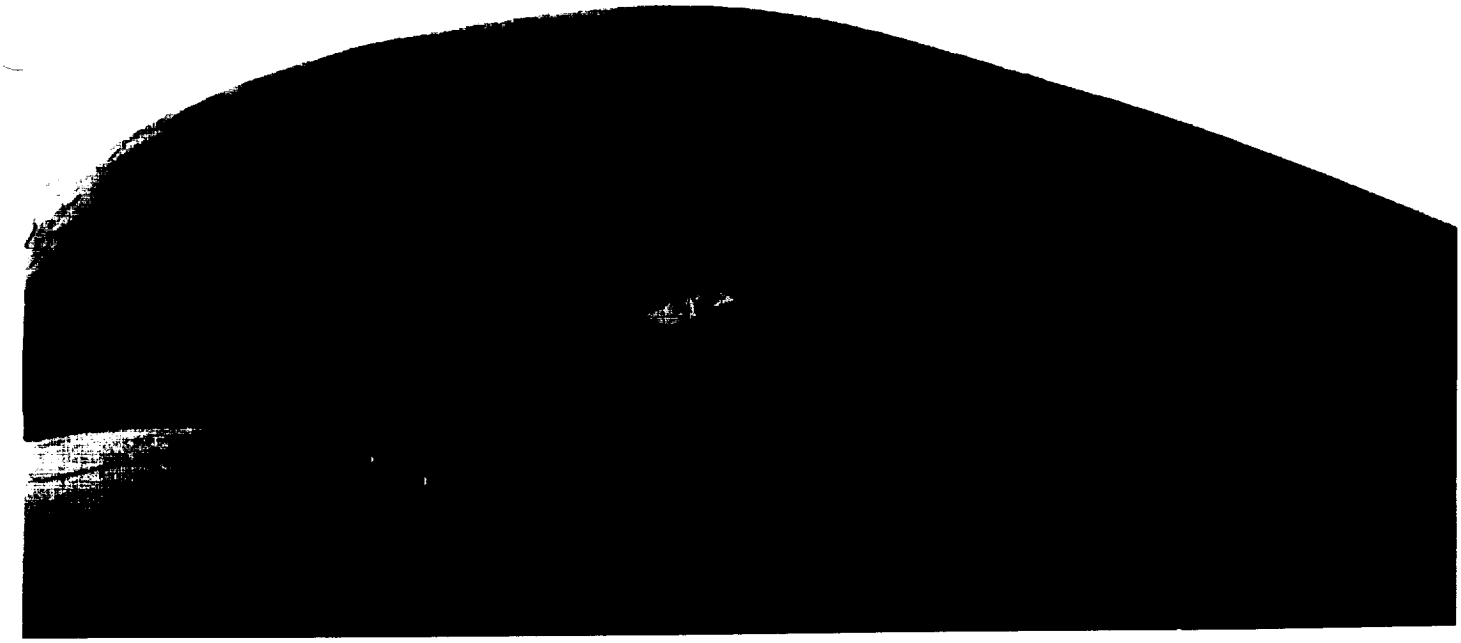


Photo 31: Windows 1 - 3

A 7.5-inch long by 1.8-inch wide by 0.2-inch deep impact was found forward of Window #3. This damage site spanned the 391020-453 white tile and two unidentified adjacent black tiles. These damage sites are believed to be the result of impacts from excessive RTV adhesive used in attaching paper covers to the FRCS thrusters. In fact, a 2-inch long scorched piece of FRCS thruster paper cover was wedged between the window #2 glass and perimeter tiles adjacent to three tile damage sites.

