Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-91

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DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-91

2 June 1998

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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-91

1.0 SUMMARY

An overall pretest debris inspection of the launch pad and Shuttle vehicle was performed on 17 May 1998. The walkdown of Pad 39A also included the primary flight elements OV-103 Discovery, ET-96, and BI-091 SRB's. There were no significant vehicle or launch pad anomalies.

A major configuration change, and the reason for the tanking test, was the first use of the new Super Light Weight (External) Tank (SLWT). Other than the sanded intertank stringers, most of the changes were internal and therefore not visible. However, postulated contour deviations on the LO2 tank forward-to-aft ogive weld (station 536, +Z side) could have resulted in as-sprayed NCFI TPS cracking after the tank was pressurized. Per FEC, a local area 100 inches long by 11 inches wide was sanded over the suspect area to reduce the TPS outer fiber strain and increase the strain capability of the foam. The foam thickness was reduced from an average of 2.30 inches to 1.25 inches. After machining, the edges of the trim area were beveled. This modification met all ground, ascent, and re-entry aero/thermal requirements. Nevertheless, the trimmed area was assessed during cryoloading for the formation of condensate or ice.

The Thermal Protection System performed nominally during the tanking test. No anomalies were detected on the composite nose cone though condensate could be seen over the attach bracket fastener area between the -Y louver and the fairing. Two cracks were detected in stringer valleys in the +Y+Z quadrant of the intertank. The cracks appeared to originate from the as-sprayed foam at the LH2 tank splice extending forward approximately 7 inches. Each crack was no greater than 1/16 inch wide with no visible offset or ice/frost formation. Although the NSTS-08303 Ice/Debris Inspection Criteria documents an intertank TPS crack in the -Y-Z quadrant as acceptable for flight, no such case was available for cracks in the +Y+Z quadrant. Consequently, an IPR was taken to determine this condition was acceptable for flight as well.

The new cameras mounted in the GOX vent hood were partially successful. The camera observing the northeast louver failed prior to LO2 tank loading. However, the camera observing the southwest louver showed no frost formation until the seal was deflated and the hood retracted. After the GOX vent arm was retracted, no ice formation was detected on either louver using the regular OTV cameras. During the Final Inspection, condensate had been detected on the composite nose cone between the fairing and the southwest GOX seal. The condensate may have formed due to the thermal conductivity of the underlying attachment brackets. If the formation of condensate in this area is a characteristic of the new composite nose cones, problems with icing may be encountered during cold weather conditions.

A series of post drain inspections were conducted after the tanking test. From an Ice and TPS perspective, the tanking test was successful resulting in only minor TPS defects. There were no TPS constraints for launch cryoload.

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 1 June 1998. The detailed walkdown of Pad 39A and MLP-1 also included the primary flight elements OV-103 Discovery (24th flight), ET-96 first Super Light Weight Tank, and BI-091 SRB's. There were no significant vehicle or launch pad anomalies.

The Final Inspection of the cryoloaded vehicle was performed on 2 June 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. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

The Thermal Protection Systems performed nominally during cryoload. The sanded area on the LO2 tank ogive exhibited no anomalies. Light condensate was again visible on the composite nose cone between the fairing and the southwest louver.

Two small cracks were detected in the +Y+Z quadrant of the intertank. The cracks appeared to originate from the as-sprayed foam at the aft end of the stringers extending forward approximately 7 inches from the LH2 tank splice. These two cracks had been documented during the tanking test. Two new, similar cracks were detected. A 4-inch crack was located in the -Y+Z quadrant and a 6-8 inch crack was located in the -Y-Z quadrant. All four cracks were no greater than 1/16 inch wide with no visible offset or ice/frost formation and were acceptable for flight per the NSTS-08303 criteria and tanking test PR rationale.

A drive adapter used to extend/retract the side platforms on an MLP Tail Service Mast was discovered by the Final Inspection Team at the northeast corner of the LO2 TSM. The steel adapter was 2-inches in diameter and weighed a half pound. A recent modification called for the adapters (three adapters per TSM) to be permanently attached to the drive shafts with set screws. In this case, the set screw apparently backed out during platform operations causing the adapter to hang loosely at the end of the shaft. As a result of this finding, all adapters have been changed to a pinned design.

After the 6:06 p.m. (local time) launch on 2 June 1998, a debris walk down of Pad 39A was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Although Boeing - Downey reported an Orbiter liftoff lateral acceleration of 0.19 g's, which is above the threshold (0.14 g's) for stud hang-ups, an actual stud hand-up did not occur on this launch. The right SRB aft skirt GN2 purge line was intact and upright after liftoff. The left GN2 purge flex line was bent in half in the +Z direction and exhibited structural damage (holes) and melting of the wire braid. Overall, damage to the launch pad was minimal.

A total of 110 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission. 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.

OV-103 was equipped to carry umbilical cameras (for the first time): 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. The flight crew provided 33 hand held still images.

Twenty to twenty-five light colored spots were detected in the -Y thrust panel acreage in an area bordered by the LO2 and LH2 tank-to-intertank flange closeouts and from the thrust panel-to-intertank splice to the tank curving out of view in the -Y direction. These light colored spots were most likely small, shallow divots, most of which were in the areas between the ring frames. However, some of the possible divots could be seen on the forward ring frame. The +Y thrust panel was in shadow and no detail could be discerned.

The Solid Rocket Boosters were inspected at Hangar AF after retrieval. Both frustums were in excellent condition. No missing TPS or debonds/unbonds were detected over fasteners on the frustums. All eight BSM aero heat shield covers had locked in the fully opened position. The forward skirts exhibited no debonds or missing TPS. Separation of the aft ET/SRB struts appeared normal. TPS on the external surface of both aft skirts was intact and in good condition. Significant areas of missing insulation/cork from the aft surface of the IEA showed the insulation had not bonded properly. The pristine condition of the primed substrate indicated the insulation was lost at water impact rather than in flight.

After the 2:00 p.m. local/eastern time landing on 12 June 1998, a post landing inspection of OV-103 Discovery was conducted at the Kennedy Space Center on SLF runway 15.

The Orbiter TPS sustained a total of 198 hits, of which 50 had a major dimension of 1-inch or larger. A comparison of these numbers to statistics from 71 previous missions of similar configuration indicates both the total number of hits and the number of hits 1-inch or larger was greater than average

The Orbiter lower surface sustained 145 total hits, of which 45 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. Virtually no damage occurred on the Orbiter centerline. These damage sites follow the same location/damage pattern documented on STS-86, STS-87, STS-89, and STS-90, though it should also be noted that this was the first flight of the new Super Light Weight Tank. The average size and quantity of damage sites were greater than the favorable trend established on STS-89 and STS-90:

The largest lower surface tile damage site forward of the main landing gear wheel wells was located on the left chine and measured 3-inches long by 1.25-inches wide by 0.25-inches deep. The deepest lower surface tile damage site of 0.5-inches was located on the right chine.

The Space Shuttle Program continues to work an IFA to prevent loss of foam from the ET thrust panels and preclude further damage to Orbiter tiles.

2.0 PRE-TANKING/LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for tanking test activities was conducted on 15 May 1998 at 1400 hours. The briefing for all launch activities was conducted on 1 June 1998. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

P. Weber	NASA - KSC	Chief, ET/SRB Mechanical Systems Branch
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 - SPC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SPC	ET Mechanical Systems
W. Richards	USA - SPC	ET Mechanical Systems
M. Wollam	USA - SPC	ET Mechanical Systems
G. Fales	USA - SPC	ET Mechanical Systems
T. Ford	USA - SPC	ET Mechanical Systems
J. Stone	BNA - DNY	Shuttle Aerodynamics
C. Hill	BNA - LSS	Systems Integration
B. St. Aubin	THIO - LSS	SRM Processing
S. Otto	LMSO - LSS	ET Processing
J. Ramirez	LMSO - LSS	ET Processing
D. Maxwell	USA - Safety	

3.0 TANKING TEST

3.1 PRE-TANKING SSV/PAD INSPECTION

An overall pretest debris inspection of the launch pad and Shuttle vehicle was performed on 17 May 1998. The detailed walkdown of Pad 39A and MLP-1 also included the primary flight elements OV-103 Discovery, ET-96, and BI-091 SRB's. There were no significant vehicle or launch pad anomalies.

A major configuration change, and the reason for the tanking test, was the first use of the new Super Light Weight (External) Tank (SLWT). Other than the sanded intertank stringers, most of the changes were internal and therefore not visible. However, postulated contour deviations on the LO2 tank forward-to-aft ogive weld (station 536, +Z side) could have resulted in as-sprayed NCFI TPS cracking after the tank was pressurized. Per FEC KET-0037, a local area 100 inches long by 11 inches wide was sanded over the suspect area to reduce the TPS outer fiber strain and increase the strain capability of the foam. The foam thickness was reduced from an average of 2.30 inches to 1.25 inches. After machining, the edges of the trim area were beveled. This modification met all ground, ascent, and re-entry aero/thermal requirements. Nevertheless, the trimmed area was assessed during cryoloading for the formation of condensate or ice.

With the exception of lightning, local weather conditions were not expected to be a constraint to performing the tanking test. Ambient weather conditions the day of the test consisted of temperatures in the mid-to-high 70's, relative humidity averaging 65 percent, and 10 knot winds out of the southwest.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded STS-91 vehicle was performed on 18 May 1998 from 1300 to 1515 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 or Debris IPR's were taken. However, IPR 091V-0152 was taken against cracks in the ET intertank TPS.

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 anomalies were noted on the Orbiter.

3.2.2 SOLID ROCKET BOOSTERS

No anomalies were noted on the SRB's.

3.2.3 EXTERNAL TANK

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

The Thermal Protection Systems performed nominally during the tanking test. The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures ranged from 69 to 88 degrees F depending on sunlit or shadowed areas. The sanded area on the LO2 tank ogive exhibited no anomalies and averaged 4 degrees Fahrenheit less (as measured by the infrared radiometer) than the adjacent acreage foam.

The new cameras mounted in the GOX vent hood were partially successful. The camera observing the northeast louver failed prior to LO2 tank loading. However, the camera observing the southwest louver showed no frost formation until the seal was deflated and the hood retracted. After the GOX vent arm was retracted, no ice formation was detected on either louver using the other OTV cameras. During the Final Inspection, condensate had been detected on the composite nose cone between the fairing and the southwest GOX seal. The condensate may have formed due to the thermal conductivity of the underlying attachment brackets. If the formation of condensate in this area is a characteristic of the new composite nose cones, problems with icing may be encountered during cold weather conditions.

3.4 LH2 AND LO2 DRAIN

Other than venting from the LH2 recirculation line burst disks - a typical occurrence during ET drain - no anomalies or concerns were identified. The venting may have originated from a PDL repair on the recirculation line bellows cover. No cracks in the TPS, venting of vapors, liquid air drips, or unexpected ice formations were detected.

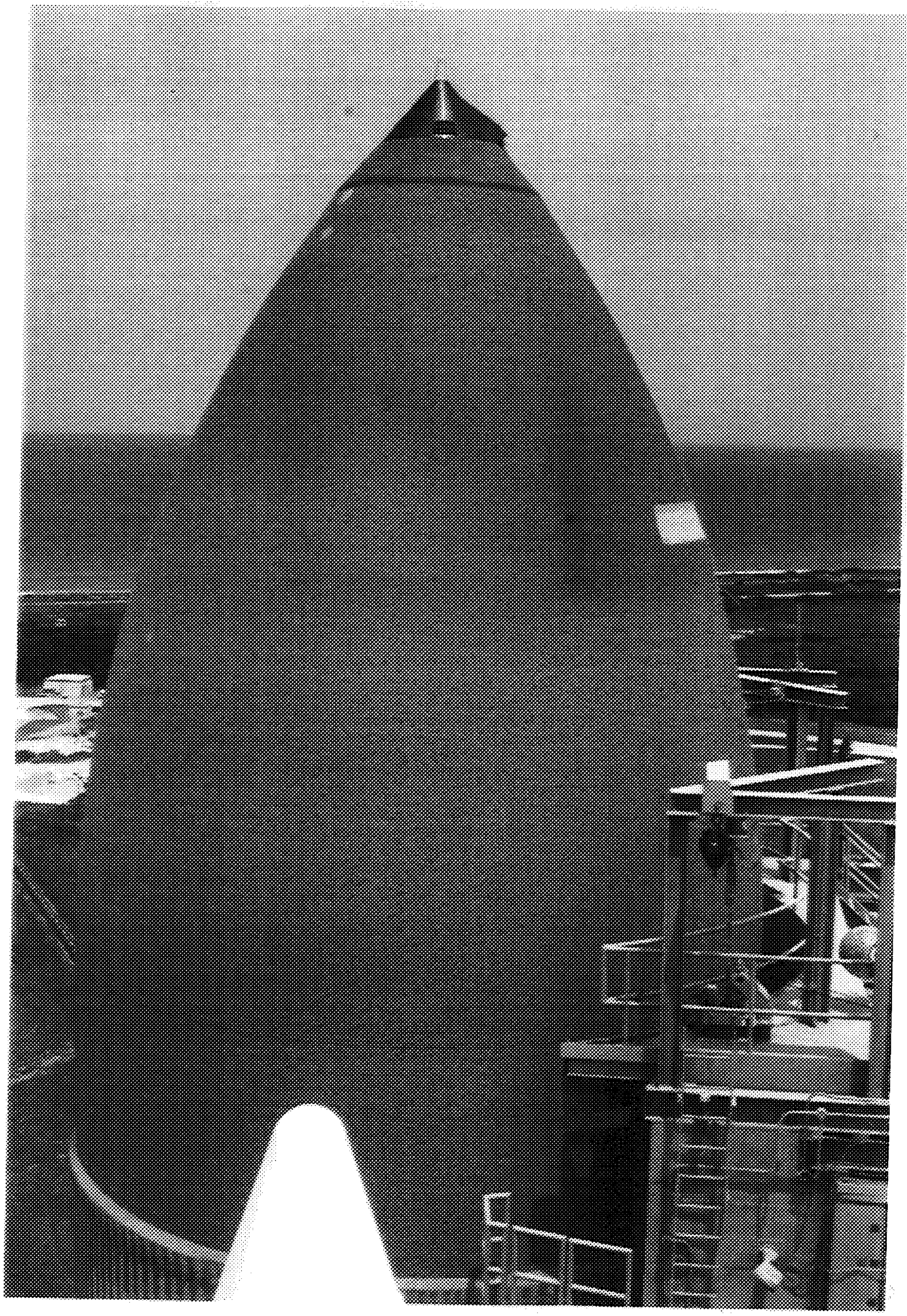


Photo 2: ET-96 SLWT LO2 Tank

A major vehicle configuration change, and the reason for the tanking test, was the first use of the new Super Light Weight (External) Tank (SLWT). Note black composite nose cone, visible welds along panel lines due to the thinner foam, and the sanded area on the +Z side.

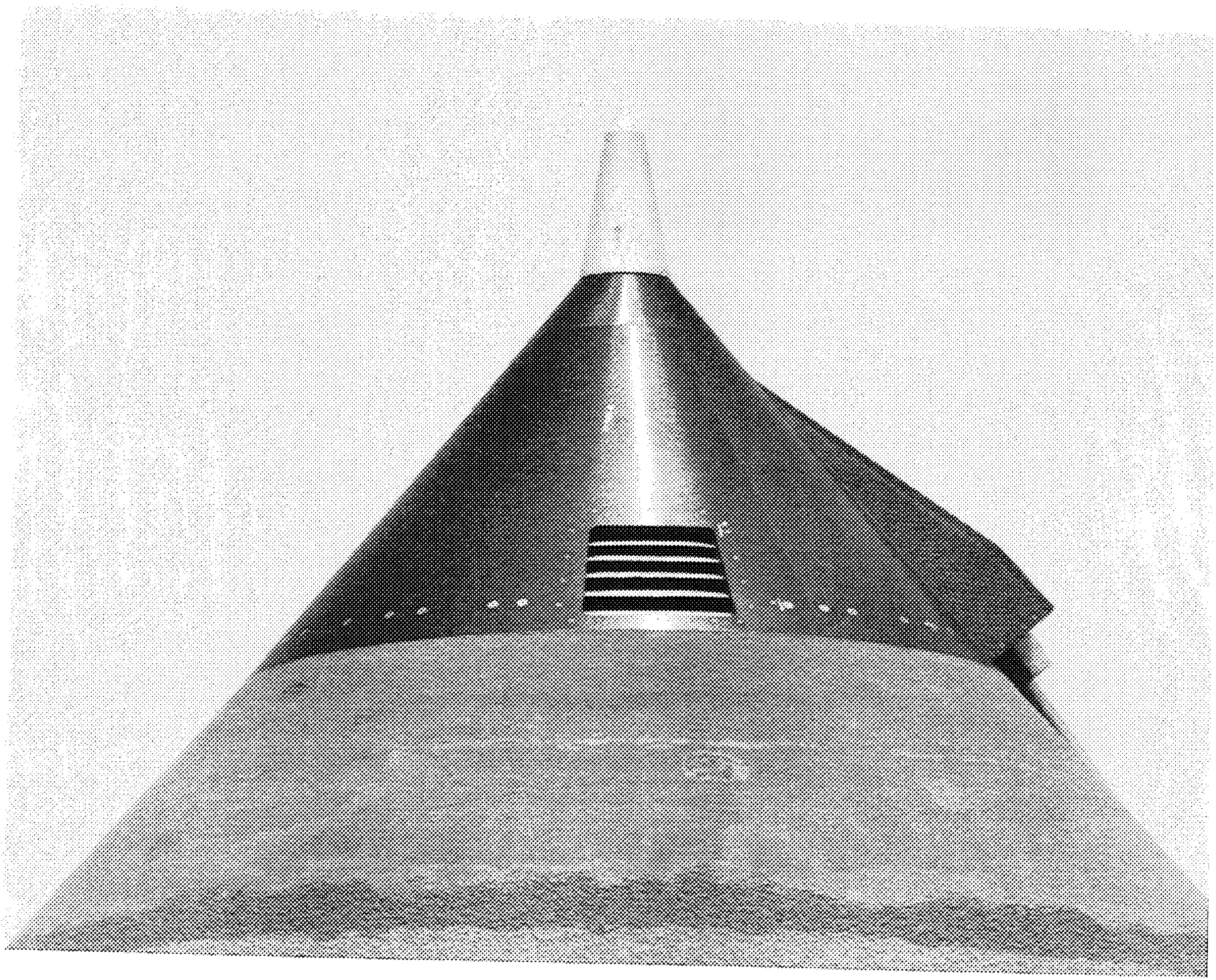


Photo 3: Composite Nose Cone

This is the second use/flight of the graphite-epoxy composite nose cone

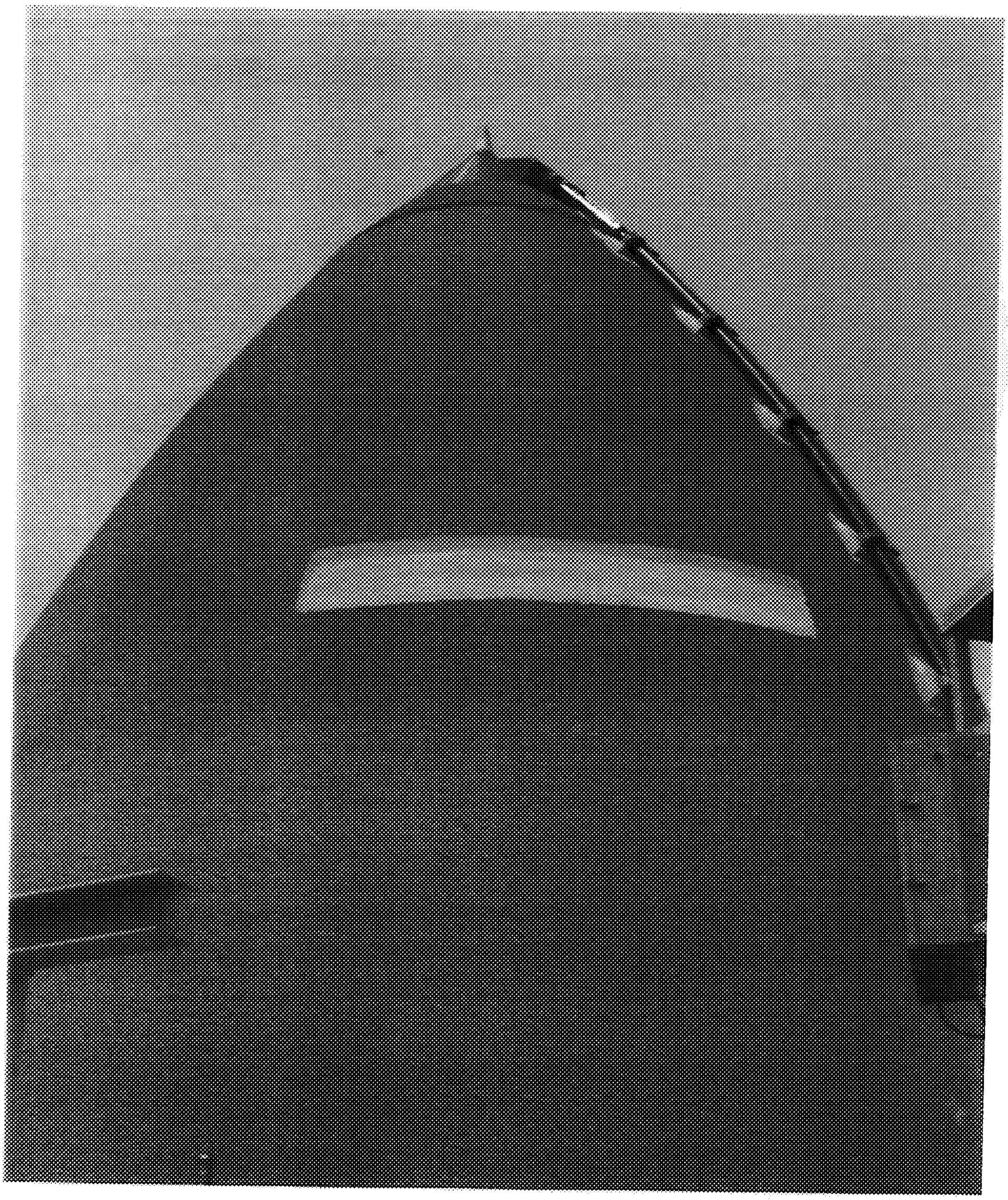


Photo 4: +Z Side Sanded Area

Postulated contour deviations on the LO2 tank forward-to-aft ogive weld (station 536, +Z side) could have resulted in as-sprayed NCFI TPS cracking after the tank was pressurized. Per FEC, a local area 100 inches long by 11 inches wide was sanded over the suspect area to reduce the TPS outer fiber strain and increase the strain capability of the foam. The foam thickness was reduced from an average of 2.30 inches to 1.25 inches. After machining, the edges of the trim area were beveled.

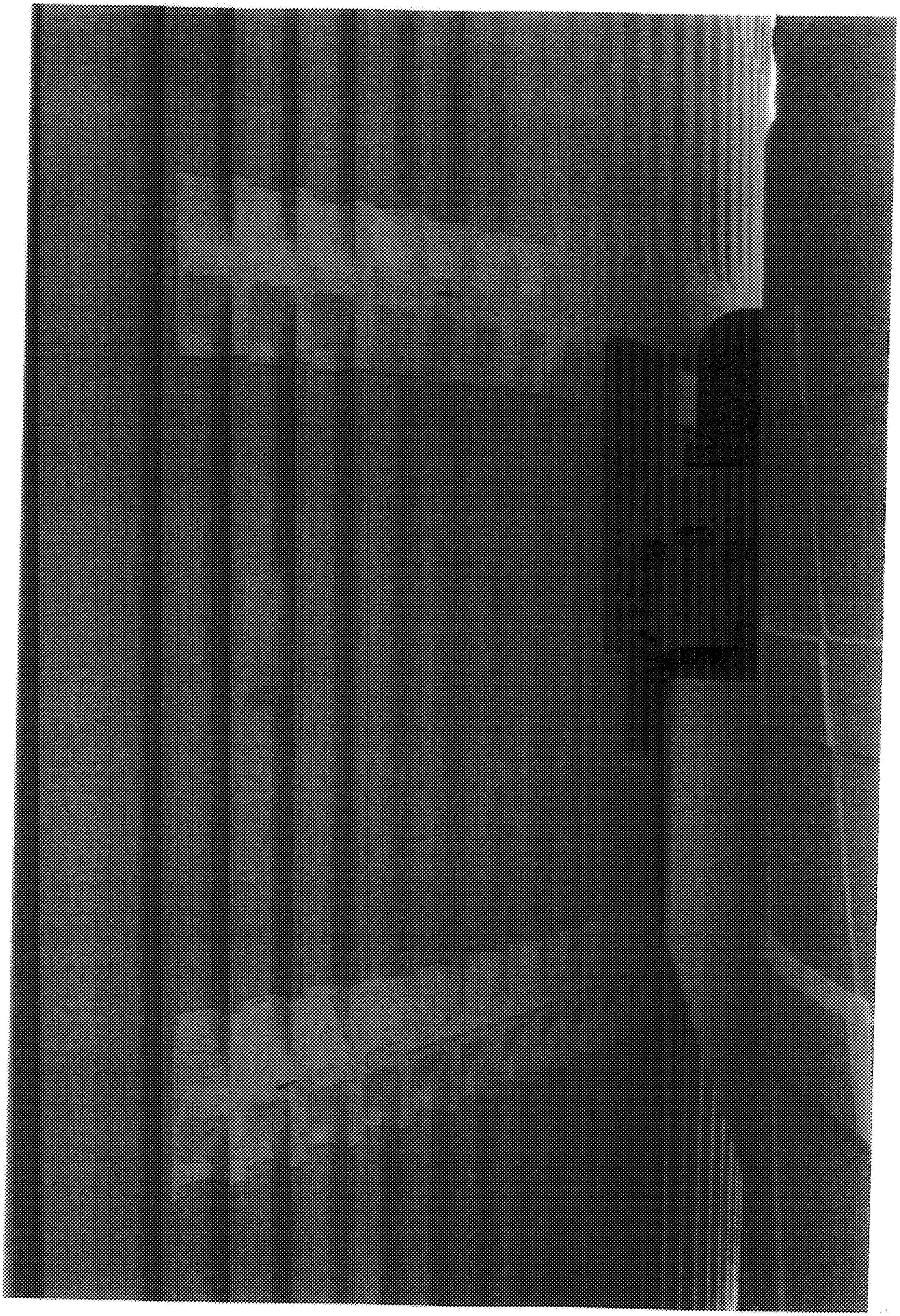


Photo 5: SLWT Intertank Stringers

Intertank and thrust panel stringer heads/valleys are machined in the SLWT configuration

Photo 6: STS-91 Tanking Test

The tanking test was conducted on Pad 39A with the STS-91 SSV including the primary flight elements OV-103 Discovery, ET-96, and BI-091 SRB's

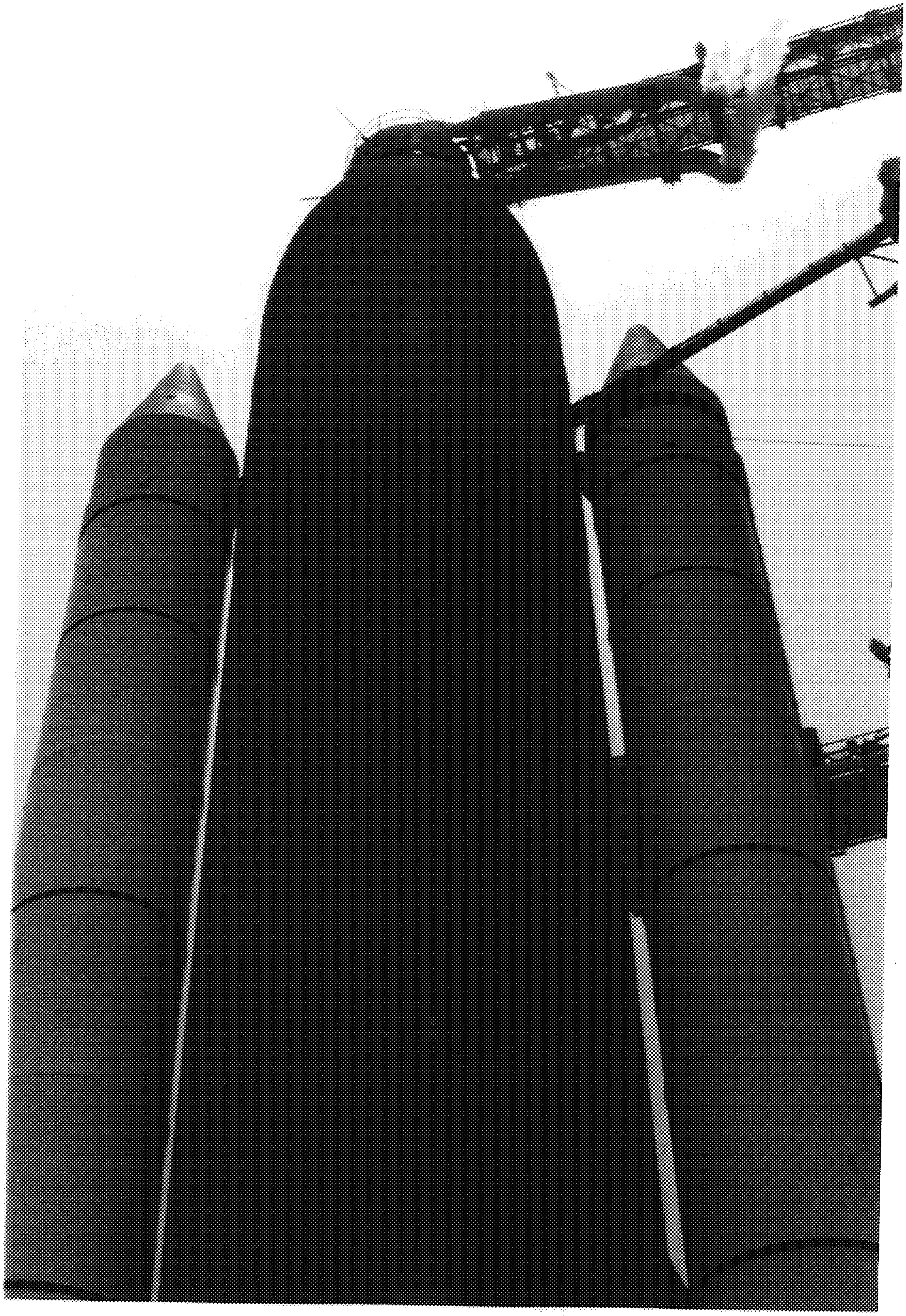


Photo 7: SLWT -Z Side

No anomalies were detected on the -Z side of the SLWT after cryoload.
Note black composite flight door and sanded stringer heads/valleys on the intertank.

