

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-103

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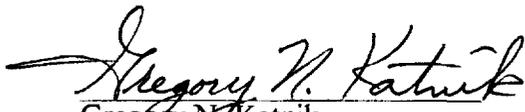
**DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-103**

19 December 1999

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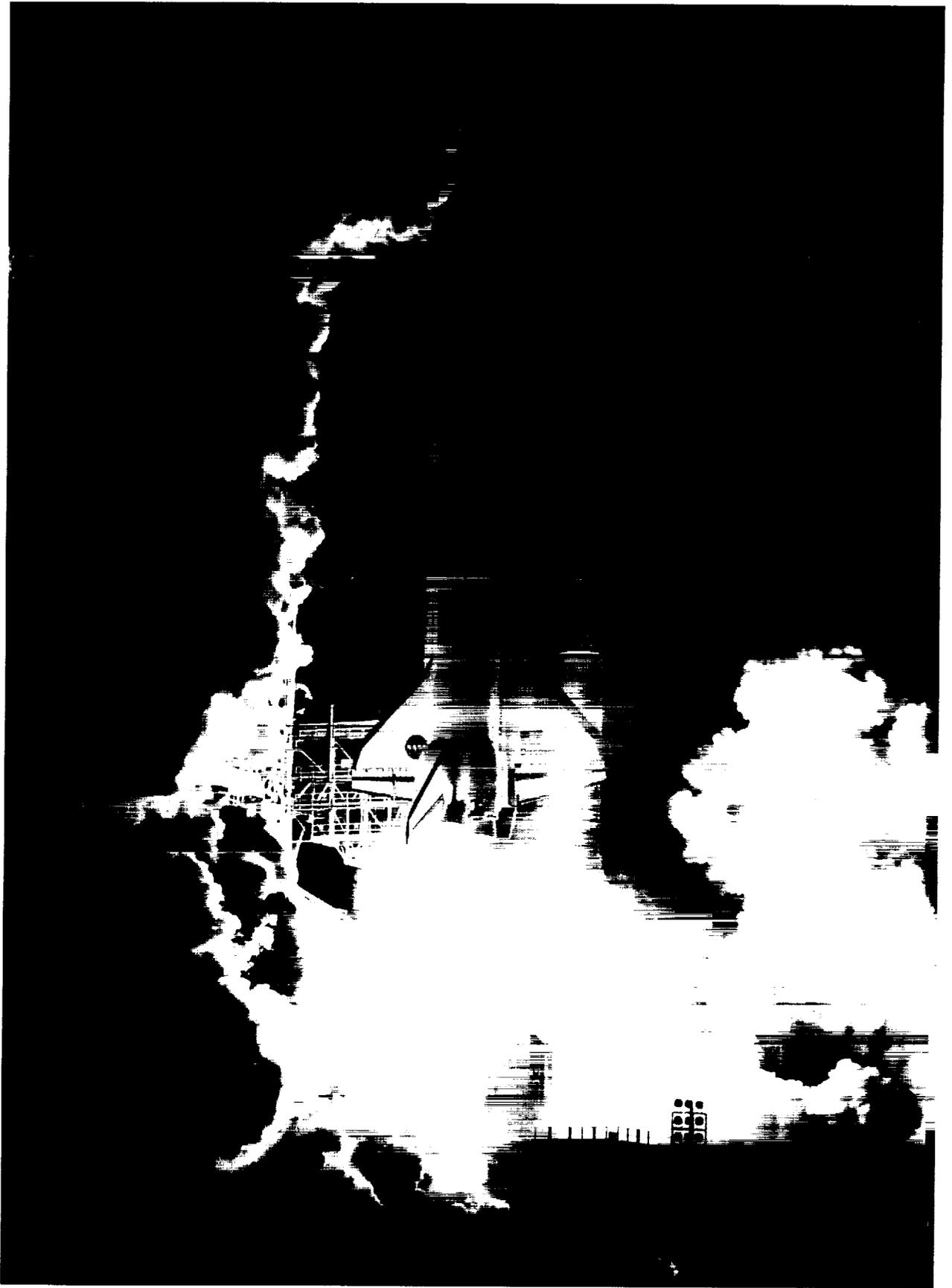


Photo 1: Launch of Shuttle Mission STS-99

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-103 consisted of OV-103 (27th flight), ET-101 and BI-099 SRB's on MLP-2 and Pad 39B. Discovery was launched at 99:354:00:49:59.986 UTC (7:50 p.m. local) on 19 December 1999. Landing was at 7:02 p.m. local/eastern time on 27 December 1999.

ET Thrust Panels

An 8mm video camera was flown in each SRB forward skirt for the purpose of documenting any TPS loss from the ET-101 thrust panels from launch through SRB separation. This flight incorporated thousands of pin-size vent holes with 0.3-inch spacing and 0.032-inch diameter holes to substrate in the intertank foam. The vented surfaces (thrust panels, circumferential ribs, and skin stringer acreage) were the most extensive to date and covered all possible areas affected by shock wave aero heating. In terms of general observations, both the number and size of TPS divots in the camera field of view were significantly reduced from that observed on previous flights since STS-86.

The Orbiter lower surface sustained 84 total hits, of which 13 had a major dimension of 1-inch or larger. Approximately half of this damage was concentrated from the nose gear to the main landing gear wheel wells on both left and right chines following a similar location/damage pattern documented on STS-86, -87, -89, -90, -91, -95, -88, -96, and -93.

However, some significant differences on the STS-103 flight include: 1) only one of the tile damage sites forward of the main landing gear was larger than 1-inch in length, 2) only two of the damage sites forward of the main landing gear reached a depth of 1/4-inch, and 3) some of the damage sites on the right side of the Orbiter lower surface could be attributed to impacts from ice in the ET LO2 feedline bellows.

In general, the lower surface tile damage on this flight may be considered at the low end of the damage spectrum since the symmetrical damage pattern on the forward part of the Orbiter first began on STS-86. It would appear that venting of the ET intertank TPS had a profound effect on reducing the number and size of divots in the TPS, which in turn reduced the number and size of tile damage sites on the Orbiter forward lower surface. Venting was not expected to prevent the foam from "popcorning" and is only a temporary solution to the problem until a new type of foam can be formulated and applied. Although the lower surface damage pattern will continue, the severity of the damage is expected to be decreased accordingly.

Damage to Orbiter Left Wing RCC Panel #8

Close inspection after landing in the OPF revealed a damage site to left wing RCC panel #8. The damage site measured approximately 1.5 inches long by 0.5-inches wide by 0.25 inches deep with a "pink" residue in the cavity. The residue was sampled for lab analysis, but no "foreign" substance was identified in the sample. Micrometeorite impact specialists at JSC determined the damage was not the result of a high velocity impact typically caused by on-orbit debris. Since pre-launch inspection revealed no damage prior to launch and no debris impacts were observed in launch films, the cause of the low velocity impact has not been determined.

3.0 SCRUB

3.1 FINAL INSPECTION - WEATHER SCRUB

A Final Inspection of the cryoloaded vehicle was performed on 19 July 1999 from 1855 to 2040 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. Although technically a "winter" launch, there were no acreage icing concerns due to relatively warm ambient temperatures and strong winds. There were also no protuberance icing conditions outside of the established database. Two cracks were detected in ET intertank stringer valley TPS: one 10-12 inches long in the -Y+Z quadrant, and one 6-8 inches long in the -Y-Z quadrant. Neither crack exhibited ice, frost, nor offset. Therefore, the cracks were acceptable for flight per the NSTS-08303 criteria. No anomalies were detected on the facility, SRB's, and Orbiter. Although all RCS thruster paper covers were intact, three (R2D, R2R, L1L) were tinted a light green.

Launch was scrubbed at the end of the window due to numerous weather violations.

3.2 POST DRAIN INSPECTION

The post drain inspection of STS-103, MLP-2, and Pad B FSS was conducted on December 18, 1999, from 0200 to 0300 hours under dark conditions and steady rain. Nevertheless, visibility was adequate for the inspection.

No MLP deck or facility anomalies were detected. Likewise, no anomalies were observed on the SRB's.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact, though all were wet in varying degrees due to the rain. The wetted areas began at the RTV bondlines and progressed radially inward. However, the wetted areas were not soaked to the point of water intrusion to the thruster throats.

The External Tank was in excellent condition. No topcoat was missing from the ogive area under the GOX vent seal footprint. The two cracks in the intertank stringer valleys (-Y-Z and -Y+Z quadrants) previously reported by the Final Inspection Team had closed, as expected. Bipod jack pad standoff closeouts were in nominal condition. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets. The stress relief crack in the -Y vertical strut forward facing TPS was still present. A very small thermal short with venting occurred momentarily at the 6:00 position of the aft dome manhole cover.

The warm rain had removed most of the ice/frost accumulations. The only ice remaining was located in the LO2 feedline bellows and on the ET/ORB umbilical purge vents.

In summary, no IPR conditions and no flight hardware concerns were detected during the post drain inspection. There were no constraints for the next cryoload.

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

A 10-inch long by 1/4-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/frost had formed in the LH2 feedline bellows. Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side and forward surface. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

4.2.4 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.

4.3 T-3 HOURS TO LAUNCH

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

STS-103 was launched at 99:354:00:49:59.986 UTC (7:50 p.m. local) on 19 December 1999.

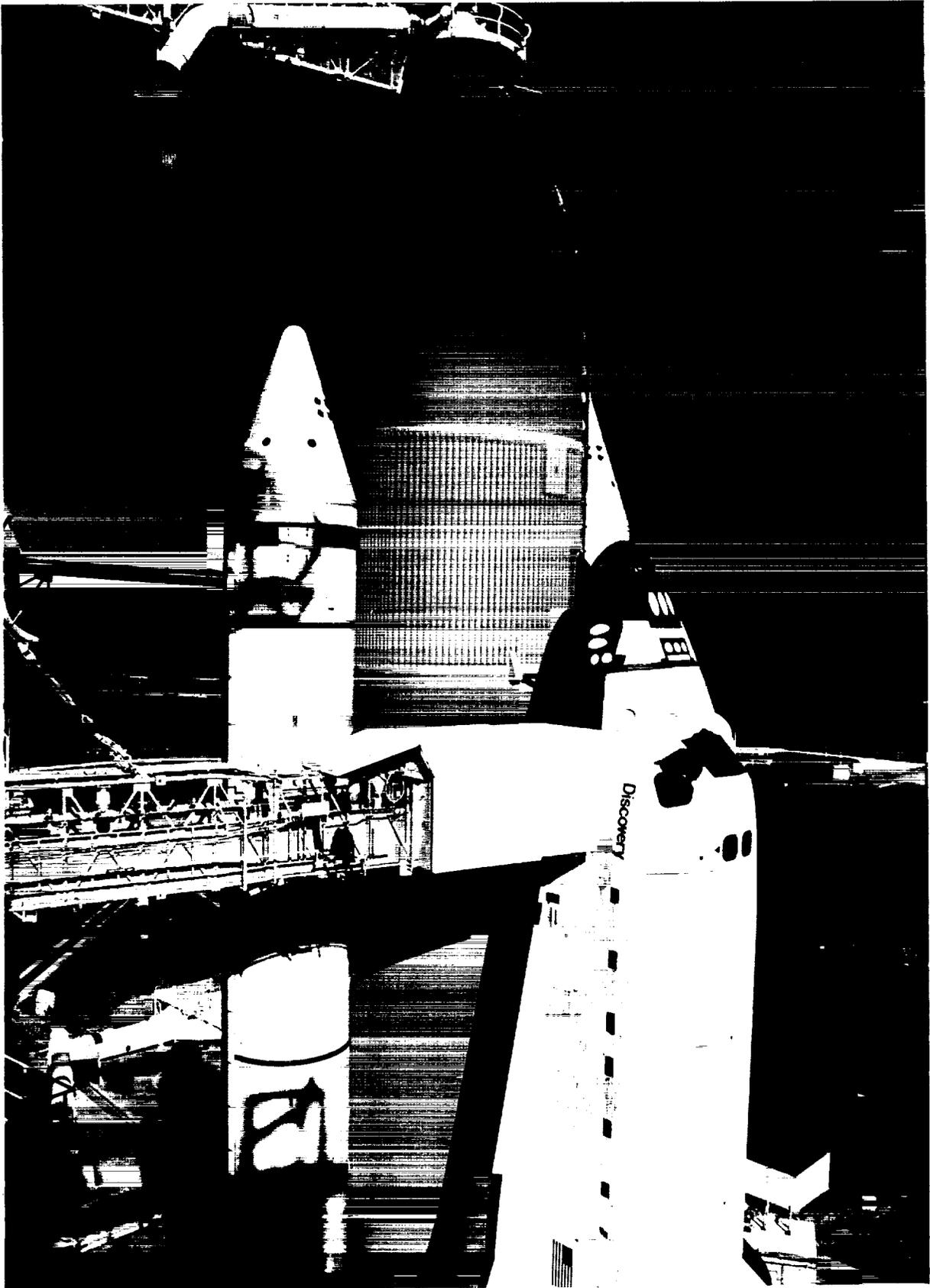


Photo 2: ET LO2 Tank and Intertank

The Final Inspection Team observed some wet TPS on the LO2 tank acreage due to light condensate, but no ice or frost accumulations. No anomalies were detected in the intertank TPS though numerous small frost spots had formed on the intertank-to-LH2 tank and -LO2 tank flange closeouts.

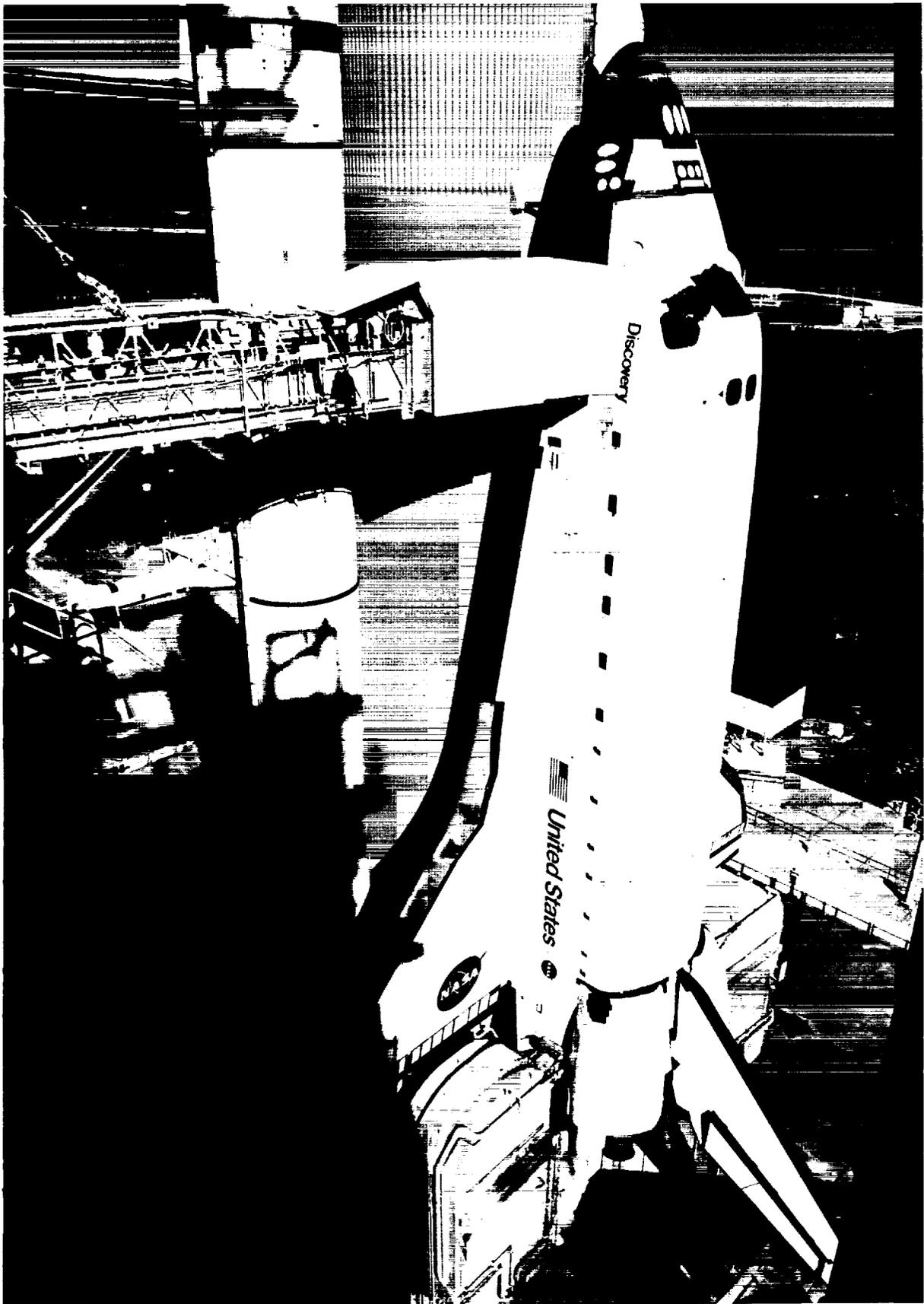


Photo 3: LH2 Tank and Orbiter

The Final Inspection Team observed some wet TPS on the LH2 tank acreage due to light condensate, but no ice or frost accumulations. No Orbiter tile or RCC panel anomalies were observed. The paper covers on the FRCS had been replaced.



Photo 4: Cracks in Flange TPS Closeout

Two cracks were detected in ET intertank stringer valley TPS: one 10-12 inches long in the $-Y+Z$ quadrant, and one 6-8 inches long in the $-Y-Z$ quadrant. Two similar cracks in the $+Y+Z$ quadrant were not photographed. None of the cracks exhibited ice, frost, or offset. Therefore, the cracks were acceptable for flight per the NSTS-08303 criteria.

5.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP, Pad B FSS and RSS was conducted on 19 December 1999 from Launch + 2 to 4 hours. No flight hardware was found.

A stud hang-up occurred on this launch. Boeing-Downey reported an Orbiter liftoff lateral acceleration of 0.29g's which is above the threshold (0.14g's) for stud hang-ups. However, the south SRB holddown post were inspected and showed no indication of hang-up. Erosion was typical for the south posts. North holddown post blast covers and T-0 umbilical exhibited typical exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, though the protective tape was eroded away.

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

The MLP deck was in good shape with no significant debris items.

The GH2 vent line latched in the second of eight teeth of the latching mechanism. The GUCP 7-inch QD sealing surface exhibited only minor roughness on the inner edge in two locations. All observations indicated a nominal retraction and latchback.

The GOX vent arm, hood, ducts and structure appeared to be in good shape with no indications of plume damage.

Debris findings on the FSS included a variety of small signs/tags, pipe insulation and tie wraps. One section of cable tray cover had broken loose and was found on the grating at the 135-foot level. A communication panel box was open at the 235-foot level, but had no apparent damage. The power control box for the slidewire basket retrieval winch was found broken loose from the support structure at the 255-foot level.

No damage was noted in the flame trenches.

Overall, damage to the pad appeared to be minimal.