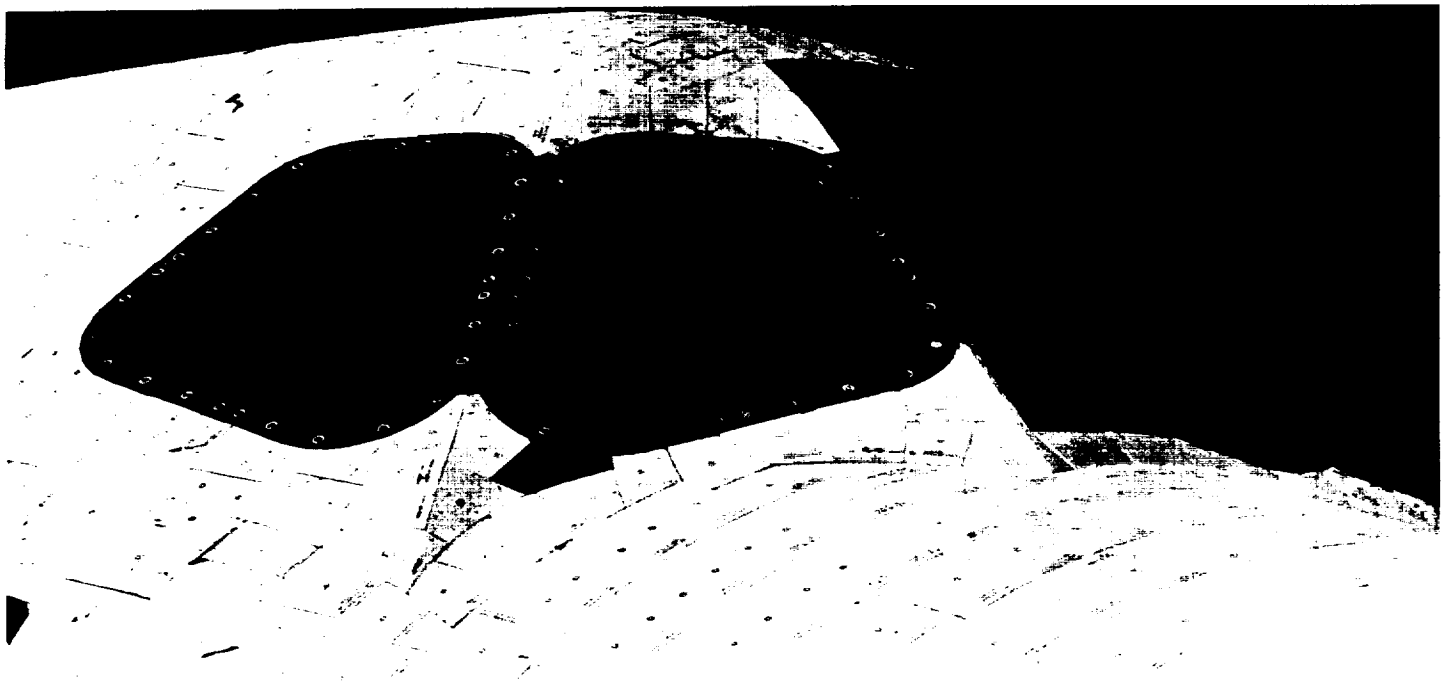


Photo 32: Windows 4 - 6

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

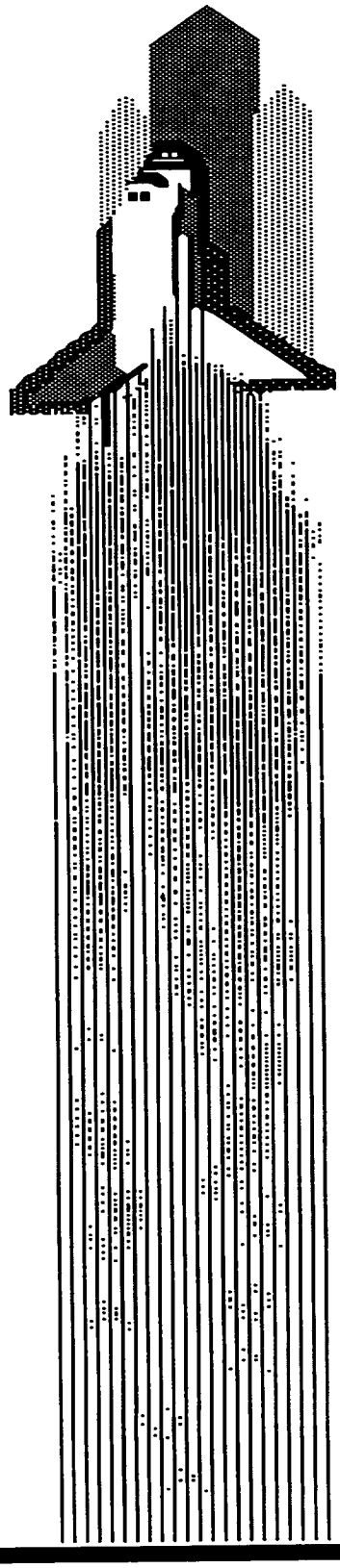
Space Shuttle

Earth Science Branch

Image Science and
Analysis Group

STS-94 Summary of Significant Events

August 14, 1997



Space Shuttle Image Science and Analysis Group

STS-94 Summary of Significant Events

Project Work Order - SN-5LA

Approved By

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Prepared By

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

Table of Contents

List of Tables and Figures

1. STS-94 (OV-102): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-94 afternoon launch of Columbia (OV-102) from pad A occurred on Tuesday, July 1, 1997 (day 182) at 18:02:00.003 Coordinated Universal Time (UTC), as seen on camera E10. Solid Rocket Booster (SRB) separation occurred at 18:04:03.467 UTC, as seen on camera E212.

On launch day, 24 of the 24 expected videos were received and screened. Following launch day, twenty films were screened. Twenty-three additional films were received for contingency support and anomaly resolution, but were not screened since there were no major launch/ascent issues.

Detailed Test Objective 312 was performed using umbilical well film (Method 1) and handheld still photography (Method 4). The DTO-312 ET separation photography was analyzed for indications of the possible debris source that caused the damage to the right SRB on the forward edge of the right-hand center field joint protection system. Although several items of interest on the ET TPS were noted, none are believed to attribute to the RSRB damage.

1.1.2 On-Orbit

On mission day three, six Electronic Still Camera (ESC) pictures were down-linked by the STS-94 crew of a damage area on the outer pane of an Orbiter overhead window (Window #7). This damage probably resulted from a micro-meteoroid or orbital debris impact. Figure 1.1.2 is a view of the impact area from down-linked ESC picture number S94E5028. The impact area is enhanced and enlarged (inset) to show the extent of damage. No on-orbit analysis support was requested.

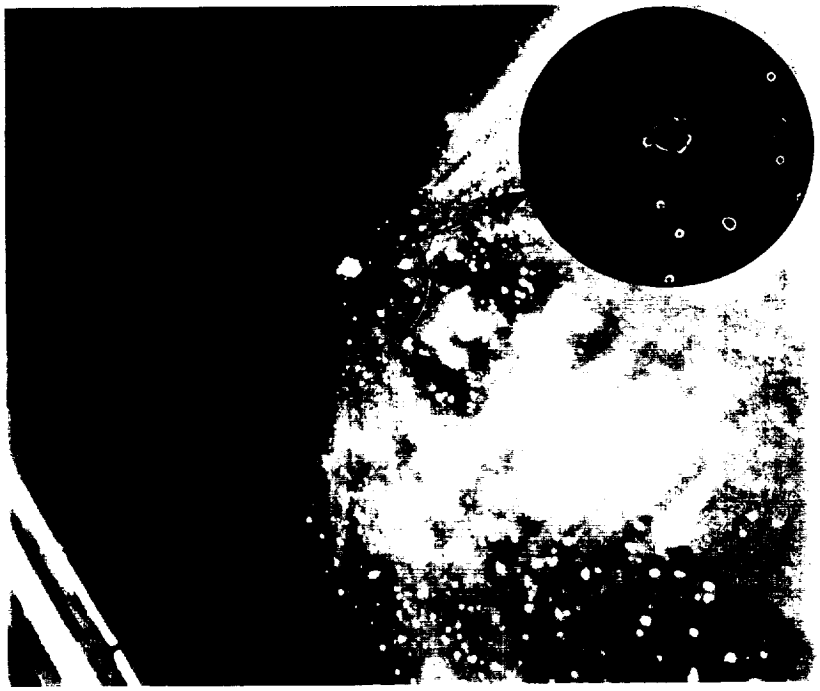

Figure 1.1.2 Debris Impact on Overhead Window #7

1.1.3 Landing

Columbia landed on runway 33 at the KSC Shuttle Landing Facility early on the morning of July 17, 1997. Twelve videos were received and screened. Following landing, eleven films were screened.

Contrails were seen trailing from the Orbiter wing tips prior to landing (Cameras EL1, EL2, EL4, EL7, EL9, EL10, EL12, KTV5L, KTV6L, KTV12L, KTV15L, KTV33L, SLF-North, SLF-South).

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

The drag chute deployment appeared normal.

1.1.4 Post Landing

The following items were seen on the post landing walk-around video: a dark-colored blemish or divot on the leading edge of the left OMS pod, typical erosion/chipping of the surface area of the base heat shield tiles between the SSMEs, minor single-tile damage on the base of the left RCS stinger, slight tile damage on the upper left surface of the body flap, tile damage on the lower

perimeter tiles between Orbiter forward windows number two and number three, and several small cut marks on the right main gear outboard tire.

1.2 TIMING ACTIVITIES

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

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

Event Description	Time (UTC)	Camera
Landing Gear - Doors Opened	198:10:46:12.830	KTV12L
Left Main Wheel Touchdown	198:10:46:33.183	EL9
Right Main Wheel Touchdown	198:10:46:33.468	EL15
Drag Chute Initiation	198:10:46:36.710	EL9
Pilot Chute at Full Inflation	198:10:46:37.503	EL9
Bag Release	198:10:46:38.186	KTV33L
Drag Chute Inflation in Reefed Configuration	198:10:46:39.178	EL2
Drag Chute Inflation in Disreefed Configuration	198:10:46:42.480	EL4
Nose Wheel Touchdown	198:10:46:44.210	EL12
Drag Chute Release	198:10:47:11.836	KTV15L
Wheel Stop	198:10:47:28.327	EL10

Table 1.2 Landing Events Timing

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION TO LIFTOFF

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

Figure 2.1 (A) Light-colored Debris near RSRB Stinger during SSME Ignition

A single piece of light-colored debris, possibly RCS paper or ice debris, was seen coming from behind the RSRB stinger during SSME ignition (18:01:56.821 UTC) (Cameras OTV070, 0TV051).