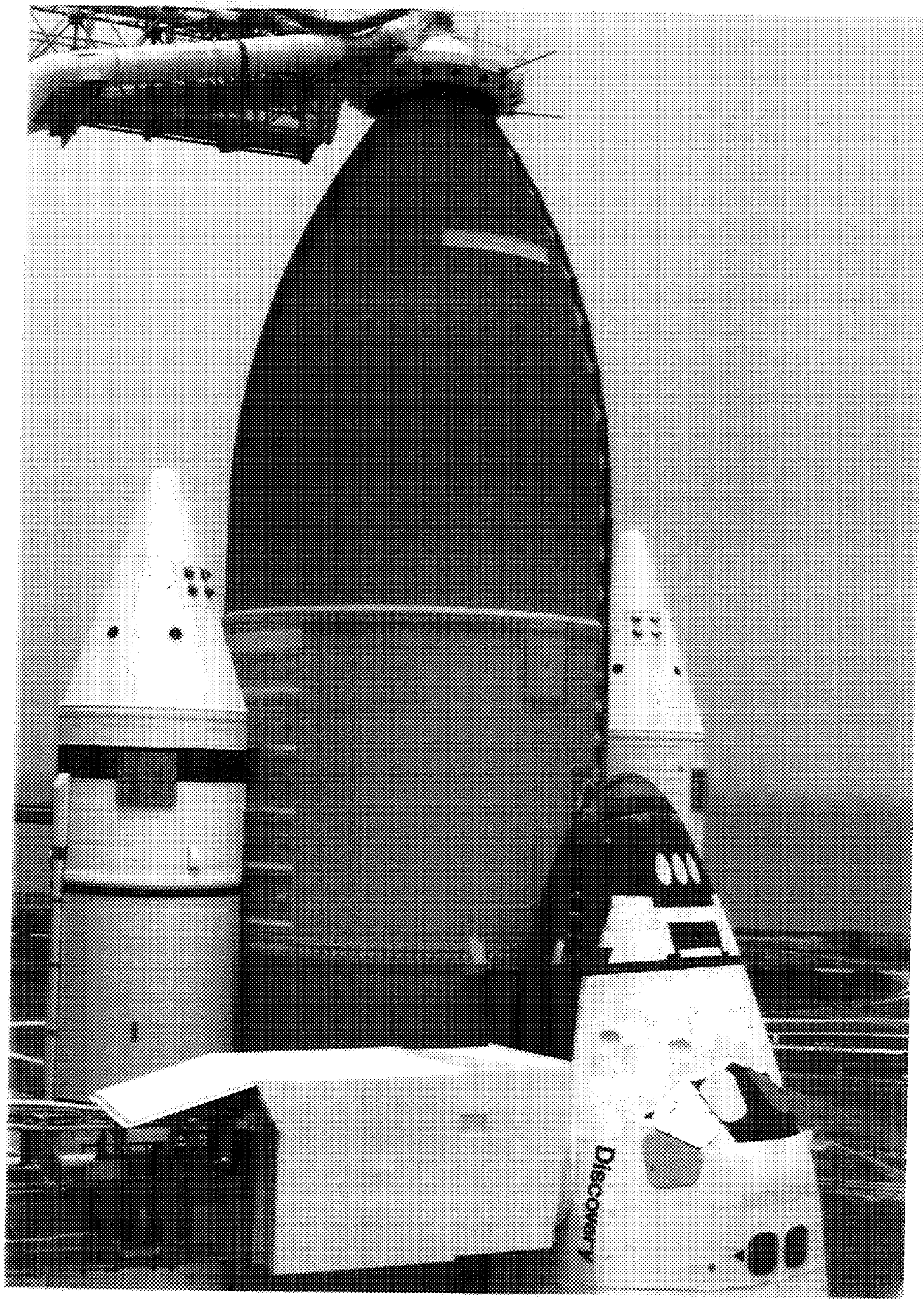


Photo 8: LO2 Tank After Cryoload

The Thermal Protection Systems performed nominally during the tanking test. The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures ranged from 69 to 88 degrees F depending on sunlit or shadowed areas.

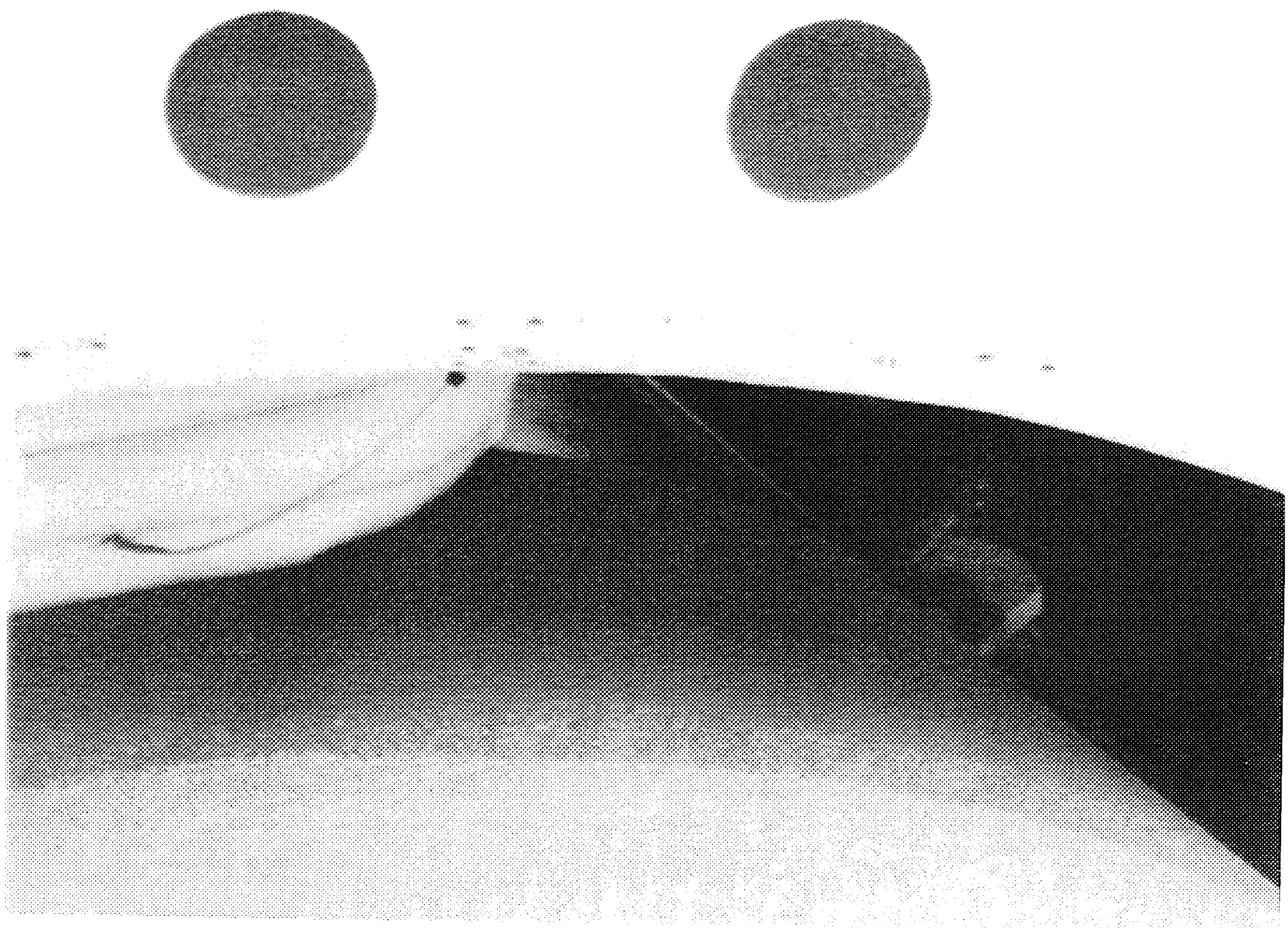


Photo 9: Composite Nose Cone

No anomalies were detected on the composite nose cone though condensate could be seen over the attach bracket fastener area between the -Y louver and the fairing.

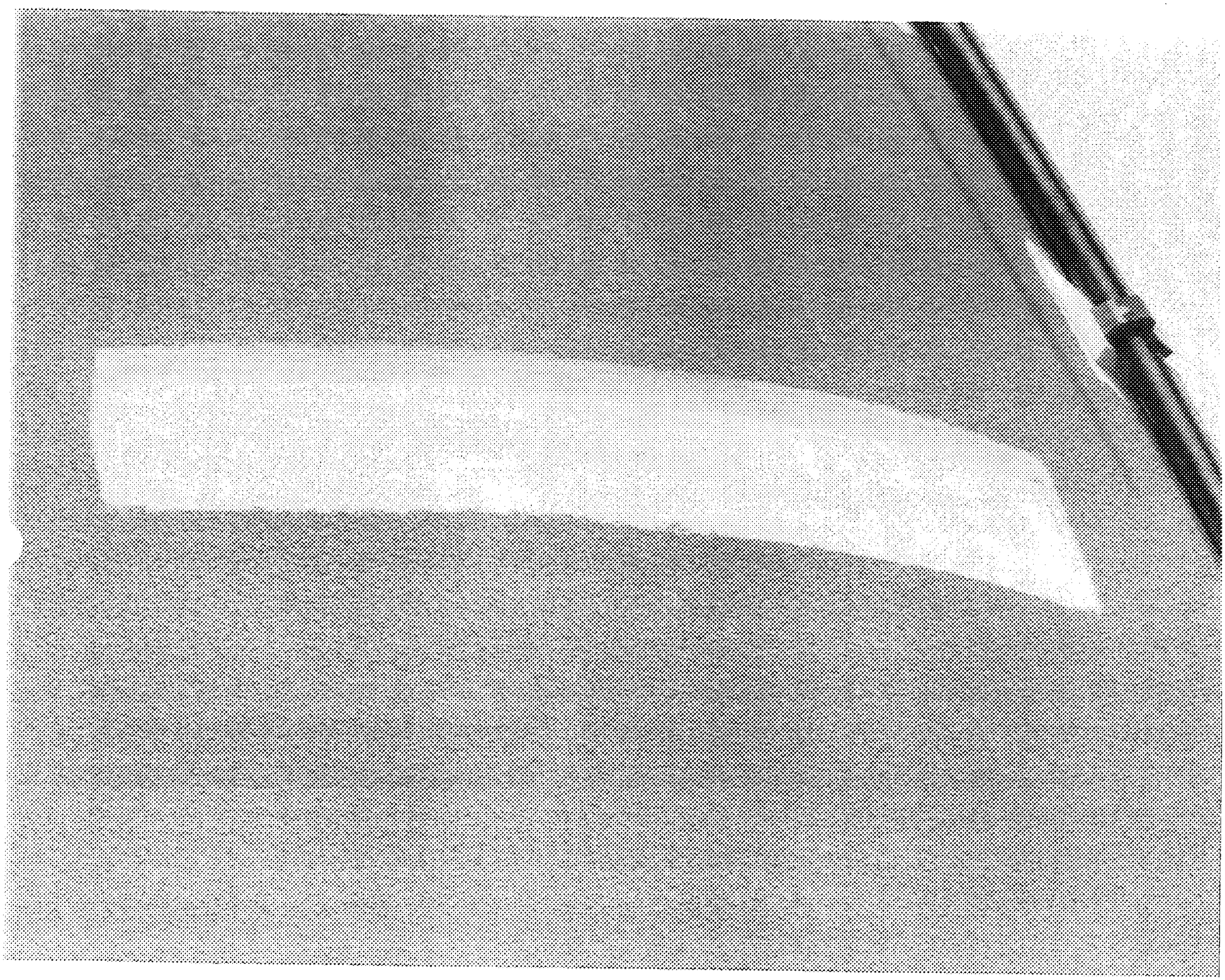


Photo 10: +Z Side Sanded Area

The sanded area on the LO2 tank ogive exhibited no anomalies and averaged 4 degrees Fahrenheit less (as measured by the infrared radiometer) than the adjacent acreage foam. No ice, frost, or condensate accumulations were detected.

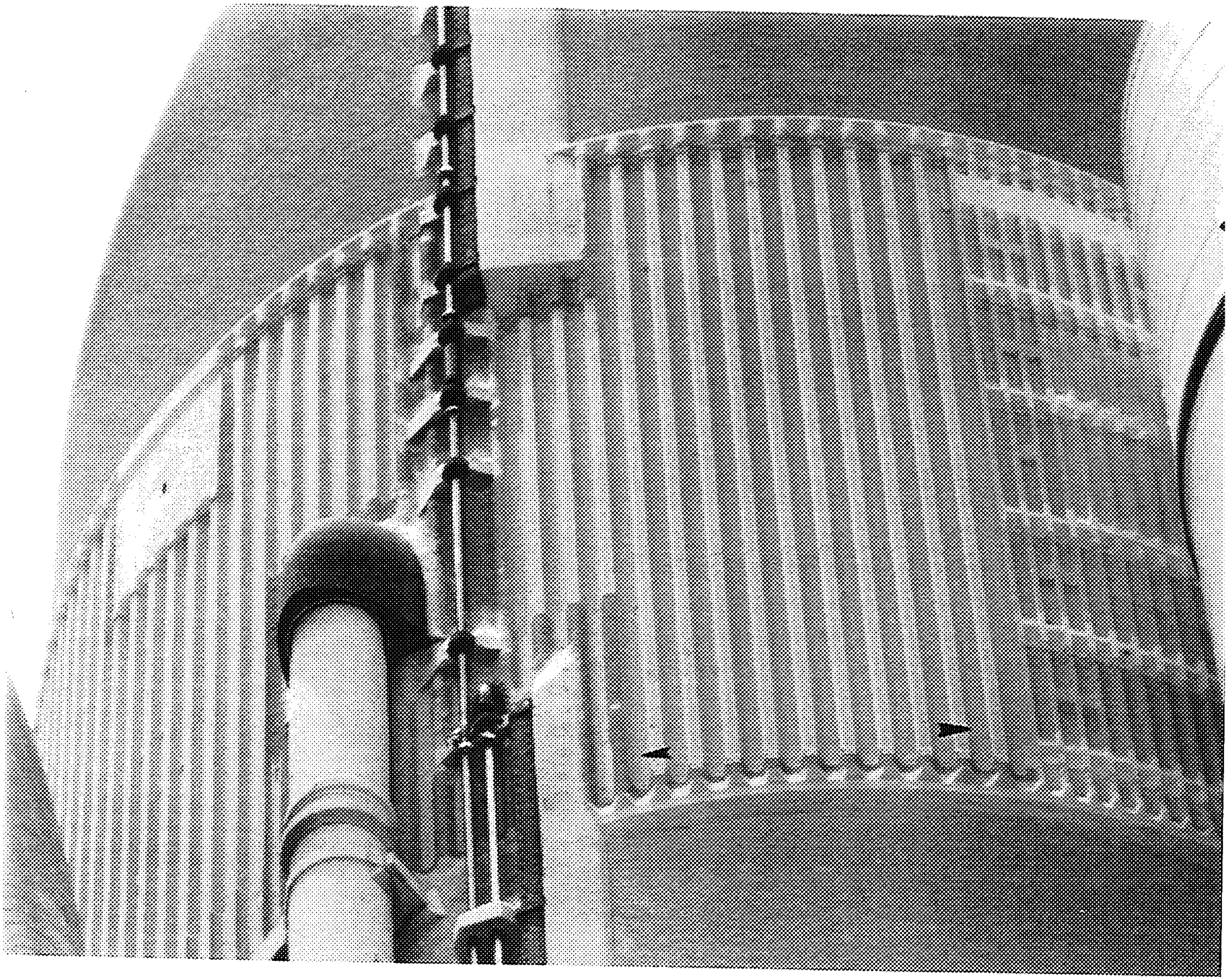


Photo 11: Intertank Stringers

Two cracks were detected in the +Y+Z quadrant of the intertank. One crack was located in the second stringer valley in the +Y direction from the PAL ramp; the second crack was located in the second stringer valley in the +Z direction from the +Y thrust panel (arrows). The cracks appeared to originate from the as-sprayed foam at the aft end of the stringers extending forward approximately 7 inches from the LH2 tank splice. Each crack was no greater than 1/16 inch wide with no visible offset or ice/frost formation. Although the NSTS-08303 Ice/Debris Inspection Criteria documents an intertank TPS crack in the -Y-Z quadrant as acceptable for flight, no such case was available for cracks in the +Y+Z quadrant. Consequently, an IPR was taken to determine this condition was acceptable for flight as well.

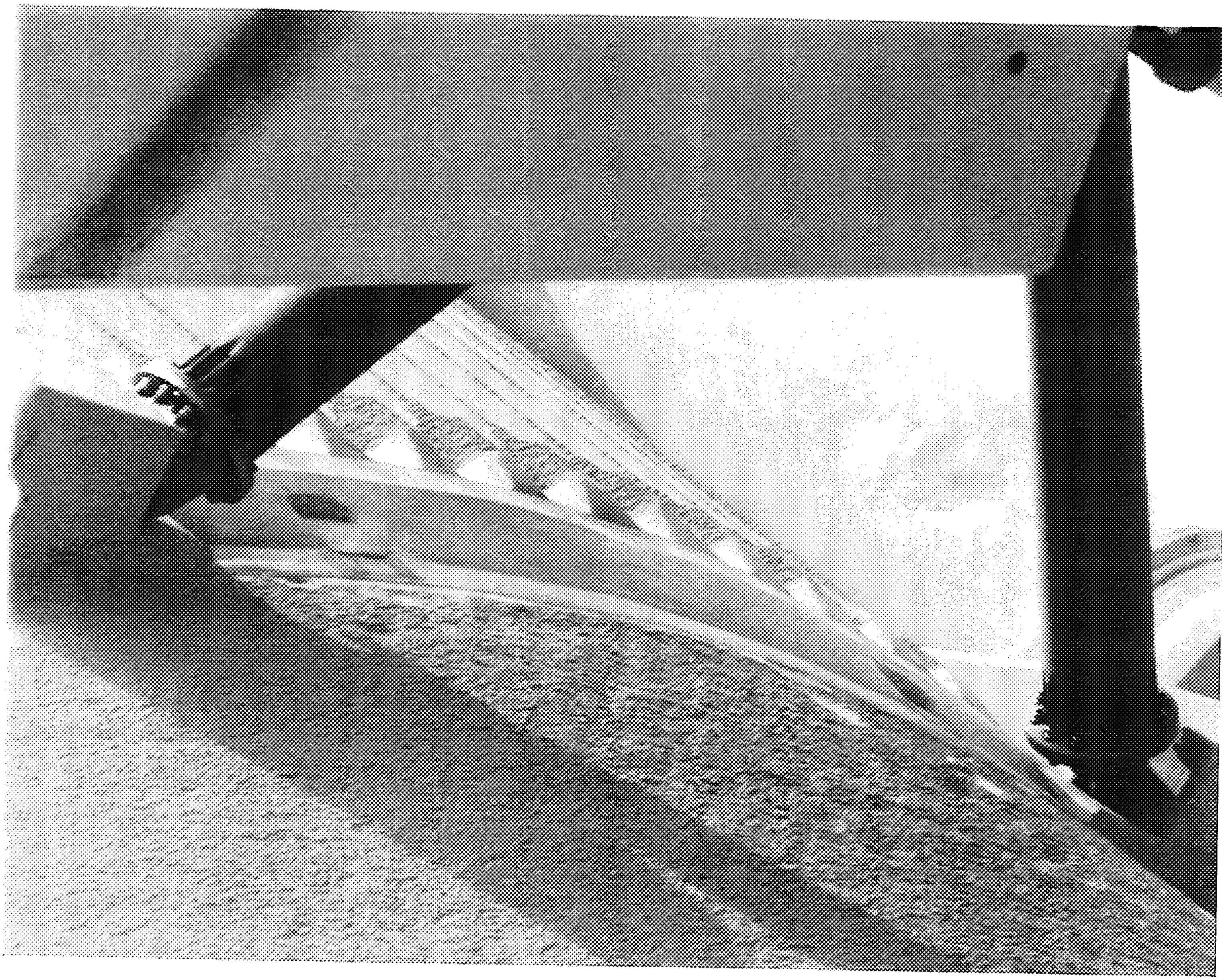


Photo 12: Bipods

No anomalies were detected on the bipod stand-off jack pad closeouts or the spindle housing closeouts

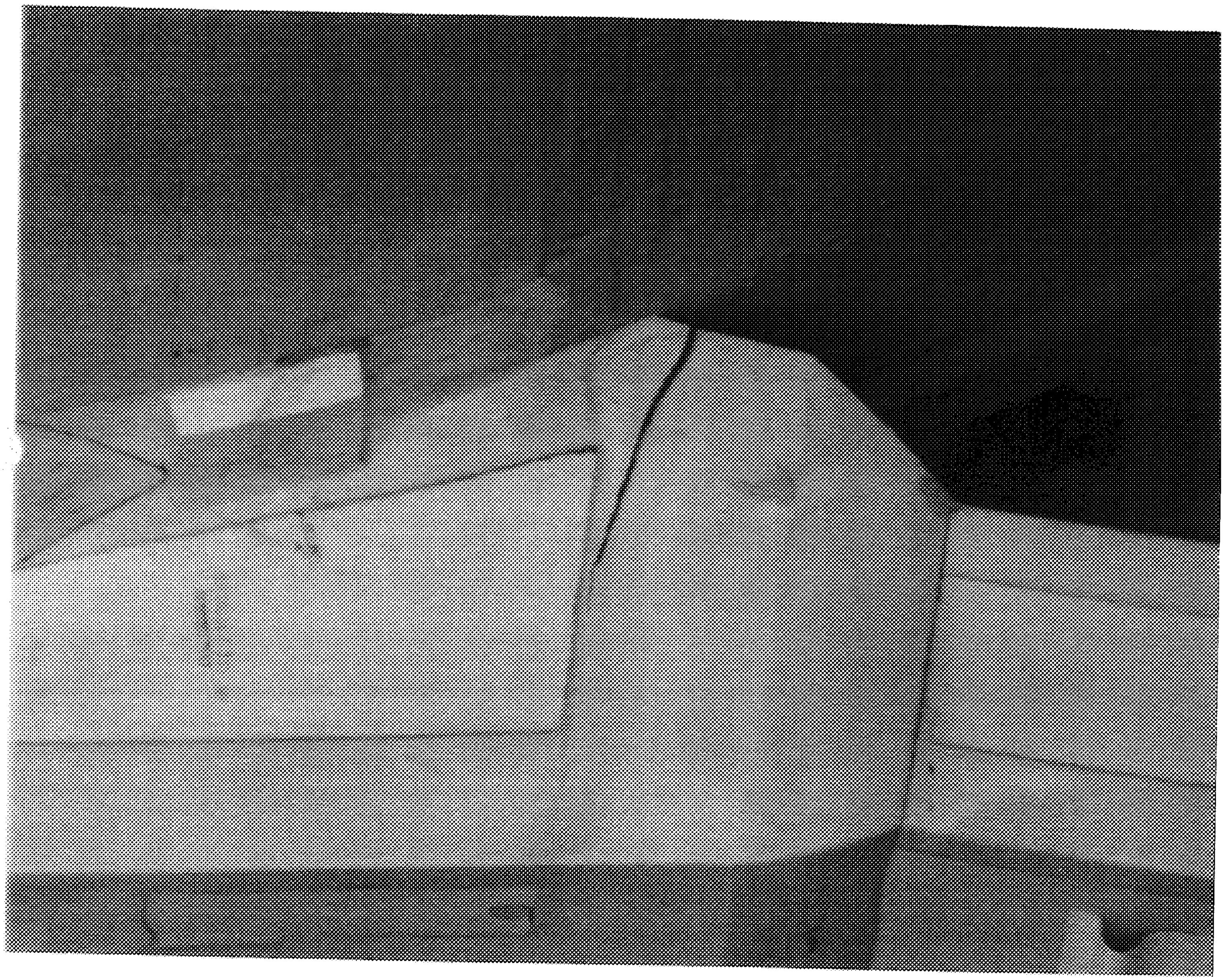


Photo 13: -Y Vertical Strut

A 10-inch long by ¼-inch wide stress relief crack had formed, as expected, on the -Y vertical strut forward facing TPS.

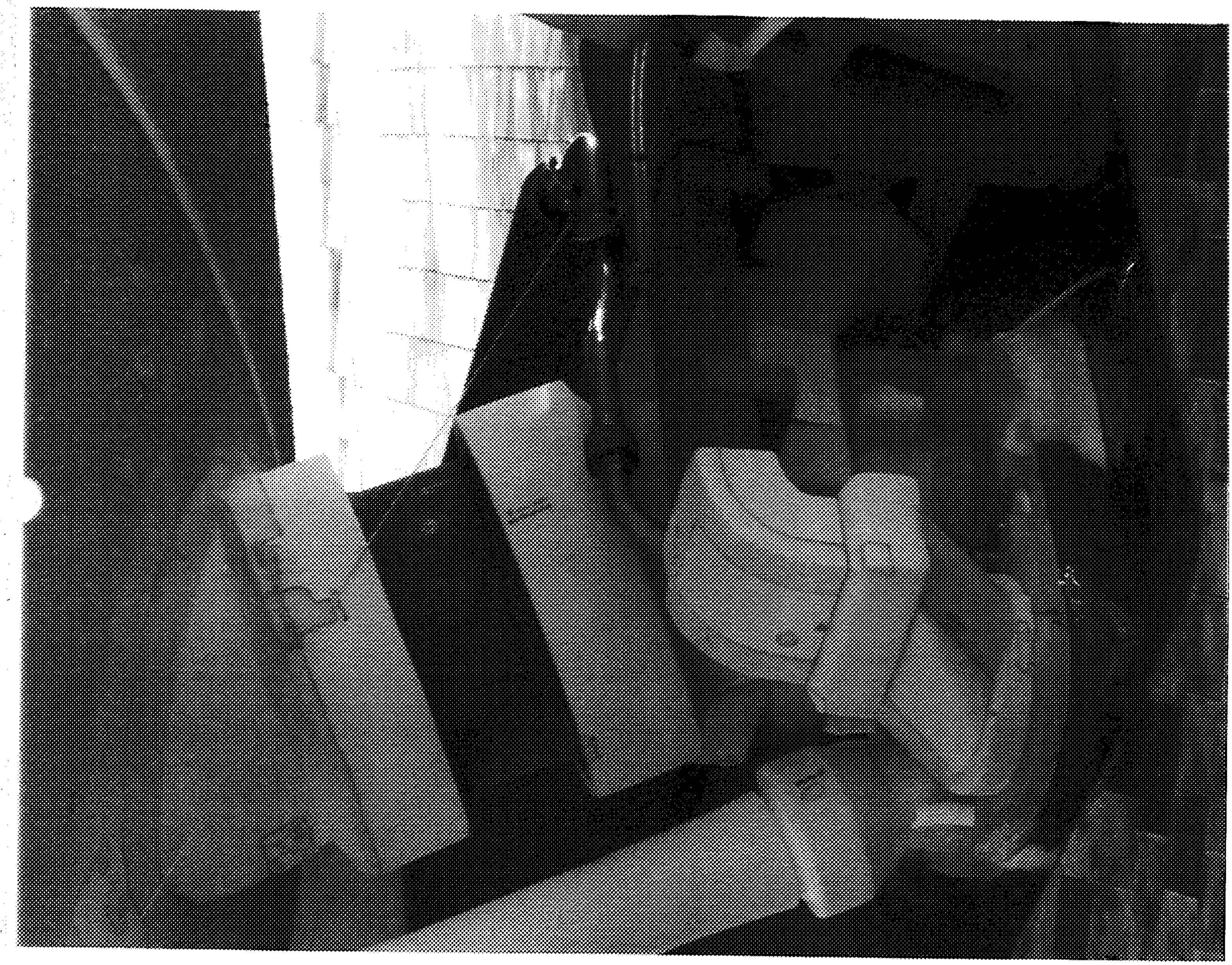


Photo 14: LH2 ET/ORB Umbilical

Typical 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 and stable replenish.