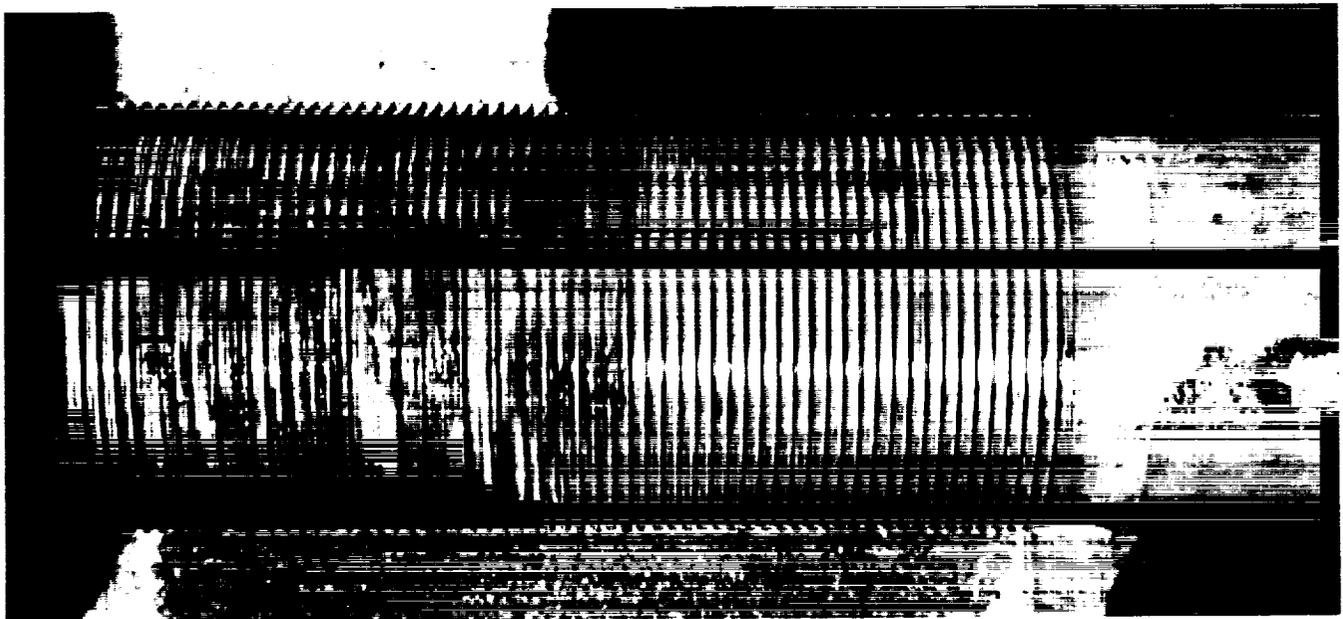
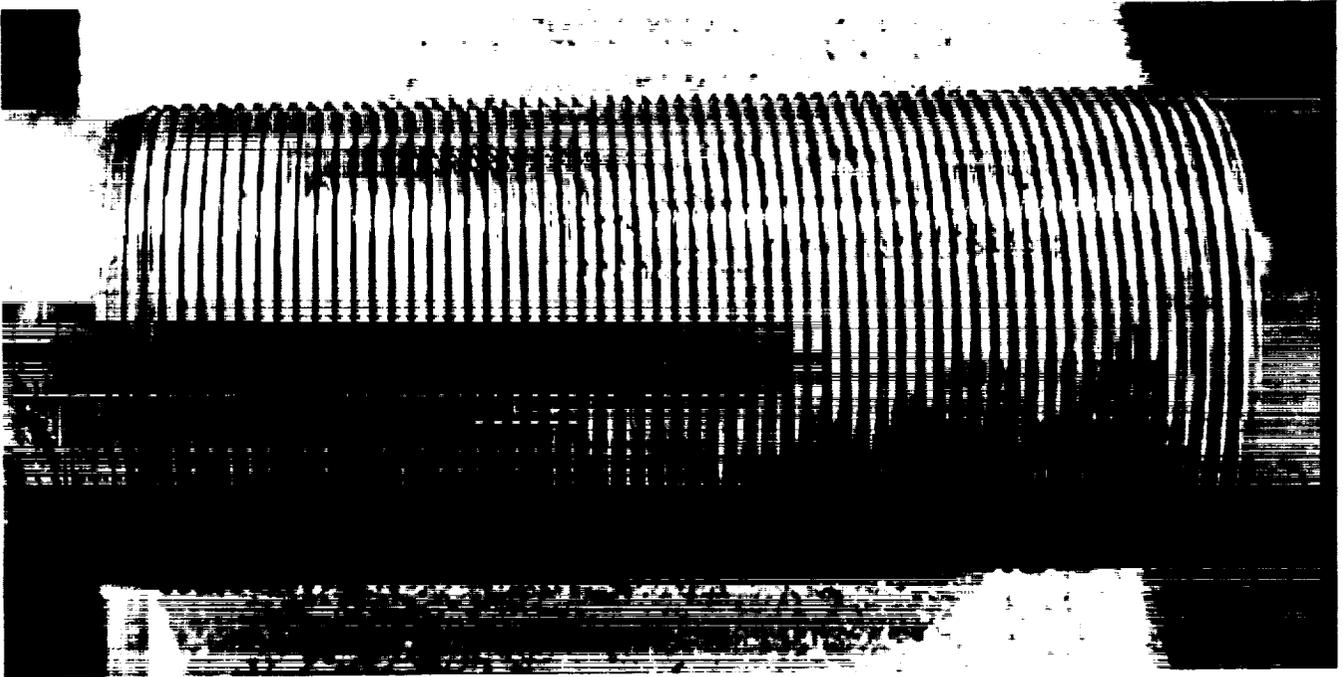


Photo 5: Holddown Post Stud Hangup

Stud from holddown post #4 shows aluminum shavings from the SRB aft skirt in the threads



Photo 6: GN2 Purge Lines

Both SRB aft skirt GN2 purge lines were intact, though the protective tape was eroded away

6.0 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.

6.1.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 81 films and videos, which included twenty-nine 16mm films, thirteen 35mm films, and thirty-nine videos, were reviewed starting on launch day.

Frost, but no ice, formed on the ET louvers after GOX vent seal retraction. Topcoat had been pulled loose in two places (OTV 161).

SSME ignition appeared normal and the Mach diamonds formed in a 3-2-1 sequence. Five streaks occurred in the SSME #1 exhaust plume during start-up through early liftoff (OTV 151, 170, 171; E-213)

Free burning hydrogen was visible in the base heat shield area and drifted past the vertical stabilizer during SSME ignition (OTV 170, 171, TV-7)

SSME start-up caused numerous pieces of ice from the LH2 ET/ORB umbilical to fall aft. Some pieces impacted the umbilical cavity sill, but no damage was visible (OTV 109, 154, 163).

A square piece of purge barrier material from the LH2 ET/ORB umbilical closeout near the ET door aft hinge came loose just before T-0, flapped in the air flow, but remained attached (OTV 109, 154, 163). OTV 163 showed the best view of this event.

Small pieces of tile surface coating material were lost during ignition from 13 places on the base heat shield, 3 places on the +Y APCS pod, 2 places on the -Y APCS pod, 1 place on the SSME #3 dome heat shield, and one place on the body flap outboard of SSME #3 (OTV 149, 150, 170; E-17, -18, -19, -20).

Two pieces of ice from the LO2 feedline upper bellows fell aft and disappeared behind the Orbiter (OTV 161).

A holddown post stud hang-up was expected based upon a liftoff lateral acceleration of 0.29 g's and broaching of the right SRB HDP #4 bore. Unfortunately, film item E-7 viewing this holddown post malfunctioned. Films of the other seven holddown posts revealed no stud hang-ups and no debris falling from the HDP stud holes.

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. No anomalies were observed (E-8, -13).

A considerable amount of SRB throat plug, including four large pieces, and some of the primary sound suppression water trough material were ejected from the SRB exhaust holes in a northward direction just after T-0. There was no contact with the flight hardware (E-4, -57; OTV 148, TV-7)

Numerous pieces of ET/ORB umbilical purge barrier material fell aft during and after the roll maneuver. Other pieces still attached flapped in the air stream and most likely will have caused some tile coating damage in the vicinity of the umbilicals (E-207).

A light colored object in the upper right corner field of view first appeared at T+40 second MET and crossed the vehicle plume 8 seconds later before falling aft somewhat near the SRB exhaust plume. The object is believed to be a moth or insect near the camera lens (TV-5).

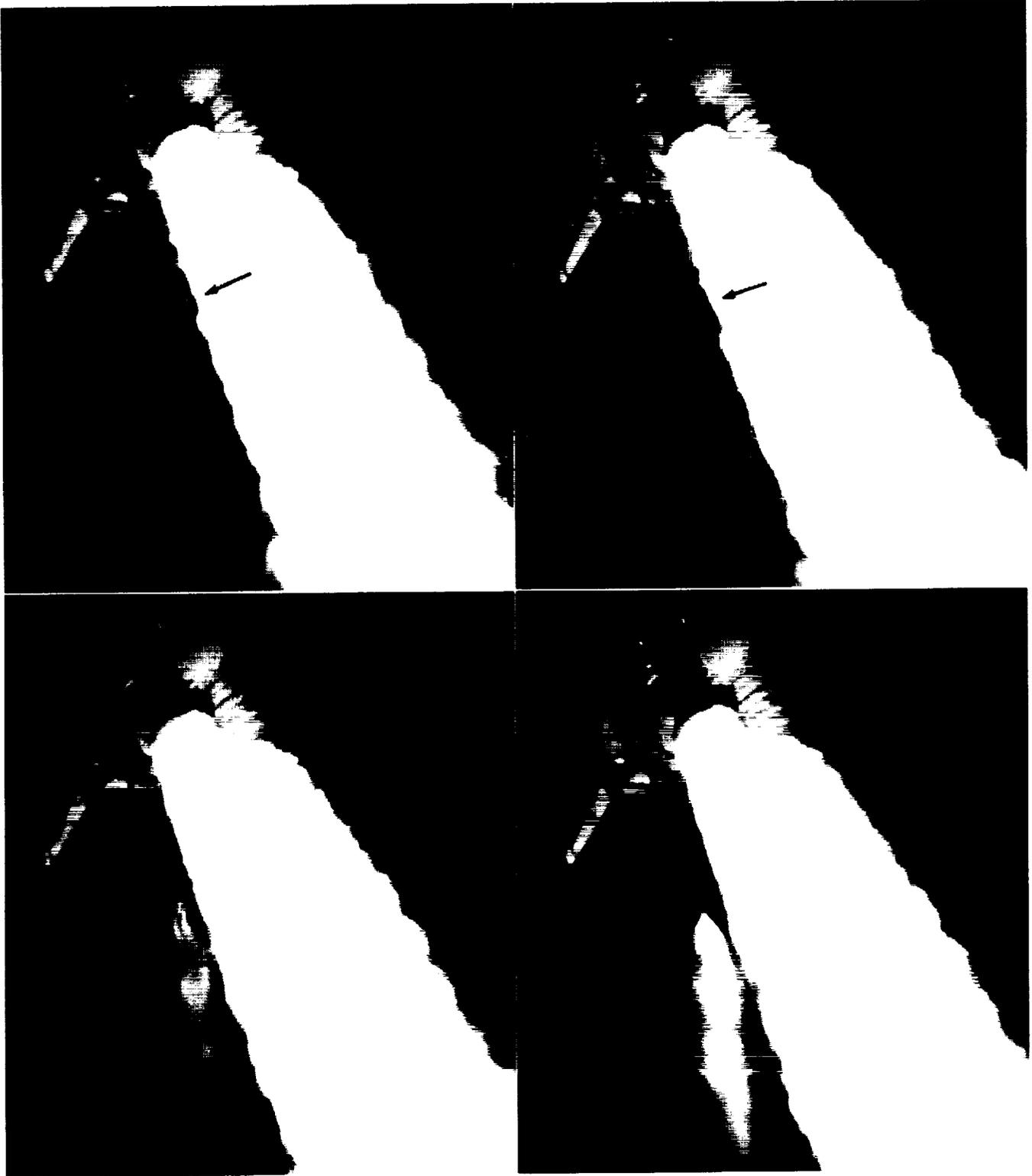


Photo 7: Flash in SSME Plume

A light-colored debris object well aft of the vehicle, visible for just two frames, caused a very large flash in the SSME #2/#3 exhaust plume from 00:50:33.783 to 00:50:33.857 UTC (T+33 seconds MET). This debris is believed to be a piece of SRB aft skirt aft ring instafoam.

6.1.2 SRB CAMERA VIDEO SUMMARY

An 8mm video camera was flown in each SRB forward skirt for the purpose of documenting any TPS loss (in the camera field of view) from ET-101 during launch through SRB separation.

General Notes

Camera provided good view with the available lighting. However, glare and shadows made precise divot identification difficult

Divots were smaller in size than those noted in previous reviews. Divots were very shallow with no primed substrate visible. Most divots were ≤ 0.25 inches in diameter. And no thrust panel divots were larger than 0.5 inches in diameter.

Most thrust panel divots in the field of view occurred in the valley nearest to the EB fitting.

Few and very small divots occurred outside the thrust panel in the stringer section. These divots occurred near the stringer sidewalls and top edges.

-Y Side Divot Count

95 seconds MET	First divot appeared in vented rib area.
98 sec MET	First stringer divot appeared on 1 st stringer adjacent to thrust panel.
98-108 sec MET	18 total divots - 10 stringer - 8 ribs
108-118 sec MET	34 total divots - 16 stringer - 18 ribs
118-124 sec MET	37 total divots - 16 stringer - 21 ribs
After separation	Shallow stringer divots visible aft of GUCP and flight door.

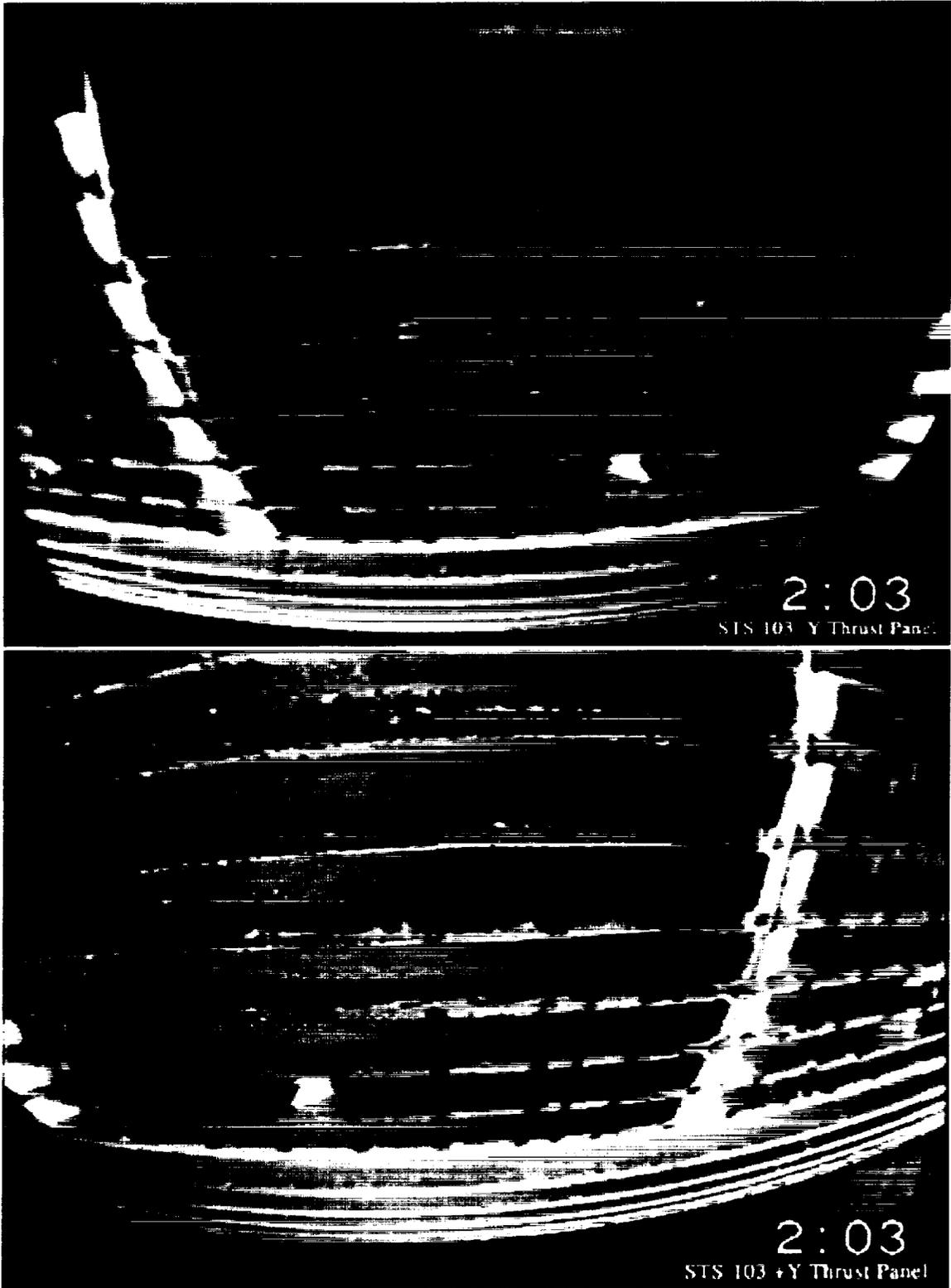


Photo 8: Thrust Panel TPS

Views from the SRB 8mm video camera just prior to SRB separation shows TPS divots that are significantly reduced in both number and size compared to previous flights

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-103 was equipped to carry ET/ORB umbilical cameras: 16mm motion picture with 5mm lens and 16mm motion picture with 10mm lens from the LH2 side; 35mm still views from the LO2 side. The flight crew also had the capability to provide hand held still images and video from the camcorder. However, the dark conditions of a night launch precluded any useful data on the post-ascent condition of ET foam.

6.2.1 ET/ORB UMBILICAL FILMS

SRB separation from the External Tank appeared nominal. Illumination from the SRB exhaust plumes showed typical erosion/flaking of thin layers of TPS from the aft surfaces of the -Y upper strut fairing, -Y vertical strut, and LH2 ET/ORB cable tray. TPS charring and "popcorn" divoting of the aft dome was also typical.

The wide angle ET/ORB LH2 umbilical camera provided a view of the left SRB falling away from the ET. However, the illumination had diminished by the time the forward skirt came into view. Consequently, no detail on frustum/nose cap TPS could be discerned.

6.3 LANDING FILM AND VIDEO SUMMARY

A total of 18 films and videos, which included eight 35mm large format films and ten videos, were reviewed. There was not much detail for engineering assessment due to the dark conditions of a night landing.

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

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

A somewhat unusual occurrence was the infrared signature of the three main engines during touchdown and rollout. The SSME #2 nozzle was warmer than the nozzles on SSME #1 and #3. However, no anomalies were detected to explain this condition.

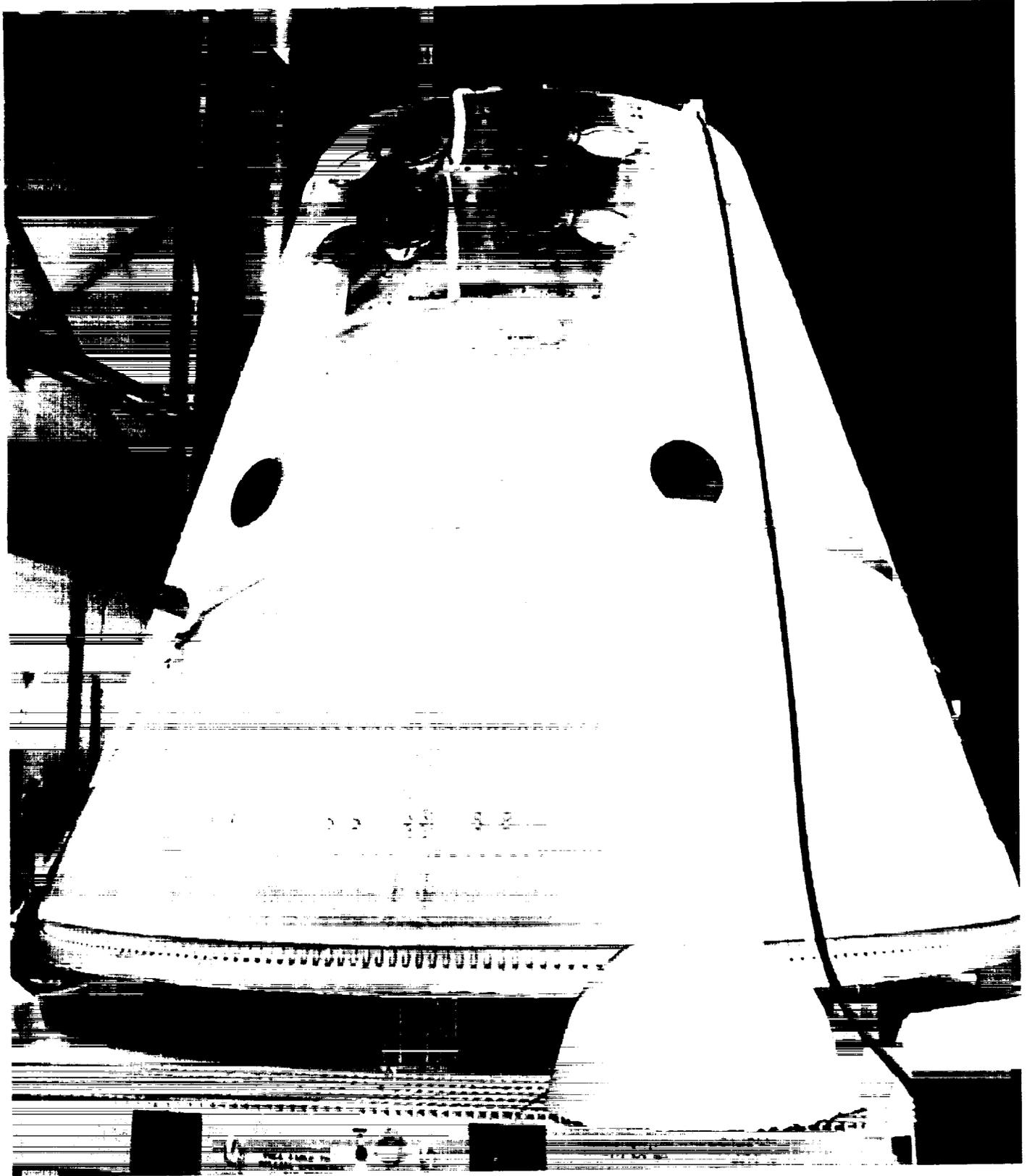


Photo 9: Frustum Post Flight Condition

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.