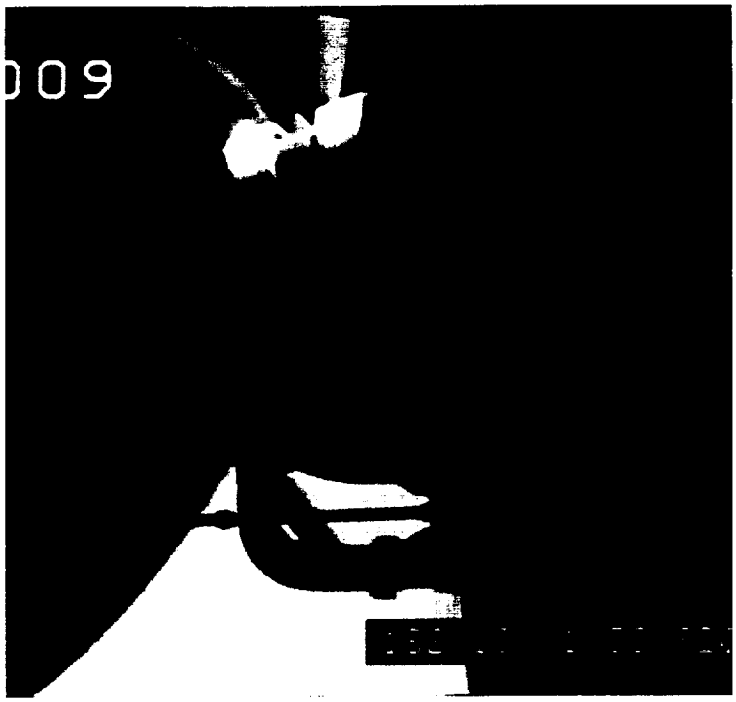

Figure 2.1 (B) Ice Debris Strike to LH2 Umbilical Well Door Sill

Multiple pieces of ice debris from the LH2 ET/Orbiter umbilical were seen falling during SSME ignition. A piece of ice debris was seen to strike the LH2 umbilical well door sill (18:01:56.920 UTC)(Camera OTV009).

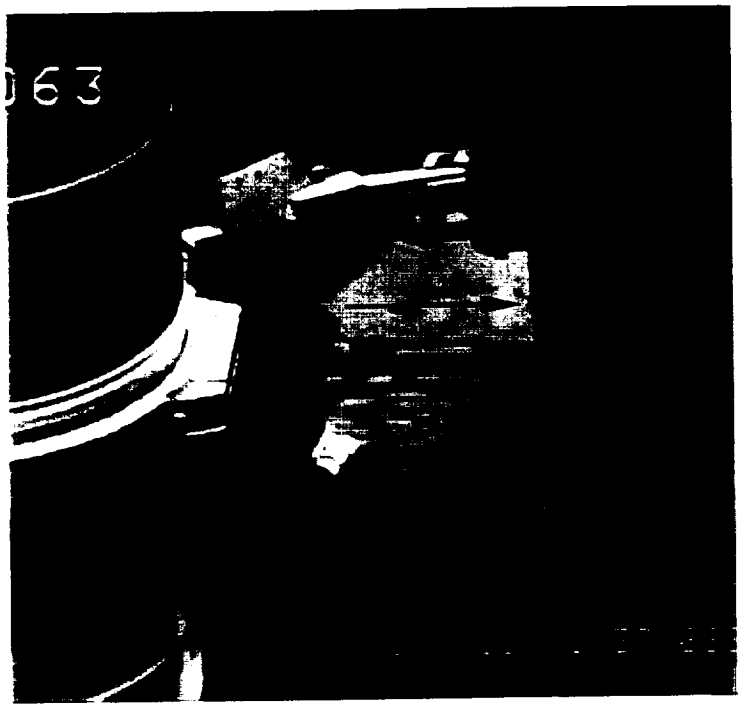

Figure 2.1 (C) Ice Debris Contacts Orbiter Tiles

A single piece of ET/Orbiter umbilical ice debris appeared to contact the Orbiter tiles aft of the ET/Orbiter LH2 umbilical during SSME ignition (18:01:57.688 UTC) (Camera OTV063).

Two dark-colored pieces of debris (possibly birds) were seen traveling across the camera field-of-view between the LO2 TSM and the RSRB at liftoff (18:02:00.57 UTC) (Camera E2).

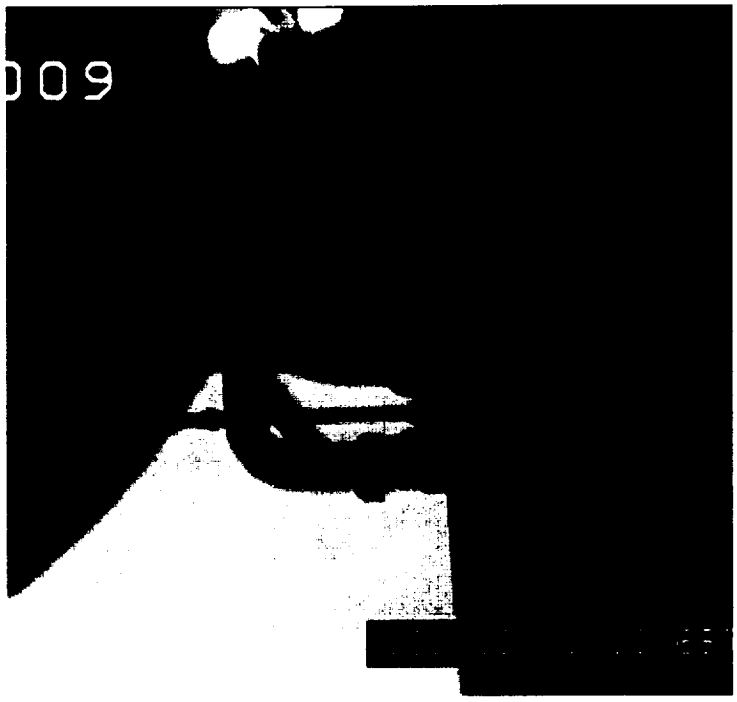

Figure 2.1 (D) Debris Forward of ET/Orbiter Umbilicals

During liftoff, a single light-colored piece of debris was seen falling from an unidentified area forward of the ET/Orbiter umbilicals (18:02:00.657 UTC) (Camera OTV009). Also, during liftoff, multiple pieces of ET/Orbiter umbilical ice were seen falling along the body flap (Camera E4). The debris did not appear to contact the vehicle.