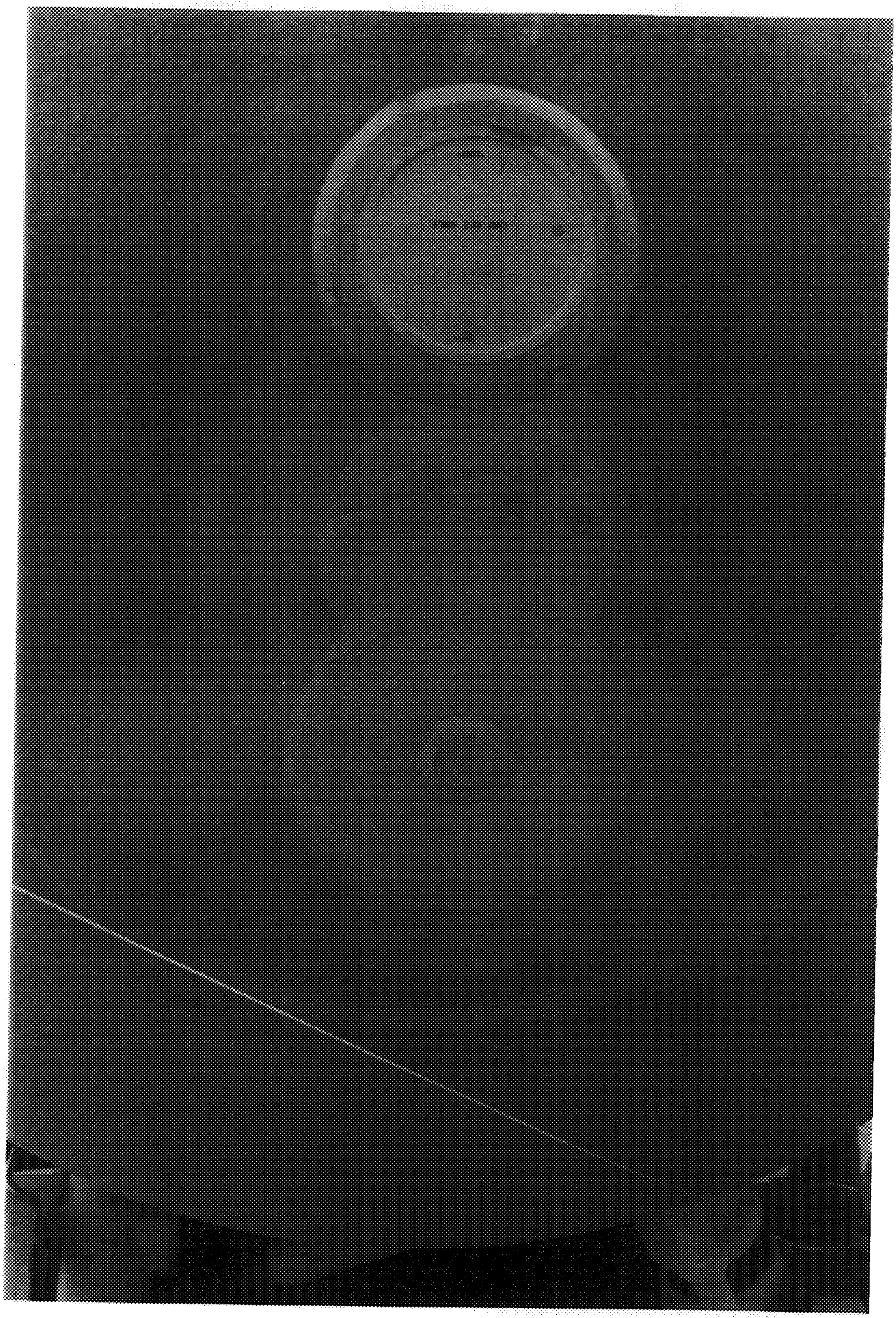


Photo 15: Aft Dome Apex

New configuration of the aft dome apex eliminated the +Z manhole cover

4.0 POST TANKING SSV INSPECTION

A Post Drain Inspection of the Space Shuttle Vehicle, with emphasis on the new Super Light Weight External Tank (ET-96), was performed from May 18^{th} to May 20^{th}, 1998.

No anomalies were detected during the first ET post drain inspection on 18 May 1998 immediately after drain was completed.

The dimensions of the stress relief crack in the -Y vertical strut had not changed. No crushed foam in the LO2 feedline brackets could be seen from the MLP deck. The sanded area on the LO2 tank ogive exhibited no ice formations or foam damage.

The two 7-inch cracks in the intertank stringer valley foam had closed completely.

A more detailed, "hands-on" inspection using RSS platforms was performed on 20 May 1998.

No anomalies were detected in the sanded area on the LO2 ogive at the XT-536 weld.

The two 7-inch cracks in the ET intertank stringer valleys (+Y+Z quadrant), had closed to barely visible hairline cracks. The IPR taken during the tanking test was upgraded to a PR with an MRB to use as-is rationale.

Inspection of the LO2 feedline revealed a small piece of loose foam in the XT-1123 support bracket (aft side). The foam particle was removed and the remaining foam was only superficially damaged. Likewise, a small piece of loose foam was removed from the XT-1377 inboard support bracket (aft side). A second piece, measuring 2-3/8 inches long by 1-5/8 inches wide by 1-1/8 inches deep at the thickest point, was removed from the support bracket shock absorber (inboard side). All of these damage sites were typical of an ET detank, considered to be acceptable for flight, and submitted as an MRB to use as-is with no repair required.

A 0.5-inch diameter void occurred in the approximate center of a repair on the LH2 feedline to aft dome closeout. The loose foam in this void was removed and the discrepant area repaired prior to launch.

As expected, the stress relief crack on the -Y vertical strut had closed to a barely discernible hairline crack. This condition is acceptable for flight per the NSTS-08303 criteria.

From an Ice and TPS perspective, the tanking test was successful resulting in only minor TPS defects. There were no TPS constraints for launch cryoload.

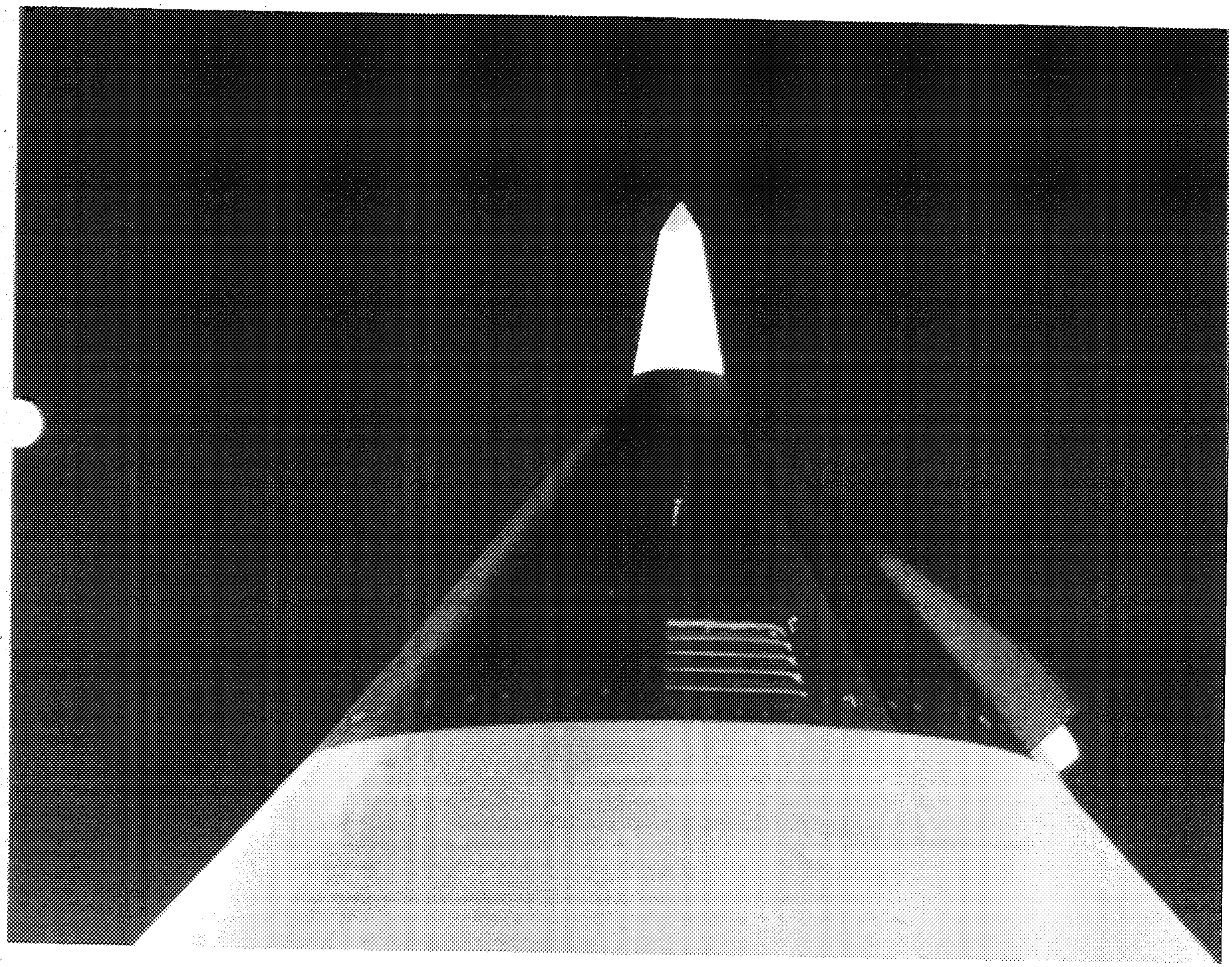


Photo 16: Composite Nose Cone

No anomalies were detected on the black graphite-epoxy composite nose cone

Photo 17: +Z Side Sanded Area

The sanded area on the LO2 tank ogive at the XT-536 weld exhibited no ice formations or foam damage.

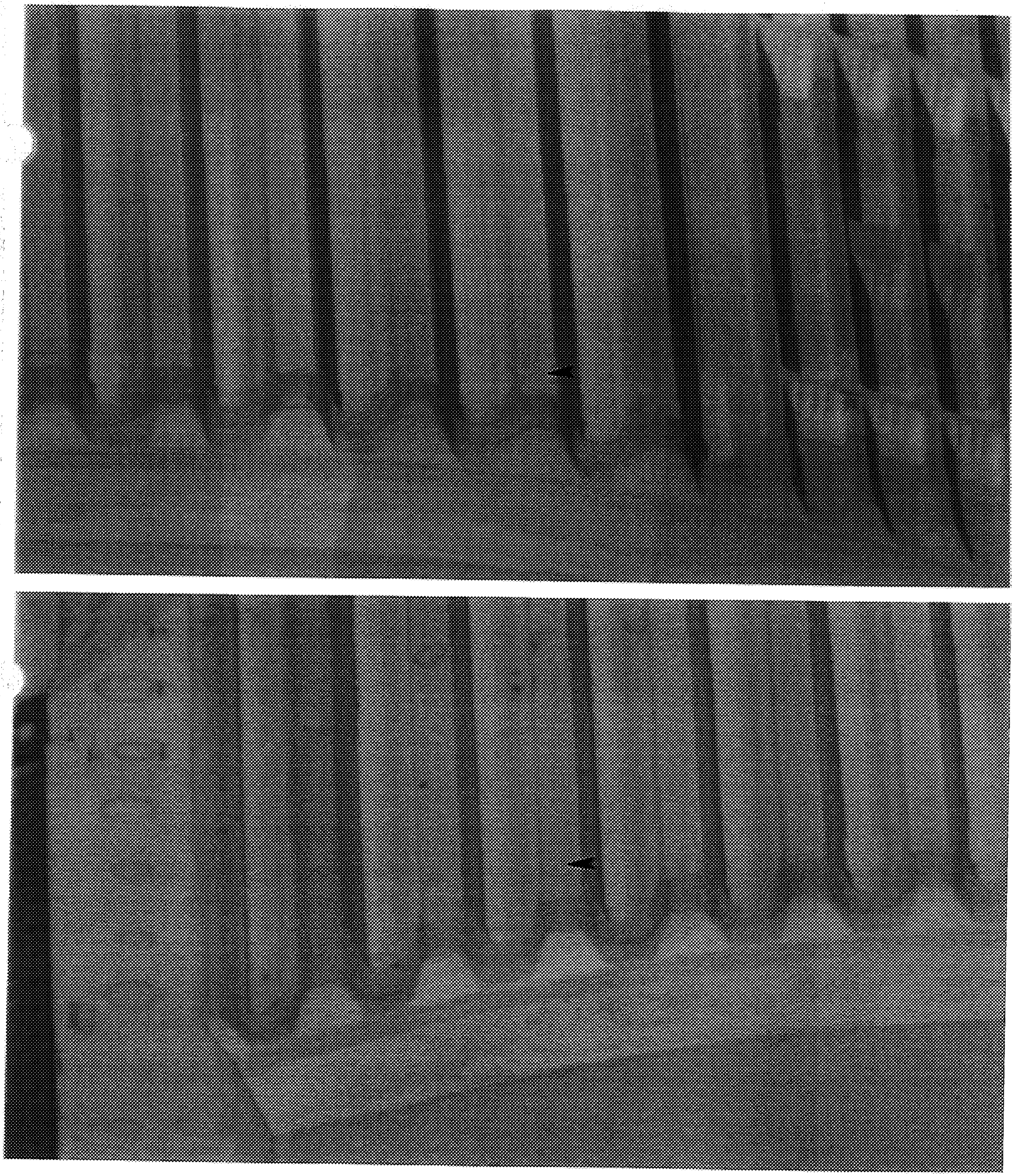


Photo 18: Intertank Stringer Foam Cracks

The two 7-inch cracks in the ET intertank stringer valleys (+Y+Z quadrant), had closed to barely visible hairline cracks. The IPR taken during the tanking test was upgraded to a PR with an MRB to use as-is rationale.

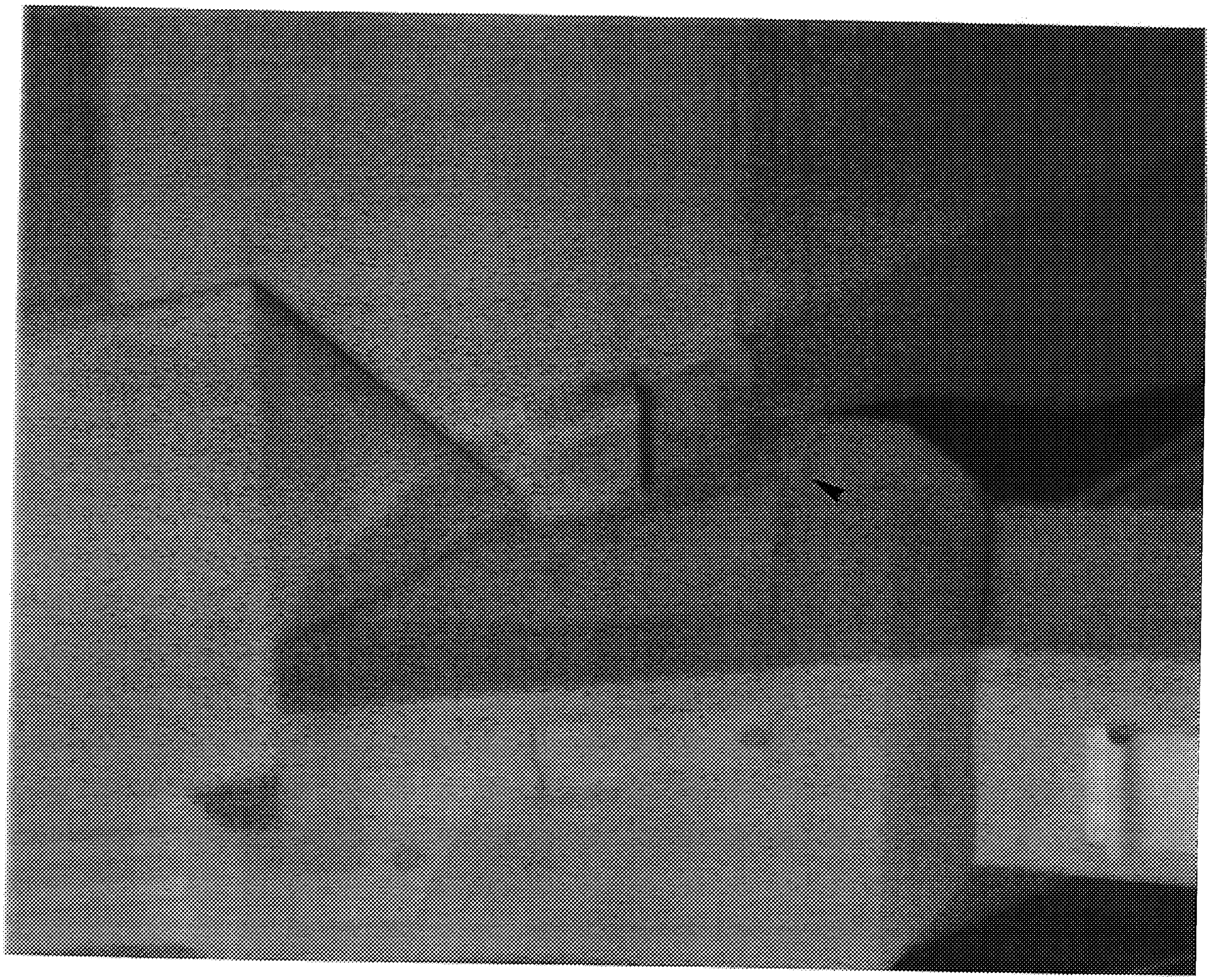


Photo 19: -Y Vertical Strut

The size of the stress relief crack in the -Y vertical strut had not changed during drain

5.0 LAUNCH

STS-91 was launched at 98:153:22:06:17.008 UTC (6:06 p.m. local) on 2 June 1998.

5.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 1 June 1998. The detailed walkdown of Pad 39A and MLP-1 also included the primary flight elements OV-103 Discovery (24th flight), ET-96 first Super Light Weight Tank, and BI-091 SRB's. There were no significant vehicle or launch pad anomalies.

With the June launch and a liftoff time late in the day before sunset, weather conditions were expected to be warm and preclude the formation of acreage ice on the External Tank.

5.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 2 June 1998 from 1240 to 1420 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. There were no acreage icing concerns. There were also no protuberance icing conditions outside of the established 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.

5.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster covers were intact though one cover on thruster L1L was slightly wet. Condensate had formed on SSME #1 and #2 heat shield-to-nozzle interfaces. The SSME #3 heat shield was dry. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields.

5.2.2 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 77 degrees F, which was within the required range of 44-86 degrees F.

5.2.3 EXTERNAL TANK

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

The Thermal Protection Systems performed nominally during cryoload. The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures ranged from 82 to 92 degrees F depending on sunlit or shadowed areas. The sanded area on the LO2 tank ogive exhibited no anomalies. Light condensate was visible on the composite nose cone between the fairing and the southwest louver.

Two cracks were detected in the +Y+Z quadrant of the intertank. One crack was located in the second stringer valley in the +Y direction from the PAL ramp; the second crack was located in the second stringer valley in the +Z direction from the +Y thrust panel. The cracks appeared to originate from the as-sprayed foam at the aft end of the stringers extending forward approximately 7 inches from the LH2 tank splice. These two cracks had been documented during the tanking test.

Two new, similar cracks were detected. A 4-inch crack was located in the -Y+Z quadrant in the second stringer valley from the thrust panel and a 6-8 inch crack was located in the -Y-Z quadrant in the second stringer valley from the thrust panel.

All four cracks were no greater than 1/16 inch wide with no visible offset or ice/frost formation and were acceptable for flight per the NSTS-08303 criteria and tanking test IPR rationale.

A small area of frost with no ice formation was visible at the aft outboard corner of the +Y bipod jack pad standoff bolt hole closeout.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures ranged from 76 to 82 degrees F depending more on sunlit versus shadowed area readings than the "thick/thin" TPS configuration. A 2-inch diameter ice/frost ball at the +Y vertical strut to ET aft dome interface was determined to be no threat to the Orbiter. Both TPS repairs on the LH2 feedline and LH2 umbilical were in nominal condition.

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

A 12-inch long by 3/8-inch wide stress relief crack had formed, as expected, on the -Y vertical strut forward facing TPS. There was no ice/frost present and no offset. The condition was acceptable for launch per the NSTS-08303 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.

A typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side. Ice/frost formation on the forward surface of the umbilical was somewhat heavier than usual. 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.

5.2.4 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.

A drive adapter used to extend/retract the side platforms on an MLP Tail Service Mast was discovered by the Final Inspection Team at the northeast corner of the LO2 TSM during the T-3 hour inspection. The steel adapter was 2-inches in diameter and weighed a half pound. A recent modification called for the adapters (three adapters per TSM) to be permanently attached to the drive shafts with set screws. In this case, the set screw apparently backed out during platform operations causing the adapter to hang loosely at the end of the shaft. As a result of this finding, all adapters have been changed to a pinned design.

5.3 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. Even with the decrease in ambient temperature, no icing concerns were predicted. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers and area of the composite nose cone surrounding the louvers until liftoff.

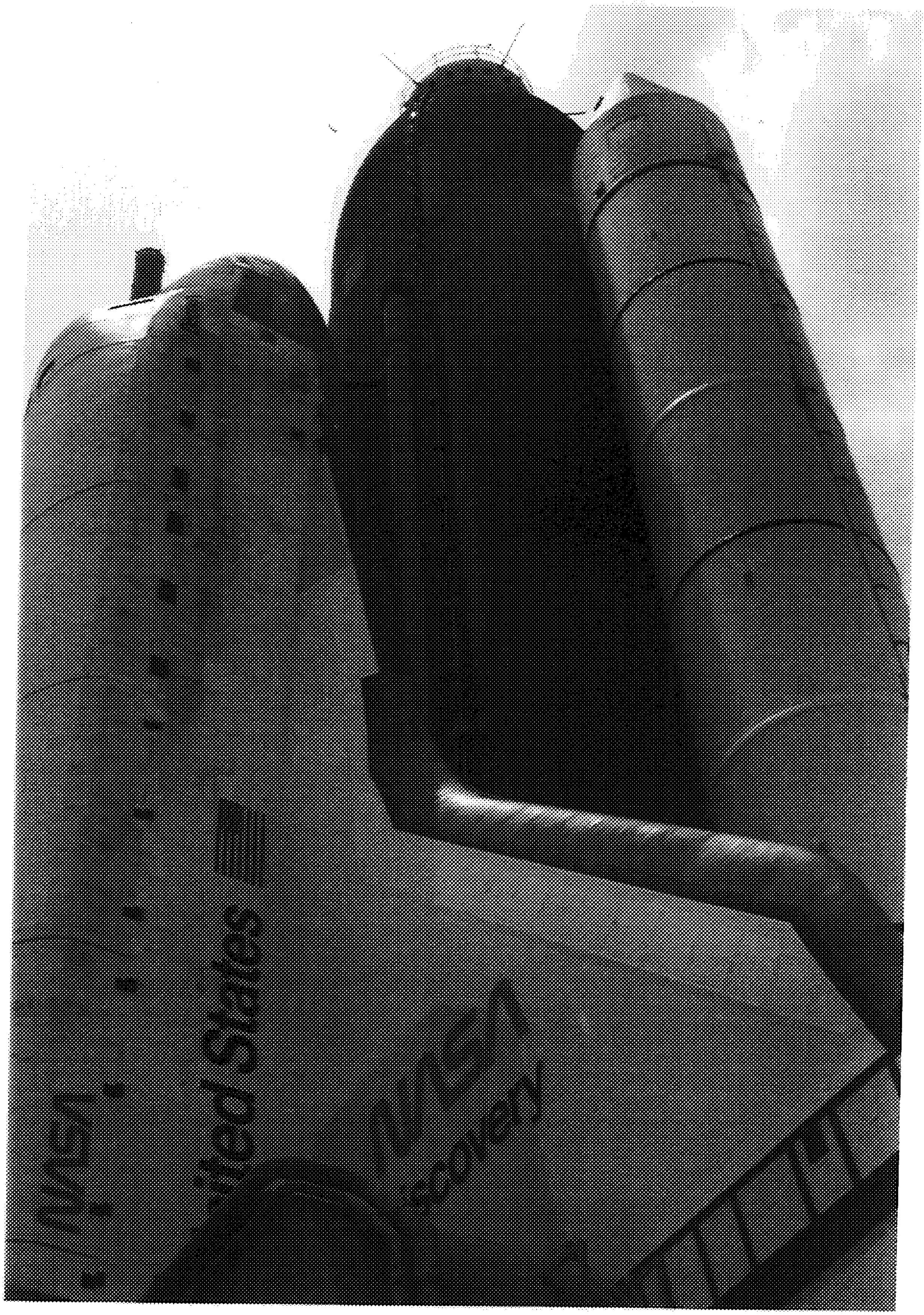


Photo 20: STS-91 Ready for Launch

OV-103 Discovery, ET-96 first Super Light Weight Tank, and BI-091 SRB's. The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures ranged from 76 to 82 degrees F.

Photo 21: LO2 Tank After Cryoload

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures ranged from 82 to 92 degrees F. Note configuration change to the intertank stringer heads and valleys, which have been sanded.

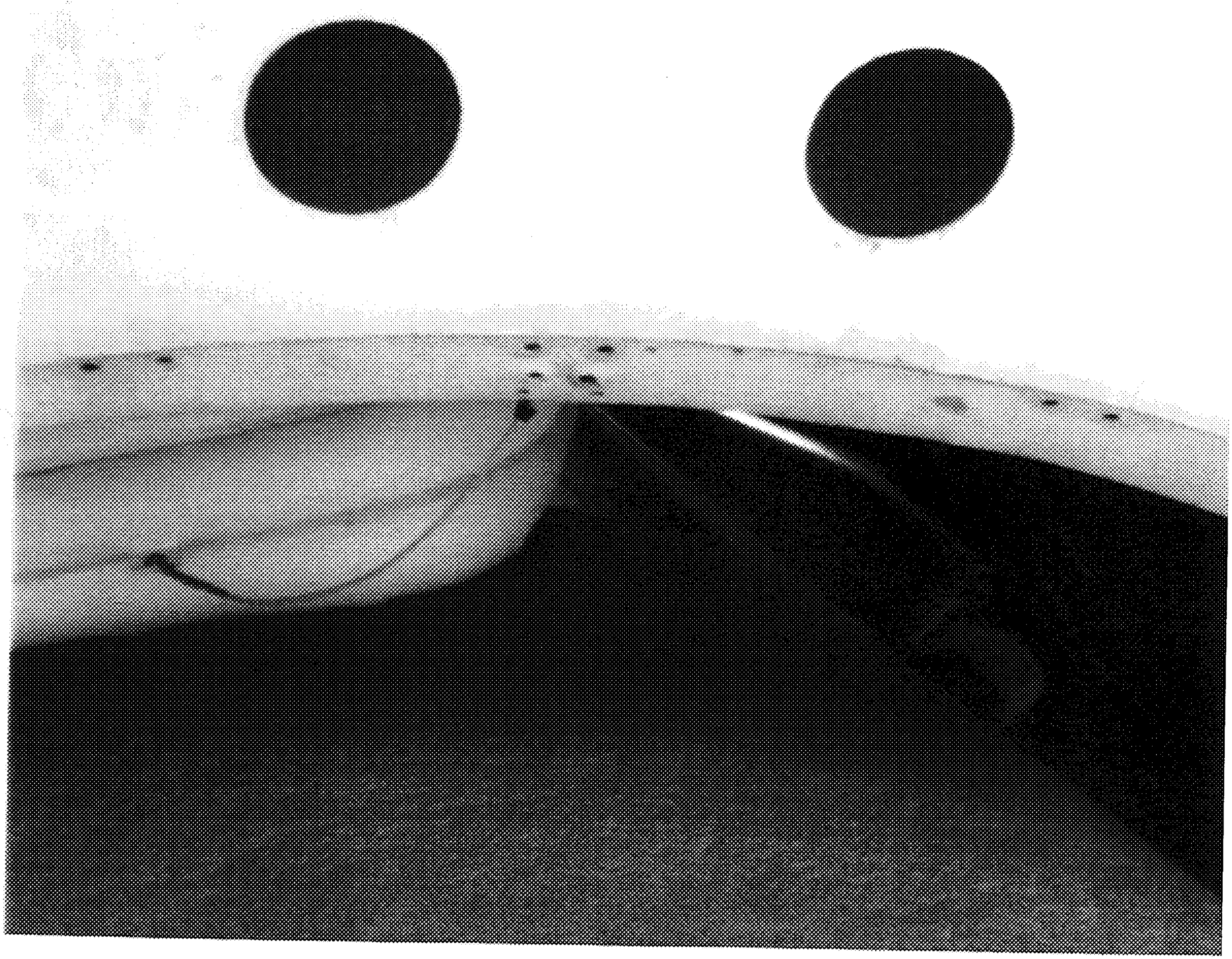


Photo 22: Composite Nose Cone

Light condensate was visible on the composite nose cone between the fairing and the southwest louver