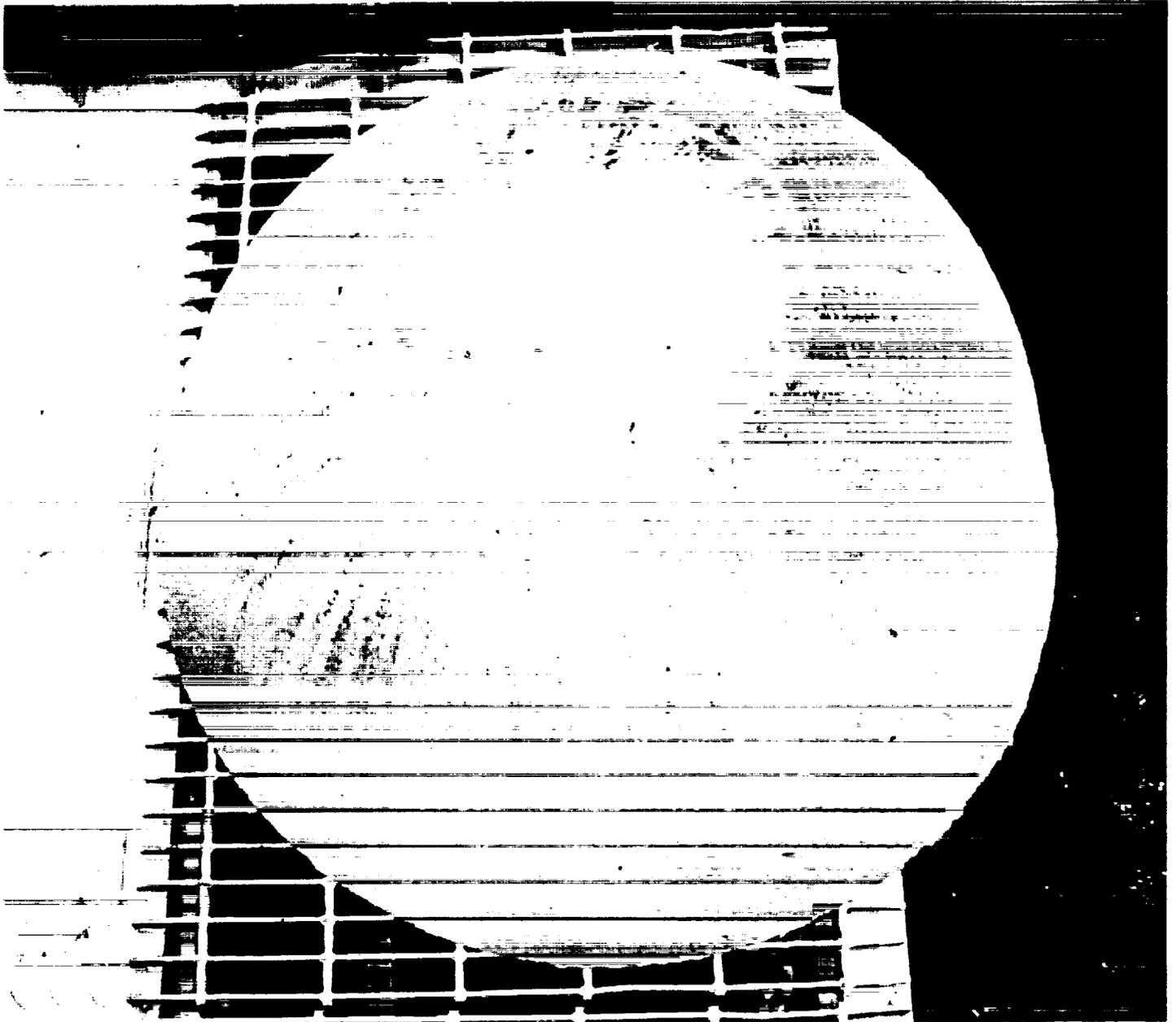


Photo 10: Right Nose Cap

The nose cap from the right SRB was recovered and found to be in excellent condition with no TPS missing or debonded

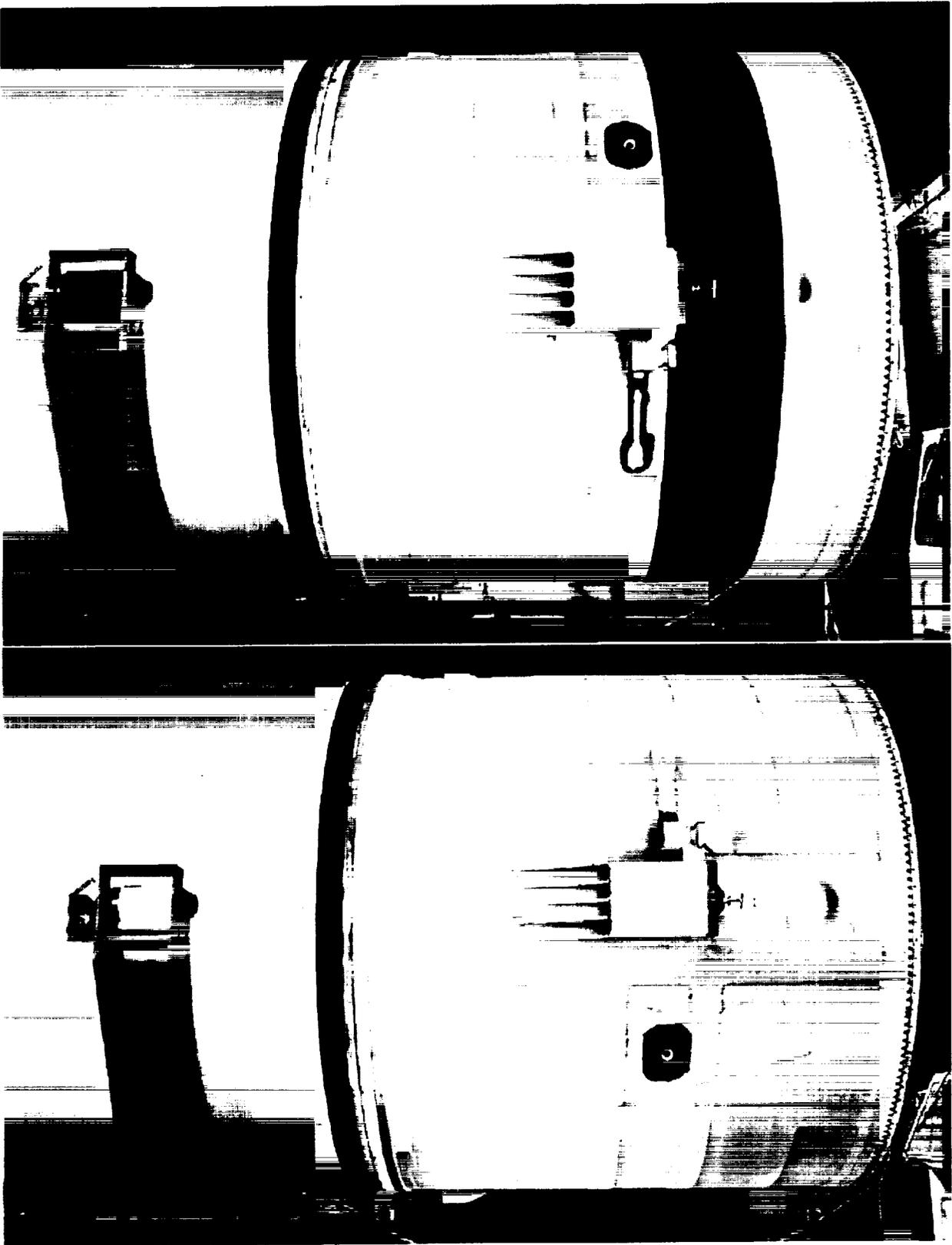


Photo 11: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. All primary frustum severance ring pins and retainer clips were intact with the exception of one missing retainer clip on the left SRB pulled loose by the parachute risers.

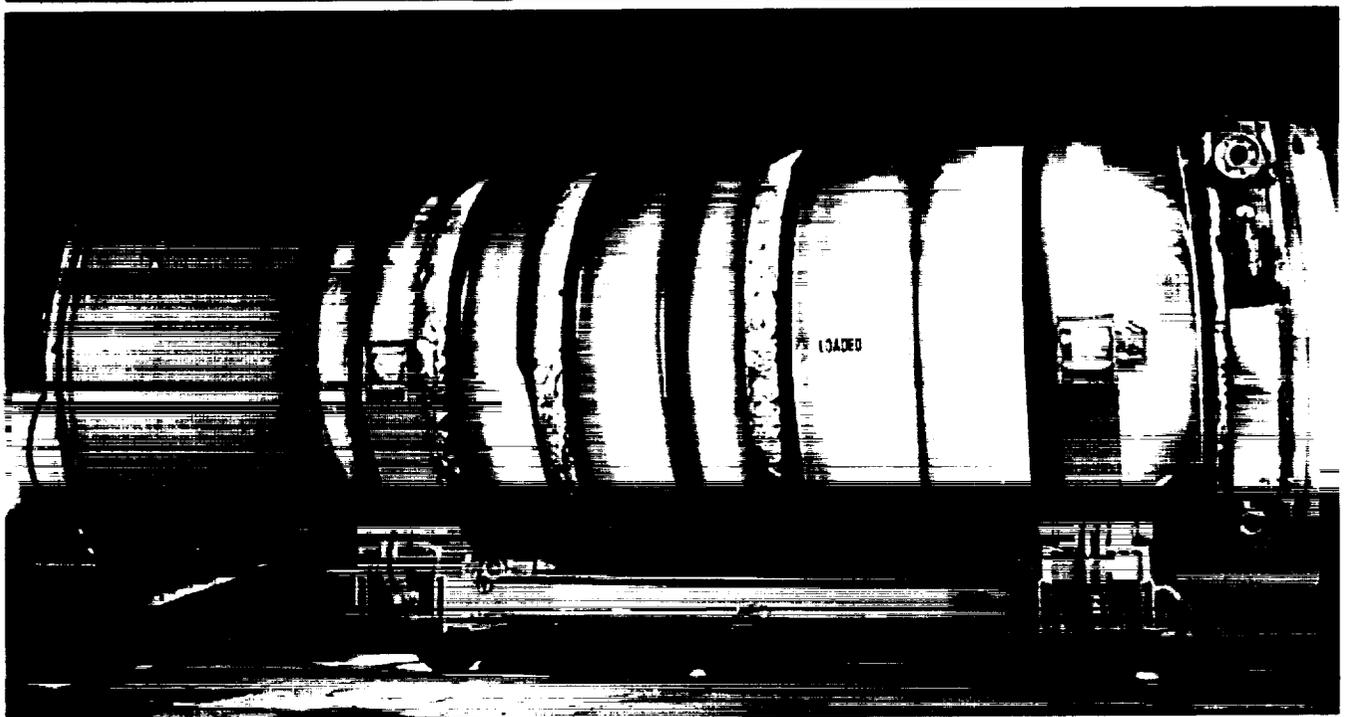
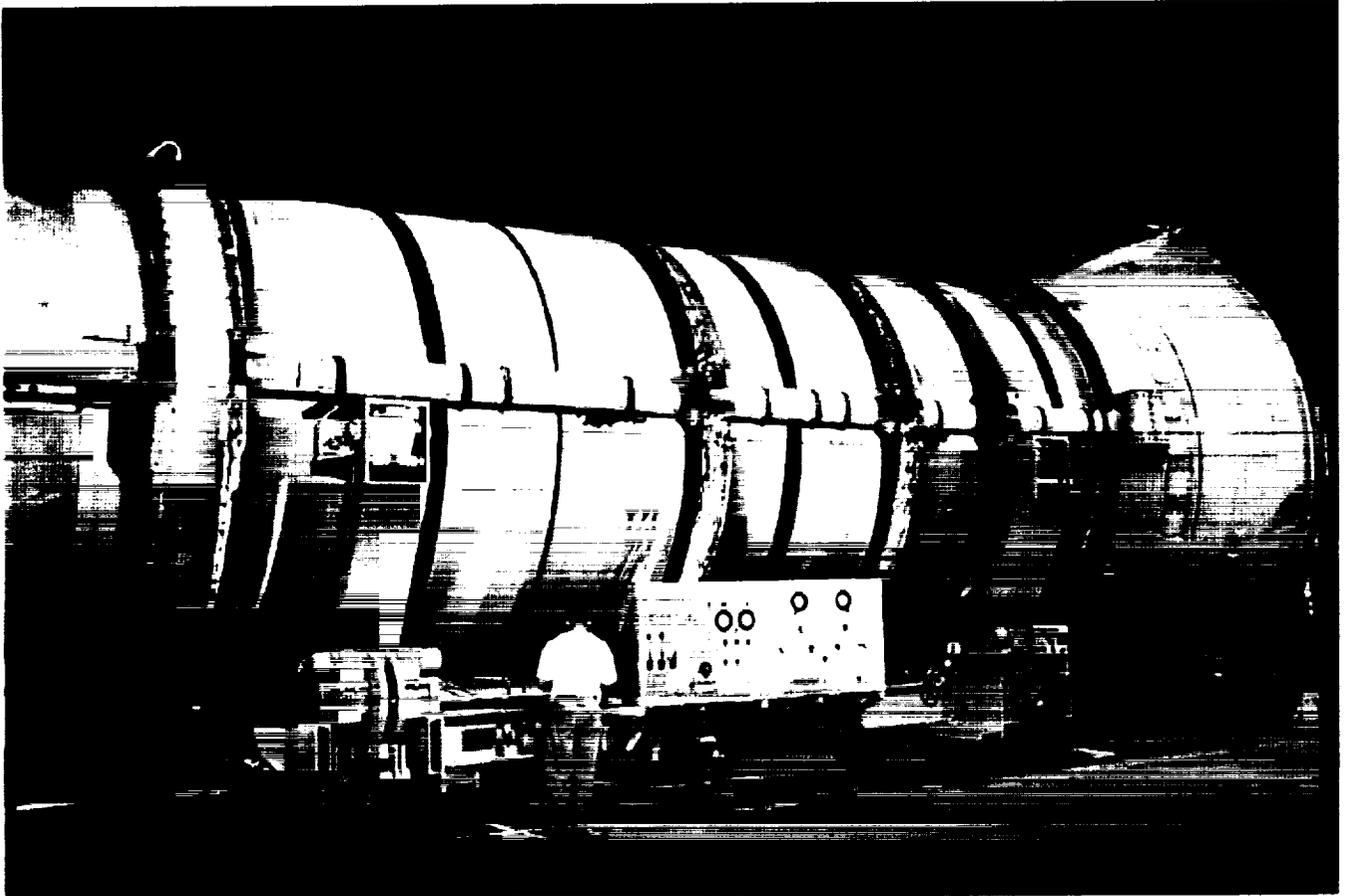


Photo 12: Aft Skirt Post Flight Condition

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

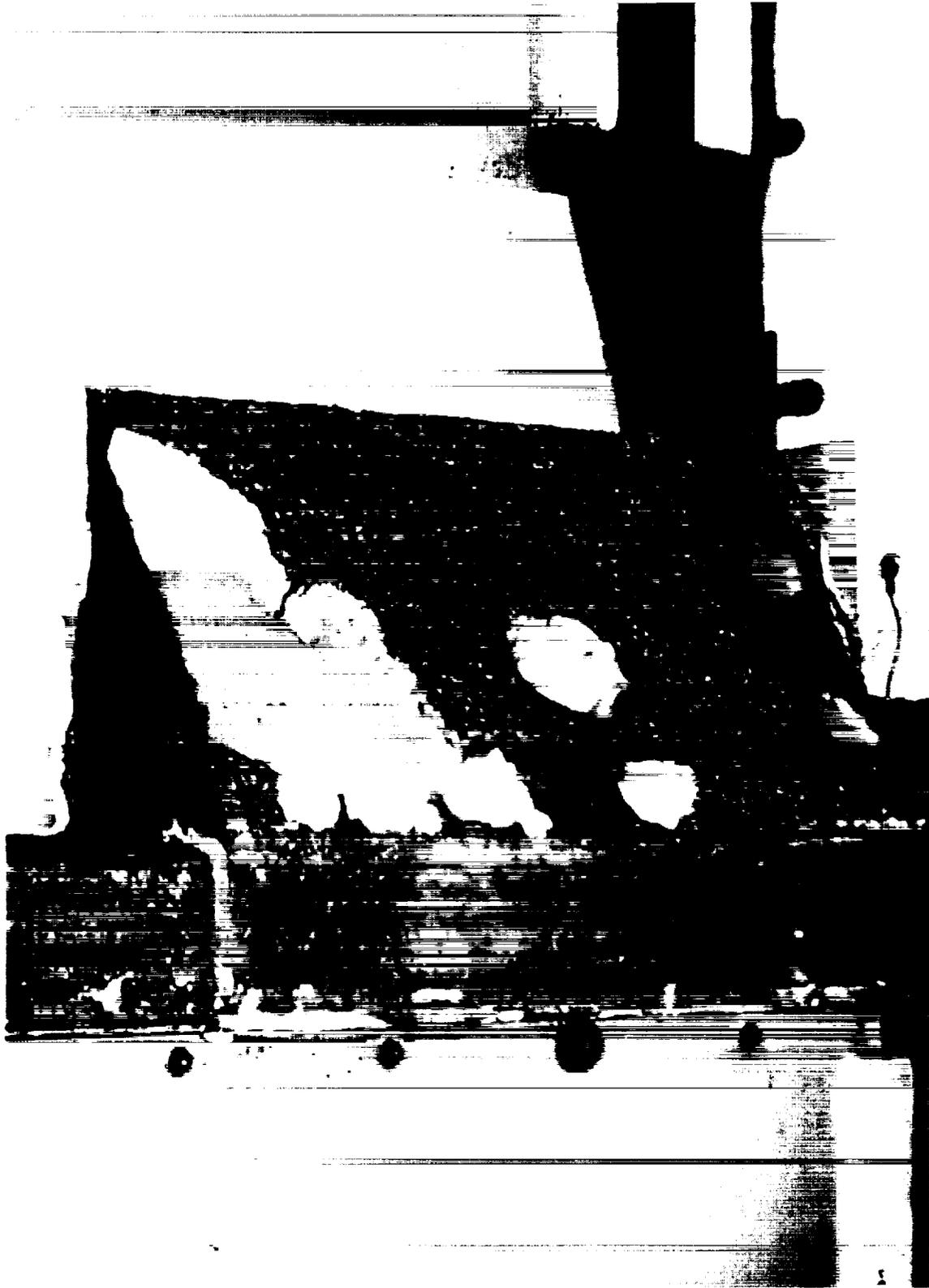


Photo 13: Power Cable Ramp TPS

The TPS covering the power cable ramp adjacent to the left SRB systems tunnel was missing in several areas of the top layer (including the rind). The missing foam extended to the knit line as if the final sprayed layer did not achieve complete adhesion. However, the remaining foam was relatively clean indicating the foam loss occurred late in flight after SRB separation.