A rectangular-shaped piece of debris (probably a paper tag) fell from the LO2 TSM T-O umbilical into the SSME #3 exhaust plume during liftoff (18:02:01.2 UTC) (Camera E17) .

Multiple pieces of SRB flame duct debris were seen at liftoff. None of the debris were seen to contact the Shuttle Launch Vehicle.

2.2 DEBRIS DURING ASCENT

During ascent, multiple pieces of debris (probably umbilical ice and RCS paper) fell aft of the launch vehicle after liftoff, through the roll maneuver, and beyond. No damage to the vehicle was noted. No follow-up action was requested. (Cameras E31, E34, E222, E223, E224).

Two large, light-colored objects (probably birds close to the camera) were seen near the SRB aft skirts during early ascent (18:02:06.313 and 18:02:07.821 UTC) (Camera E222).

Several light-colored pieces of debris were seen near the SRB exhaust plume during ascent (18:02:17.633 and 18:02:20.878 UTC) (Camera E224).

A small light-colored piece of debris (probably forward RCS paper) was seen near the right wing tip at 18:02:30.750 UTC (Camera E222).

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

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

SSME #3	18:01:56.695 UTC
SSME #2	18:01:56.893 UTC
SSME #1	18:01:56.957 UTC

Table 2.3 Mach Diamond Formation

Orange vapor, probably free burning hydrogen, was seen above the SSME rims and near the base of the vertical stabilizer during SSME ignition (18:01:54.8 UTC) (Cameras OTV070, E2, E5, E17, E19, E20). Orange vapors have been seen on previous missions.

2.4 ASCENT EVENTS

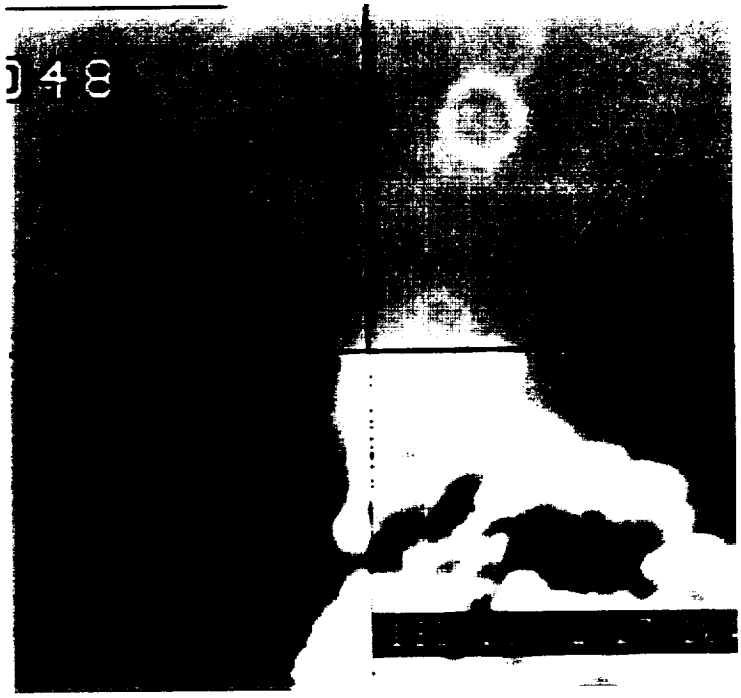

Figure 2.4 (A) Unusual Vapor-like Puff along Exhaust Plume

A white vapor-like puff (probably a cloud) appeared to extend laterally away from the SRB exhaust plume during ascent (18:02:17.1 UTC) (Camera OTV048).

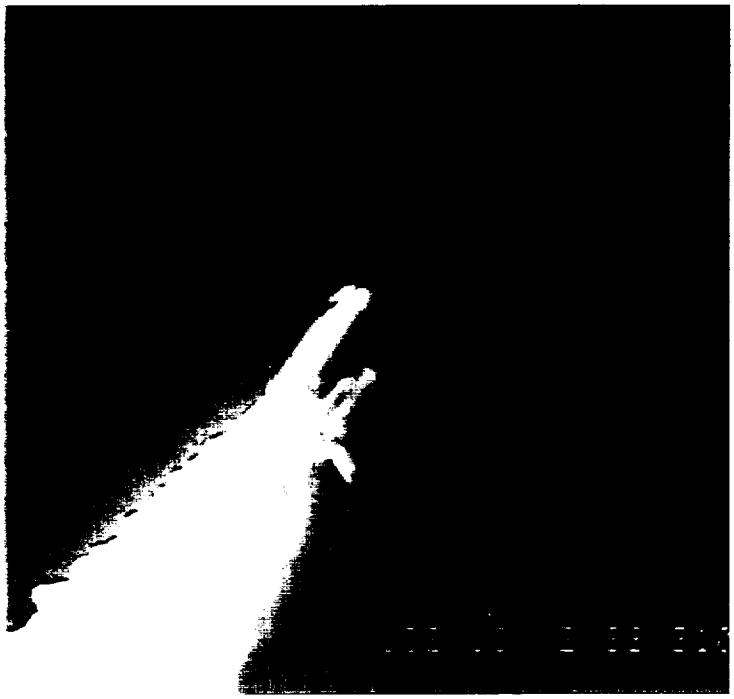

Figure 2.4 (B) Orange-colored Flare in SSME Exhaust Plume

Approximately five orange-colored flares (probably debris induced) were seen in the SSME exhaust plume during ascent between 18:02:27.984 and 18:02:36.31 UTC (Cameras E222, E224, KTV4A, KTV21A, ET213).

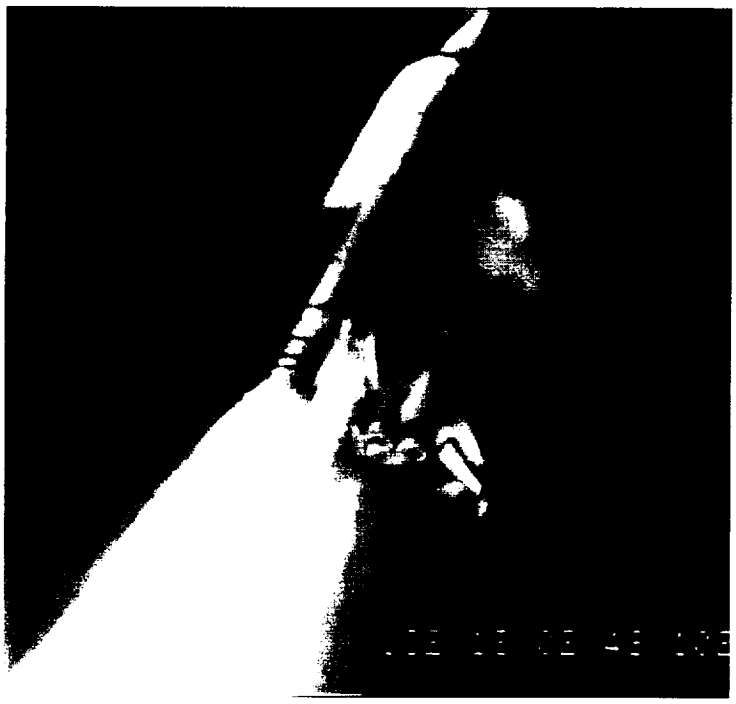

Figure 2.4 (C) Condensation Around the Launch Vehicle

Atmospheric condensation appeared to form a collar around the launch vehicle between 18:02:35.2 and 18:02:50 UTC (Cameras E207, E212, E222, E223, E224, ET207, ET208, ET212, KTV2, KTV13).