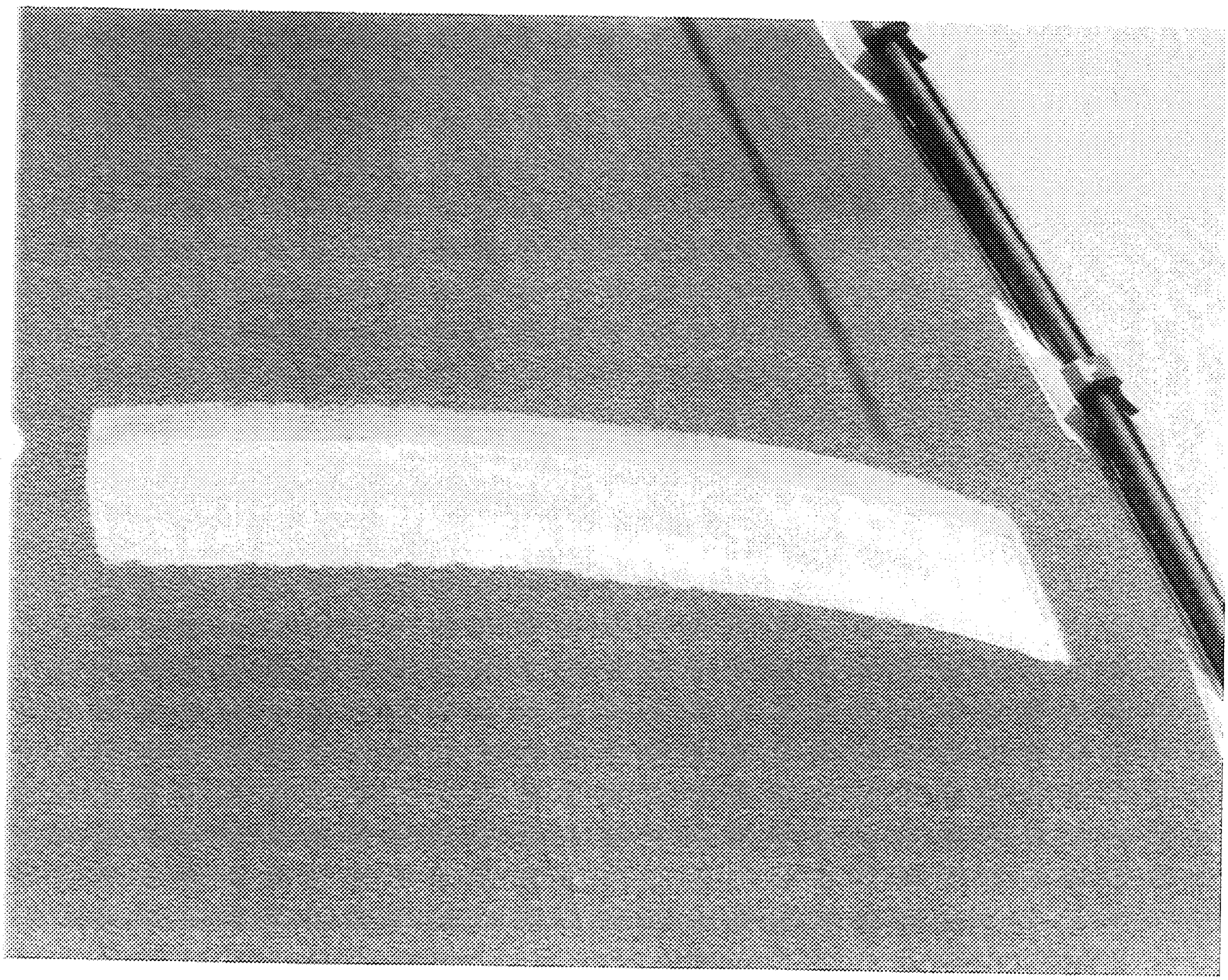


Photo 23: LO2 Tank Sanded Area

The sanded area on the LO2 tank ogive exhibited no anomalies

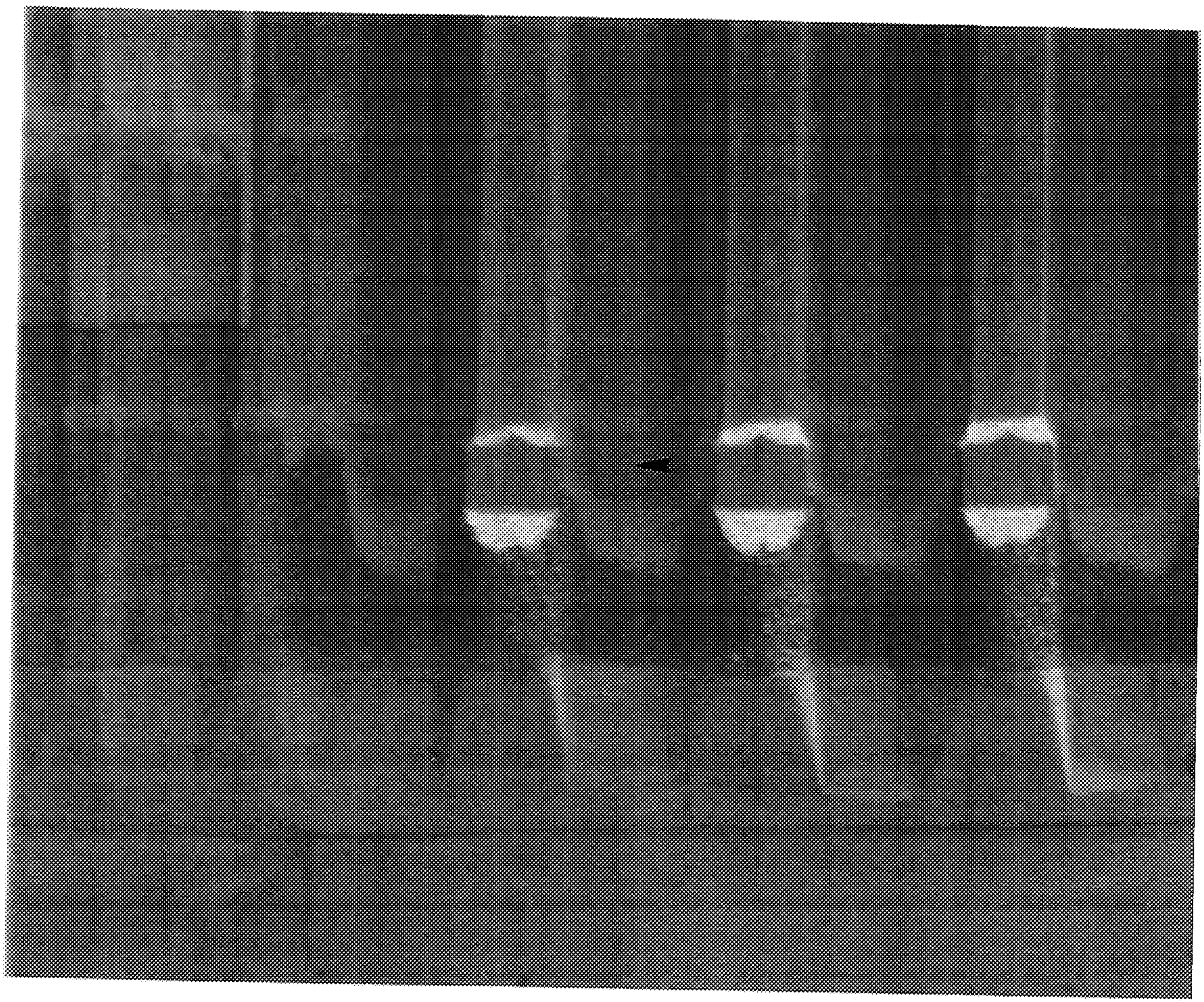


Photo 24: Cracks in Intertank Foam

Small cracks, ranging in length from 4 to 8 inches, were detected in three of the four intertank quadrants in stringer valleys near the LH2 tank-to-intertank flange closeout. The cracks appeared to originate from the as-sprayed foam at the aft end of the stringers extending forward from the LH2 tank splice.

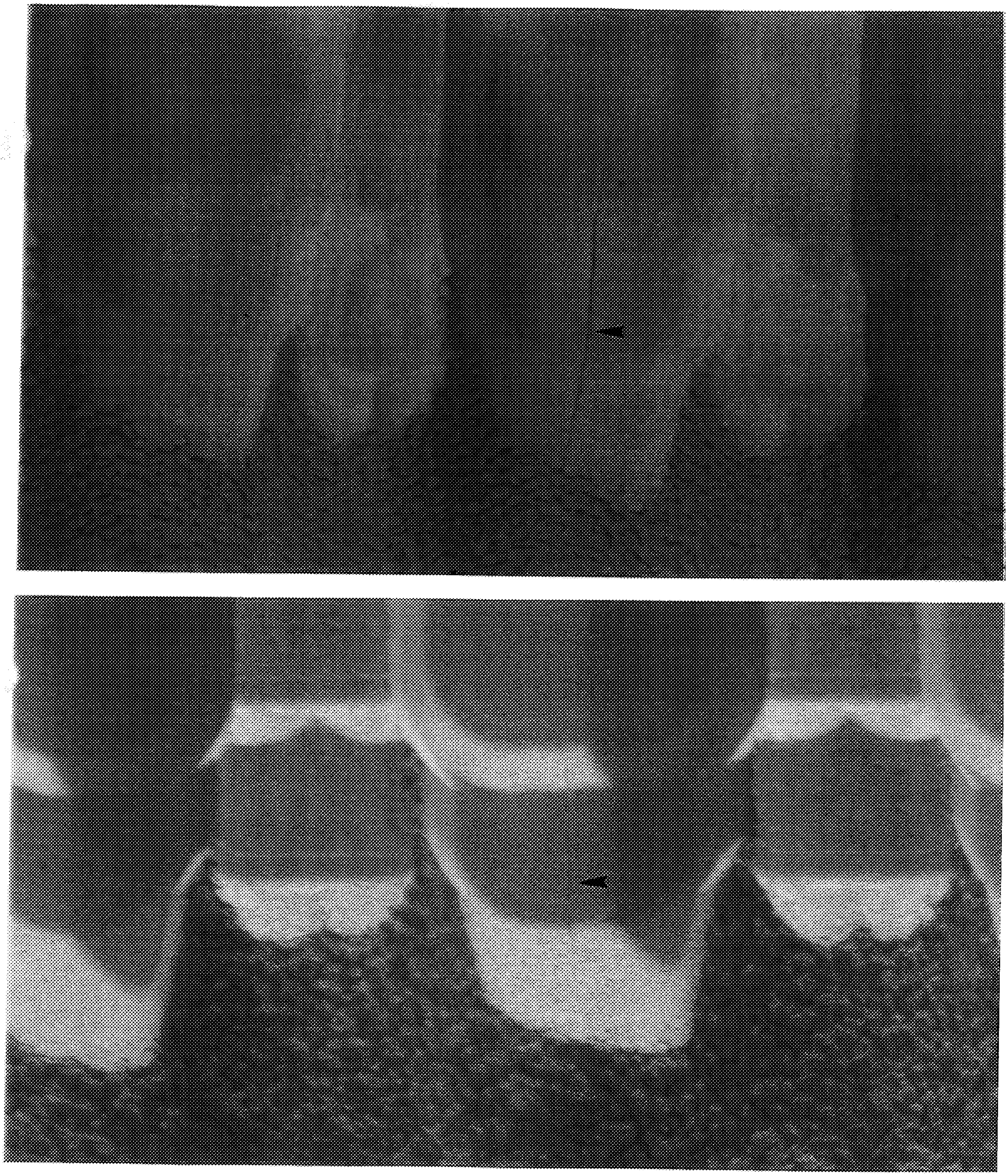


Photo 25: Cracks in Intertank Foam

All of the cracks were no greater than 1/16 inch wide with no visible offset or ice/frost formation and were acceptable for flight per the NSTS-08303 criteria and tanking test IPR rationale.

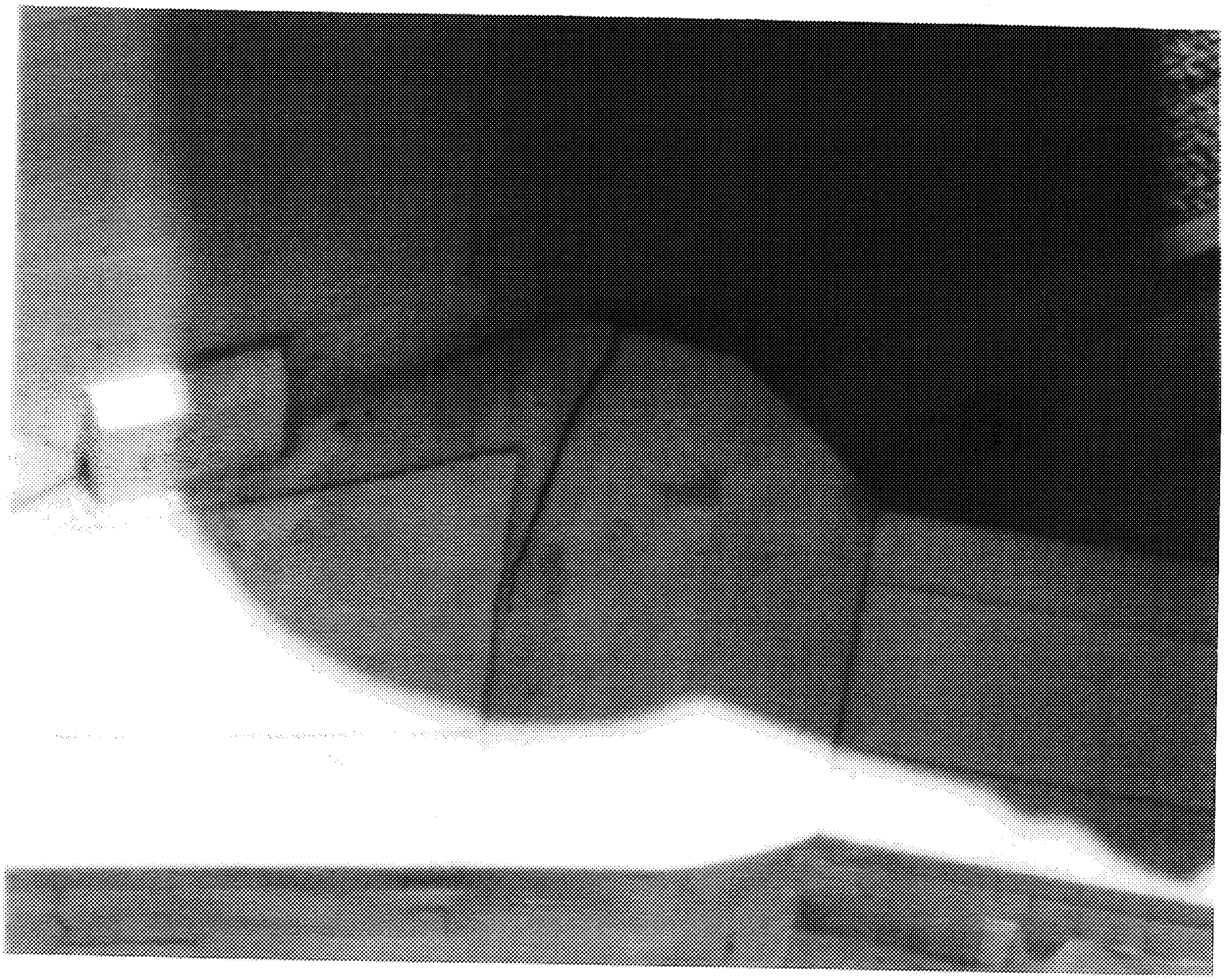


Photo 26: -Y Vertical Strut

A 12-inch long by 3/8-inch wide stress relief crack had formed, as expected, on the -Y vertical strut forward facing TPS. There was no ice/frost present and no offset. The condition was acceptable for launch per the NSTS-08303 criteria.

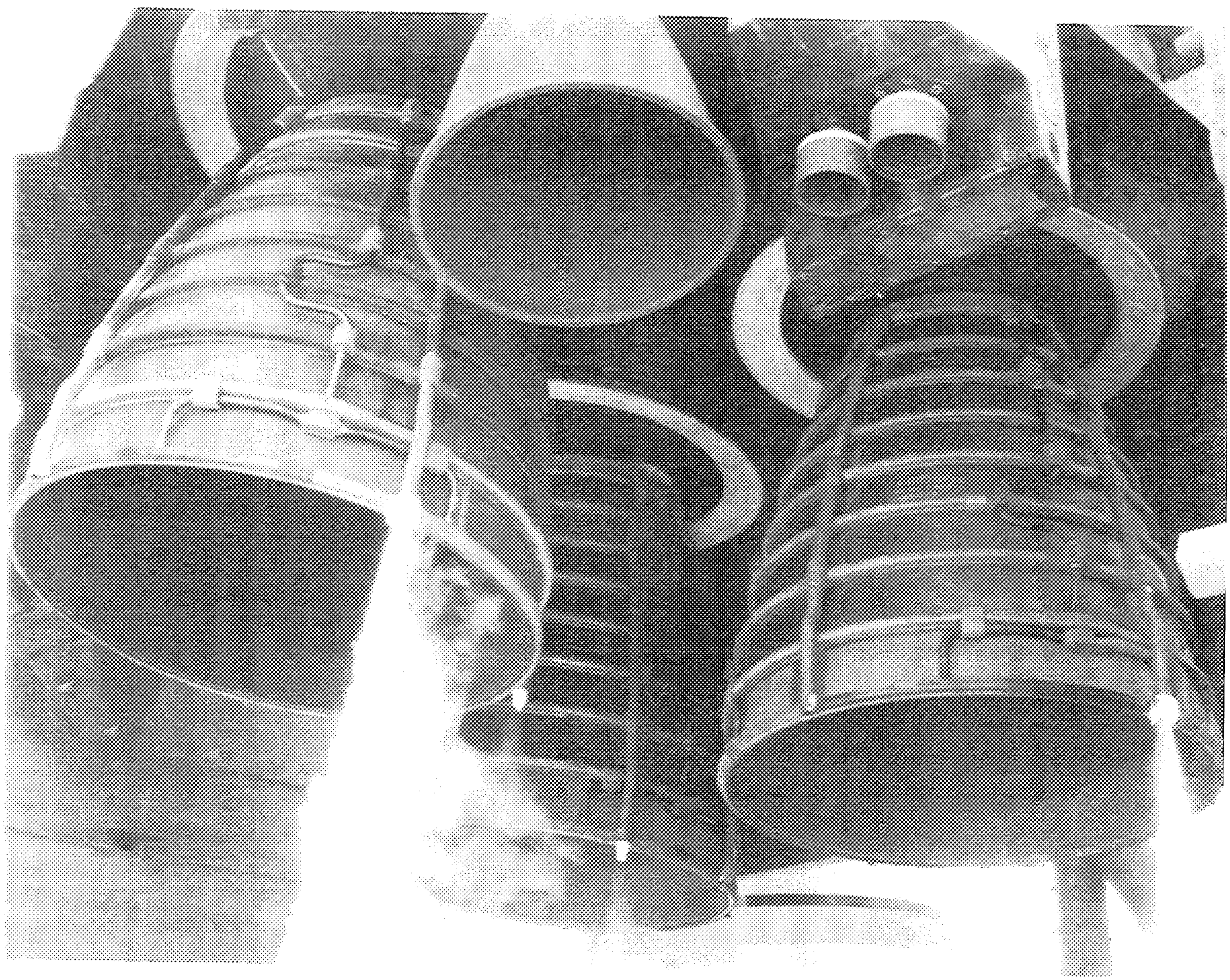


Photo 27: Overall View of SSME's

6.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 1, Pad A FSS, RSS, and pad apron was conducted on 2 June 1998 from Launch + 2 to 3.5 hours. No flight hardware was found.

Although Boeing - Downey reported an Orbiter liftoff lateral acceleration of 0.19 g's, which is above the threshold (0.14 g's) for stud hang-ups, an actual stud hand-up did not occur on this launch. SRB south holddown post erosion was less than usual. North holddown post blast covers and T-0 umbilicals exhibited typical exhaust plume damage. The right SRB aft skirt GN2 purge line was intact and upright after liftoff. The left GN2 purge flex line was bent in half in the +Z direction and exhibited structural damage (holes) and melting of the wire braid.

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 though the doors to the White Room were unhinged.

The GH2 vent line was latched in the eighth 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 aluminized thermal blanket was destroyed by the plume. The peripheral seal was scorched.

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

Debris findings on the FSS included loose floor gratings on the 115 foot level, approximately 20 feet of ¼-inch purge tube hanging loose from the south side of the RBUS deck, loose bolts/FOD on the OIS station roof on the west side of the 115 foot level stairs, a loose cover on a 135 foot level inactive panel, a 5-inch by 3-inch piece of zinc scale and a large grate clamp on the 195 foot level. Several of the stadium light lenses were broken.

Though a close inspection was not performed, no obvious unusual debris was noted in the flame trench, in the north SRB plume blast area, or in the acreage. Those areas will be inspected Wednesday. Overall, damage to the pad appeared to be minimal.

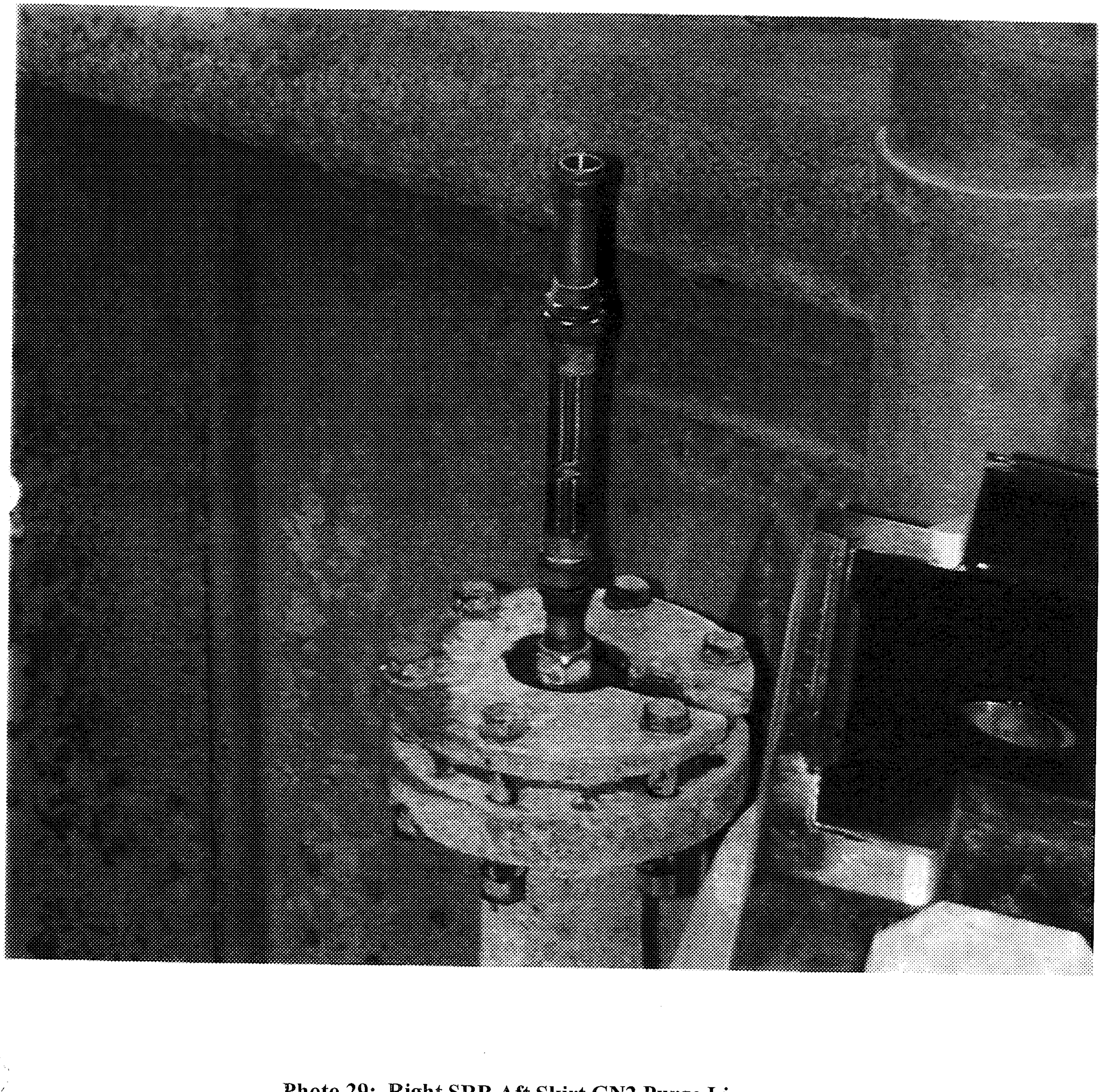


Photo 29: Right SRB Aft Skirt GN2 Purge Line
The right SRB aft skirt GN2 purge line was intact and upright after liftoff

7.0 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.

7.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 83 films and videos, which included twenty-seven 16mm films, eighteen 35mm films, and thirty-eight videos, were reviewed starting on launch day.

Most of the long range tracker imagery was degraded due to atmospheric haze. In addition, the view from the northern trackers was often obscured by clouds.

SSME ignition appeared normal though formation of SSME Mach diamonds occurred in a 2-1-3 sequence (E-63, -76; OTV 071). A debris induced streak occurred in the SSME #1 exhaust plume prior to T-0 at 22:06:23.661 UTC (E-2, -3, -19, -20, -52, -76).

SSME ignition caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft. Some pieces impacted the umbilical cavity sill, but no damage was visible (OTV-009, 063).

Surface coating material was lost during ignition from three small areas on base heat shield tiles outboard of SSME #3, one area on the OMS base, three places on the right ACPS stinger, one place on the aft surface of the left ACPS stinger, two places on the base heat shield outboard of SSME #2, two places on the SSME #2 dome mounted heat shield, and two places on the body flap upper surface outboard of SSME #3 (E-17, -18, -19, -20, -76; OTV-049, 050).

No anomalies were detected on the External Tank nose cone. No ice was present in the louvers or "no ice" zone (OTV 013, 061, 062).

Although the lateral acceleration at liftoff was 0.19g, 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 debris object 1-2 inches long, possibly a K5NA trimming, emerged from the DCS area of HDP #1 after T-0 (E-9).

Water leaked from the sound suppression water pipe joint near holddown post #4 (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. At that time, no anomalies had been observed (E-8, -13).

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

An object that appeared to be a transparent plastic bag entered the field of view (FSS side) at 06:25.424 UTC and passed by the camera lens moving generally north away from the vehicle (E-4).

GUCP disconnect and GH2 vent line retraction from the ET was normal. A dark particle falling aft along with the pieces of ice is believed to be an insect (E-33).

A light colored particle appeared from the upper surface of the right wing and fell aft at T+1 second MET (OTV 054).

A dark object in the left SRB exhaust plume at 22:06:26.900 UTC was most likely a large piece of SRB sound suppression water trough material (E-76).

As the vehicle was leaving the field of view, one of the yellow primary SRB sound suppression water troughs was blown toward the SSME exhaust hole (E-5).

Condensation collars formed on the vehicle during ascent - an expected occurrence due to the ambient weather conditions (TV-4, TV-21).

Debris induced streaks occurred in the SSME exhaust plumes during ascent at 22:06:52.839, 22:06:54.035, 22:07:01.818, and 22:07:05.922 UTC (E-213, -222, -223).

SRB tailoff and separation appeared normal. Slag falling out of the exhaust plume before, during, and after SRB separation was typical (TV-13).

7.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-103 was equipped to carry umbilical cameras (for the first time): 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. The flight crew provided 33 hand held still images and some video from the camcorder. Unfortunately, the video footage was not usable. The still images were underexposed, but usable. The +X translation and a manual pitch maneuver from the heads-up position were performed to bring the tank into view through the overhead windows.

7.2.1 ET/ORB Umbilical 16mm Films

In the 16mm films, lighting of the ET after separation was very good though all areas to the +Y side of the LO2 feedline were in shadow. Focus and field of view was good.

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, were intact and appeared to be in good condition.

ET-96 separation from the Orbiter was normal. No divots were detected in the LO2 and LH2 tank acreage. No anomalies were detected on the composite nose cone (second flight). The sanded area on the LO2 tank at XT-536 was darkened somewhat due to ascent aeroheating, but no divoting or loss of foam occurred.

Twenty to twenty-five light colored spots were detected in the -Y thrust panel acreage in an area bordered by the LO2 and LH2 tank-to-intertank flange closeouts and from the thrust panel-to-intertank splice to the tank curving out of view in the -Y direction. These light colored spots are most likely small, shallow divots, most of which are in the areas between the ring frames. However, some of the possible divots could be seen on the forward ring frame. Sunlight reflection on the other ring frames made detection of possible divots more difficult. The +Y thrust panel was in shadow and no detail could be discerned.

The +Z side of the intertank appeared to be in good condition with no acreage divots though some very small "popcorn" type divots could be seen near the -Y thrust panel interface. Heating from the shock waves off both forward EB fittings left black marks on the intertank acreage in a diagonal line 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 were intact. A 6-inch diameter divot was visible between the bipods near centerline in the LH2 tank-to-intertank flange closeout. The divot may be associated with a repaired area documented in the pre-launch photography. Two divots, 4-6 inches in diameter, were present in the flange closeout -Y+Z quadrant. A much larger 10-inch long divot was also present in the flange closeout near the -Y thrust panel. All three of these divots may be associated with repaired areas documented in pre-launch photos. None of the divots were deep enough to show primed substrate in this view.

Three light-colored areas, or spots, aft of the bipods on the LH2 tank acreage have been matched to sanded areas documented in the pre-launch photography. Both +Y and -Y thrust struts exhibited typical ascent erosion and very small divoting. No damage was observed on the LO2 feedline or either ET/ORB umbilical. Charring and "popcorn" divoting of the aft dome was typical.

Photo 31: SRB Separation from External Tank

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, were intact and appeared to be in good condition.

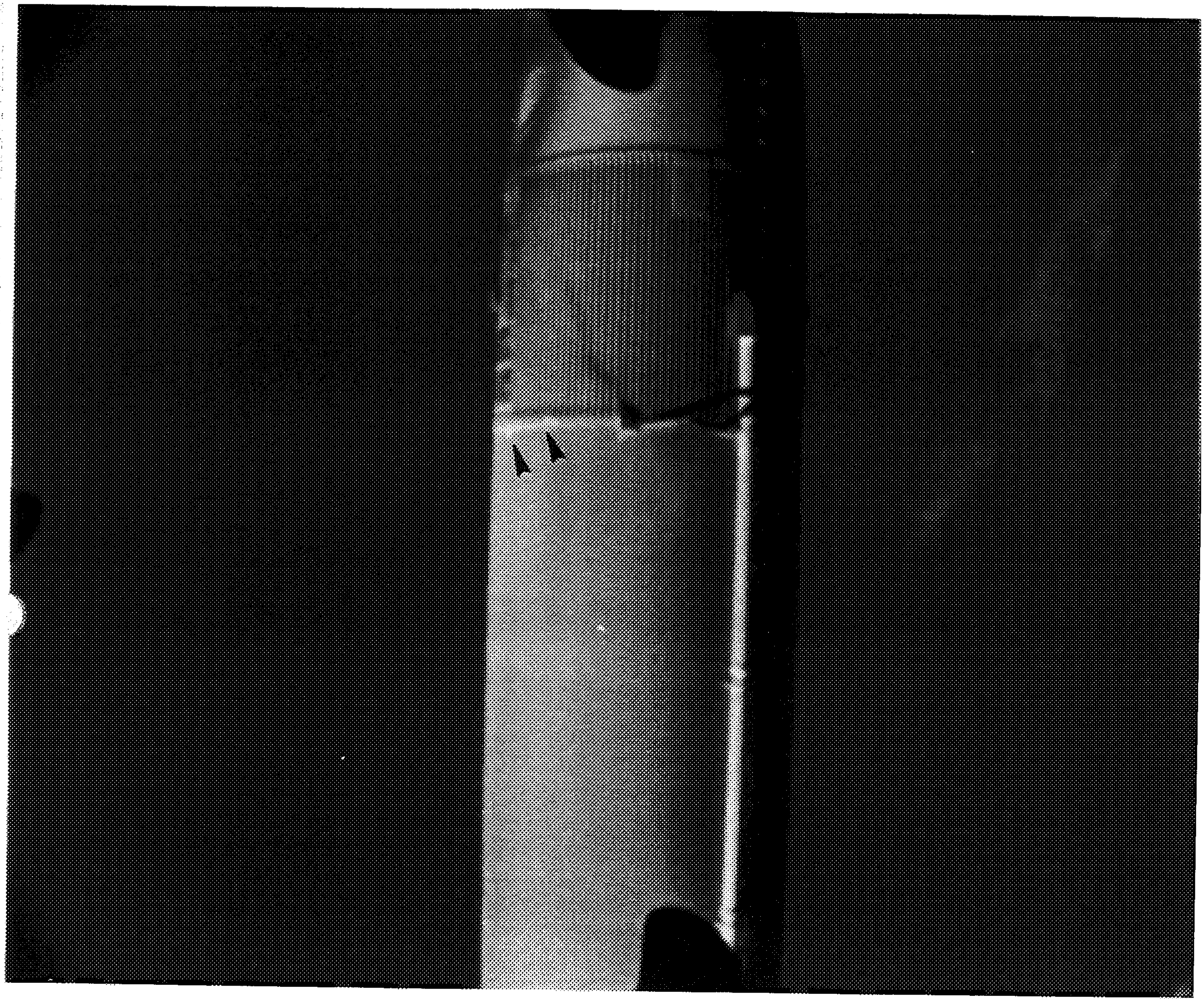


Photo 32: ET After Separation from Orbiter

No divots were visible in the LO2 and LH2 tank acreage. Twenty to twenty-five light colored spots were detected in the -Y thrust panel acreage in an area bordered by the LO2 and LH2 tank-to-intertank flange closeouts and from the thrust panel-to-intertank splice to the tank curving out of view in the -Y direction. These light colored spots are most likely small, shallow divots, most of which are in the areas between the ring frames. However, some of the possible divots could be seen on the forward ring frame. Two divots, 4-6 inches in diameter, were present in the flange closeout -Y+Z quadrant. A much larger 10-inch long divot was also present in the flange closeout near the -Y thrust panel (arrows).