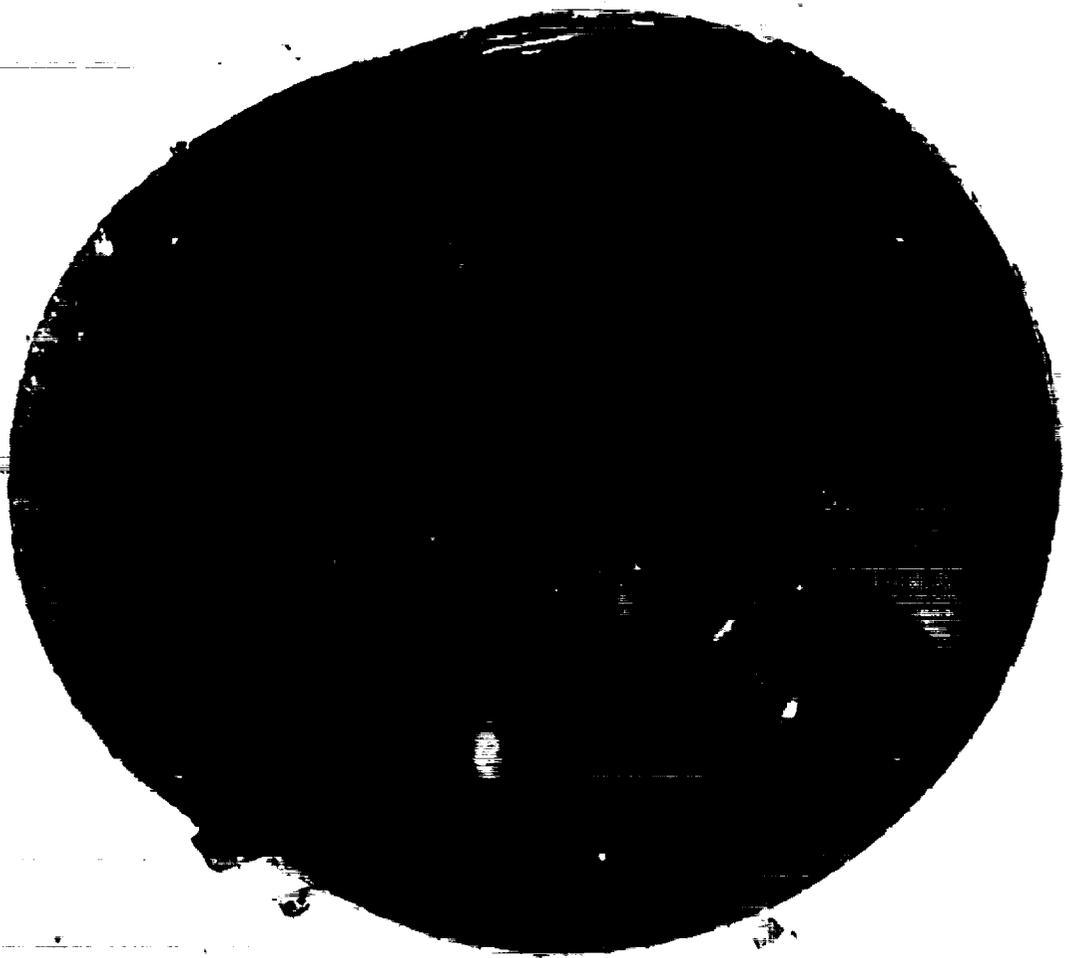


Photo 14: Holddown Post Broaching

There was evidence of a stud hang-up on this launch. In addition to the measured lateral acceleration of 0.29 g's, broaching occurred on holddown post #4 and abraded/scraped metal was exposed in the bore.

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 7:02 p.m. local/eastern time landing on 27 December 1999, a post landing inspection of OV-103 Discovery was conducted at the Kennedy Space Center on SLF runway 33 and in the Orbiter Processing Facility bay #1. This inspection was performed to identify debris impact damage and, if possible, debris sources.

A black tile from the right inboard elevon, -Y side edge, was missing (infrared data revealed no objects fell from the Orbiter during final approach and touchdown). The remaining adhesive and SIP was charred, but no burn through of the substrate was detected. Some thin pieces of tile material still adhered to the SIP at the aft end of the tile cavity. However, the SIP and adhesive at the forward end of the cavity was relatively unaffected and even exhibited signs the tile had not been bonded over the entire surface. The tile immediately aft of this location exhibited impact damage (probably from the missing tile falling aft) and slumping of one corner exposed to the re-entry airflow heating. A tile on the Orbiter aft fuselage adjacent to the damage location on the elevon also showed impact damage. The side of the elevon is relatively sheltered and an impact by debris traveling from another location is believed to be unlikely. Further investigation concluded the tile had not been bonded properly when installed at Palmdale.

Close inspection after landing in the OPF revealed a damage site to left wing RCC panel #8. The damage site measured approximately 1.5 inches long by 0.5-inches wide by 0.25 inches deep with a "pink" residue in the cavity. The residue was sampled for lab analysis, but no "foreign" substance was identified in the sample. Micrometeorite impact specialists at JSC determined the damage was not the result of a high velocity impact typically caused by on-orbit debris. Since pre-launch inspection revealed no damage prior to launch and no debris impacts were observed in launch films, the cause of the low velocity impact has not been determined.

The Orbiter TPS sustained a total of 153 hits, of which 24 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 (Reference Figures 1-4. Figure 5 shows fleet averages prior to the loss of ET thrust panel foam starting at STS-86).

The following table breaks down the STS-103 Orbiter debris damage hits by area:

	<u>HITS > 1"</u>	<u>TOTAL HITS</u>
Lower surface	13	84
Upper surface	1	9
Window Area	9	43
Right side	1	5
Left side	0	2
Right OMS Pod	0	4
Left OMS Pod	0	6
TOTALS	24	153

The Orbiter lower surface sustained 84 total hits, of which 13 had a major dimension of 1-inch or larger. Approximately half of this damage was concentrated from the nose gear to the main landing gear wheel wells on both left and right chines following a similar location/damage pattern documented on STS-86, -87, -89, -90, -91, -95, -88, -96, and -93.

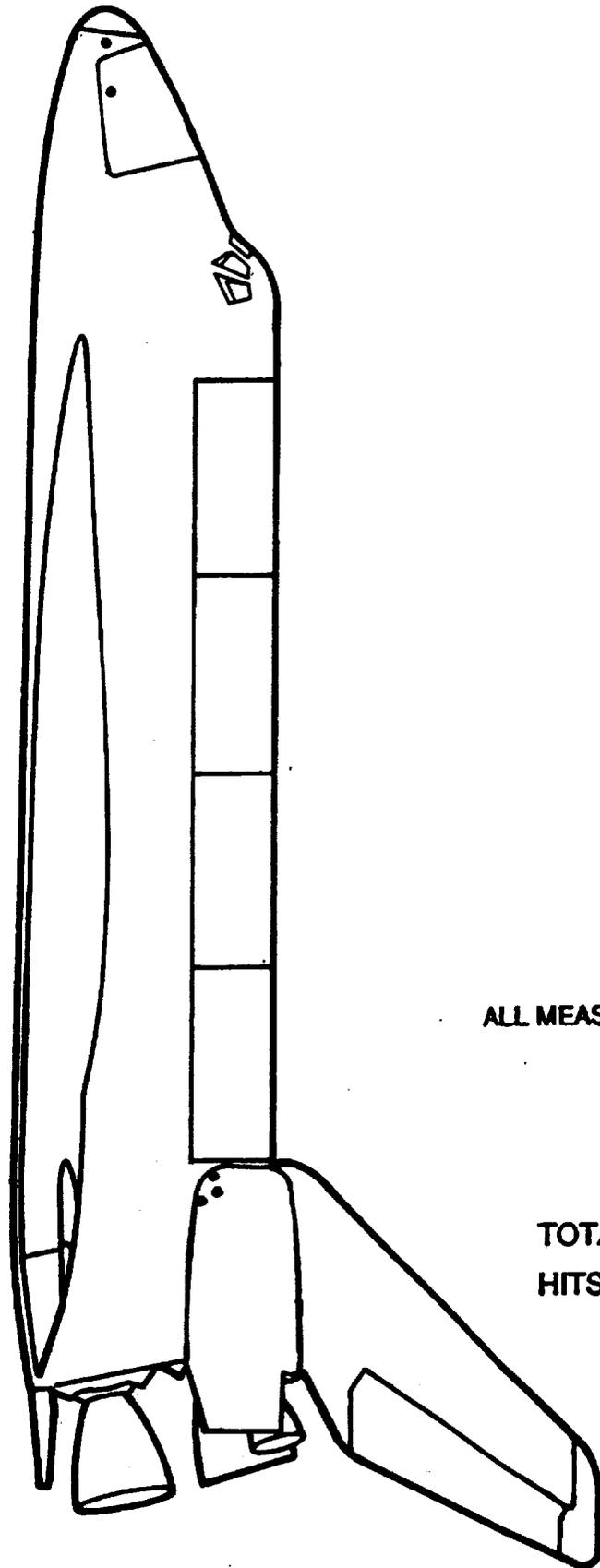
Typical amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in good condition though the material was torn/frayed at the 12:00 o'clock position on SSME #1 and the 9:00-12:00 position on SSME #3.

No major tile damage occurred on the leading edges of the OMS pods and vertical stabilizer.

Damage sites on the window perimeter tiles were greater than usual in both quantity and size. There were 43 hits with 9 larger than 1-inch in the vicinity of the windows. This damage may be attributed to impacts from FRCS thruster paper covers and RTV adhesive. The six damage sites in white tiles just forward of window #4 reported in the preliminary assessment were old and had occurred on a previous flight. Hazing and streaking of forward-facing Orbiter windows was moderate.

The post landing walkdown of Runway 33 was performed immediately after landing. No debris concerns were identified. All components of the drag chute were recovered and appeared to have functioned normally. Both reefing line cutter pyrotechnic devices were expended.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were significantly reduced compared to the number and size of damage sites on previous missions since STS-86. IFA STS-87-T-01 documenting loss of ET foam will be closed. A Technical Directive-type plan to test and apply a replacement TPS will be presented to the Program by the External Tank Project.