An orange-colored flash was seen near the Orbiter right wing tip at 18:02:45.802 UTC. The flash was not seen on the other long range tracking views screened. This flash occurred at the same time condensation was visible around the launch vehicle and was probably a reflection of the SRB exhaust plume on an area of visible moisture.

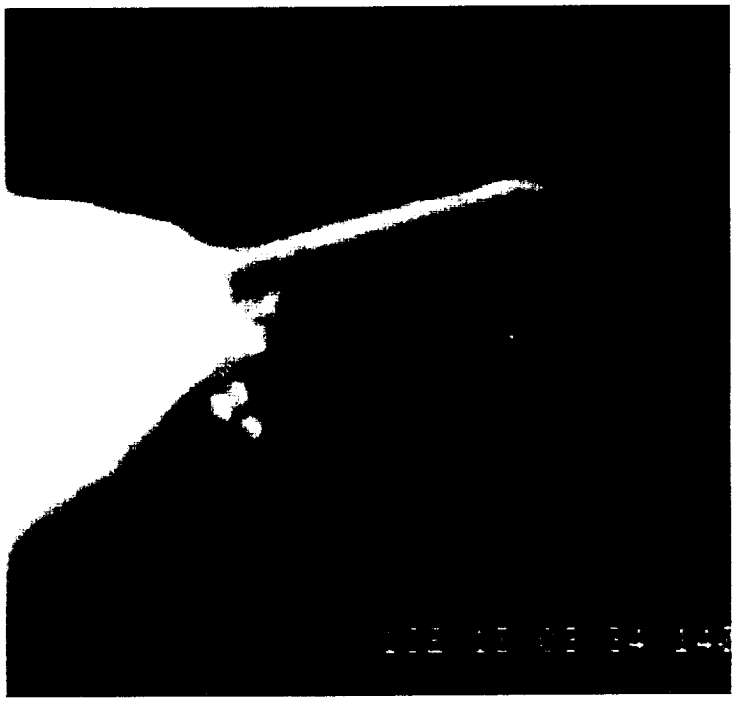

Figure 2.4 (D) Recirculation

Recirculation, or the expansion of burning gasses at the aft end of the vehicle, was seen during ascent (18:02:32.4 through 18:03:44.9 UTC) (Cameras E212, KTV13, ET208, ET212, KTV21A).

Linear optical effects were seen along the launch vehicle between 18:02:56.054 and 18:03:02.367 UTC (Cameras E212, ET212).

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

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

Three rolls of STS-94 umbilical well camera film were acquired (DTO-312, Method 1): the 35mm film from the LO2 umbilical, the 16mm film (5mm lens) and the 16mm film (10mm lens) from the LH2 umbilical. The +X translation maneuver was performed on STS-94. While the following items are of interest, nothing was seen that is considered anomalous or is related to the post-flight damage found on the right SRB.

Numerous light-colored pieces of debris (insulation and frozen hydrogen), and dark debris (probably charred insulation), were seen throughout the SRB separation sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the horizontal section of the -Y ET/SRB vertical strut was seen. Ablation and charring of the TPS on the aft dome was normal. The LSRB separation appeared normal. Several small, dark discolorations were seen on the LSRB segment case aft of the LSRB/ET attach point.

Typical frozen hydrogen debris was seen throughout the ET separation sequence. Although difficult to see due to backlighting, the LH2 carrier plate appeared normal. A large piece of frozen hydrogen was visible on the LH2 17-inch line orifice. Two white areas (probably frozen hydrogen) were visible to the right of the LH2 umbilical near the cross beam. A divot was visible by the ET/Orbiter attach -Y bipod jackpad close-out.

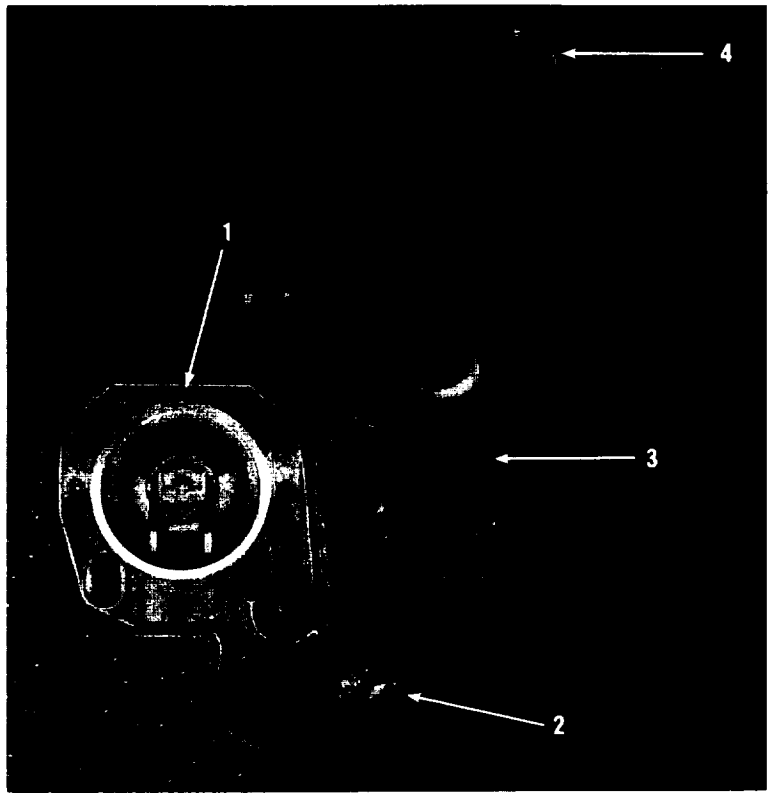

Figure 2.5.1 (A) ET/Orbiter LO2 Umbilical

One of the five lightning contact strips (12 o'clock position) appeared to be missing from the ET/Orbiter LO2 umbilical interface plate (1). KSC reported that STS-94 (ET-86) was the first vehicle to use the new "wire-mesh" electrical contact plates (lightning contact strips) on the LO2 ET/Orbiter umbilical. This new material is similar in form to umbilical foam and can give the appearance that a contact plate is missing. KSC confirmed that all five of the LO2 umbilcal contact plates were intact and properly attached.

TPS erosion/divots were visible on the vertical section of the LO2 electric cable tray (2).