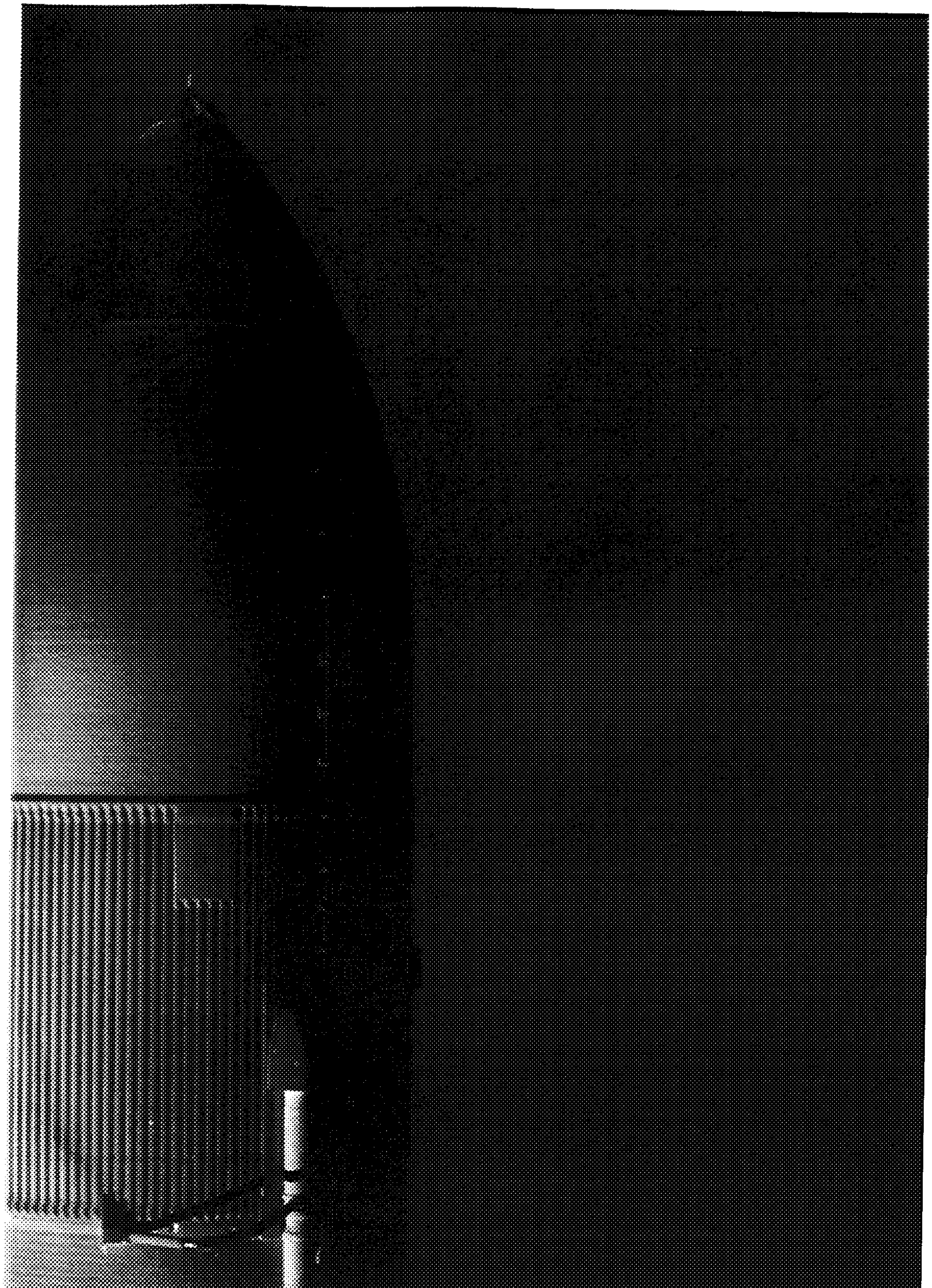


Photo 33: ET After Separation From Orbiter

The ET nose cone and ogive experienced ascent heating such that thin layers of foam from the machined area between the top-coated area of the nose cone to the as-sprayed area on the LO2 tank ogive (on both +Y and -Y sides of the pressurization line/cable tray) charred and flaked off in a pattern similar to that typically observed on the aft surfaces of the vertical struts. The loss of charred foam left bright areas as "new" underlying foam was exposed. However, in perhaps 2 or 3 cases, the thin layers of lost foam may have been somewhat deeper almost to the point of being very small divots. The sanded area on the LO2 tank at XT-536 was darkened somewhat due to ascent aeroheating, but no divoting or loss of foam occurred.

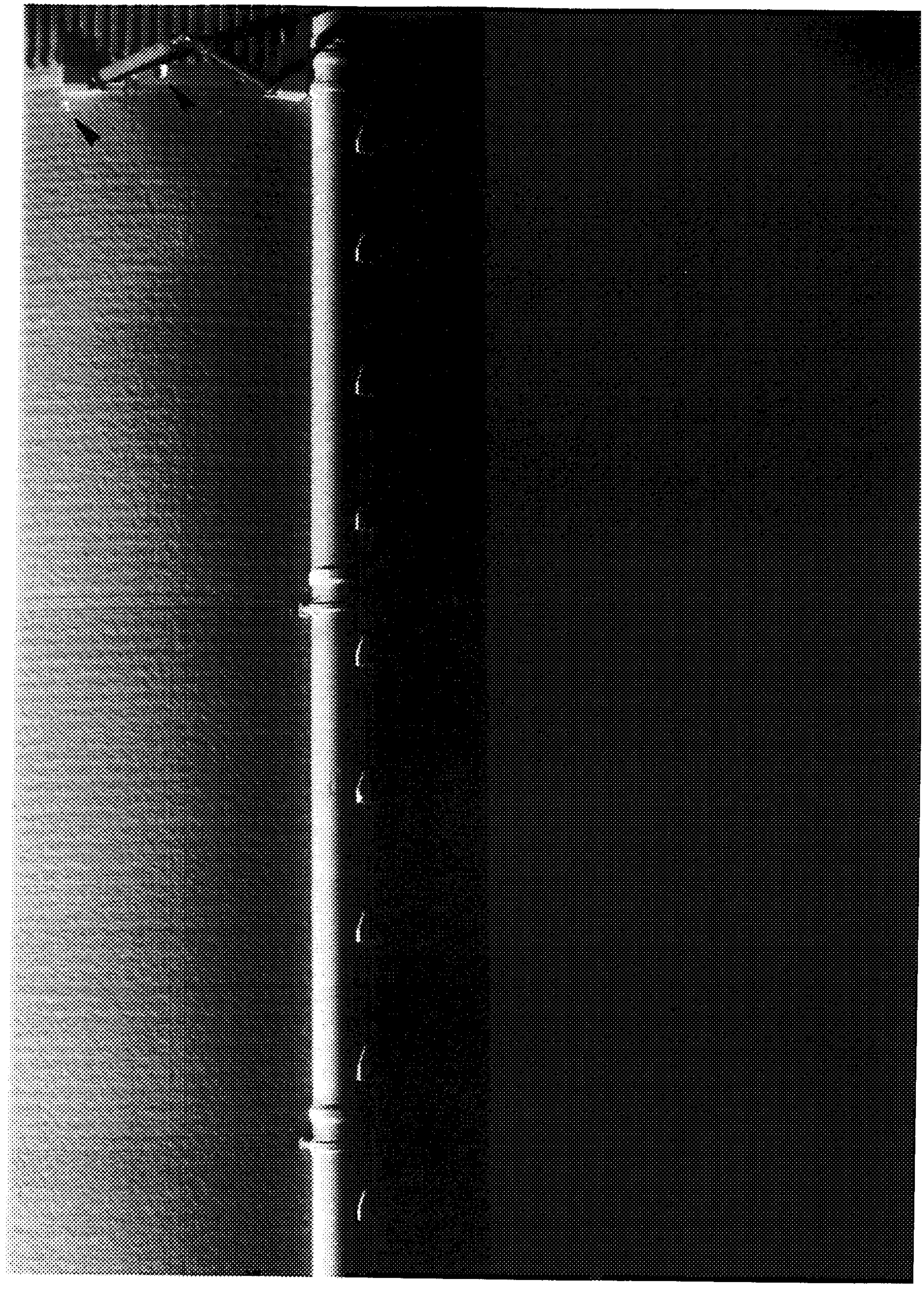


Photo 34: LH2 Tank Flange Closeout

The jack pad standoff closeouts were intact. A 6-inch diameter divot was visible between the bipods near centerline in the LH2 tank-to-intertank flange closeout. The divot may be associated with a repaired area documented in the pre-launch photography. Shadow, but no substrate, was visible in this divot. A divot just aft of the -Y bipod spindle housing closeout appears to be related to a previous repair documented in the pre-launch photography at the same location.

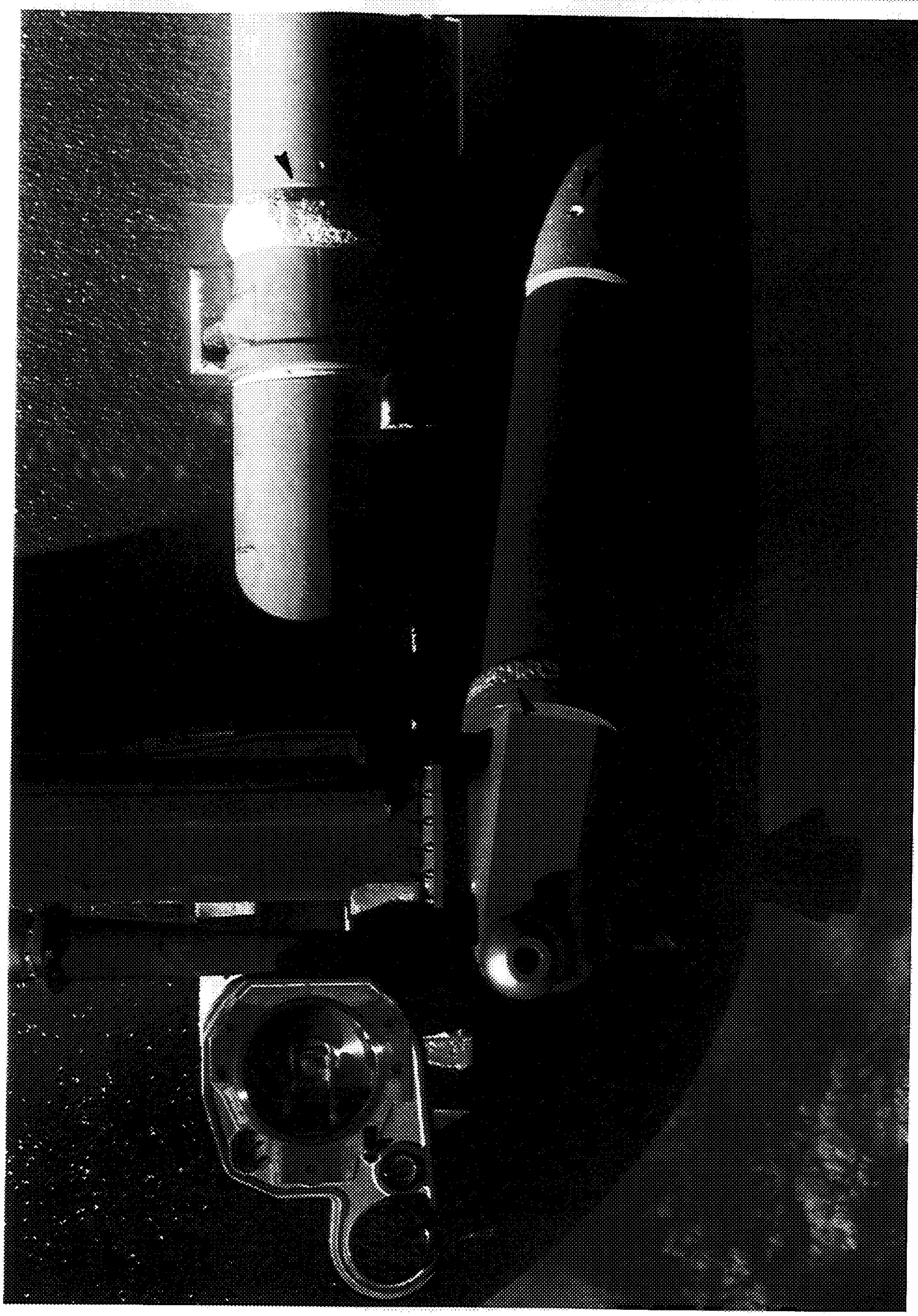


Photo 35: ET LO2 ET/ORB Umbilical

The LO2 ET/ORB umbilical cable tray exhibited typical erosion and divoting. The umbilical itself was undamaged. A 2-inch diameter divot was visible in the +Y thrust strut TPS. Note typical erosion of foam from the LO2 feedline and thrust strut flange closeouts.

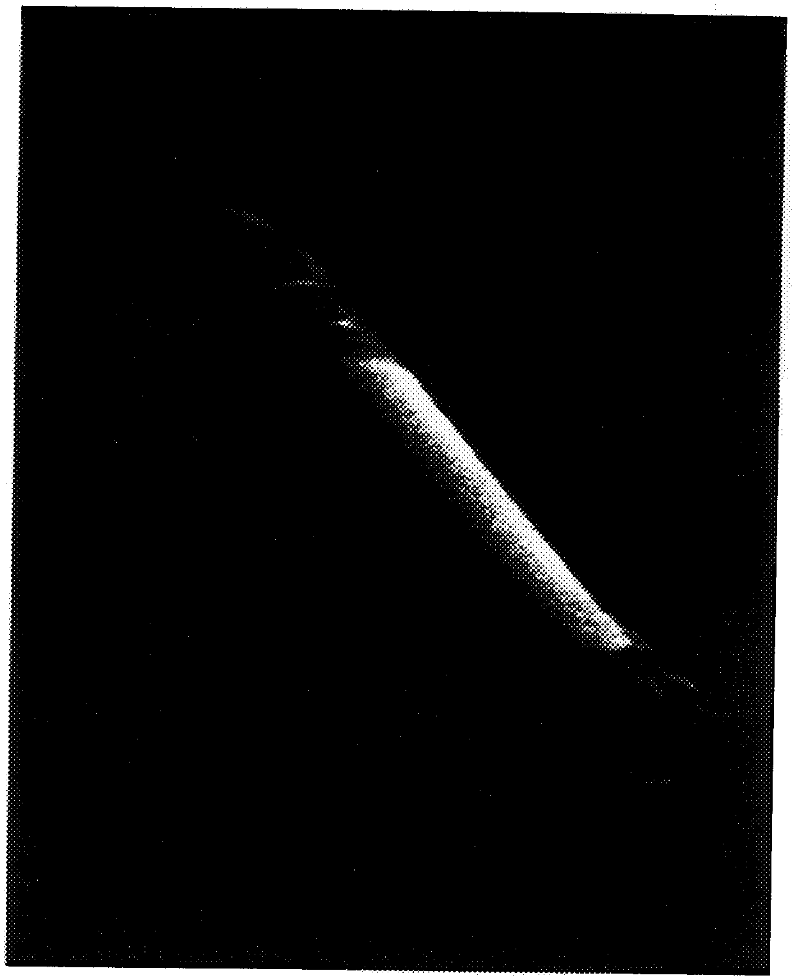


Photo 36: -Y Thrust Panel

Lack of resolution prevented the clear confirmation of foam loss and divoting on the -Y thrust panel

7.3 LANDING FILM AND VIDEO SUMMARY

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

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach.

Due to a cross wind out of the east, the Orbiter left main gear contacted the runway first followed almost immediately by the right gear. The Orbiter became airborne again for approximately 1000 feet with the right main gear re-contacting the runway first.

Drag chute operation appeared nominal though the chute was intentionally deployed after the nose gear contacted the runway because of the cross wind. 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. More than usual tile damage sites were also visible on the base heat shield.

8.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-091 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 8 June 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 with the exception of a fore-to-aft line of BTA closeout on the -Z side of the right frustum. 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 though one phenolic layer on both +Z and -Z sides of the right SRB antenna 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. Significant areas of missing insulation/cork from the aft surface of the IEA showed the insulation had not bonded properly. The pristine condition of the primed substrate indicated the insulation was lost at water impact rather than in flight.

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 #1, 4, 6, and 8 DCS plungers were unseated by water impact. Although the vehicle experienced a lateral acceleration of 0.19 g's at liftoff, the high speed launch films showed no stud hang-ups. The aft skirt stud holes exhibited no new broaches.

Overall, the external condition of the SRB's appeared to be excellent.

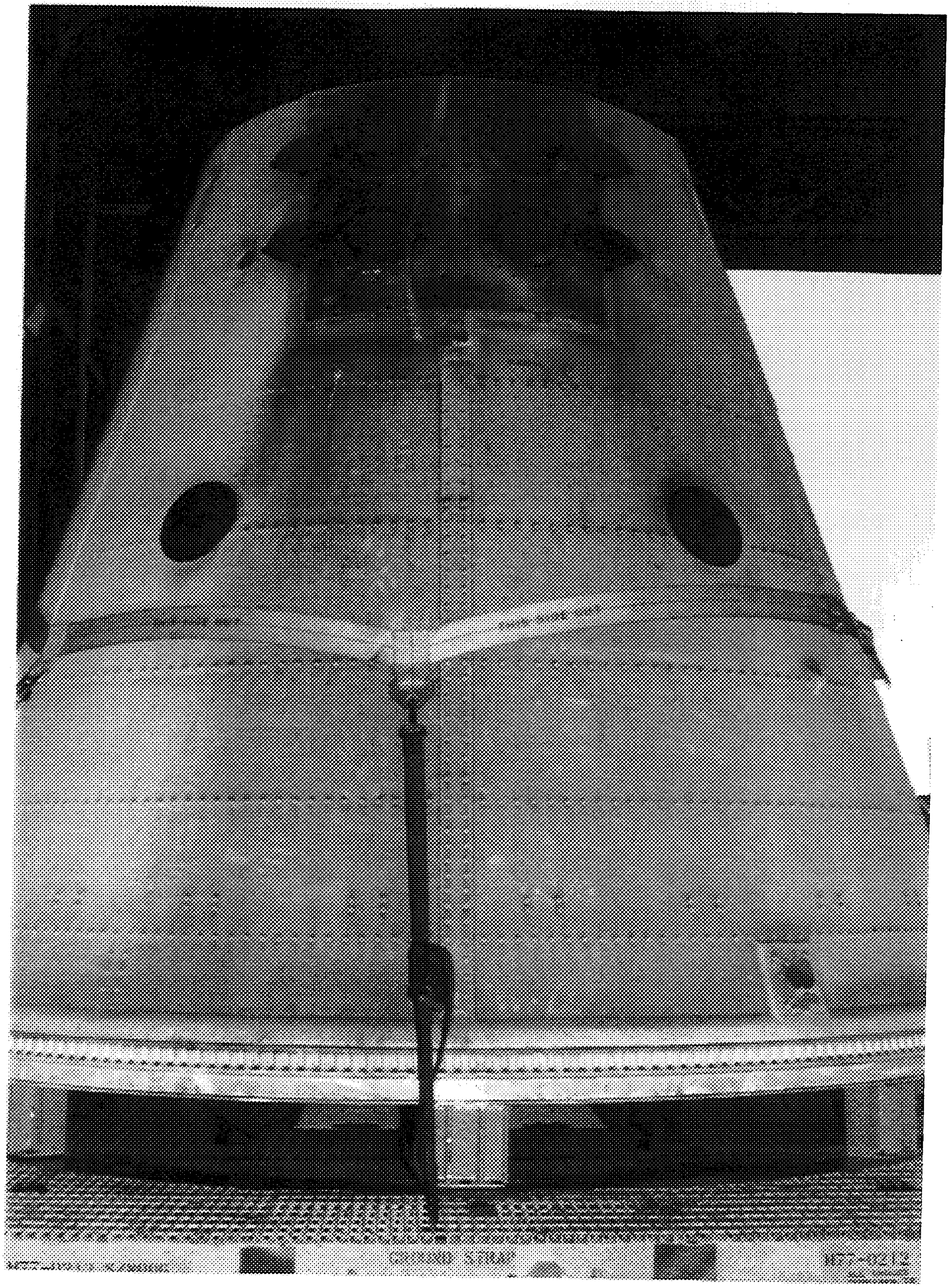


Photo 37: Frustum Post Flight Condition

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

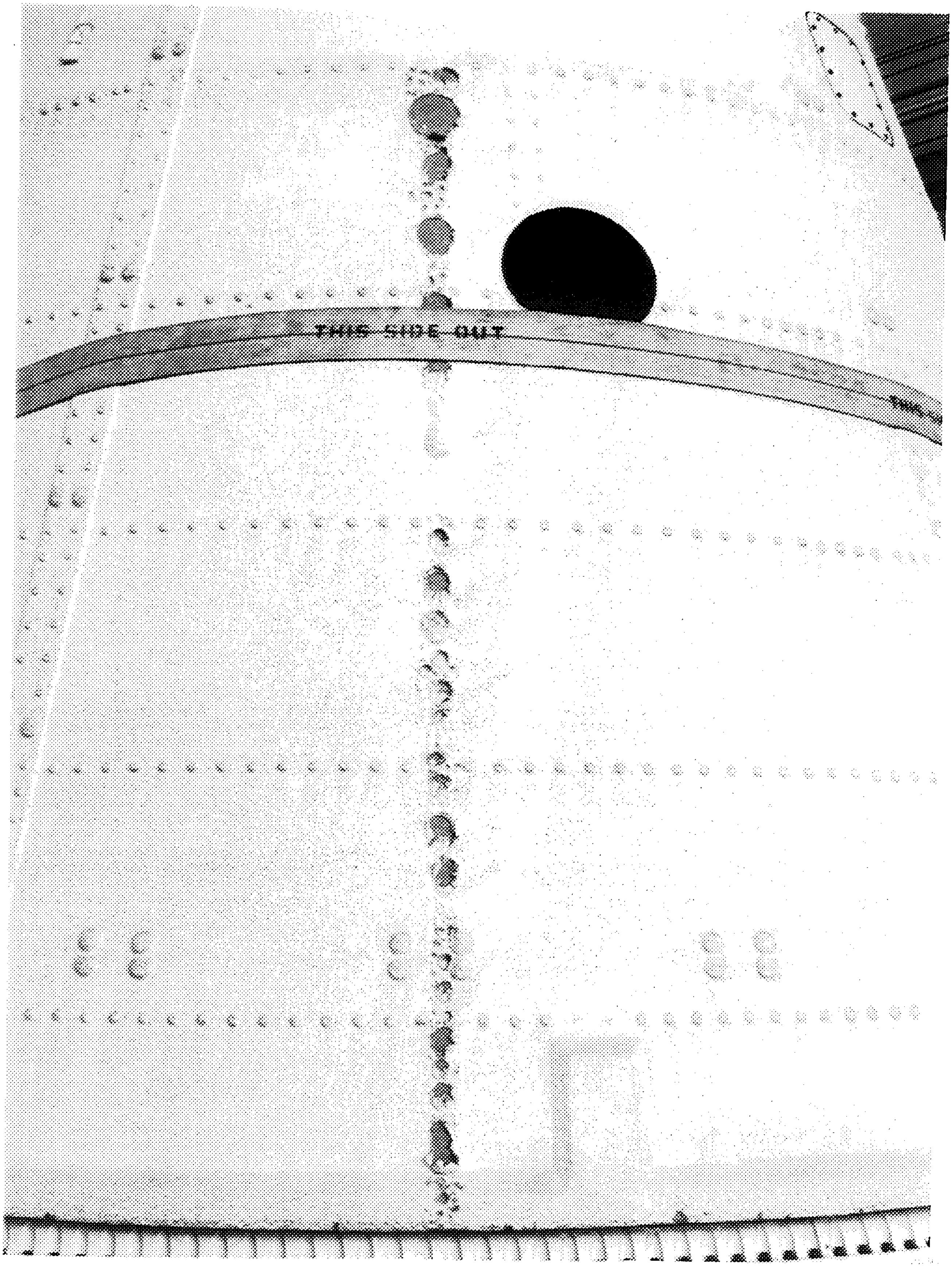


Photo 38: Blistered Hypalon Paint

Virtually none of the Hypalon paint had blistered or peeled with the exception of a fore-to-aft line of BTA closeout on the -Z side of the right frustum.

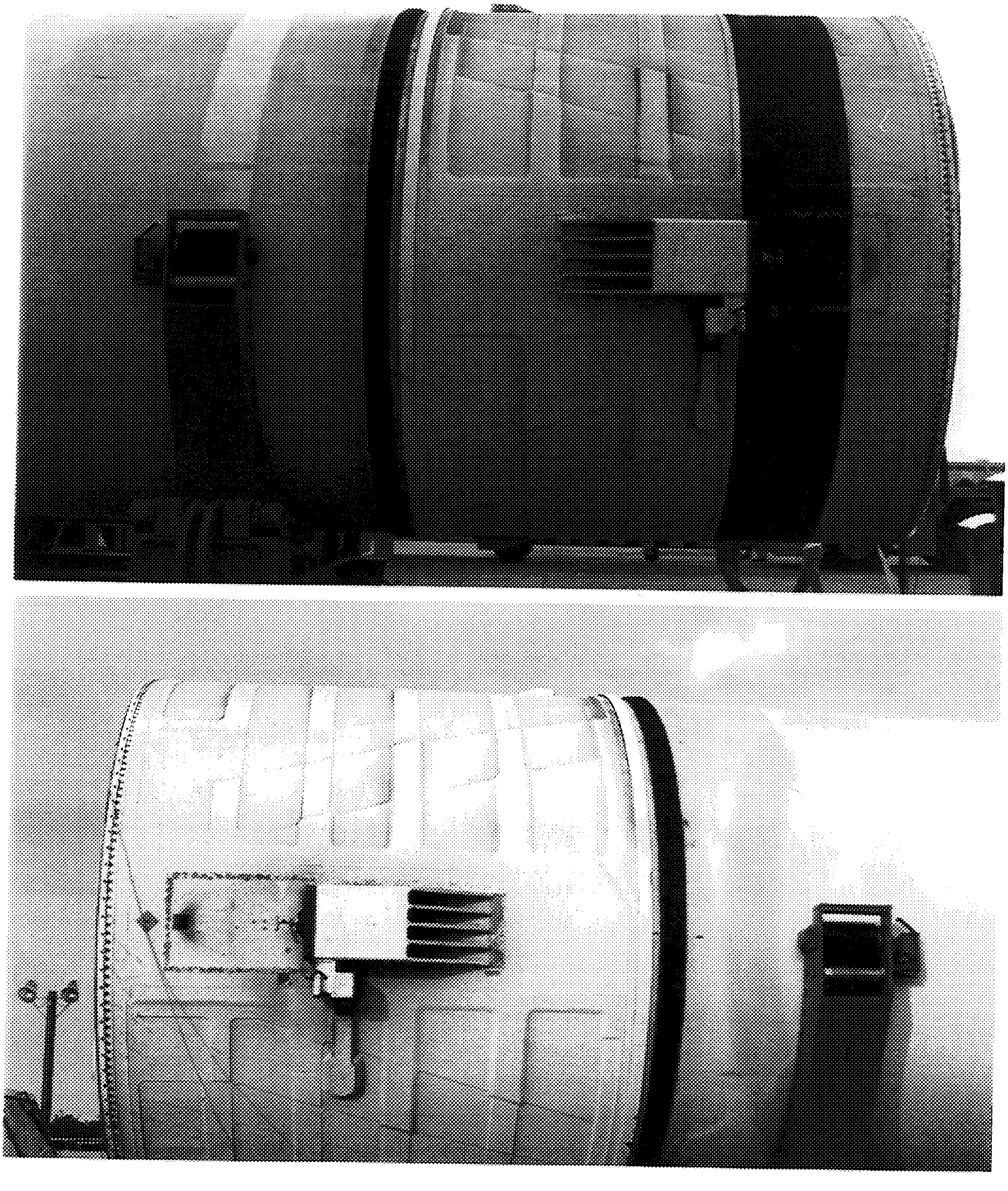


Photo 39: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact though one phenolic layer on both +Z and -Z sides of the right SRB antenna 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.