ALL MEASUREMENTS IN INCHES

TOTAL HITS = 5

HITS > 1 INCH = 0

Figure 2: Orbiter Left Side Debris Damage Map

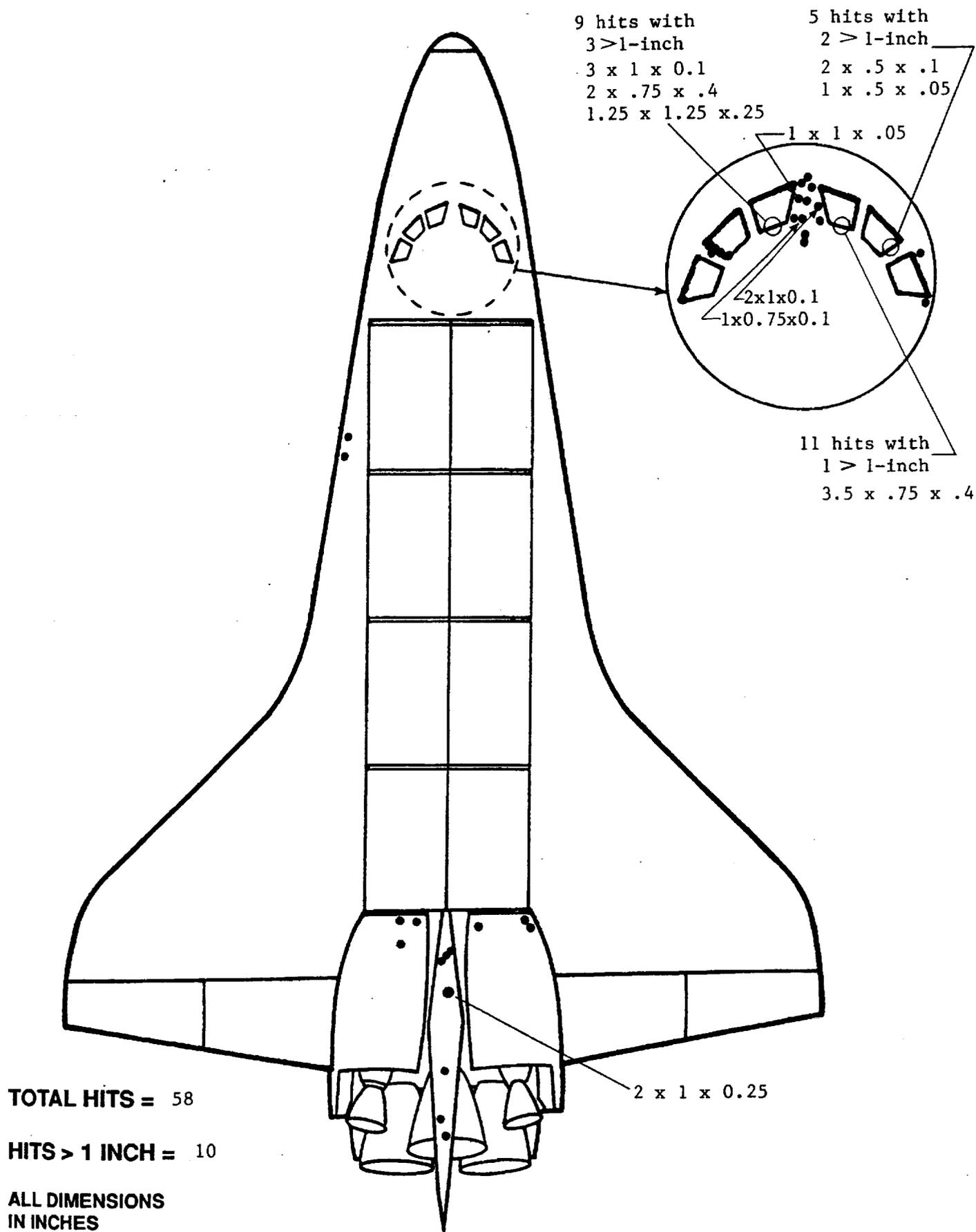


Figure 4: Orbiter Upper Surface Debris Damage Map

Orbiter Post Flight Debris Damage Lower Surface Total Hits

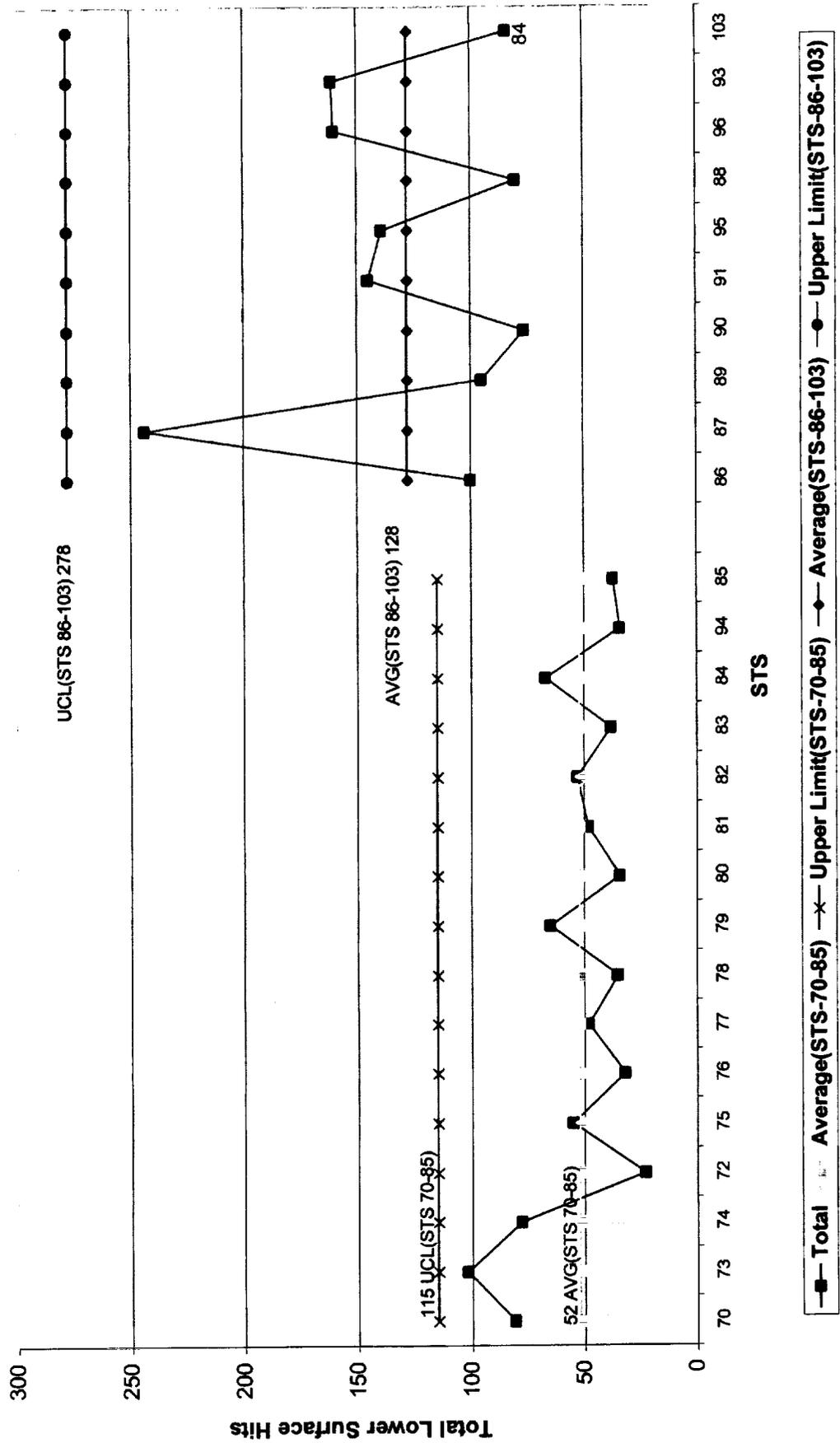


Figure 6: Control Limits for Lower Surface Total Hits

Orbiter Post Flight Debris Damage Lower Surface Hits >1 inch

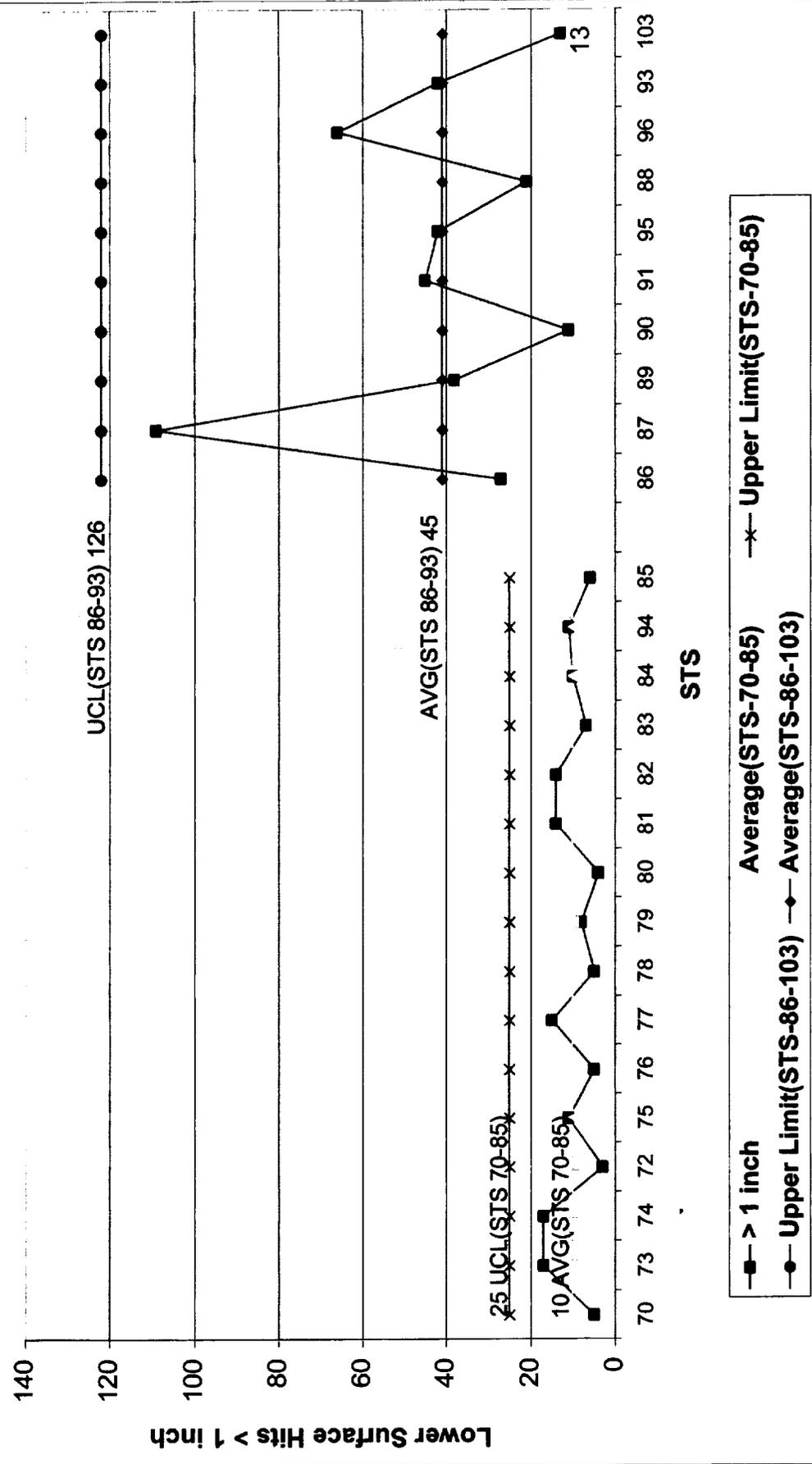


Figure 7: Control Limits for Lower Surface Hits > 1-inch

Orbiter Post Flight Debris Damage Total Hits

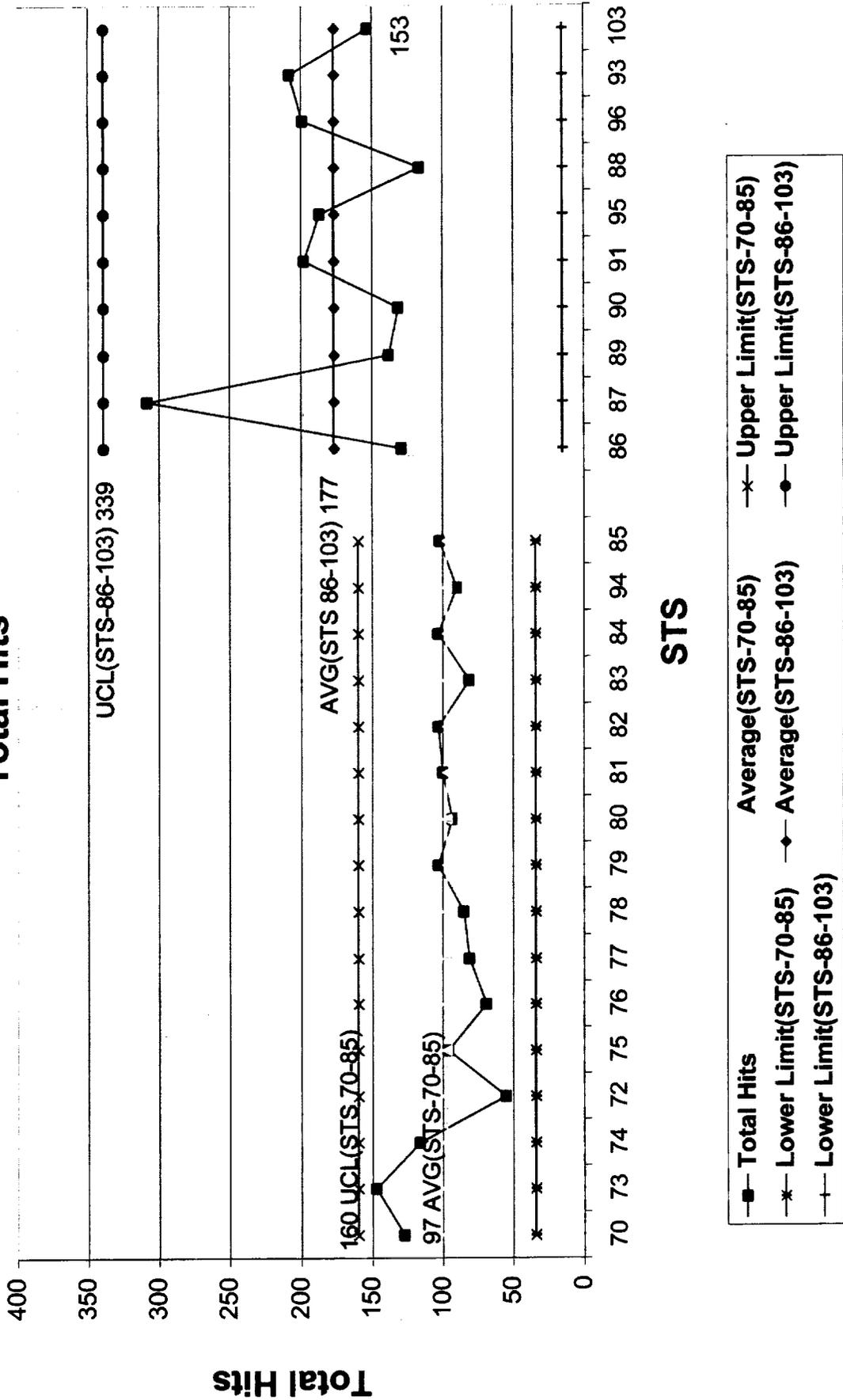


Figure 8: Control Limits for Total Hits

Orbiter Post Flight Debris Damage Total Hits > 1 Inch

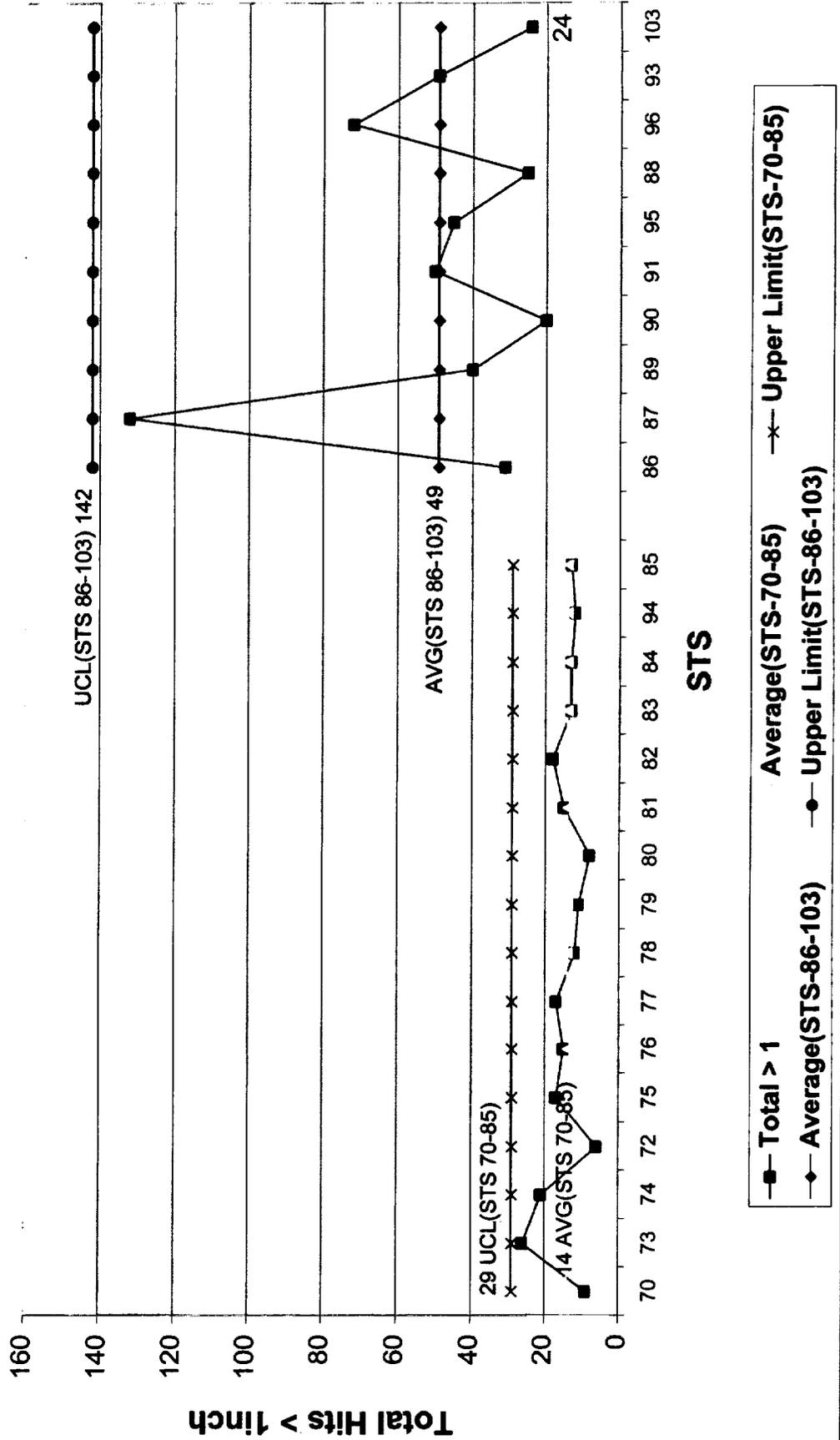


Figure 9: Control Limits for Total Hits > 1-inch

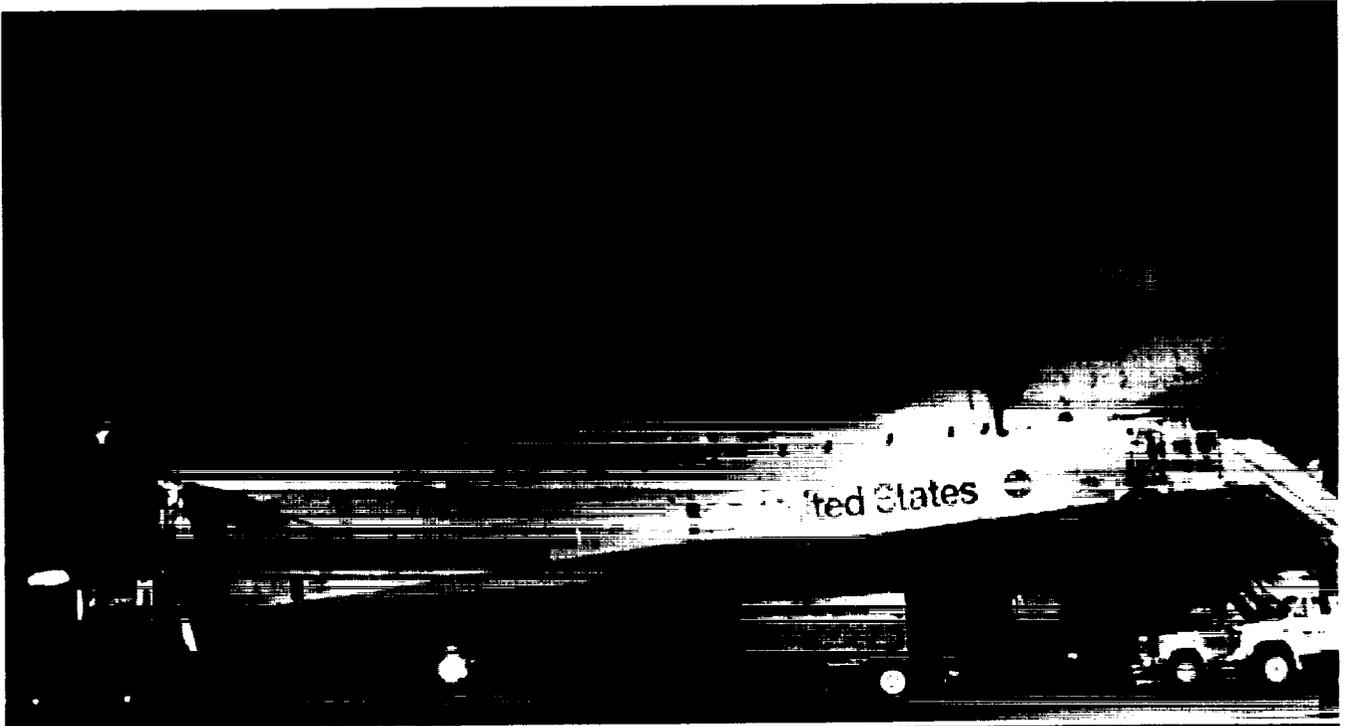


Photo 15: Overall View of Orbiter Sides

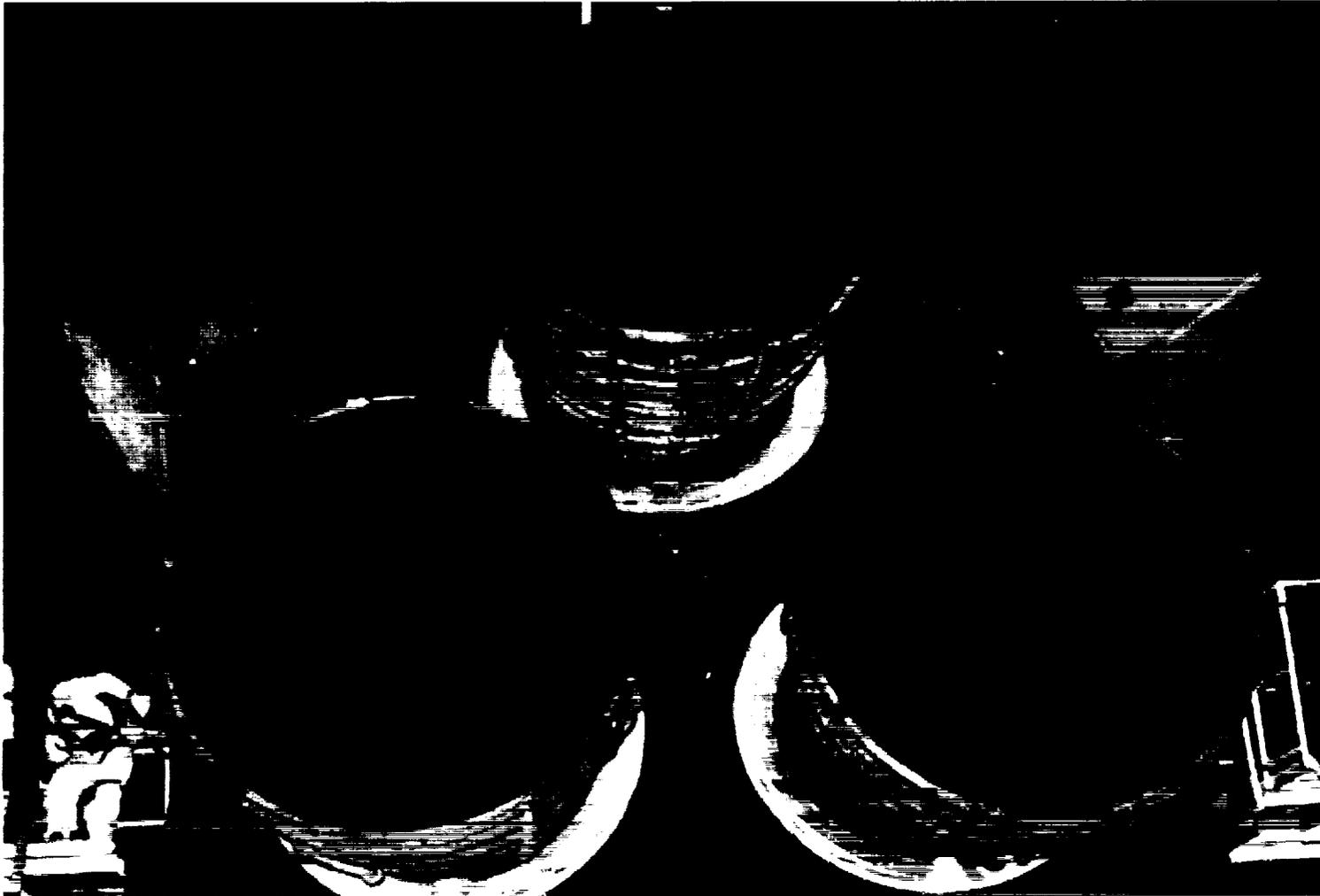


Photo 16: SSME's and Base Heat Shield

Typical amounts of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in good condition though the material was torn/frayed at the 12:00 o'clock position on SSME #1 and the 9:00-12:00 position on SSME #3.

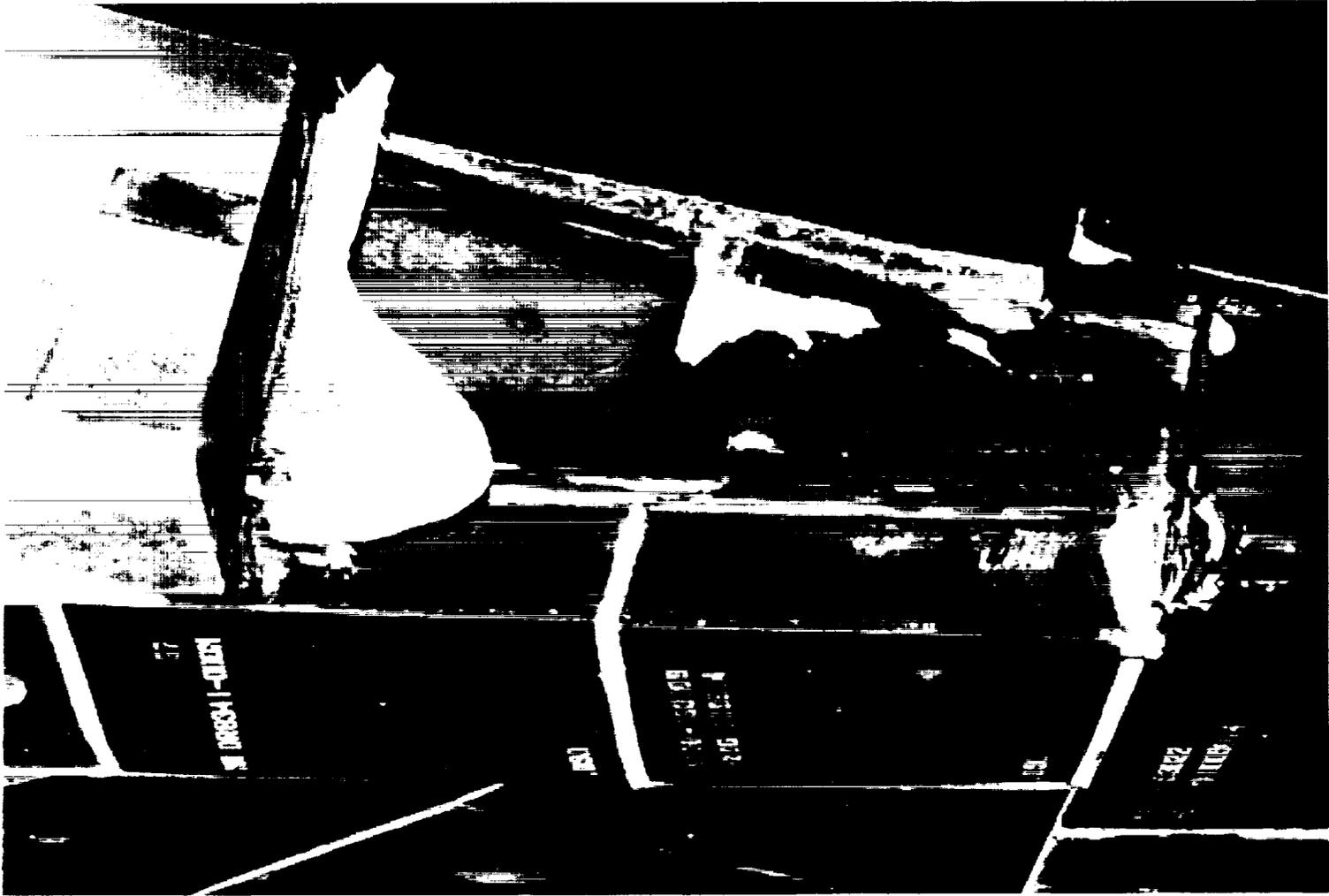


Photo 17: Tile Missing from Right Inboard Elevon

A black tile from the right inboard elevon, -Y side edge, was missing. The remaining adhesive and SIP was charred, but no burn through of the substrate was detected. Some thin pieces of tile material still adhered to the SIP at the aft end of the tile cavity. However, the SIP and adhesive at the forward end of the cavity was relatively unaffected and even exhibited signs the tile had not been bonded over the entire surface. Further investigation concluded the tile had not been bonded properly when installed at Palmdale.