The red-colored thermal barrier on the EO-3 fitting was partially detached (3).

Chipping of the TPS on the aft LO2 feedline flange was visible (4). Chipping of the TPS on the aft portion of the +Z side of the LH2 tank and TPS erosion on the LH2 tank in the -Y direction of the LO2 feedline were visible.

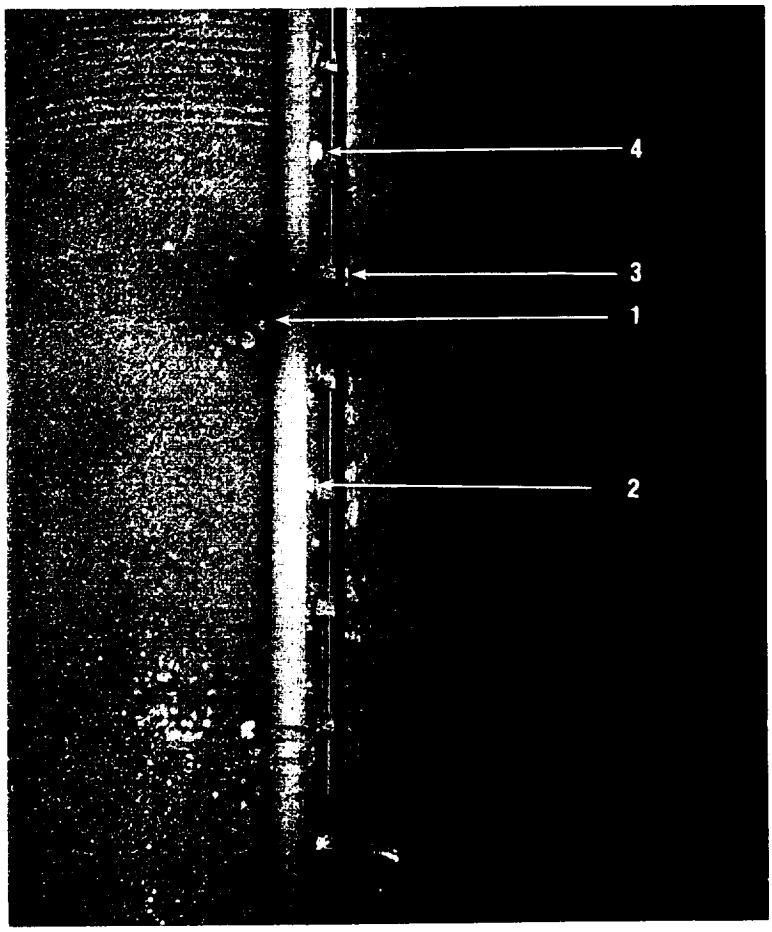

Figure 2.5.1 (B) LH2 Tank Divots

A shallow white mark (divot) approximately four inches in diameter was seen to the left of the LO2 feedline on the LH2 tank TPS at approximately station XT-1623 (1). Several divots were seen near the LH2 tank pressurization line and the LO2 feedline support brackets: a white mark (divot), approximately six inches in size, is visible between the LO2 feedline and the electric cable tray forward of the +Y thrust strut at approximate station XT 1722 (2), a 14-inch long divot was noted outboard (+Y) of the electric cable tray ramp at approximate station 1593 (3), and a 16-inch long divot was visible between the LO2 feedline and the pressurization line at approximate station XT 1528 (4).

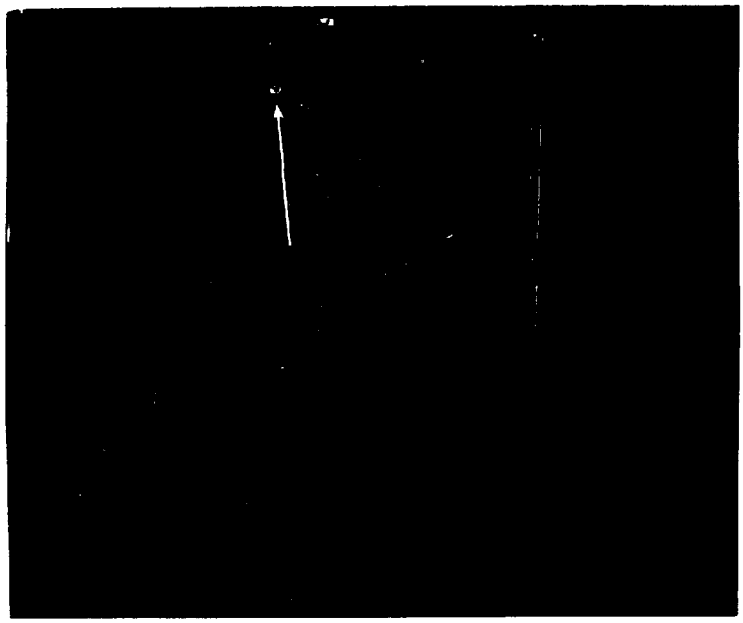

Figure 2.5.1 (C) -Y Jackpad Close-out Divot

An approximately four-inch diameter divot with primer visible was seen by the ET/Orbiter attach -Y bipod jackpad close-out. Several small (one-inch diameter) intertank stringer-head divots were visible forward of the right leg of the ET/Orbiter attach bipod.

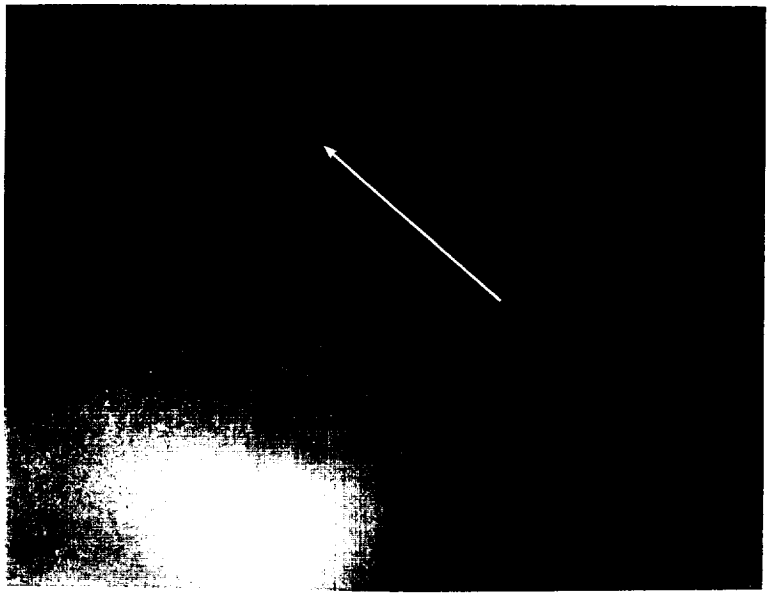

Figure 2.5.1 (D) White Mark (Possible Divot) on ET Nose

A small, white mark (divot) was seen on the ET nose to the left of the electric cable tray. The PAL ramp and the LO2 feedline fairing appeared normal.