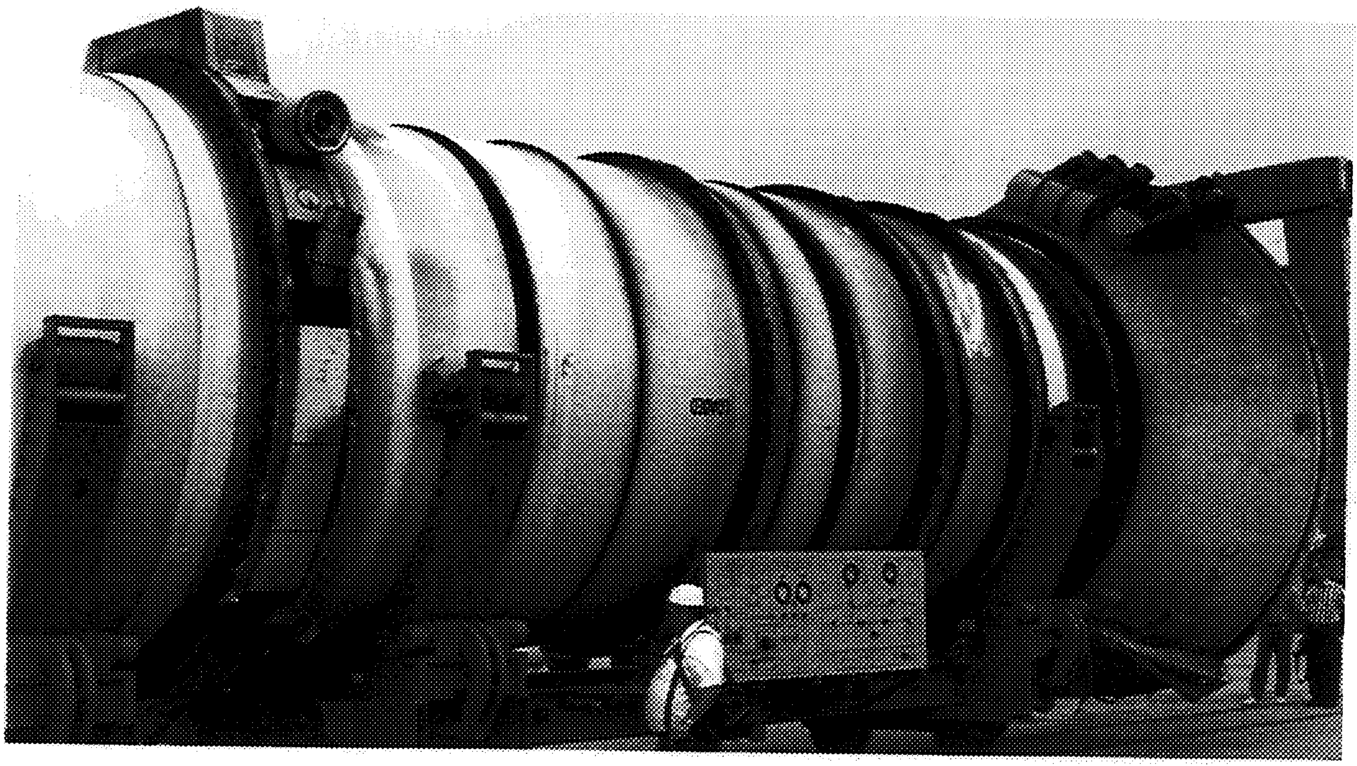


Photo 40: Aft Booster/Aft Skirt Post Flight Condition

Separation of the aft ET/SRB struts appeared normal. TPS on the external surface of both aft skirts was intact and in good condition.

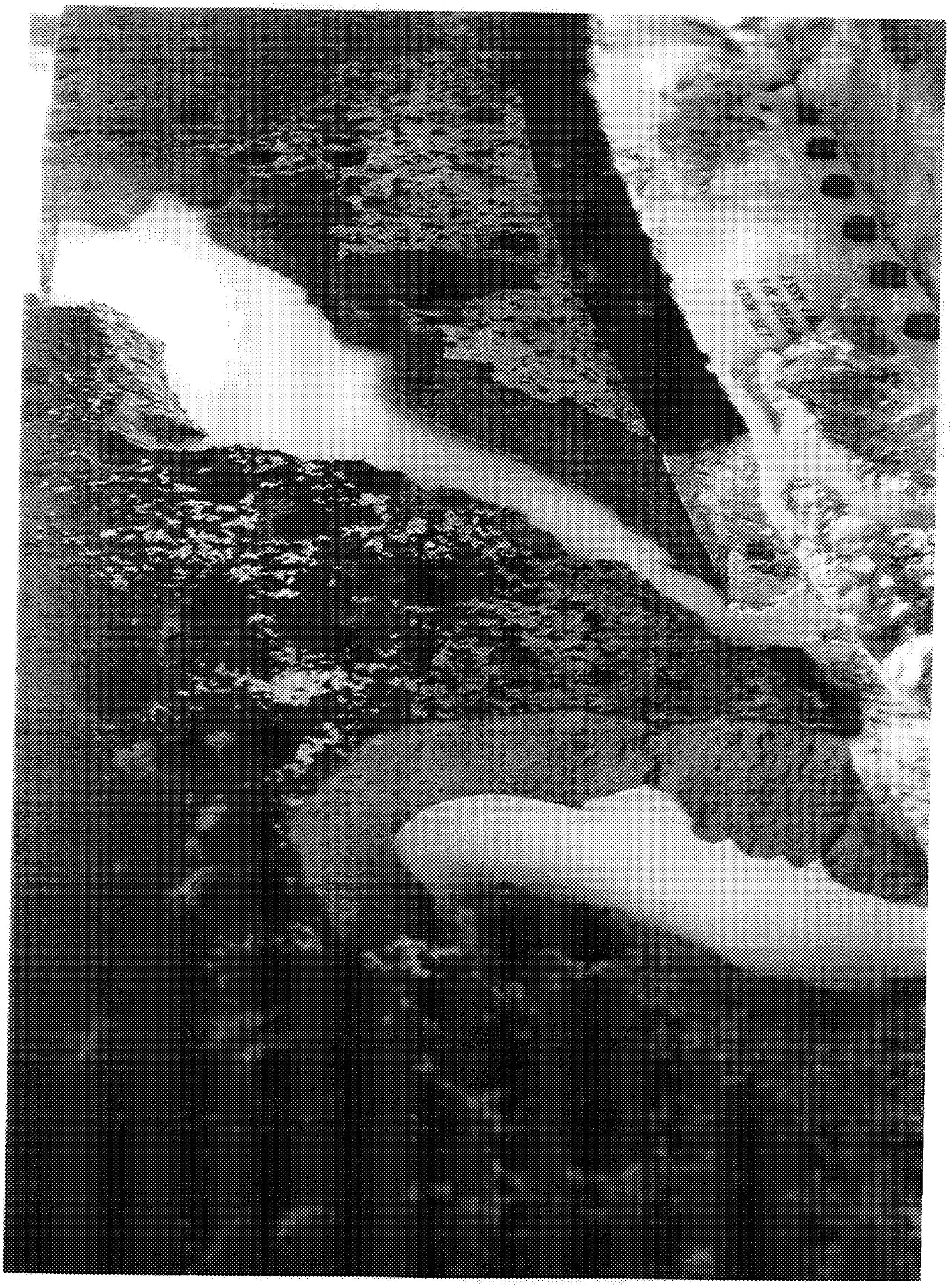


Photo 41: Missing IEA Insulation/Cork

Significant areas of missing insulation/cork from the aft surface of the IEA showed the insulation had not bonded properly. The pristine condition of the primed substrate indicated the insulation was lost at water impact rather than in flight.

9.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 2:00 p.m. local/eastern time landing on 12 June 1998, a post landing inspection of OV-103 Discovery was conducted at the Kennedy Space Center on SLF runway 15 and in the Orbiter Processing Facility bay #2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 198 hits, of which 50 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, 89, and 90, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was greater than average (reference Figures 1-4).

The following table breaks down the STS-91 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	45	145
Upper surface	0	3
Window Area	0	22
Right side	1	11
Left side	1	7
Right OMS Pod	2	5
Left OMS Pod	1	5
TOTALS	50	198

The Orbiter lower surface sustained 145 total hits, of which 45 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. Virtually no damage occurred on the Orbiter centerline. These damage sites follow the same location/damage pattern documented on STS-86, STS-87, STS-89, and STS-90, though it should also be noted that this was the first flight of the new Super Light Weight Tank. The average size and quantity of damage sites were greater than the favorable trend established on STS-89 and STS-90:

	STS-86	STS-87	STS-89	STS-90	STS-91	Fleet Avg.
Lower surface total hits	100	244	95	76	145	83
Lower surface hits > 1-inch	27	109	38	11	45	13
Longest damage site	7 in.	15 in.	2.8 in.	3.0 in.	3.0 in.	N/A
Deepest damage site	0.4 in.	1.5 in.	0.2 in.	0.25 in.	0.5 in.	N/A

At this time, most likely no lower surface tiles will be scrapped due to debris damage. The largest lower surface tile damage site forward of the main landing gear wheel wells was located on the left chine and measured 3-inches long by 1.25-inches wide by 0.25-inches deep. The deepest lower surface tile damage site of 0.5-inches was located on the right chine.

A damage site measuring 3.5-inches long by 0.38-inches wide by 0.25-inches deep on the right inboard elevon did not appear to have been caused by an ice impact from the LO2 ET/ORB umbilical. This damage site is directly aft of the right chine damage areas and may have been caused by a 'secondary' debris impact.

Tile damage sites around and aft of the LH2 and LO2 ET/ORB umbilicals were much less than usual in size and quantity. This damage is usually caused by impacts from umbilical ice or shredded pieces of umbilical purge barrier material flapping in the airstream.

The tires, which exhibited ply undercutting only on the RH inboard tire, were reported to be in average condition for a landing on the KSC concrete runway.

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. The EO-2 and EO-3 fitting retainer springs were in nominal configuration. No clips were missing from the "salad bowls". Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

The usual amounts of tile damage occurred on the base heat shield. A clustering of tile damage sites at the acoustic focal point between SSME's #1 and #3 (14 hits total with 12 of the hits larger than 1-inch in size) was not mirrored on the -Y side between SSME's #1 and #2. All SSME Dome Mounted Heat Shield (DMHS) closeout blankets were in excellent condition. Two small hits were located on tiles adjacent to the drag chute cavity. Two small tile hits on the stinger were caused by debris in the plume recirculation rather than contact with the drag chute risers.

No unusual tile damage was detected on the leading edges of the OMS pods. However, a 2.5-inch long by 0.75-inch wide by 0.25-inch deep gash on the left OMS pod may have been caused by ice from the waste water dump nozzle. A 5-inch long by 1.5 inch wide by 1.5 inch deep cavity along the edge of a blanket on the left OMS pod probably was caused by a portion of the blanket coming loose and flailing in the air flow. An adjacent white tile did not appear to be damaged. Three small damage sites were observed on the leading edge of the vertical stabilizer.

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. Some of the damage sites were attributed to old repair material falling out and were not included in this assessment.

The post landing walkdown of Runway 15 was performed immediately after landing. No debris concerns were identified. All drag chute hardware was recovered and appeared to have functioned normally. The two pyrotechnic devices on the reefing line cutters had been expended.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger was greater than the fleet average when compared to previous missions (reference Figures 5-6).

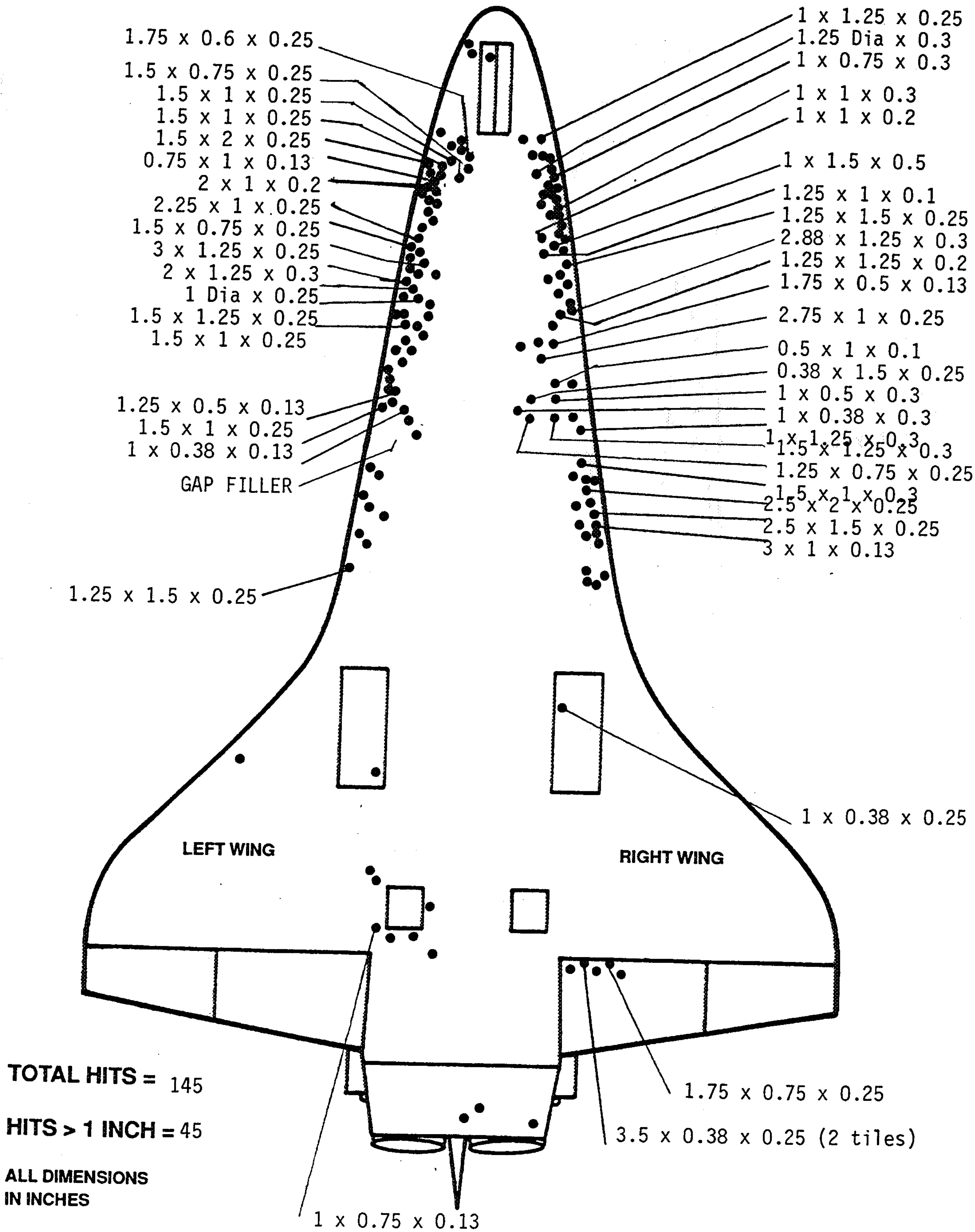


Figure 1: Orbiter Lower Surface Debris Damage Map

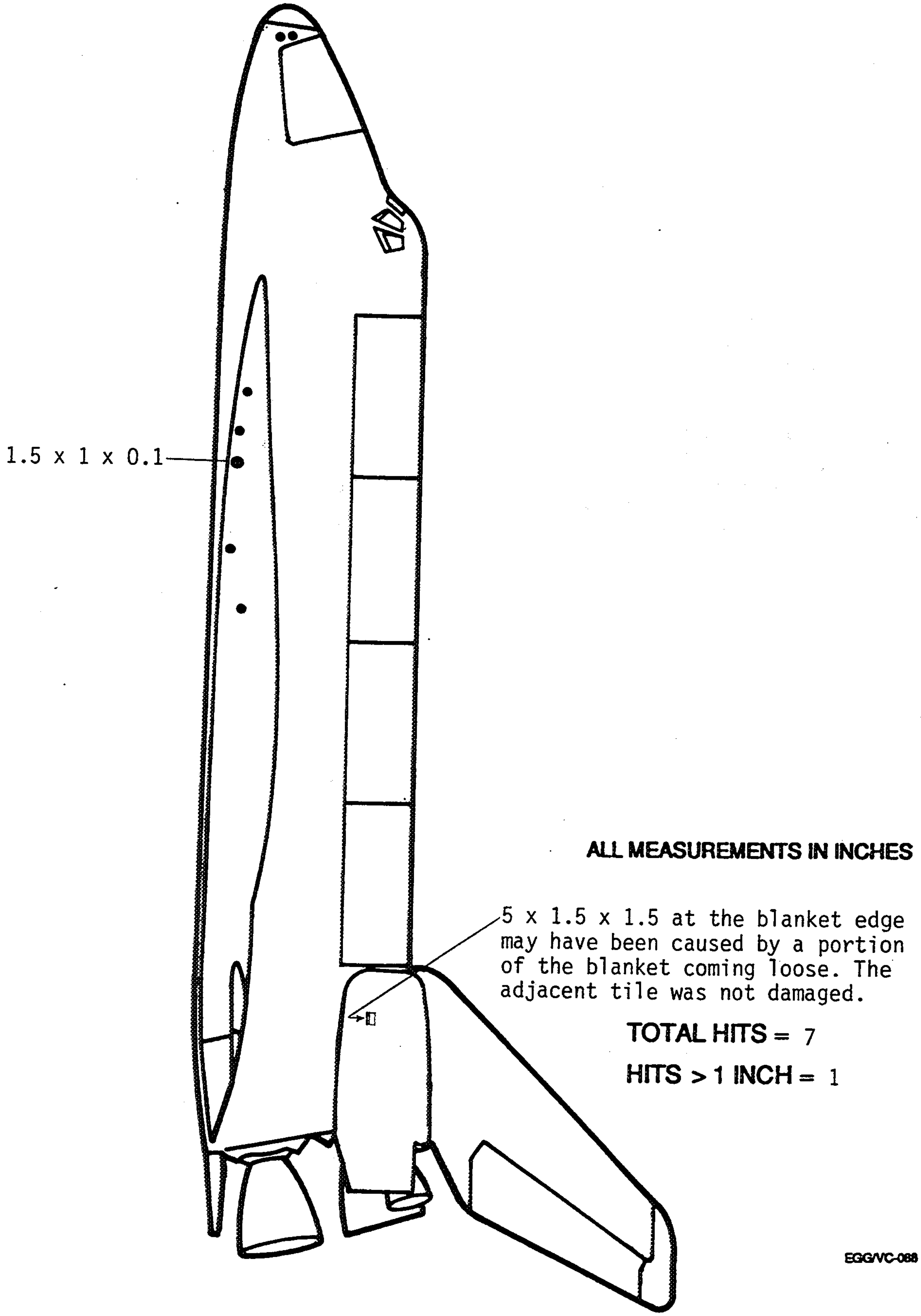


Figure 2: Orbiter Left Side Debris Damage Map

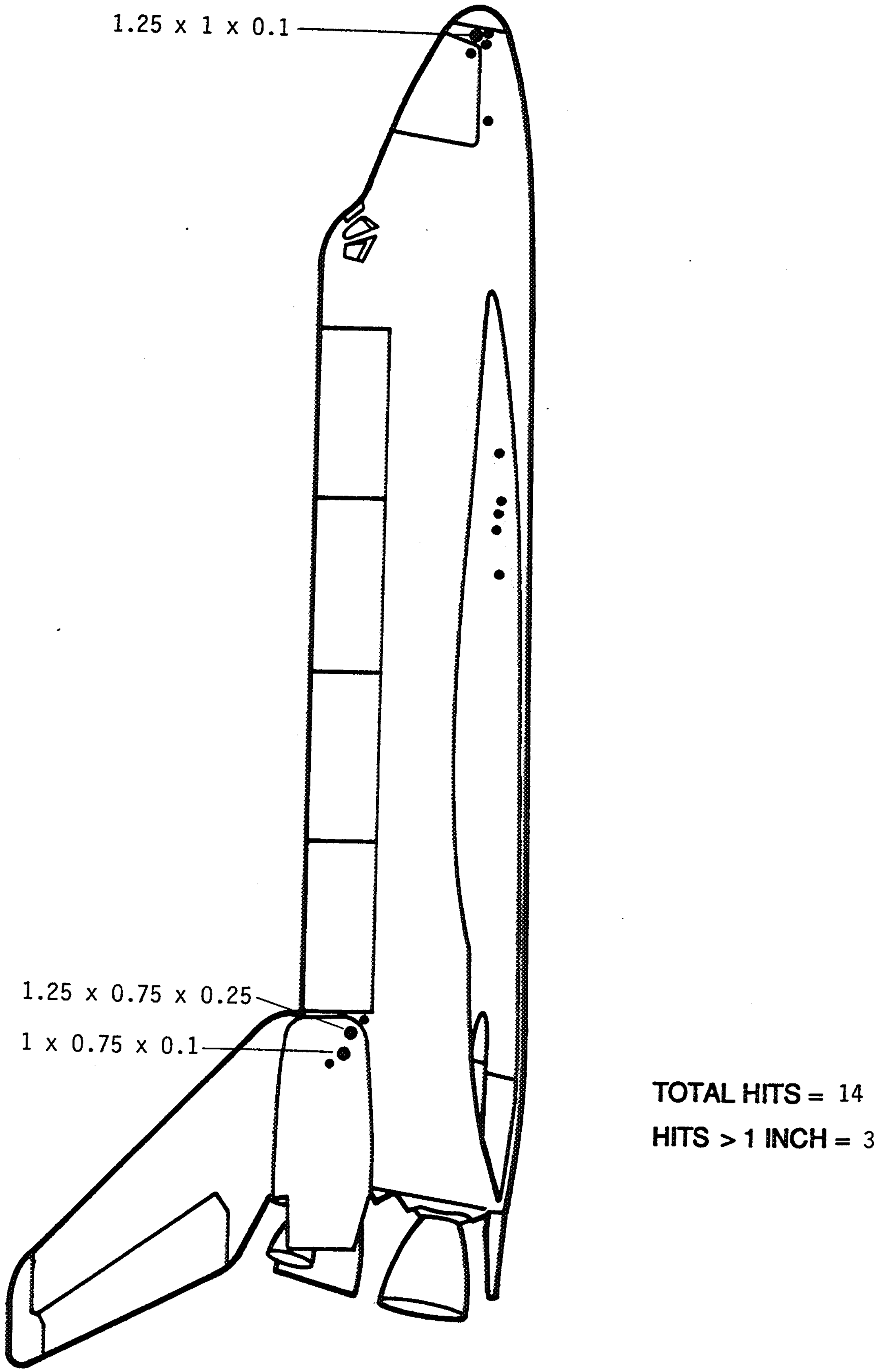


Figure 3: Orbiter Right Side Debris Damage Map

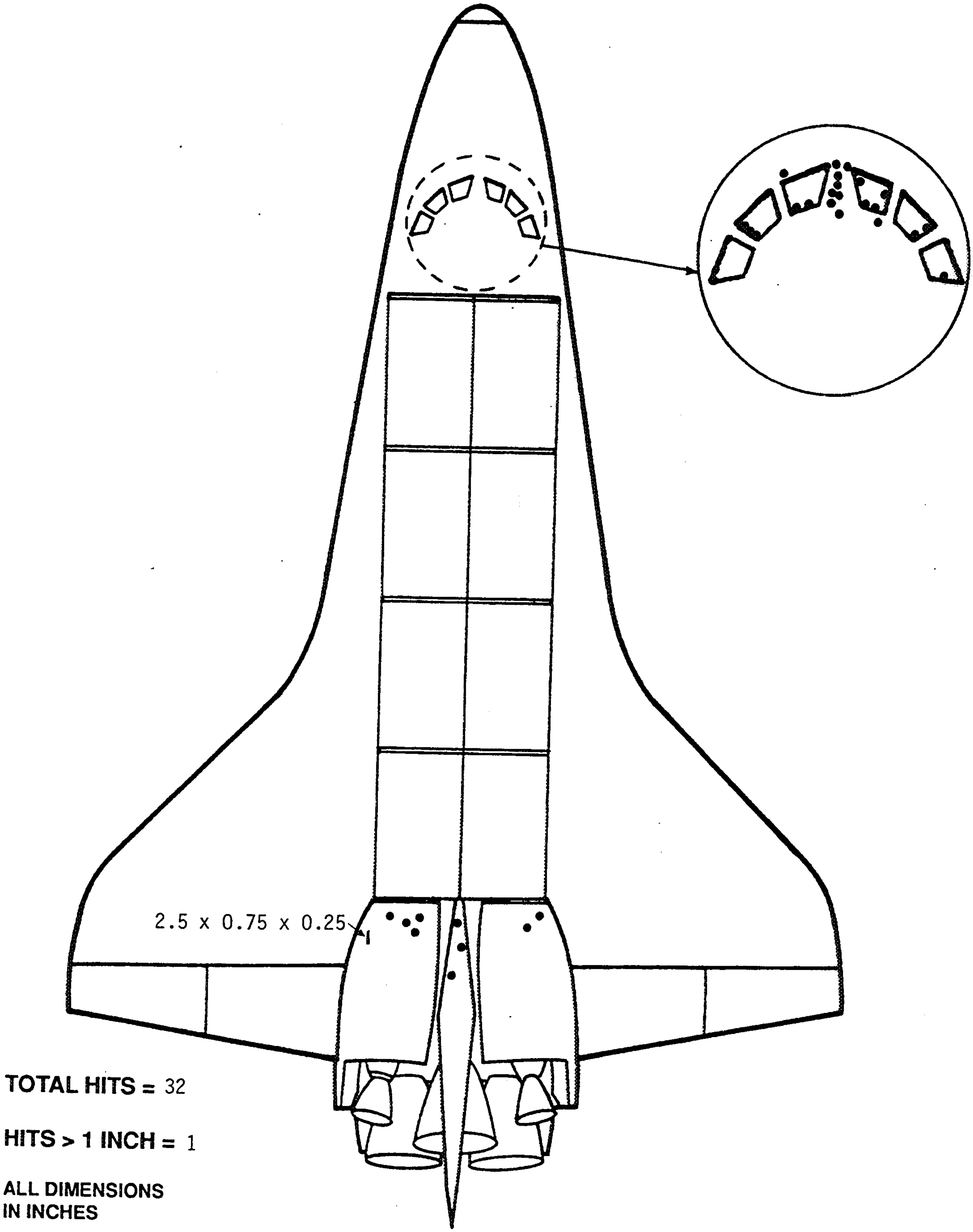


Figure 4: Orbiter Upper Surface Debris Damage Map

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

	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	22	111	28	148
STS-63	7	84	14	125
STS-67	11	47	13	76
STS-71	24	149	25	164
STS-70	5	81	9	127
STS-69	22	175	27	198
STS-73	17	102	26	147
STS-74	17	78	21	116
STS-72	3	23	6	55
STS-75	11	55	17	96
STS-76	5	32	15	69
STS-77	15	48	17	81
STS-78	5	35	12	85
STS-79	8	65	11	103
STS-80	4	34	8	93
STS-81	14	48	15	100
STS-82	14	53	18	103
STS-83	7	38	13	81
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-91	45	145	50	198

MISSIONS STS-23,24,25,26,26R,27R,30R,42,86,87,89, AND 90 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

SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES					
	LOWER SURFACE		ENTIRE SURFACE		CAUSE OR SOURCE
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS	
STS-23	Not Available	Not Available	46	152	ET Intertank TPS
STS-24	Not Available	Not Available	63	140	ET Intertank TPS
STS-25	109	231	144	315	ET Intertank TPS
STS-26	179	482	226	553	ET Intertank TPS
STS-26R	47	342	55	411	SRB DFI Cork Closeouts
STS-27R	272	644	298	707	SRB Nosecap Ablator
STS-30R	52	134	56	151	LH MLG Tire Rubber
STS-42	38	159	44	209	ET Intertank TPS
STS-86	27	100	31	129	ET Thrust Panel TPS
STS-87	109	244	132	308	ET Thrust Panel TPS
STS-89	38	95	40	138	ET Thrust Panel TPS
STS-90	11	76	20	131	ET Thrust Panel TPS
STS-91	45	145	50	198	ET Thrust Panel TPS

Figure 6: Orbiter Debris Exclusion Damage Summary

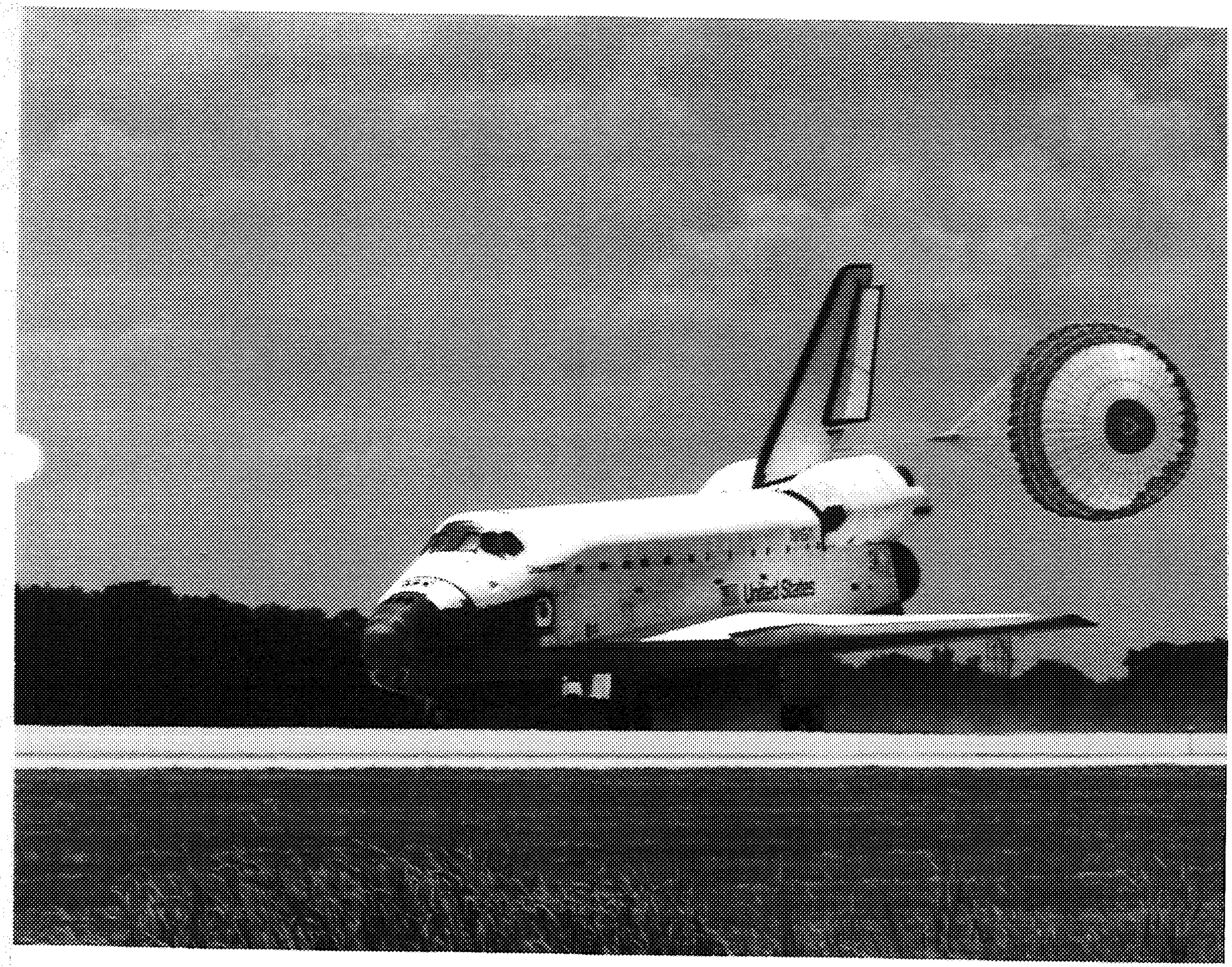


Photo 42: Orbiter Landing at KSC

OV-103 Discovery landed at 2:00 p.m. local/eastern time on 12 June 1998 at Kennedy Space Center's SLF runway 15