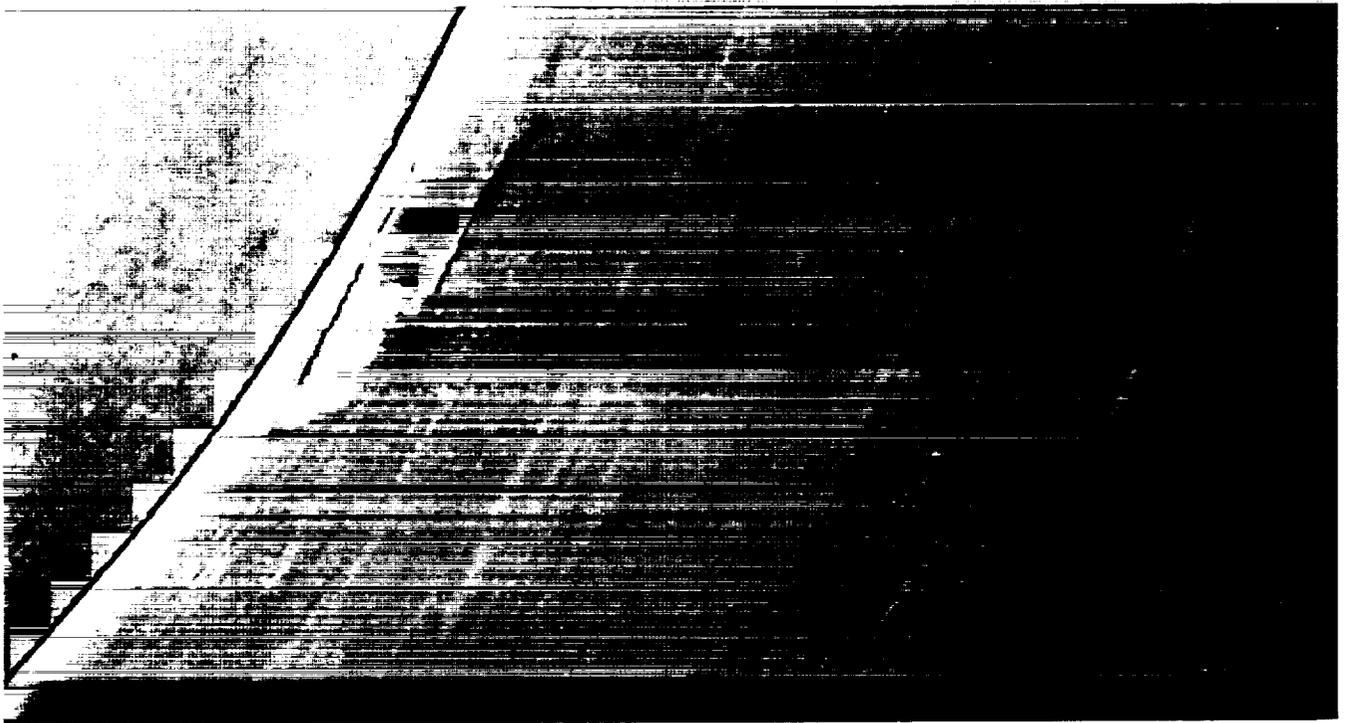
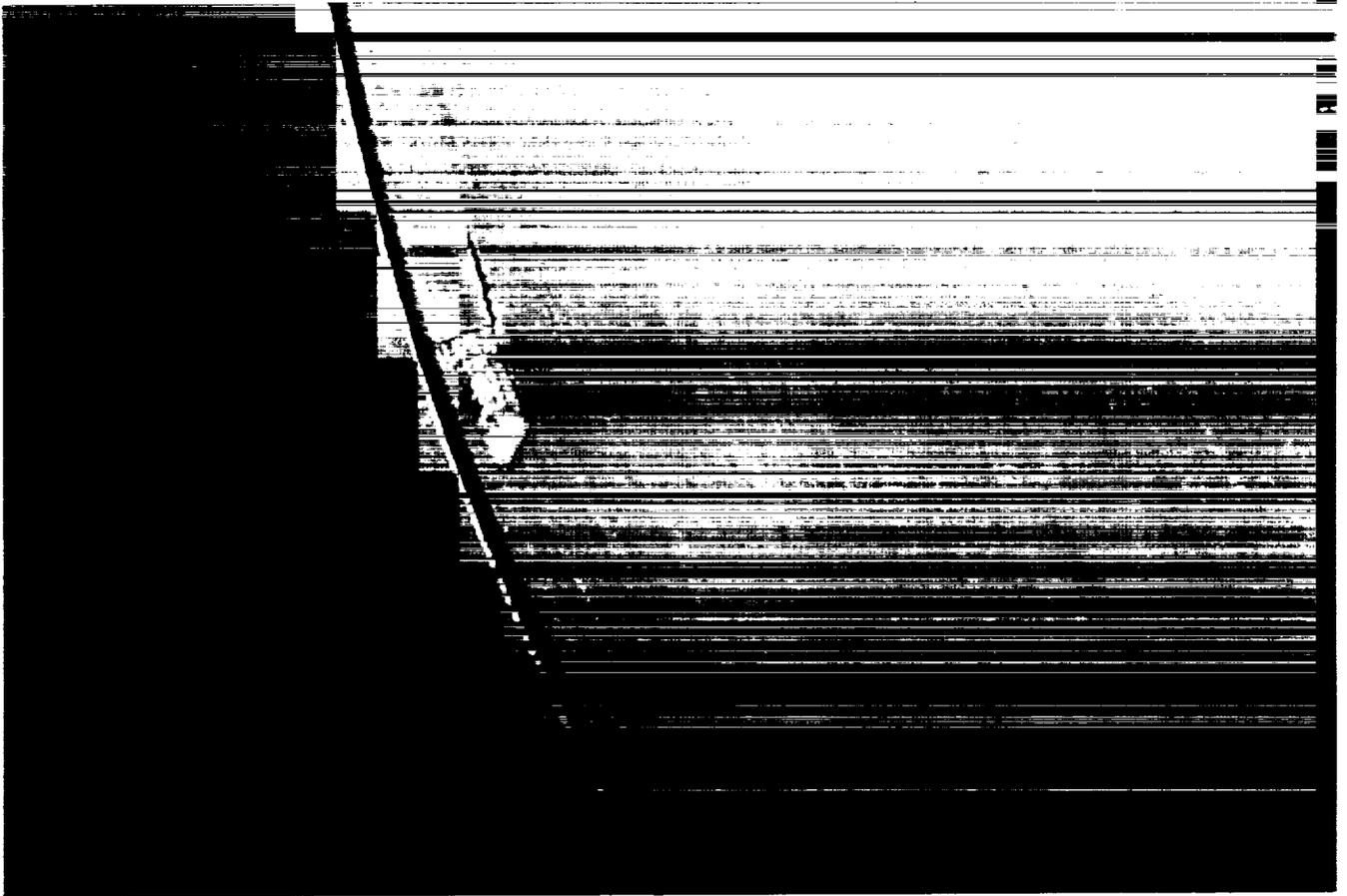


Photo 18: Damage to Left Wing RCC Panel

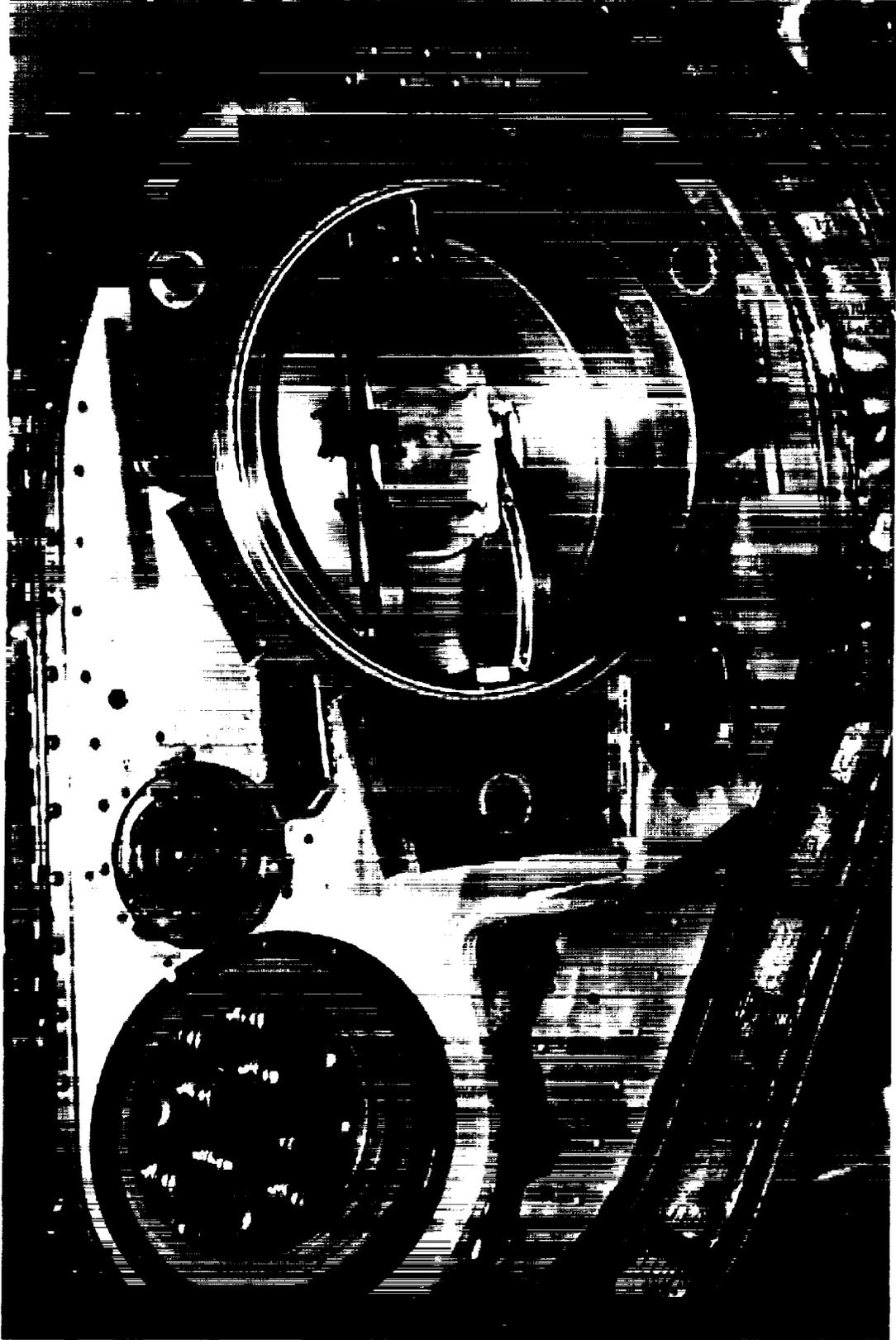


Photo 19: LO2 ET/ORB Umbilical

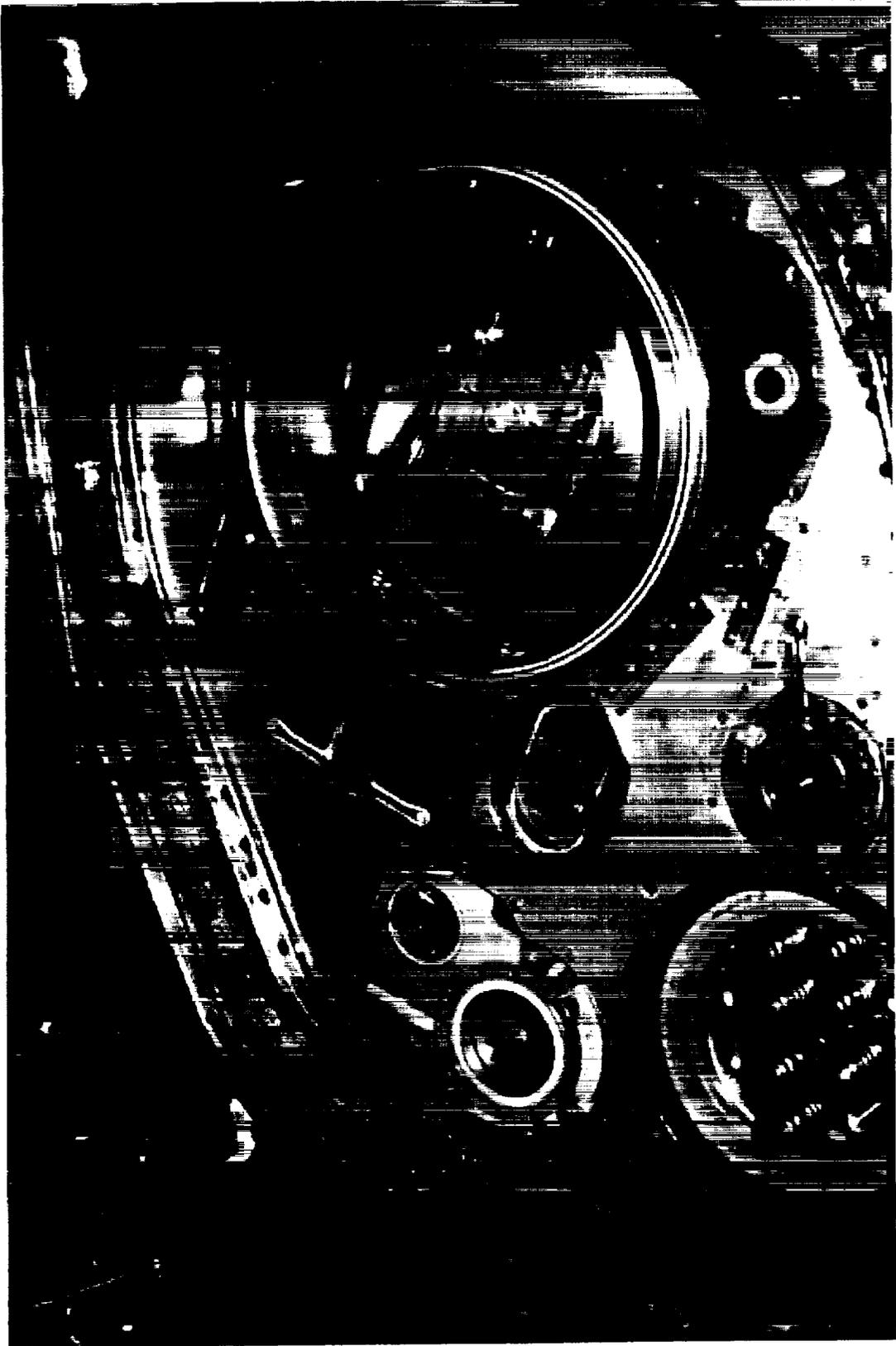


Photo 20: LH2 ET/ORB Umbilical

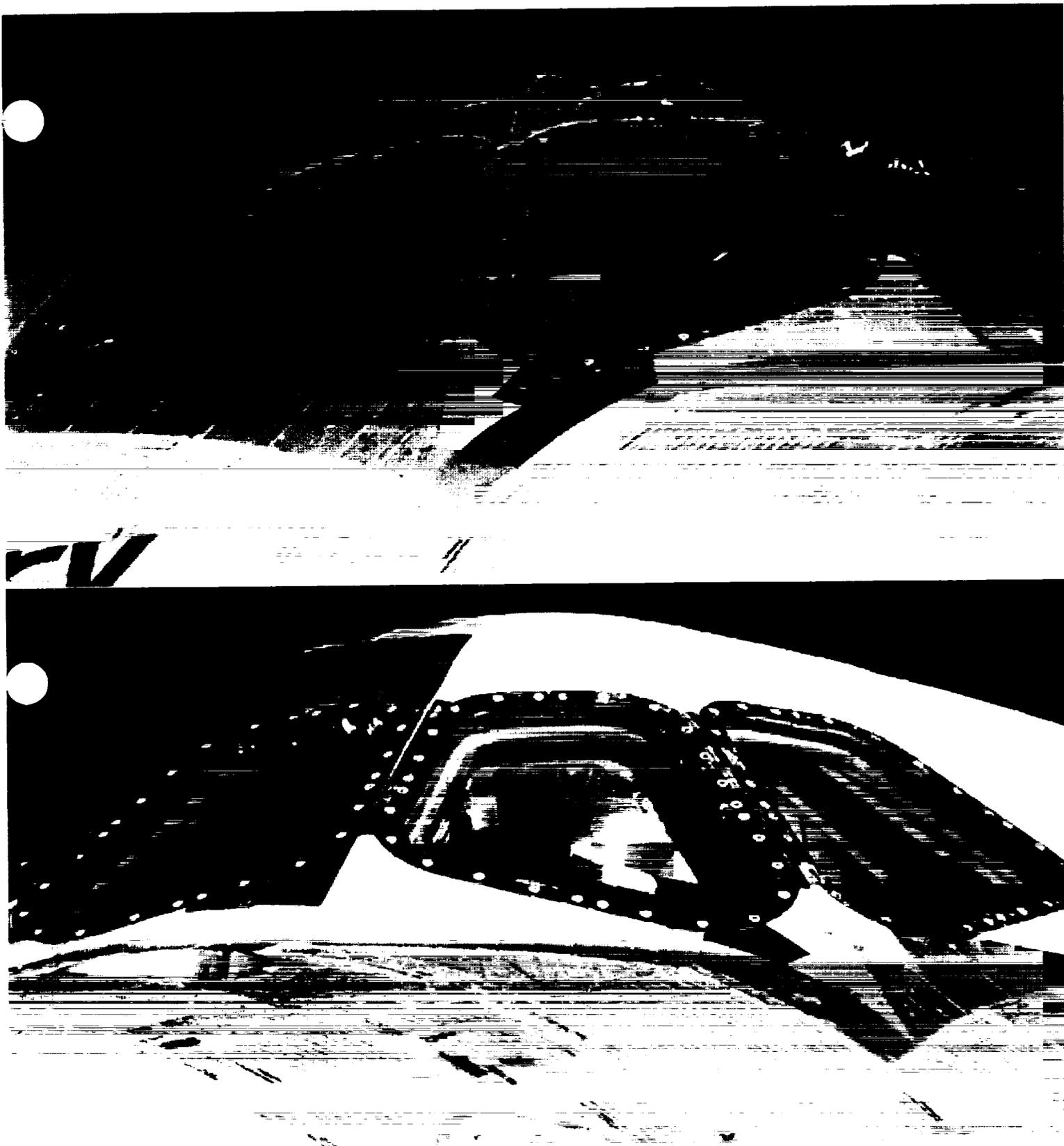


Photo 21: Windows

Damage sites on the window perimeter tiles were greater than usual in both quantity and size. There were 43 hits with 9 larger than 1-inch in the vicinity of the windows. This damage may be attributed to impacts from FRCS thruster paper covers and RTV adhesive. Hazing and streaking of forward-facing Orbiter windows was moderate.

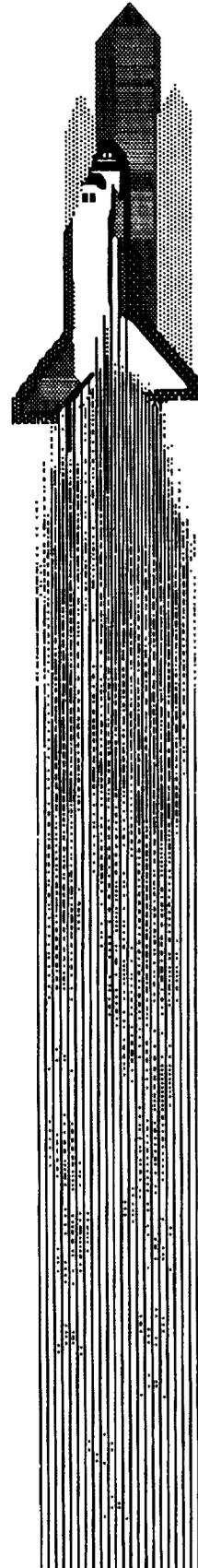
APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY



Space Science Branch

STS-103 Summary of Significant Events

January 24, 2000





Space Shuttle

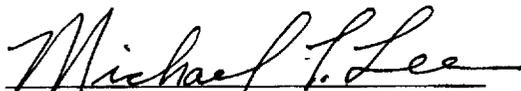
STS-103 Summary of Significant Events

Project Work Order - SN3CS

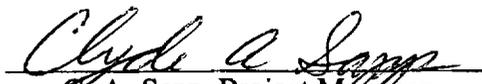
Approved By

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Space Science Branch


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

Prepared By

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

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Figure 2.2 (B)	Flare Seen in SSME Exhaust Plume During Ascent.....	A11
Figure 2.3.1	Orange Vapor Seen During SSME Ignition	A13
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STS-103 (OV-103) Film/Video Screening and Timing Summary

resolution at the greater distances beyond 52 seconds is not good enough to verify the presence of the tile with a reliable level of confidence.)

A sink rate analysis of the STS-103 main landing gear was not performed for the main gear touchdown. After a review of the landing film and video, it was concluded that the imagery quality is either too dark or at too oblique of an angle to accurately calculate a landing sink rate for STS-103 using our current procedures. We are currently working on developing new techniques for performing this calculation for similar conditions as that seen in this mission.