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

Figure 2.5.2 (A) Handheld Photograph of ET

DTO-312 handheld photography (Method 4) of the STS-94 ET was acquired after ET separation. A Nikon 35mm camera with a 400mm lens and a 2X extender was used. The OMS-2 attitude pitch maneuver was performed early to assist the crew members in acquiring the ET visually.

Thirty-seven views of the external tank were acquired (roll 444). The first three views are of the ET -Z/+Y axis. The next five views are of the ET +Z/+Y axis and the aft dome. The remaining twenty-one views are of the ET +Z/-Y axis. The first picture was taken on July 1, 1997 at 18:20:04 UTC (approximately 18 minutes after liftoff). The last picture was at 18:22:33 UTC.

While the following items are of interest, nothing was seen that is considered anomalous or that is related to the post-flight damage found on the right SRB.

STS-94 (ET-86) was the first flight of the new NCFI 24-124 TPS on the liquid oxygen tank barrel and ogive. STS-94 was the second flight of the new liquid hydrogen tank (LH2) sidewall thermal protection system (NCFI 24-184) first flown on STS-84 (ET-85). The new liquid hydrogen tank and oxygen tank barrel thermal protection system (TPS) appeared to be in good condition on the handheld photography.

The new LH2 tank aft dome TPS (NCFI 24-57), first flown on STS-79 (ET-82), appeared to be in good condition. The new intertank access door, also first flown on STS-79, was not photographed.

The following events, although not anomalous, were noted on the hand-held photography of the ET:

1) A long linear-shaped yellow-colored mark seen extending across the LO2 tank/intertank close-out flange on the far side of the tank (+Y/ -Z axis) is believed to be an optical effect caused by an image smear of the RSS antenna.

2) Two possible divots, or perhaps close-out marks, were visible in the mid-section of the LH2 tank TPS (+Y/+Z axis). A faint, linear-shaped, thin aero-heating mark extended along the length of the LH2 tank TPS. Aero-heating marks are typically seen on the hand-held photography.

3) A light-colored mark, confirmed to be a divot on the umbilical well photography, was visible near the left leg of the ET/Orbiter attach bipod close-out TPS.

4) A light-colored mark, possibly a divot, was visible on the LH2 tank-to-intertank close-out flange (-Y/+Z axis).

The normal SRB separation motor burn scars were visible on the ET TPS.

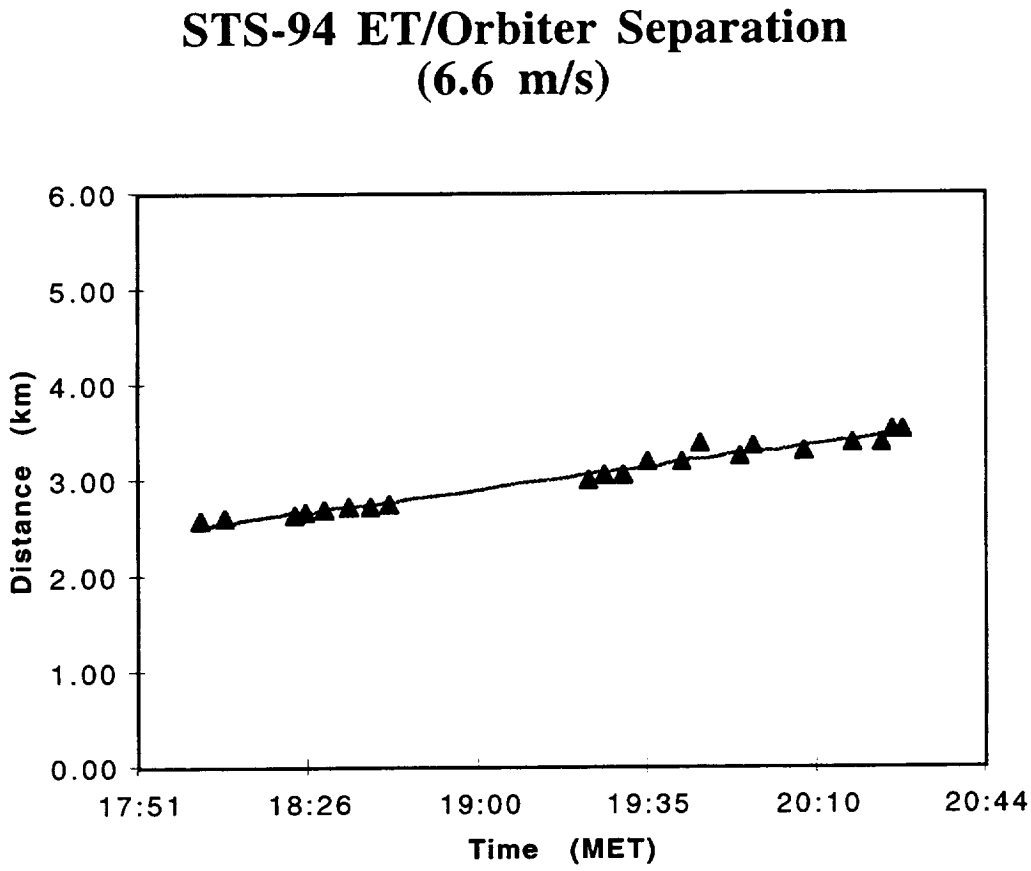

Figure 2.5.2 (B) ET Separation Velocity

The distance of the external tank was calculated on twenty frames. On the first usable view, the external tank was calculated to be at a distance of 2.6 kilometers away from the Orbiter at 18:04 MET. On the last view, 2 minutes and 23 seconds after the first view, the tank was calculated to be at a distance of 3.5 kilometers (18:06:23 MET). The tank separation average velocity was determined to be 6.6 meters/second (m/s), with an uncertainty of approximately 1 m/s. The tank tumble rate was approximately 1.8 degrees/second. The tank roll rate was 0.3 degrees/second.

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis (Task #1)

Film camera EL9 was used to determine the landing sink rate of the Orbiter main gear and EL12 was used to determine the nose gear sink rate. The sink rates of the Orbiter were determined over a one second time period prior to main and nose gear touchdown.

The measured main gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb. vehicle and 6.0 ft/sec for a 240,000 lb. vehicle. The landing weight of the STS-94 Orbiter was reported to be 230,911 lb. The sink rate measurements for STS-94 are given in Table 2.6.1. In Figure 2.6.1(A), and 2.6.1(B), the trends of the measured data points for the image data are illustrated.

Sink Rate Prior to Touchdown (1 Second)	
Main Gear	1.5 ft/sec.
Nose Gear	4.0 ft/sec.