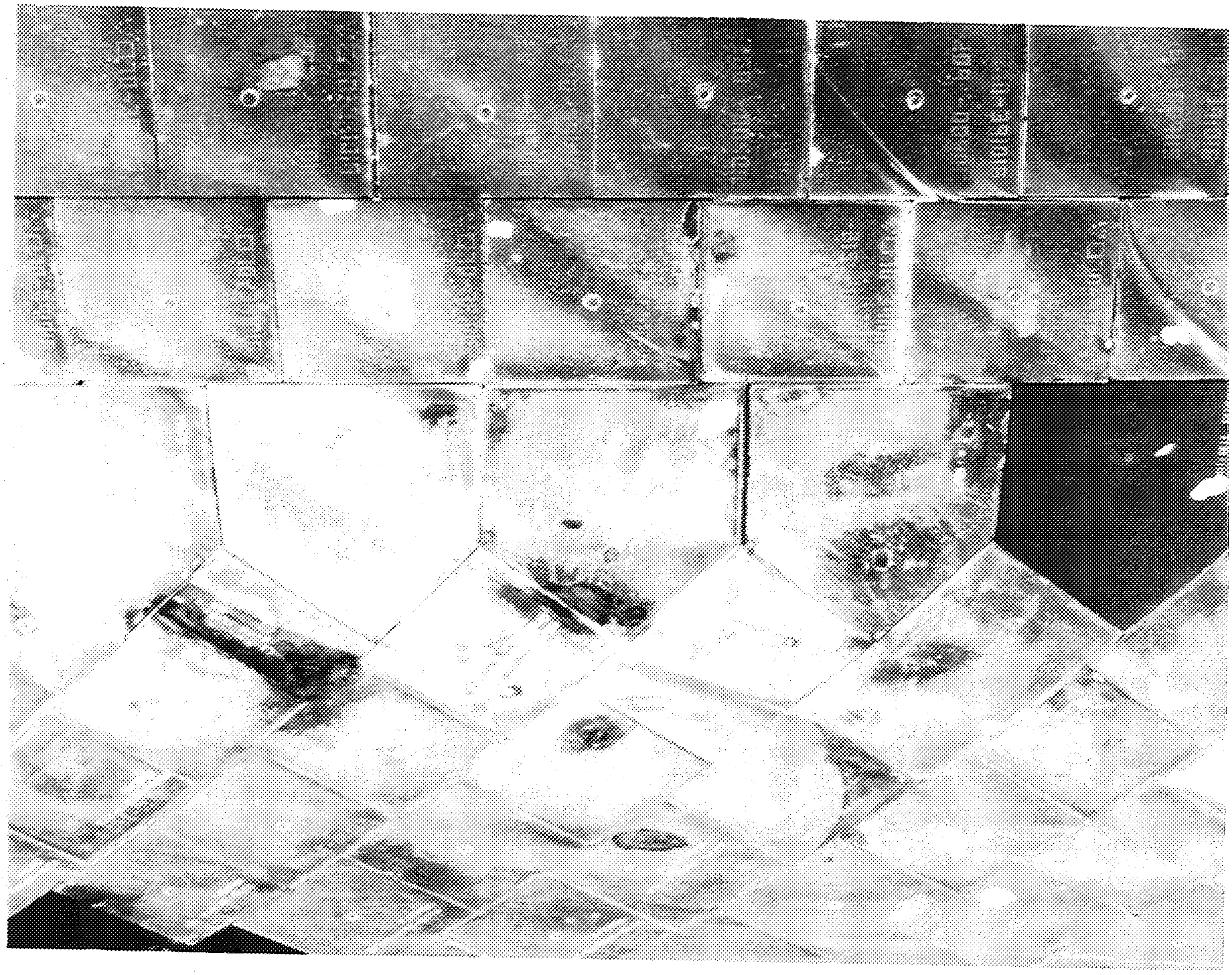


Photo 44: Lower Surface Tile Damage

The Orbiter lower surface sustained 145 total hits, of which 45 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. Virtually no damage occurred on the Orbiter centerline.

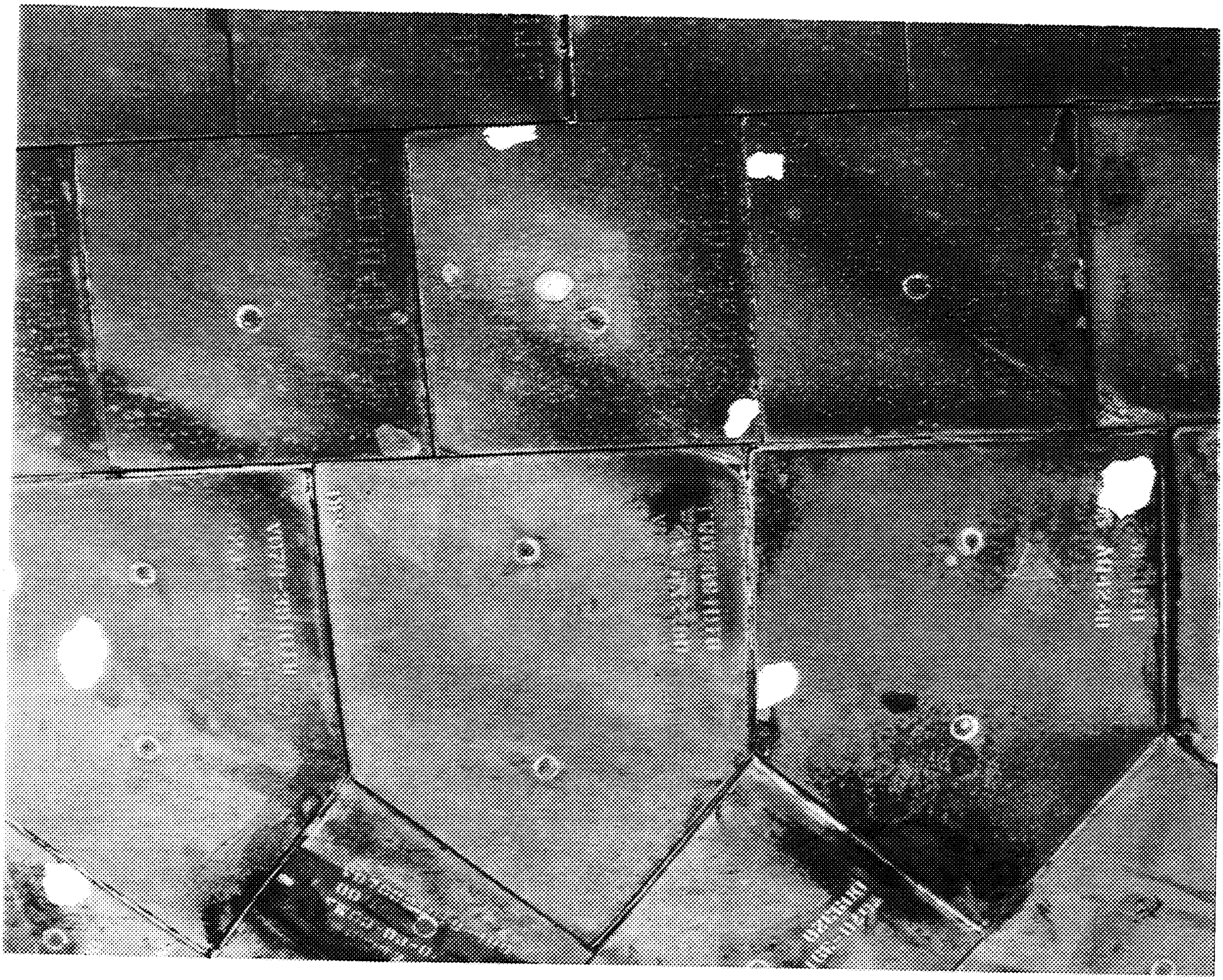


Photo 45: Lower Surface Tile Damage

These damage sites follow the same location/damage pattern documented on STS-86, STS-87, STS-89, and STS-90, though it should also be noted that this was the first flight of the new Super Light Weight Tank. The average size and quantity of damage sites were greater than the favorable trend established on STS-89 and STS-90:

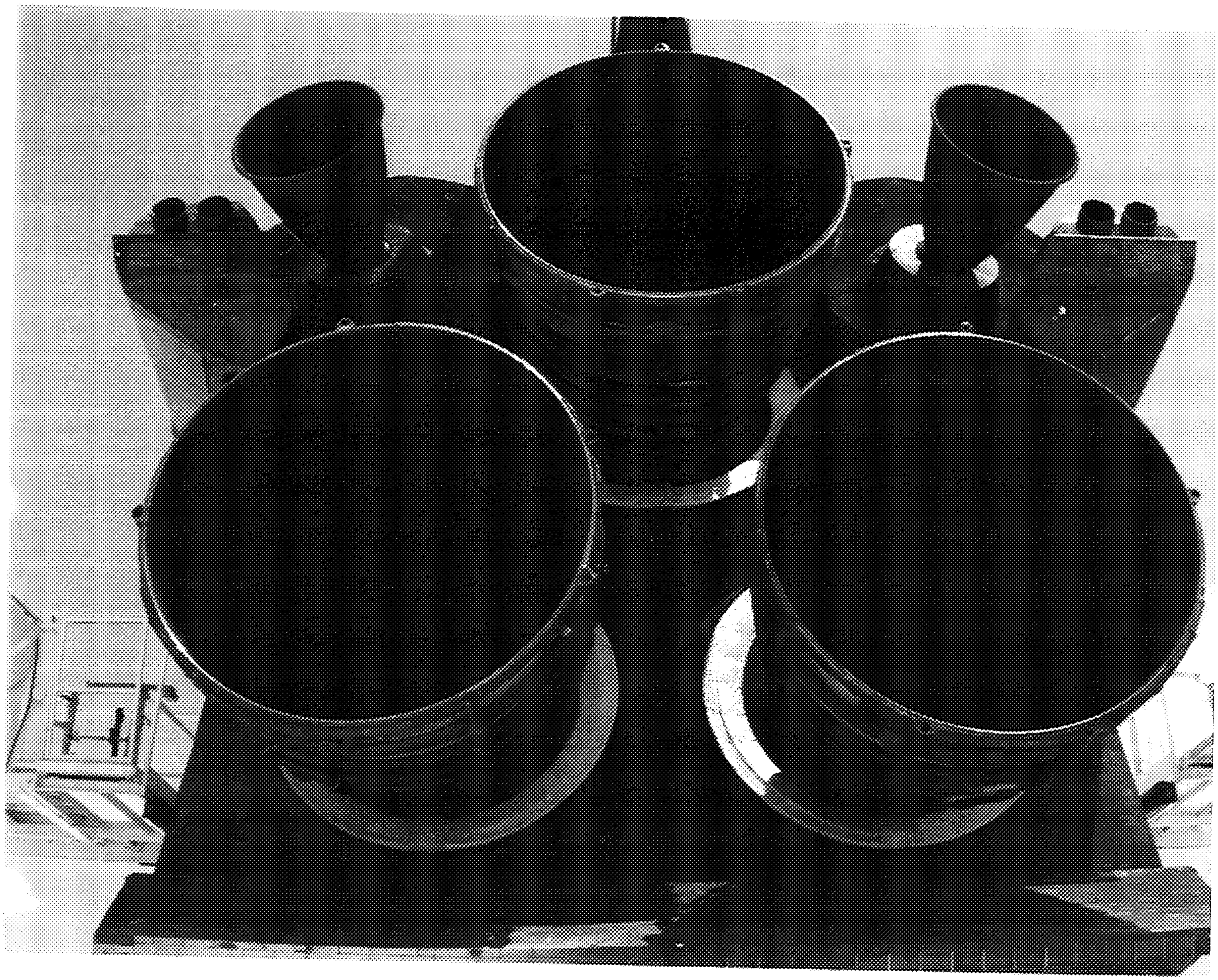


Photo 46: Base Heat Shield

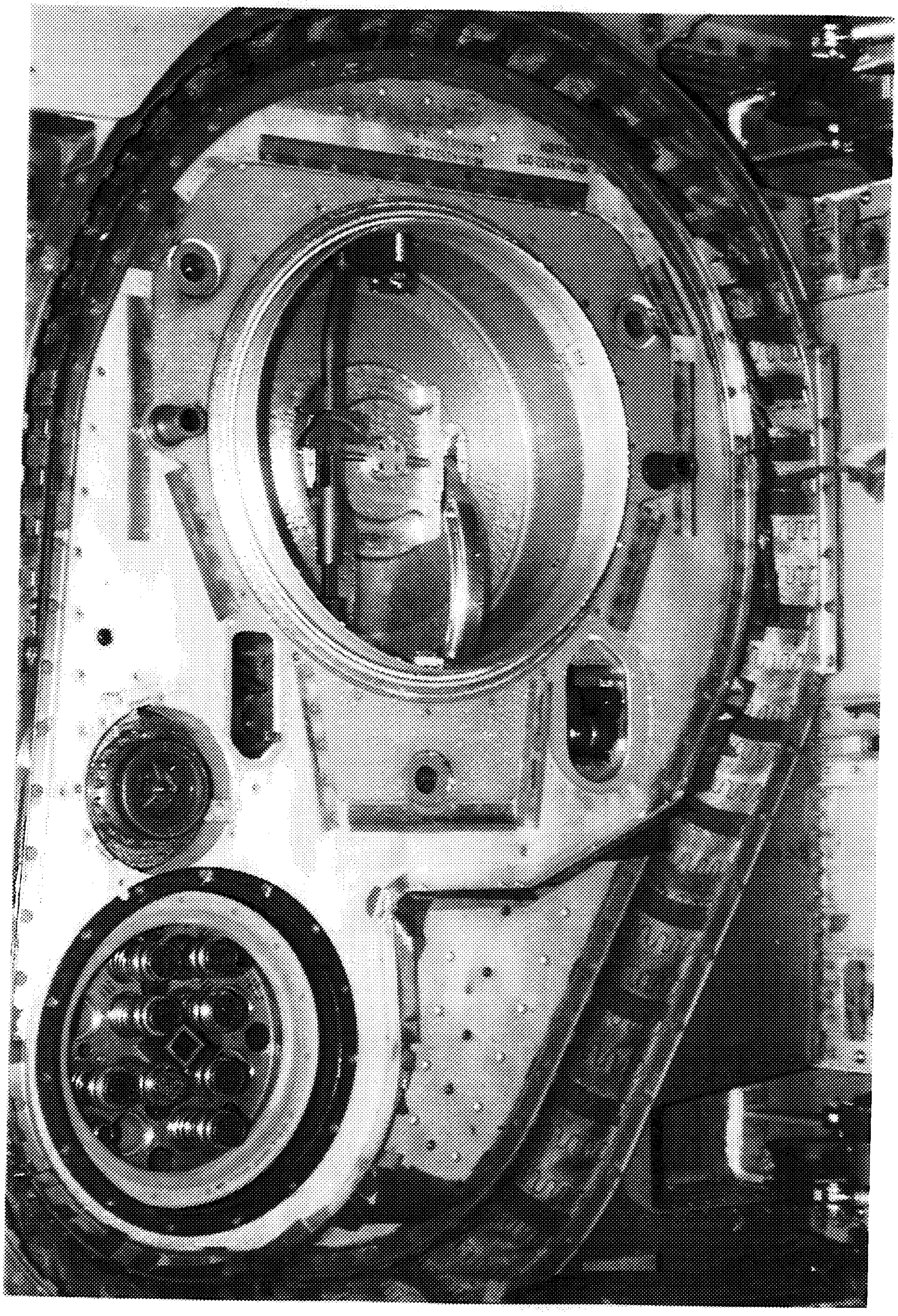


Photo 47: LO2 ET/ORB Umbilical

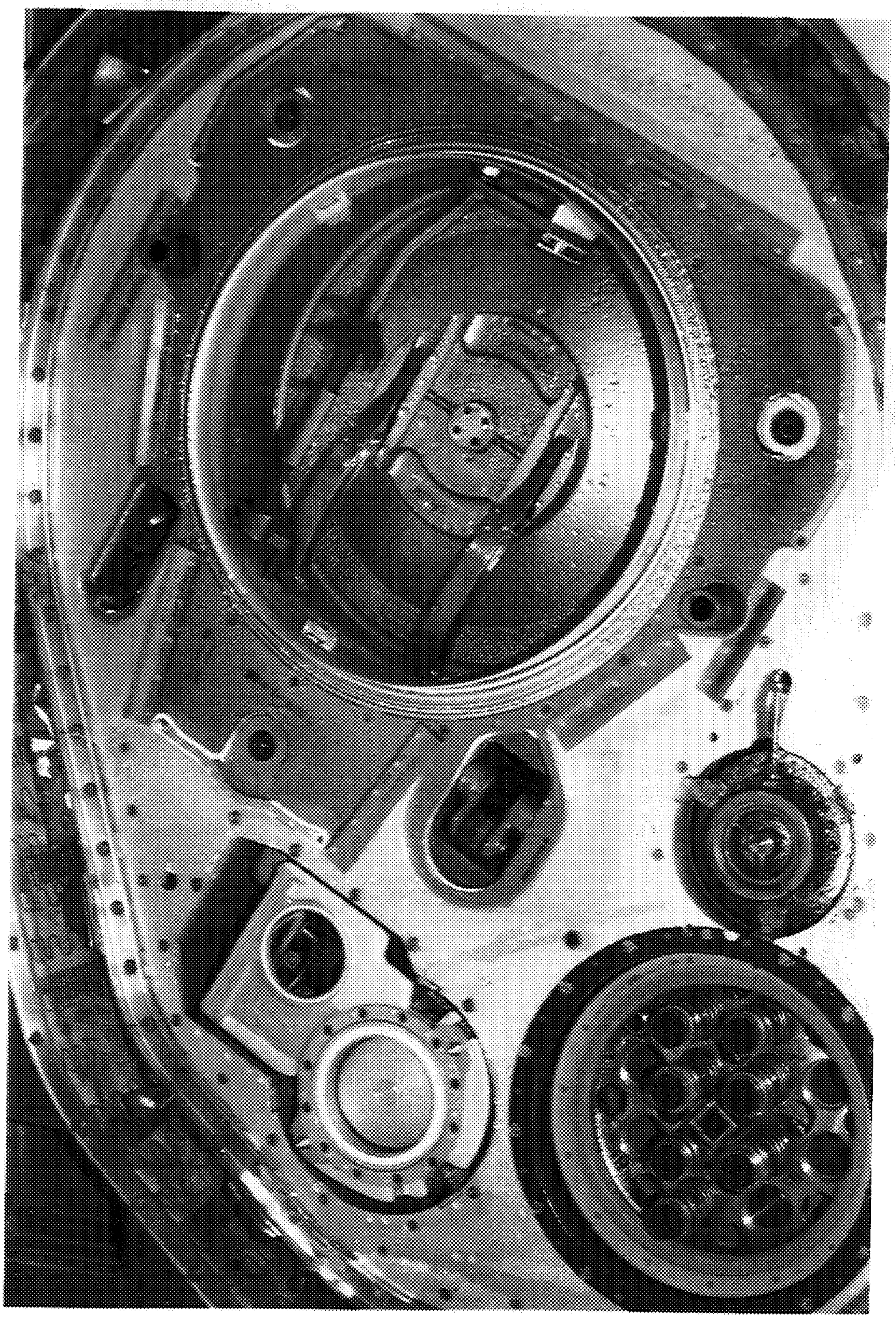


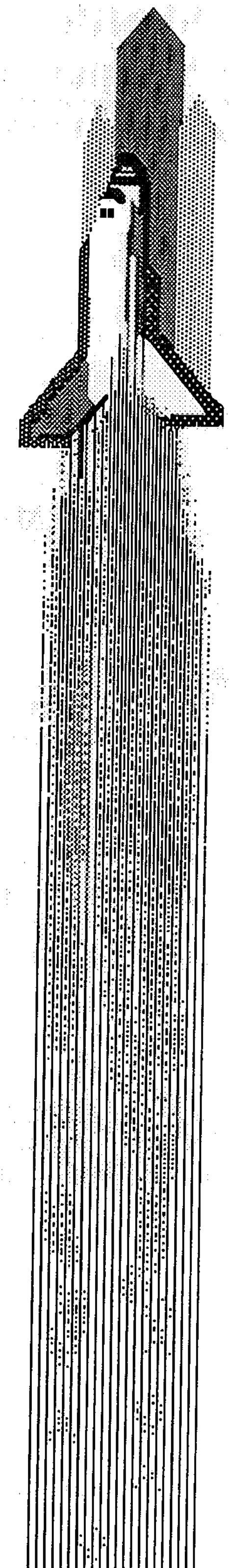
Photo 48: LH2 ET/ORB Umbilical

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Space Science Branch
Image Science and Analysis Group

STS-91 Summary of Significant Events

July 28, 1998



Space Shuttle
Image Science and Analysis Group
STS-91 Summary of Significant Events

Project Work Order - SN5CA

Approved By

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Image Science and Analysis Group

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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

Tables and Figures

1. STS-91 (OV-103): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-91 launch of Discovery (OV-103) from Pad A occurred on Tuesday, June 2, 1998 at approximately 153:22:06:24.16 UTC as seen on camera OTV050. SRB separation occurred at approximately 22:08:26.966 UTC as seen on camera ET207.

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 June 5, 1998. Twenty-two additional films were received for contingency support and anomaly resolution, but were not screened.

Umbilical well cameras flew for the first time on OV-103 on STS-91. 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.

1.1.2 On-Orbit

No on-orbit tasks were requested. However, an on-orbit video of the fuel cell product water relief nozzle (on the Orbiter starboard fuselage) was taken using the RMS arm. This video was provided after landing to Space Shuttle engineers investigating a water leak.

1.1.3 Landing

Discovery made an early afternoon landing on runway 15 at the KSC Shuttle Landing Facility on June 12, 1998. Eleven videos and ten films were received.

The landing touchdown appeared normal, but with a slight skip. A sink rate analysis of the main landing gear was performed for the touchdowns (see Section 2.6). The drag chute deployment appeared normal.

According to the pre-mission agreement, the STS-91 landing film was not screened due to budgetary constraints.

1.2 LANDING EVENTS TIMING

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). Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the body flap during SSME ignition. Two pieces of ice/frost debris were seen to contact the LH2 umbilical well door sill during SSME ignition (22:06:19.818 and 22:06:20.953 UTC). No damage to the umbilical well door sill was noted. (Cameras OTV009, OTV054, OTV061, OTV063, E5, E17, E31, E34)

Figure 2.1 (A) Dark-Colored Debris at SSME Ignition

A small dark-colored piece of debris (possibly an insect) was seen near the left ET/Orbiter attach aft strut during SSME ignition (22:06:21.920 UTC) on camera OTV009.

Prior to liftoff, a single piece of light-colored debris (possibly ice) was seen falling along the base of the ET near the ET/Orbiter aft attach point (22:06:20.419 UTC) on camera OTV054.

Figure 2.1 (B) Debris Near LSRB at Liftoff

A large light-colored flexible piece of debris (probably from the sound suppression water trough) was seen near the LSRB at liftoff (22:06:26.392 UTC) on camera E5.

2.2 DEBRIS DURING ASCENT

Less than usual debris was seen aft of the launch vehicle during ascent. This may be because of the clouds and haze that degraded the long range tracking camera views.

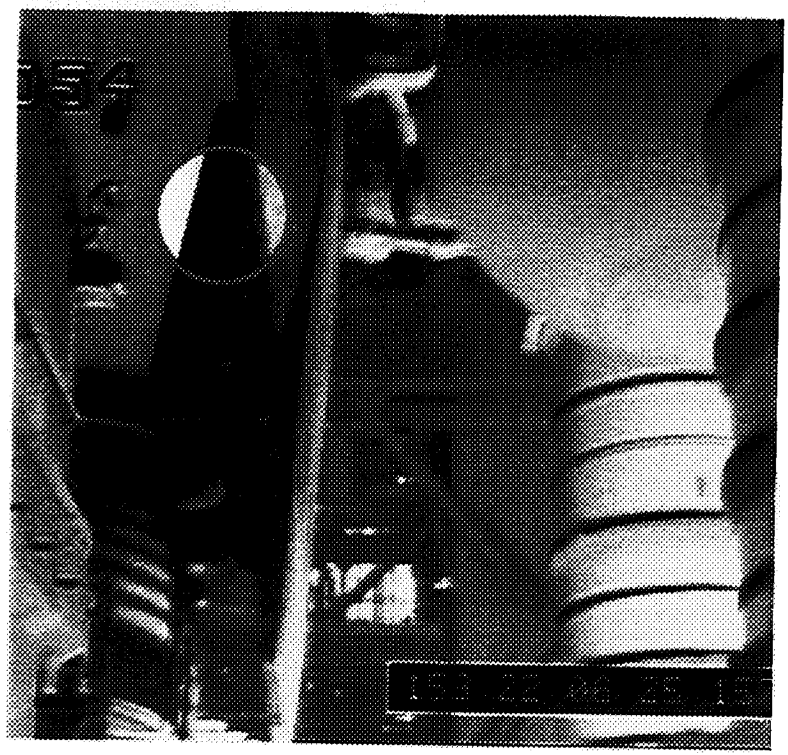


Figure 2.2 (A) Debris Near Right Wing During Liftoff

A single light-colored piece of debris was seen near the upper surface of the right wing during liftoff (22:06:25.157 UTC) on camera OTV054. This debris was probably not from the starboard water relief nozzle according to engineers investigating the water leak anomaly.

On camera E224, a single light-colored piece of debris seen in the SSME exhaust plume was timed at 22:06:31.658 UTC.

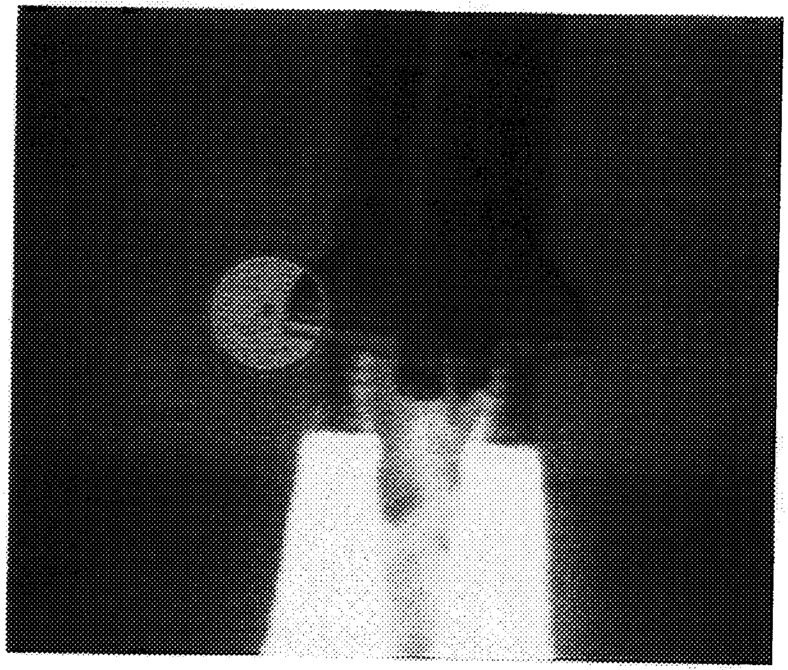


Figure 2.2 (B) Possible Bird During Liftoff

On camera ET212, a single piece of debris (possibly a bird close to the camera) appeared to be falling along the left SRB and near the left wing tip (22:06:34.377 UTC).

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

Orange vapor, probably free burning hydrogen, was seen forward of the SSME rims during SSME ignition (E17, E18, E19, E20). Orange vapors drifting forward from the aft end of the vehicle have been observed on previous missions.

Small areas of tile surface coating material erosion were seen during SSME ignition at the base of SSME #2, on the SSME #2 Dome Mounted Heat Shield (DMHS), and on the base heat shield outboard of SSME #3 (E17, E18).

A light-colored flash was seen in the SSME #1 exhaust plume prior to liftoff at 22:06:23.658 UTC (E2, E19, E20).

The SSME ignition appeared normal on the high-speed engineering films. However the SSME Mach diamonds did not form in the expected sequence. The times for the Mach diamond formation recorded in Table 2.3 below are from camera film E19.

SSME	TIME (UTC)
SSME #2	22:06:20.862
SSME #1	22:06:20.946
SSME #3	22:06:20.954

Table 2.3 SSME Mach Diamond Formation

2.4 ASCENT EVENTS

A white-colored flash (possibly debris induced) was seen in the SSME exhaust plume during ascent at 22:06:41.731 UTC (E52, E222).