The drag chute deploy sequence appeared normal on the landing imagery.

According to the pre-mission agreement, the STS-103 landing films were not screened due to budgetary constraints.

Summary of Significant Events

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

Multiple pieces of ice debris and vapors were seen falling from the ET/Orbiter umbilicals along the body flap during SSME ignition. No damage to the launch vehicle was noted. (Cameras E1, E4, E5, E31, E34, E36, E52)

Typical of previous missions, a small amount of ice debris was seen falling aft along the External Tank during the retraction of the GH2 vent arm at 00:50:00.029 UTC. (Cameras E33, E34)

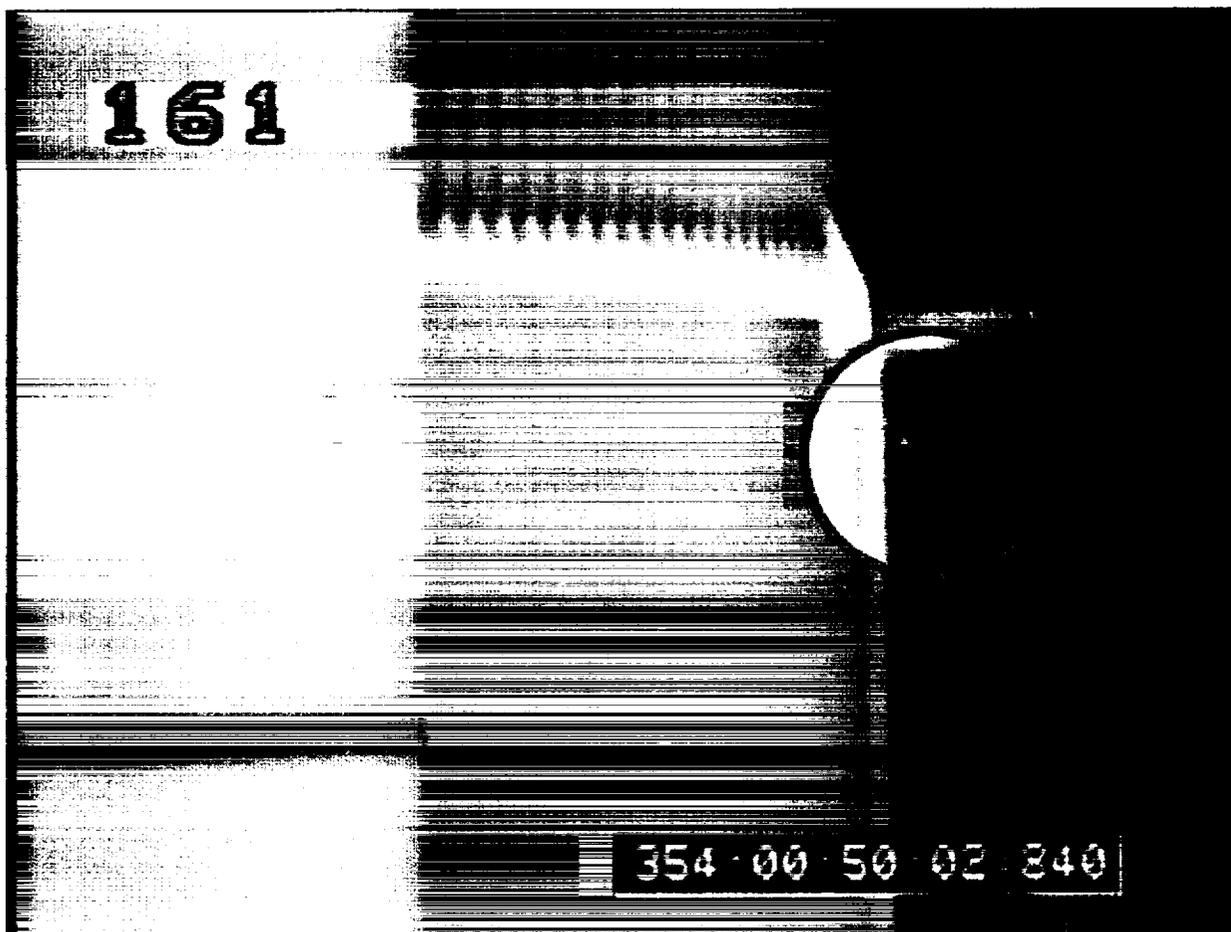


Figure 2.1 Debris Seen Falling Along Orbiter Fuselage

Two small pieces of white-colored debris were seen falling aft of the ET/Orbiter forward attach and along the Orbiter fuselage tiles during liftoff (00:50:02.840 UTC). This debris was not seen to contact the launch vehicle. (Camera OTV161) See Figure 2.1.

A single piece of SRB throat plug material and a single piece of water baffle material (debris) were seen beneath the Orbiter's right wing during liftoff (00:50:02.149 UTC) on the Camera E1 film. This debris was first seen on the north side of the RSRB and appeared to be traveling in a south-eastward direction. Additional pieces of SRB throat plug debris were seen near the base of the LSRB at liftoff on the Camera E4 view.

Summary of Significant Events

(Cameras E1, E4) Four light-colored pieces of debris (probably SRB throat plug material) were seen north of the MLP during liftoff (00:50:01.99 UTC) (Cameras KTV4, ET213).

2.2 DEBRIS DURING ASCENT

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



Figure 2.2 (A) Debris Seen Aft of Orbiter During Ascent

Multiple debris typical of most night launches were seen aft of the launch vehicle during ascent. Pieces of ET/Orbiter umbilical ice debris and RCS paper debris (too numerous to count) were seen near the SSME rims, near the vertical stabilizer, and aft of the vehicle from liftoff, through the roll maneuver, and beyond. (Cameras E207, E212, E222, E223, E224) See Figure 2.2 (A).

A light-colored object was seen aft of the vertical stabilizer during the roll maneuver and appeared to be moving perpendicular to the direction of the vehicle flight path. This

Summary of Significant Events

object may have possibly been a bird located close to the camera (00:50:09.6 UTC). (Camera OTV141)

Several large pieces of ET umbilical well purge barrier debris were seen near the ET aft dome during the roll maneuver. A partially detached piece of ET umbilical well purge barrier material was seen flapping in the slip stream during ascent. Debris, probably ET umbilical purge barrier material, was seen near the ET aft dome at 00:50:14.44 and 00:50:18.56 UTC. (Cameras ET207, E207)

Multiple pieces of ET/Orbiter umbilical well ice and RCS paper debris were seen near the Orbiter during and after the roll maneuver (00:50:09 through 00:50:40 UTC). (Cameras KTV13, ET207, ET208)

Although less than previous missions, debris was seen falling along the SRB exhaust plume during ascent (an example is debris seen at 00:50:32.117 UTC). (Cameras E207, E224)

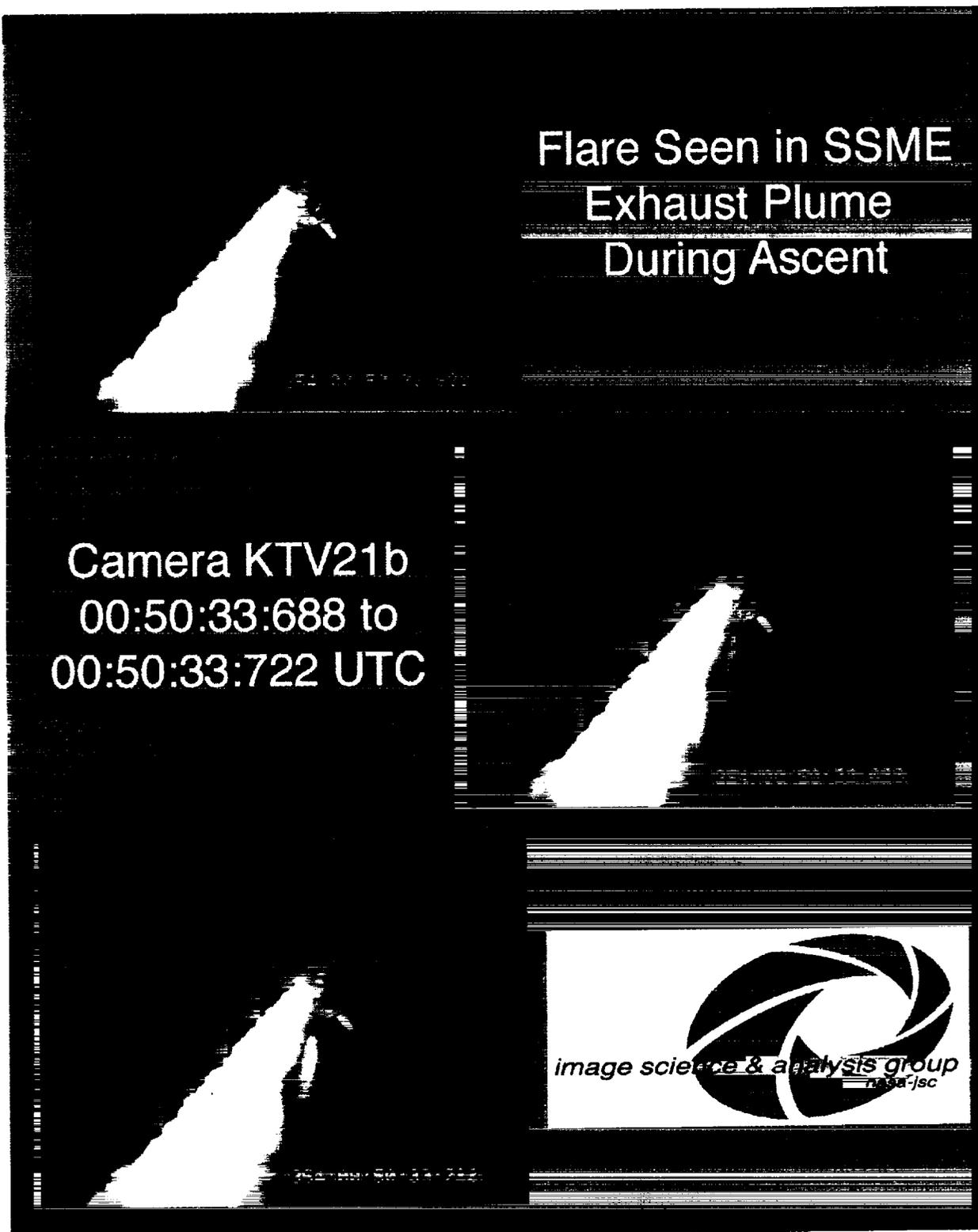


Figure 2.2 (B) Flare Seen in SSME Exhaust Plume During Ascent

Summary of Significant Events

Several orange-colored flares (debris induced) were seen in the SSME exhaust plume during ascent (00:50:33.720, 00:50:33.794, and 00:50:38.678 UTC). A single piece of light-colored debris was seen to contact the SSME exhaust plume resulting in a large appearing orange-colored flare at 00:50:33.7 UTC. The origin of this debris was not seen. A smaller flare was seen in the SSME exhaust plume at 00:50:26.5 UTC. (Cameras E207, E212, E222, E223, KTV21B, ET204, ET212, KTV4B) See Figure 2.2 (B).

A single, large, light-colored piece of debris was seen falling aft between the body flap and SSMEs 2 and 3 during ascent (approximately 62 seconds MET). (Camera E212)

A single piece of debris was seen exiting the exhaust plume and appeared to pass near the vertical stabilizer because of the camera perspective (approximately 73 seconds MET). (Camera E207)

Multiple pieces of debris were seen falling along the SRB exhaust plumes during ascent (00:50:48.4, 00:51:01.9, 00:51:09.9, 00:51:11.7, 00:51:15.7, 00:52:00.8 and 00:52:01.16 UTC). A light-colored object seen falling from the top of the KTV4B view along the launch vehicle and aft along the SRB exhaust plume was probably a bird close to the camera (00:50:31.4 UTC). (Cameras KTV4B, KTV5, KTV13, ET207)

Summary of Significant Events

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

2.3.1 Mobile Launch Platform Events

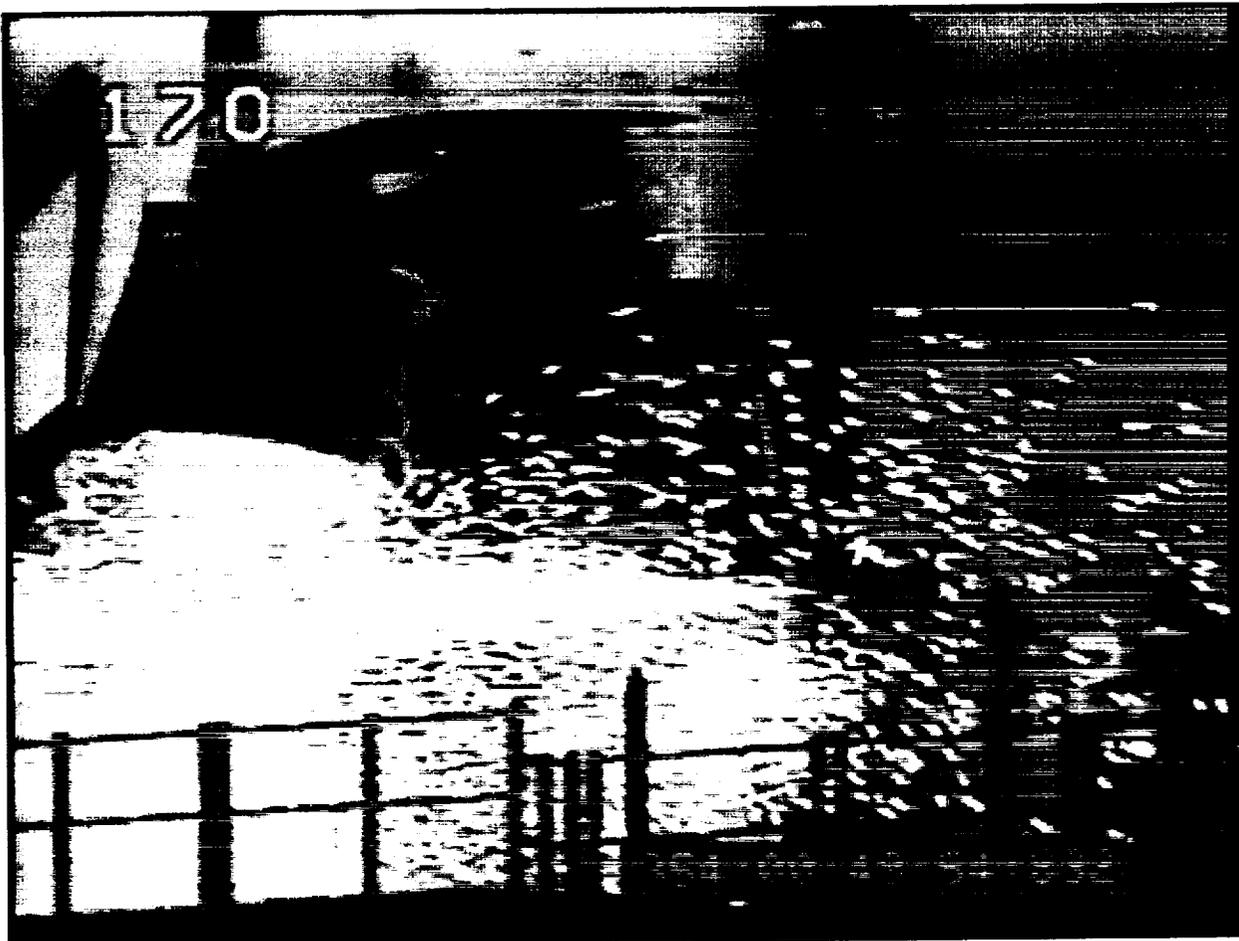


Figure 2.3.1 Orange Vapor Seen During SSME Ignition

Similar to the STS-93 night launch, an extensive amount of orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims and near the base of the vertical stabilizer during SSME ignition. Orange vapors are typically seen on night launches, but possibly not to the extent seen on the past two missions. (Cameras OTV170, OTV171, E2, E4, E5, E19, E20, E36)

The SSME ignition appeared normal on the high-speed engineering films. The SSME Mach diamonds appeared to form in the expected sequence (3, 2, 1). The times for the Mach diamond formation given in Table 2.3.1 are from camera film E19.

Summary of Significant Events

SSME	TIME (UTC)
SSME #3	00:49:56.751 UTC
SSME #2	00:49:56.801 UTC
SSME #1	00:49:56.968 UTC

Table 2.3.1 SSME Mach Diamond Formation Times

Several light orange-colored flashes were seen in the SSME #1 exhaust plume at or near the time of liftoff (00:49:59.413 through 00:50:00.175 UTC). (Camera E2)

Small areas of tile surface coating material erosion were seen during SSME ignition on the base of the left and right RCS stingers, on the base heat shield outboard of SSME #1, and inboard and outboard of SSME #3. (Cameras OTV150 E17, E18, E19, E20)

No indication of holddown post (HDP) stud hang-ups were seen. However, camera E7 viewing HDP post M-4 was not provided. (Boeing reported that acceleration data indicated a possible stud hang-up at HDP #4). No debris was seen falling from the HDP stud holes. PIC firing was timed at 00:50:00.017 UTC on HDP M-1 on camera film E9.

2.4 ASCENT EVENTS

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

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK (ET-99)

2.5.1 Analysis of the Umbilical Well Camera Films

Three umbilical well cameras (one 35mm and two 16mm cameras) flew on OV-103 during STS-103. The +X translation maneuver was not performed on STS-103 due to darkness. Timing data was present on both of the 16mm umbilical well camera films.