Table 2.6.1 Sink Rate Measurements

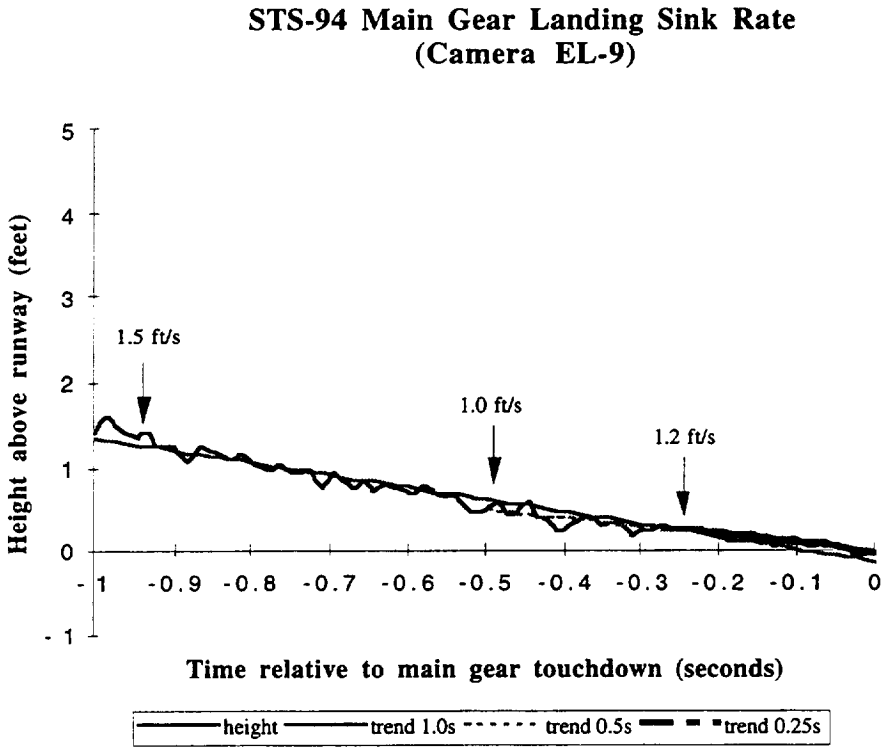

Figure 2.6.1 (A) Main Gear Height versus Time Prior to Touchdown

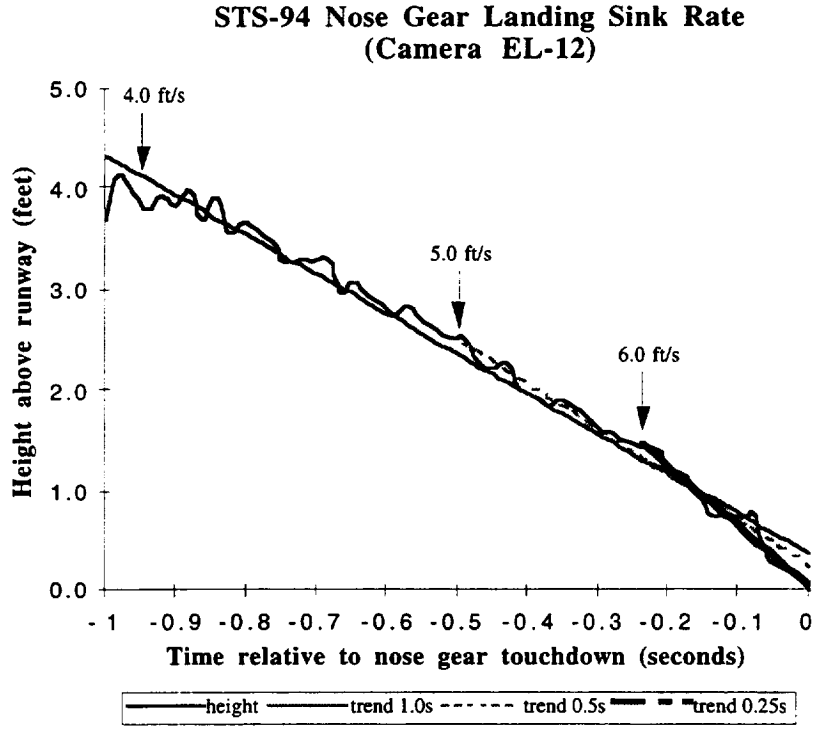

Figure 2.6.1 (B) Nose Gear Height versus Time Prior to Touchdown

2.7 OTHER

2.7.1 Normal Events

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

2.7.2 Normal Pad Events

Normal Pad events observed were: hydrogen ignitor operation, FSS deluge water operation, MLP deluge water activation, GH2 vent arm retraction, LH2 and LO2 TSM door closures, and sound suppression system water operation.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Reply to Attn of: EP42 (97-049)

AUG 0 6 1997

TO: Distribution

FROM: EP42/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-94

The launch of space shuttle mission STS-94, the twenty-third flight of the Orbiter Columbia occurred on July 1, 1997, at approximately 1:02 P.M. Central Daylight Time from Launch Complex 39A (LC-39A), Kennedy Space Center (KSC), Florida. Launch time was reported as 97:182:18:01:59.993 Universal Coordinated Time (UCT) by the MSFC Flight Evaluation Team. Photographic and video coverage were evaluated to determine proper operation of the flight hardware.

All ground based films and videos have been received and reviewed at MSFC. Film and video coverage of the launch of STS-94 is considered excellent. Camera E19 vibrated during SSME start and liftoff causing image motion and camera E11 images were slurred. The rainy weather and the high humidity impacted the performance of other film cameras. Condensation formed on the lens of cameras E52 and E54 greatly reducing resolution. Cameras E202 and E220 experienced erratic tracking of the vehicle due to the weather. Clouds temporarily obscured the view from several tracking cameras.

The astronauts recorded thirty-seven images of the ET after separation using the hand-held camera. All sides of the ET were imaged. The umbilical well cameras recorded the SRB separation, but were strongly back lighted by the sun during ET separation which resulted in reduced data. However, the 35mm sequencing camera provided useful data.

No anomalies or problems were identified from the film and video review. All MSFC elements appeared to operate normally. The typical events of ice/frost falling from the 17-inch disconnects during SSME start and liftoff, debris induced streaks in the SSME plumes and glowing debris particles being ejected from the SRM plumes after SRB separation were observed. A condensation collar formed around the vehicle during ascent.

The typical "popcorning" was observed on the lower portion of the ET LH2 tank and the aft dome. A few shallow divots in the acreage TPS were noted along the LO2 feedline and pressline ramps. One TPS divot was noted underneath the forward bipod strut.

The following event times were acquired:

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	18:02:00.001	Camera E9
M-2 PIC Firing	18:02:00.001	Camera E8
M-5 PIC Firing	18:02:00.000	Camera E12
M-6 PIC Firing	18:02:00.001	Camera E13
SRB separation	18:04:03.44	Camera E207

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

http://photo4.msfc.nasa.gov/STS/sts94/sts94.html.

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

Tom Rieckhoff

Thomas J. Rieckhoff

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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-94. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the ice/debris/thermal protection system conditions and integrated photographic analysis of Shuttle mission STS-94 and the resulting effect on the Space Shuttle Program.

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