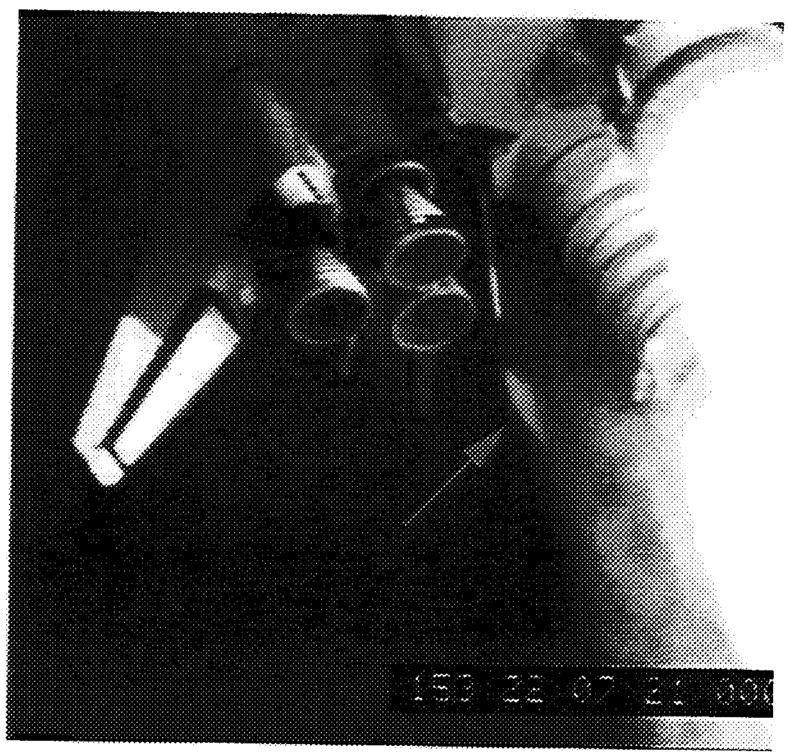


Figure 2.4 Flare in SSME Exhaust Plume During Ascent

Several orange-colored flares (probably debris induced) were seen in the SSME exhaust plume during ascent. On cameras KTV4A and ET207, flares were timed at 22:07:04.892, 22:07:18.097, and 22:07:21.0 UTC. On camera film E224 with digital timing, two of the flares were timed at 22:06:54.031 and 22:07:05.932 UTC (E207, E222, E223, E224, KTV4A, ET207).

Slight body flap motion was visible during ascent (E207, E212, E223). No follow-up action was requested.

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK

Umbilical well cameras flew for the first time on OV-103 on STS-91. Two rolls of the STS-91 16mm umbilical well film, one roll of 35mm umbilical well film, and one roll of 35mm handheld film were received. The film quality is very good on the three umbilical well camera films. The handheld film of the external tank (ET) is underexposed but useable. The camcorder view of the ET is unusable.

The +X translation maneuver was performed on STS-91 to facilitate the imaging of the ET with the umbilical well cameras. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography. (STS-91 was the fourth flight using the roll-to-heads-up maneuver).

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 film quality is very good on the three umbilical well camera films. OV-103 provided timing data to the 16mm umbilical well cameras.

35mm Umbilical Well Camera Film

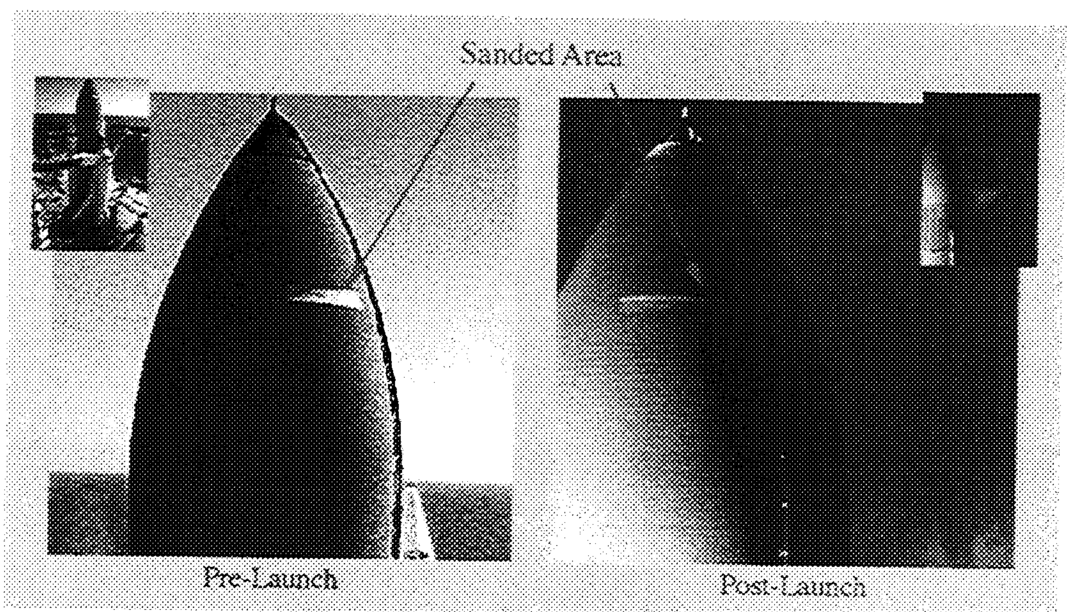


Figure 2.5.1 (A) Sanded Area on ET Nose Cone

The LH2 tank and the LO2 tank/Ojive TPS appeared to be in excellent condition on the close-up 35mm umbilical well camera film. The sanded area on the ET nose cone appeared undamaged. Similar to STS-90 and other previous missions, 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. Discoloration in this area is probably due to aero friction and heating.

The intertank TPS appeared to be in better condition than usual with only a very small divot visible on an aft intertank stringer head forward of the bipod.

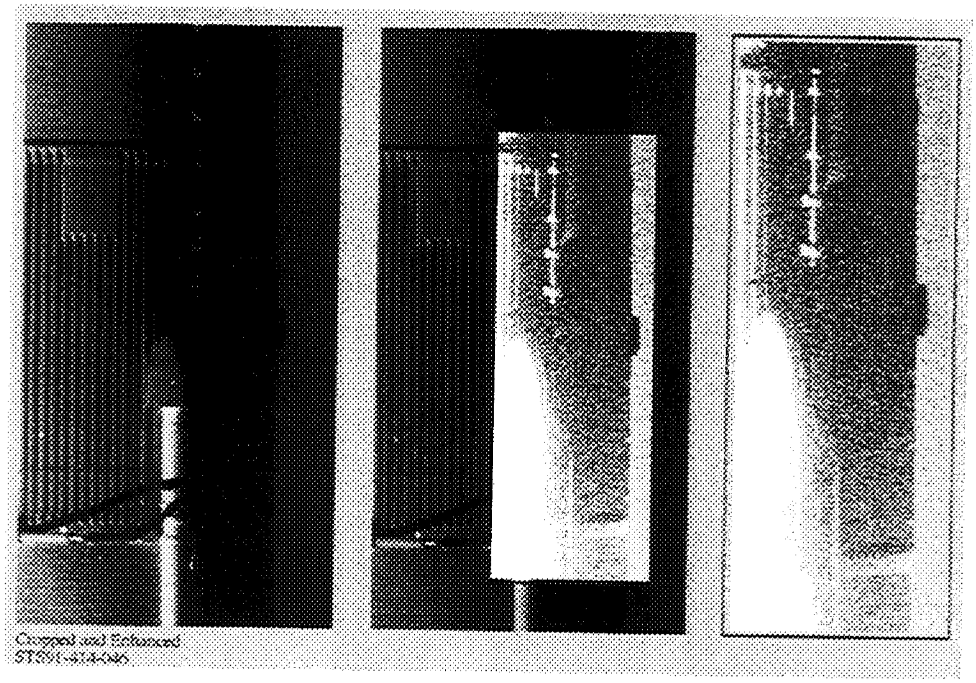


Figure 2.5.1 (B) ET +Y Thrust Panel

The visible portion (+Z/+Y) of the right SRB thrust panel was in shadow on the 35mm umbilical well film. Digital enhancements were made from the film in an attempt to detect TPS damage on the right ET intertank thrust panel. However, the presence of damage on this panel could not be confirmed. The left SRB thrust panel was not imaged on the 35mm umbilical well film.

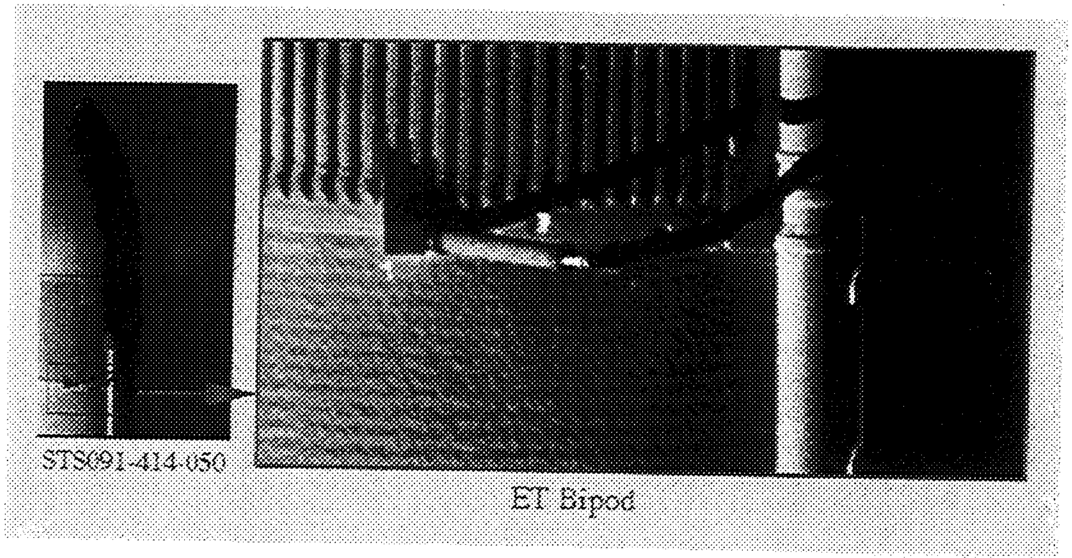


Figure 2.5.1 (C) Divot on ET Close-out Flange

A divot, approximately seven inches in size, was visible under the ET/Orbiter attach bipod in the LH2 tank-to-intertank close-out flange. The divot was not deep enough to show primed substrate. A shallow light-colored mark (possible divot) approximately three-inches in size was visible just aft of the left leg of the bipod in the LH2 tank TPS. The bipod jack pad close-outs appeared intact.

Minor TPS chipping and very small divots (typical of previous missions) were seen on the LO2 feedline, feedline flanges, the forward end of the +Y ET/Orbiter thrust strut, and on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical. The face of the LO2 umbilical carrier plate appeared to be in excellent condition (the lightning contact strips appeared to be in place).

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 dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing prior to SRB separation were seen. Numerous irregularly-shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Two pieces of TPS were seen to detach from the aft surface of the horizontal section of the -Y ET vertical strut. 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. Vapor and multiple light-colored pieces of debris were seen after the umbilical separation. Several pieces of white debris (frozen hydrogen) were seen striking the forward surface of the LH2 electric cable tray. No damage to the cable tray was detected. A linear-shaped, flexible piece of debris (possibly tape from the umbilical purge barrier material) was seen near the base of the LH2 umbilical during ET separation.

No anomalies were noted on the face of the LH2 umbilical after ET separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect.

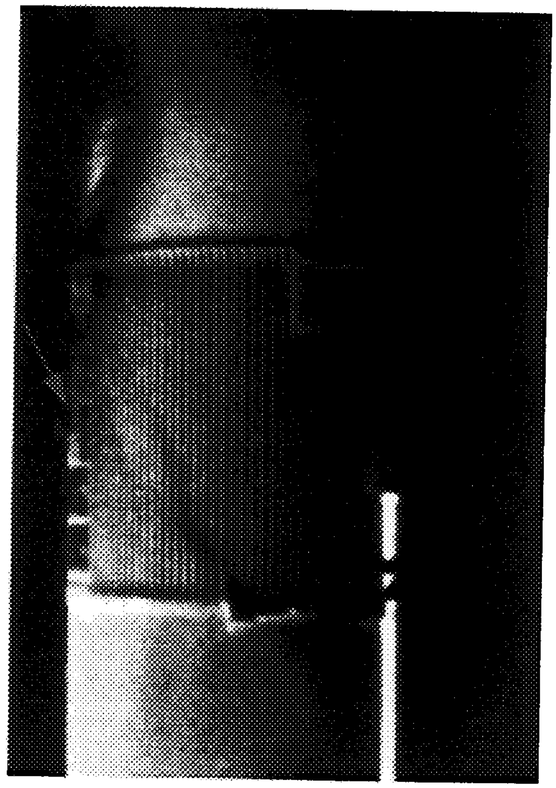


Figure 2.5.1 (D) ET -Y Intertank Thrust Panel (16mm Umbilical Film)

A large bright-colored area of possible divots was noted on the forward portion of the visible (-Y/+Z) left intertank thrust panel. Other light-colored marks were seen on the left intertank thrust panel. However, some of these light-colored marks appeared to coincide with small ramps on the thrust panel seen on the close-out photography and may not indicate damage.

A divot was visible under the ET/Orbiter attach bipod in the LH2 tank-to-intertank close-out flange. Two divots were visible in the LH2 tank-to-intertank flange close-out in the -Y/+Z quadrant. A divot approximately ten inches in diameter was also visible in the same flange near the lower right corner of the left thrust panel. Dark-colored linear-shaped marks, possibly from shock waves off the left EB fitting, were visible extending diagonally across the -Y/+Z intertank stringer heads toward the bipod.

2.5.2 Analysis of the Handheld Photography of the ET

Thirty-three images of the ET were acquired using the handheld 35mm Nikon camera with a 400mm lens (roll 333). The images of the ET were very faint and silhouetted by the late afternoon sun. The camera used for the ET handheld photography launched with the wrong camera settings resulting in under exposed photography. Views of the sides, nose, and aft end of the ET were acquired. However, the +Y side of the ET was in shadow and too dark for analysis.

The distance of the ET from the Orbiter could not be accurately measured from the photography because of the dark shadows on one side of the ET. Timing data is present on the film. The first picture was taken at 16:29 (minutes:seconds) MET.

2.5.2.1 Analysis Findings

Figure 2.5.2.1 (A) ET -Y Intertank Thrust Panel (Handheld Film)

Damage to the external tank, including both intertank thrust panels, was not confirmed from the available handheld camera views. However, approximately five light-colored marks were visible on the -Y thrust panel forward of the EB fitting. An additional three to four light-colored marks were noted on the close-out flange between the forward end of left intertank thrust panel and the LO2 tank TPS. These light-colored marks may indicate possible damage, but this was not confirmed because of the limited resolution.

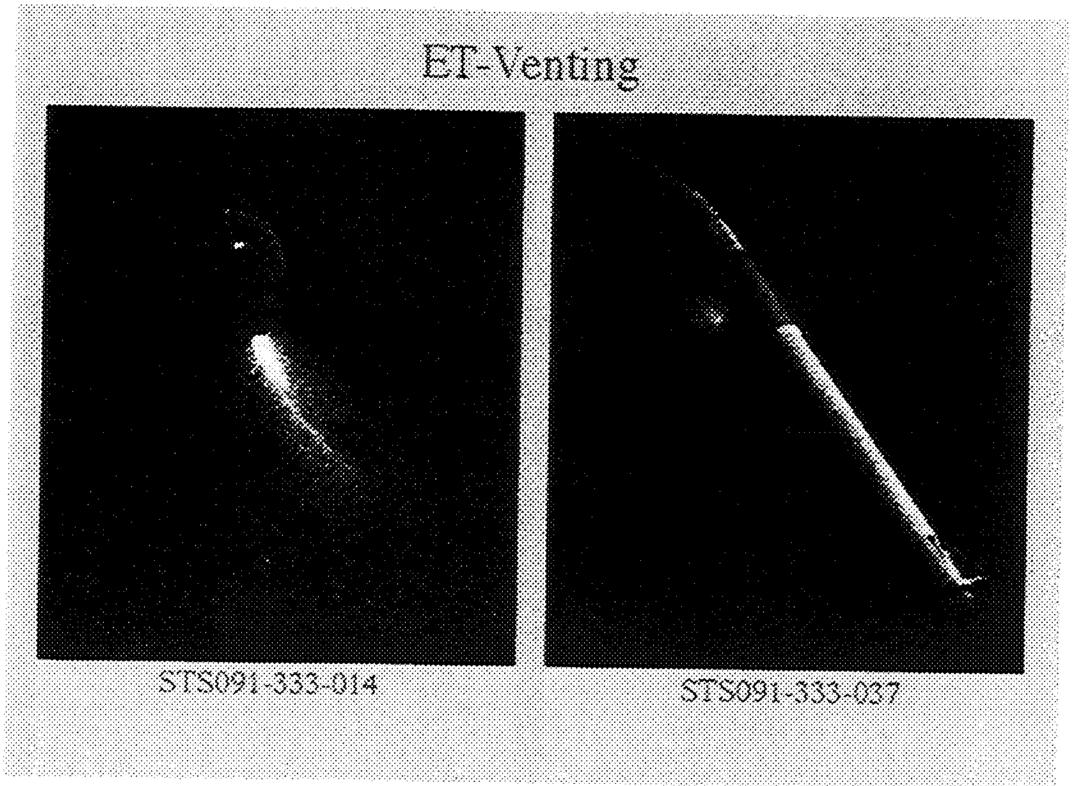


Figure 2.5.2.1 (B) ET Venting

Venting from what appeared to be the -Y intertank hydrogen vent was recorded on ten frames (see Table 2.5.2.1).

FRAME	GMT TIME (Hr:Min:Sec)	MET (Min:Sec)
STS-91-333-012	22:23:07	16:43
STS-91-333-014	22:23:09	16:45
STS-91-333-015	22:23:10	16:46
STS-91-333-018	22:23:17	16:53
STS-91-333-019	22:23:18	16:54
STS-91-333-020	22:23:21	16:57
STS-91-333-031	22:24:38	18:14
STS-91-333-032	22:24:44	18:20
STS-91-333-037	22:25:05	18:41
STS-91-333-038	22:25:10	18:46

Table 2.5.2.1 ET Venting Times from Handheld Camera

The ET rate of tumble, i.e., the end-to-end rotation of the ET about its center of mass, was estimated to be approximately 11 deg/sec. The rate of roll about the ET X axis could not be determined due to shadowing. Table 2.5.2.2 contains a comparison of the averaged tumble rate measurements for the previous four Space Shuttle missions. Venting was seen on all four missions.

MISSION	TUMBLE RATE (degrees/second)	MET (min:sec)
STS-87	11	17:23 - 18:08
STS-89	12	31:42 - 35:27
STS-90	3	14:30*
STS-91	11	16:29 - 18:46

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

Table 2.5.2.2 ET Tumble Rates

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

Images of white-colored, irregular shaped, debris were also acquired. This debris appeared to be pieces of frozen hydrogen and are typically seen on the ET post separation photography.

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis

Film camera EL-7 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touchdown was considered. Data points defining the main gear struts were collected on every frame (100 frames 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-91 landing at one second, at half a second, and at a one quarter of a second are provided in Tables 2.6.1 (A) and 2.6.1 (B). Plots of these sink rates are provided in Figures 2.6.1 (A) and 2.6.1 (B).

Time Prior to Touchdown	1.00 Sec.	0.50 Sec.	0.25 Sec.
Left Main Gear Sink Rate	4.9 ft/sec	4.2 ft/sec	3.9 ft/sec
Estimated Error (1σ)	± 0.2 ft/sec	± 0.2 ft/sec	± 0.1 ft/sec

1st Touchdown (Left Main Gear) = 18:00:17.048 (UTC)

Table 2.6.1 (A) Landing Sink Rate (1st Touchdown)

Time Prior to Touchdown	1.00 Sec.	0.50 Sec.	0.25 Sec.
Right Main Gear Sink Rate	1.1 ft/sec	1.7 ft/sec	2.6 ft/sec
Estimated Error (1σ)	± 0.4 ft/sec	± 0.3 ft/sec	± 0.2 ft/sec

2nd Touchdown (Right Main Gear) = 18:00:20.463 (UTC)

Table 2.6.1 (B) Landing Sink Rate (2nd Touchdown)

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-91 vehicle was estimated to be 226,725 lbs.

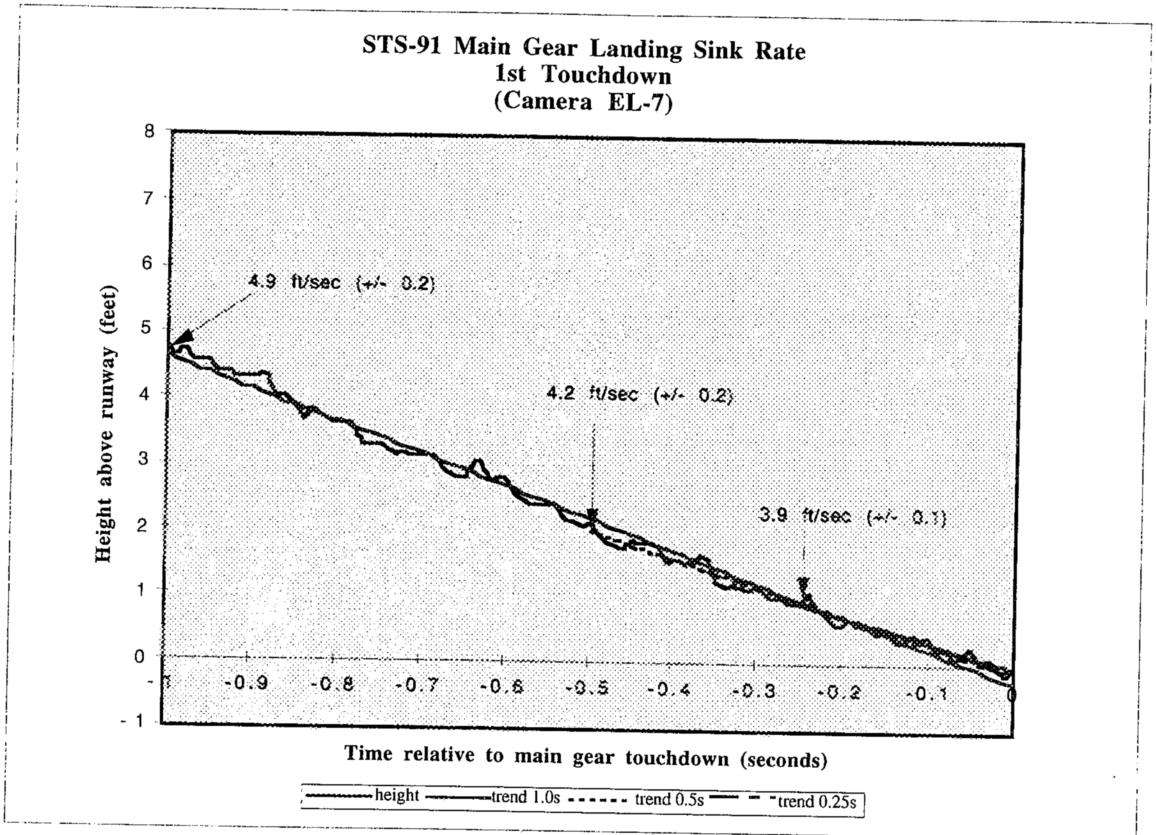


Figure 2.6.1 (A) Landing Sink Rate (1st Touchdown)

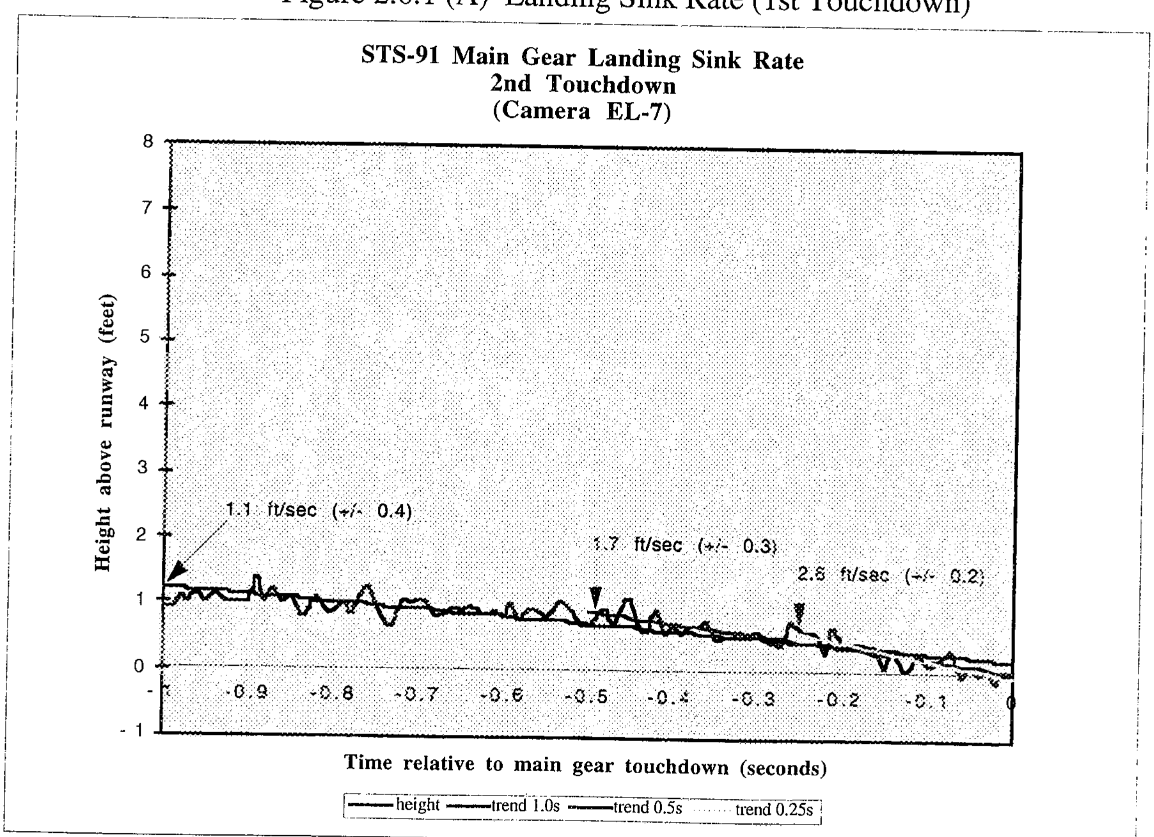


Figure 2.6.1 (B) Landing Sink Rate (2nd Touchdown)

A sink rate analysis of the nose gear was not performed on STS-91 due to budgetary constraints.

2.7 OTHER

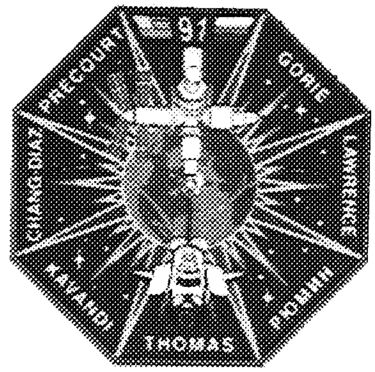
2.7.1 Normal Events

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

2.7.2 Normal Pad Events

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

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY



STS-91 Engineering Photographic Analysis Report

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Introduction

The launch of space shuttle mission STS-91, the 24th flight of the Orbiter Discovery occurred on June 2, 1998 at approximately 5:06 P.M. Central Daylight Time (CDT) from Launch Complex 39A (LC-39A), Kennedy Space Center (KSC), Florida. Launch time was reported as 98:153:22:06:17.008 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-39A perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Engineering Analysis Objectives

The planned engineering photographic and video analysis objectives for STS-91 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-91.

	16mm	35mm	70mm	Video
MLP	18	0	0	4
FSS	4	0	0	3
Perimeter	0	6	0	6
Tracking	0	10	0	11
Onboard	2	2	0	0
Totals	24	18	0	24

Total number of film and videos received:66

Individual camera assessments are provided in Appendix A.

Ground Camera Coverage

Photographic coverage of the STS-91 launch was considered good. Atmospheric haze and cloud coverage degraded images from some tracking cameras. However, some images were improved due to the afternoon sun angle. Camera E15 did not operate due to a blown fuse. The timing on camera E12 was incorrect.

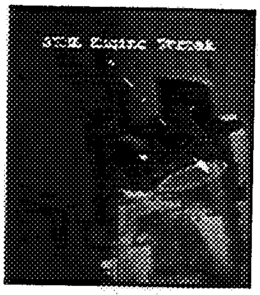
Onboard Camera Coverage

Discovery carried two 16mm carmeras located in the orbiter LH2 umbilical well and a 35mm still camera in the LO2 umbilical well recording SRB and ET separations. The Astronaunts also recorded images of the ET after separation with a 35mm still camera. The Astronauts' still camera was misconfigured prior to launch resulting in dark images of the ET. The umbilical well cameras provided good images.

Anomalies

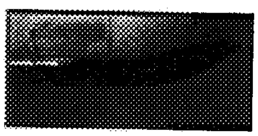
No anomalies were noted.

Observations



Prior to liftoff SSME number one produced an engine streak. This streak was not the result of debris falling into the exhaust plume. Streaks like this have been noted on previous launches and on SSME engine tests. These streaks are yellow to orange in color and are visible in only one frame. These streaks are generally thought to be caused by a small amount of contaminant in the fuel.

The onboard 16mm umbilical well camera with a 10mm lens recorded images of the ET after separation. This image shows some TPS divots on the -Y Thrust Panel. The divots appear as lighter color areas on the Thrust Panel. Also appearing as lighter color areas are raised areas of the TPS which can be seen in this close-out photograph taken of the -Y Thrust Panel prior to launch. The two photographs need to be compared to judge the amount of TPS divoting. An effort by KSC to map the TPS divots is shown in this image in-which areas of TPS divoting are drawn on the close-out photograph.



Also carried onboard the umbilical wells was a 35mm still camera which recorded this image of the forward portion of the ET. In this image two TPS divots can be seen under the forward Orbiter attach (bipod) on the L02 Tank/Intertank interface. Two additional TPS divots were noted on this interface but not imaged in this photograph. The rectangular sanded area on the L02 Tank looks in good condition as well as the nose cone. The +Y Thrust Panel is in shadow and too dark to determine if any TPS was lost.

Engineering Data Results

T-Zero Times

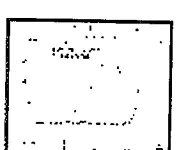
T-Zero times are determined from cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

Holddown Post	Camera Position	Time (UTC)
M-1	E9	22:06:24.016
M-2	E8	22:06:24.018
M-5	E12	Timing Incorrect
M-6	E13	22:06:24.016

SRB Separation Time

SRB separation as recorded by observations of the BSM combustion products from high speed film camera E207 occurred at 153:22:08:26.98 UTC.

ET Tip Deflection



The ET tip deflection was measured on this mission to check for consistency with previous flights since this was the first flight of the super-lightweight tank. The maximum tip deflection was measured as 31 inches with an accuracy of +/- one inch. The deflection data from STS-91 is consistent with previously measured data.

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

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A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-91. 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-91 and the resulting effect on the Space Shuttle Program.

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