16mm Umbilical Well Camera Films

The LSRB separation appeared normal on the 16mm umbilical well camera films. Numerous light-colored pieces of debris (insulation) and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing prior to SRB separation were seen. Numerous irregular-shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. A long piece of string-like material was

Summary of Significant Events

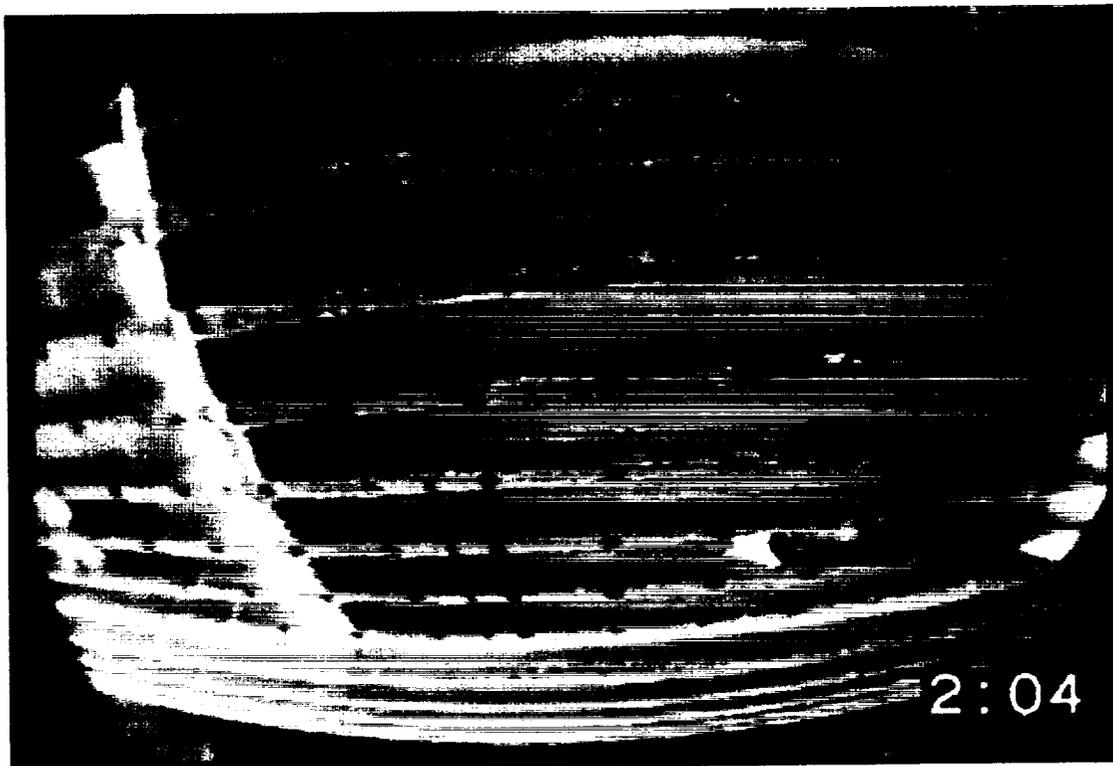


Figure 2.6 (A) LSRB View of ET Thrust Panel

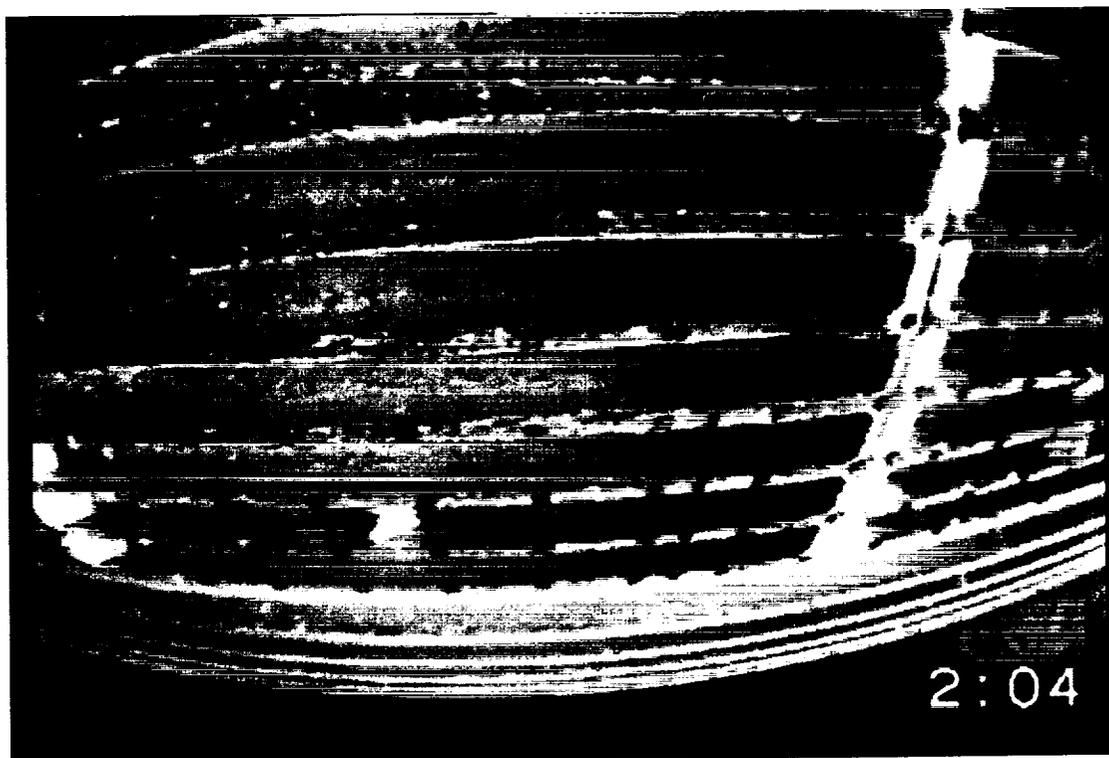


Figure 2.6 (B) RSRB View of ET Thrust Panel

Summary of Significant Events

2.7 OTHER

2.7.1 Normal Events

Normal events observed included:

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

2.7.2 Normal Pad Events

Normal pad events observed included:

- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- GH2 vent arm retraction
- TSM T-0 umbilical operations
- LH2 and LO2 TSM door closures

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY



Space Shuttle Mission STS-103

Engineering Photographic Analysis Summary Report Marshall Space Flight Center

Prepared: January 20, 2000

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Huntsville, AL 35812*

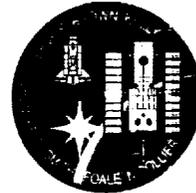
STS-103
Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

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1. STS-103 Engineering Photographic Analysis Mission

The launch of space shuttle mission STS-103, the twenty-seventh flight of the Orbiter Discovery occurred December 19, 1999, at approximately 6:50 PM Central Standard Time from launch complex 39B, Kennedy Space Center (KSC), Florida. Launch time was reported as 99:354:00:49:59.986 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.



Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle. Additional information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

<http://photo4.msfc.nasa.gov/STS/sts103/sts103.html>.

2. Photographic Coverage

Sixty-two engineering photographic products consisting of launch video, ground-based engineering films and onboard film and video were received and reviewed at MSFC. Although atmospheric conditions were favorable, the night launch only allowed coverage of areas artificially illuminated by xenon lights or plumes. Most cameras were fully functional and good coverage of the launch was obtained. No film from cameras E7 and E63 was received. Moisture in the camera housing degraded the images obtained from cameras E52 and E54. Camera coverage received at MSFC for STS-103 is illustrated in the following table.

Table 1 . Camera Coverage

Camera Location	16mm	35mm	Video
MLP	18	0	4
FSS	5	0	3
Perimeter	0	4	5
Tracking	0	10	11
Onboard	2	0	0
Totals	25	14	23

The Photographic Acquisition Document Data (PADD) and information regarding individual camera status and assessments may be found on the website.

3. Individual Camera Assessments:

Notable assessments for individual cameras are listed below. The complete assessments for all individual cameras for flight STS-103 may be found on the website.

3.1 Video Camera Assessments

TV4B - Debris induced streak in SSME plume observed at 354:00:50:33.7 UTC. Possible engine produced streak on SSME #1 at 354:00:50:33.7 UTC.

TV7B - Pad debris was noted rising and falling.

ET204 -SRB separation: 354:00:52:04.6 UTC. Debris induced streak in SSME plume at 354:00:50:33.789 UTC.

ET207 -SRB separation: 354:00:52:04.6 UTC.

ET212 -SRB separation: 354:00:52:04.6 UTC. Large debris induced streak observed at 354:00:50:33.77 UTC.

- ET213 - Pad debris north of pad observed travelling away from the vehicle at 354:00:50:02.225 UTC. Debris induced streak in SSME plume at 354:00:50:33.790 UTC. Camera loses focus before SRB separation.
- OTV149 - Unknown highlighted reflection area on cable observed at 354:00:50:00.365 UTC.
- OTV151 - Mach diamond formation in 3-2-1 order.
- OTV161 - Ice from the LOX feedline, falling between Orbiter and ET, appears not to strike the vehicle.
- OTV171 - Free hydrogen burn noted striking and flowing around drag chute door.

3.2 Film Camera Assessments

- E2 - SSME plume streaking observed.
- E8 - Image too dark for PIC firing time.
- E9 - PIC firing time 354:00:50:00.020 UTC.
- E12 - PIC firing time 354:00:50:00.020 UTC.
- E13 - PIC firing time 354:00:50:00.019 UTC.
- E17 - Several base heat shield tiles area chipped.
- E18 - Several chipped base heat shield tiles are noted.
- E19 - Faint plume streaking observed on all three engines prior to lift-off. Thirteen streaks observed on SSME #1, twelve streaks on SSME #2, and two streaks on SSME #3.
- E20 - Ice on SSME #2 eyelid observed.
- E33 - Notable ice/frost from GUCP.
- E40 - Faint streak observed in SSME plume. Timing block appears loose in camera.
- E52 - Timing display malfunction. Prior to liftoff, light sources have halos, probably caused by moisture in camera housing. Film unusable after liftoff.
- E54 - Foggy appearance of image while orbiter on launch pad, becoming overexposed during ascent. Film useless for engineering evaluation.
- E57 - Two SSME plume streaks, Engine #1, noted at 354:00:50:05.798 and 354:00:50:06.229 UTC.
- E213 - Debris object, source unknown, falls along the LOX feedline between ET and Orbiter. Film ends before Orbiter clears tower.
- E222 - Large debris induced streak in SSME plume observed at 354:00:50:33.783 UTC.
- FL101 - Apparent purge barrier material tape drifts through field of view prior to separation. Butcher paper attached to the LH2 feedline connect cable tray remains attached after separation. ET separation not visible due to dark exposure.

4. T-Zero Times

T-Zero times are determined from MLP 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.

Table 2. T-Zero Times

Holddown Post	Camera Position	Time (UTC)
M-1	E9	354:00:50:00.020
M-2	E8	Exposure dark
M-5	E12	354:00:50:00.020
M-6	E13	354:00:50:00.019

5. SRB Separation Timing

SRB separation time, as recorded by observations of the BSM combustion products from long-range camera E-204, occurred at approximately 354:00:52:04.668 UTC.

6. Observations:

6.1 Video Camera TV7B

Three debris particles were observed North of the MLP after SRB ignition. Typically, multiple pieces of water baffle material and SRB throat plug instafoam debris are noted during liftoff. Lighting conditions of night launches highlight this type of event

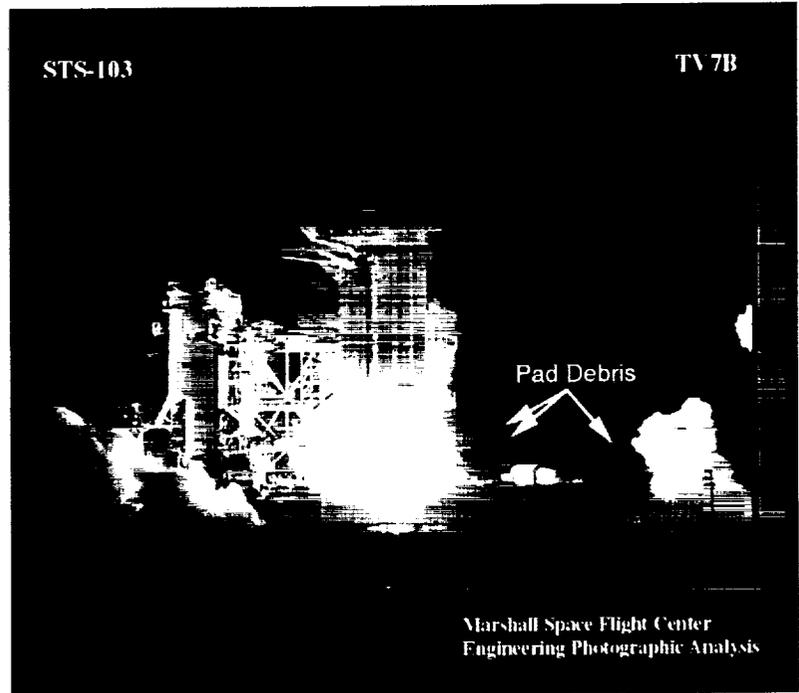


Figure 1 . Pad Debris Observation by Video Camera TV-7B

6.2 Film Camera E-57

Another view of pad debris observed during lift-off

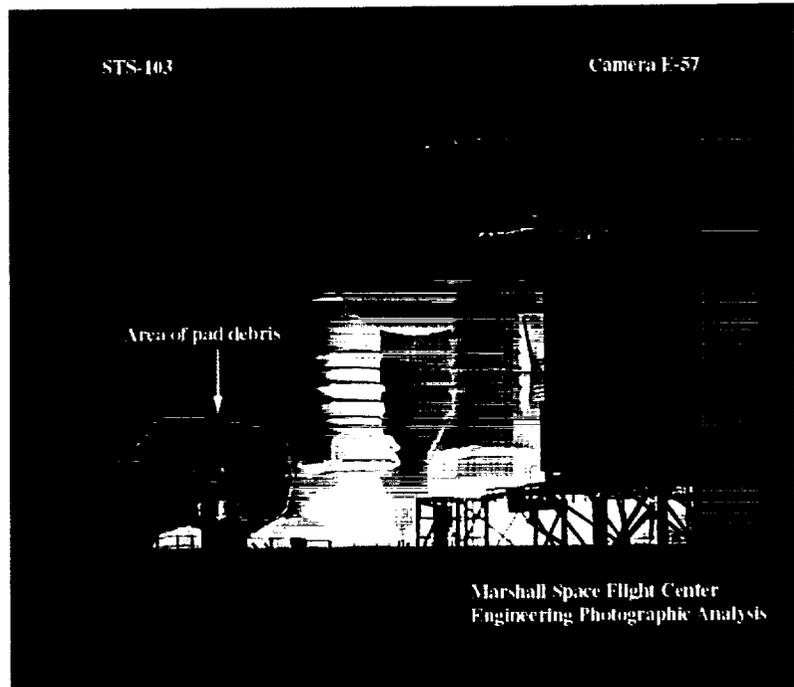


Figure 2. Pad Debris Observation by Film Camera E-57

6.3 Video Camera OTV-161

Ice from the LOX feedline falls between the Orbiter and External Tank. No damage to the orbiter tiles was noted.

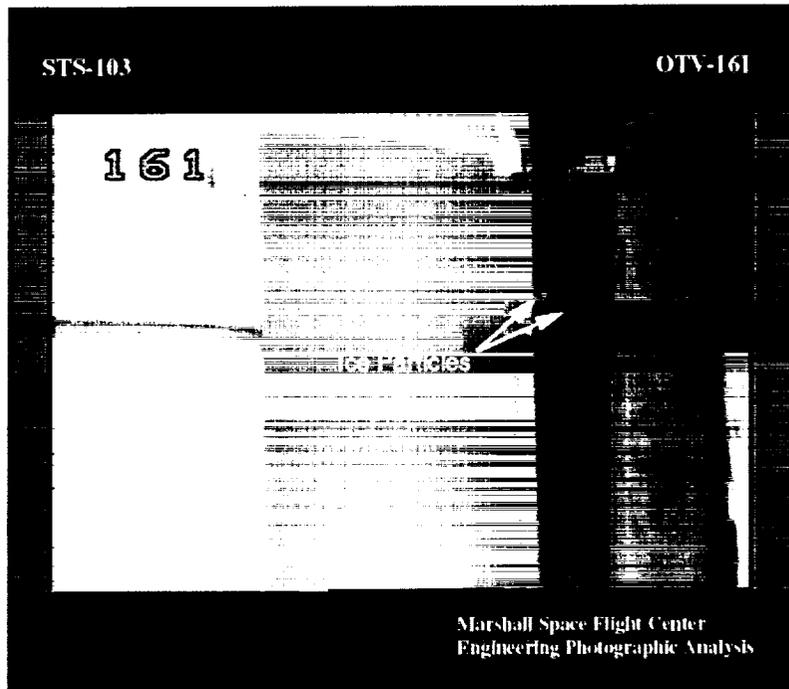


Figure 3. Ice Debris Observation by Video Camera OTV-161

6.4 Camera OTV - 171

Free burning hydrogen strikes and flows around the drag chute door prior to lift-off.



Figure 4. Hydrogen Burn Observation by OTV-171

6.5 Film Camera E-2

Several engine-produced streaks were observed in all three SSMEs after attaining mainstage and prior to lift-off. These streaks were faint and of short duration. A time-line of catalogued SSME streaks recorded by camera E-19 is provided in the following section. This view shows a streak recorded by camera E-2.

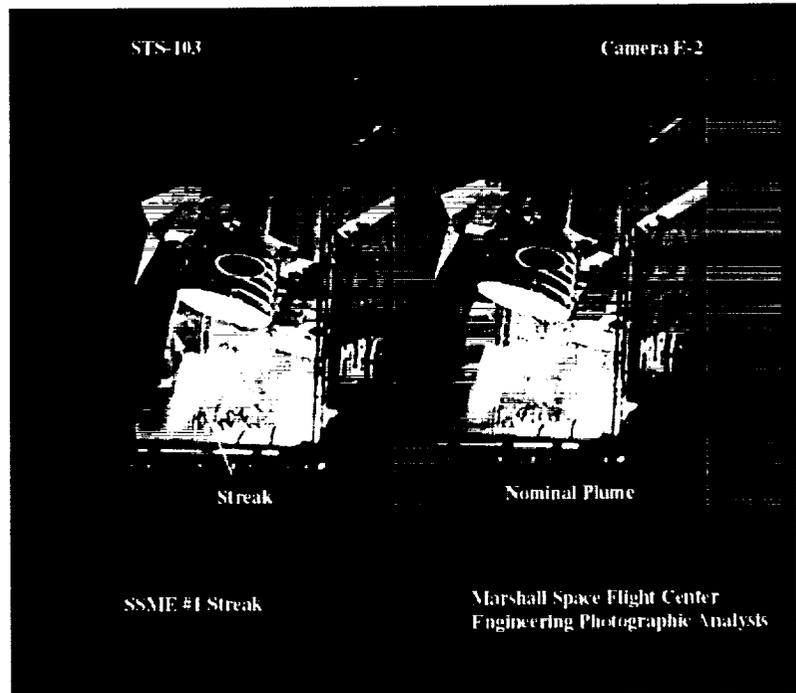


Figure 5. Engine Streaks Observed by Film Camera E-2

6.6 Film Camera E-57

An engine produced streak in SSME #1 was observed as the vehicle cleared the FSS.

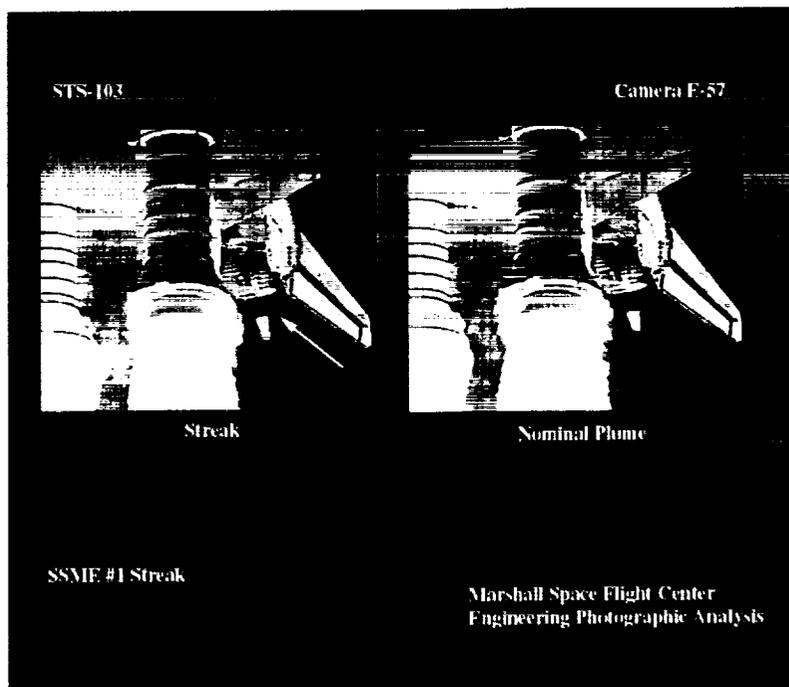


Figure 6. Engine Streak Observed by Camera E-57

6.7 Video Camera ET-204

A debris-induced streak was observed in the SSME plumes at time 354:00:50:33.789 UTC from video camera ET-204.

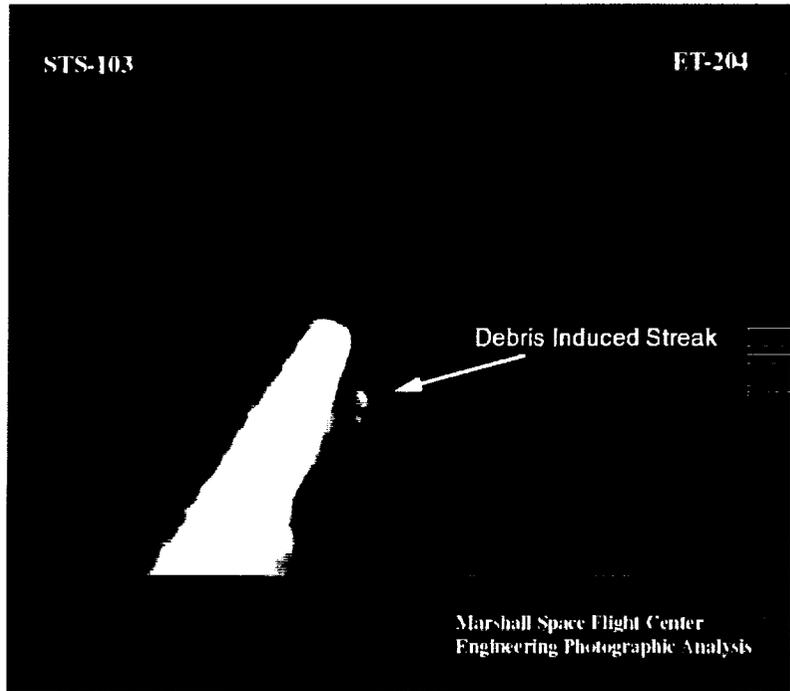


Figure 7. Debris Induced Streak Observed by ET-204

6.8 LH2 Umbilical Well Camera FL-101

This image depicts butcher paper, used as a hydrogen fire detector, attached to the LH2 disconnect cable tray. The butcher paper remained attached through SRB separation.

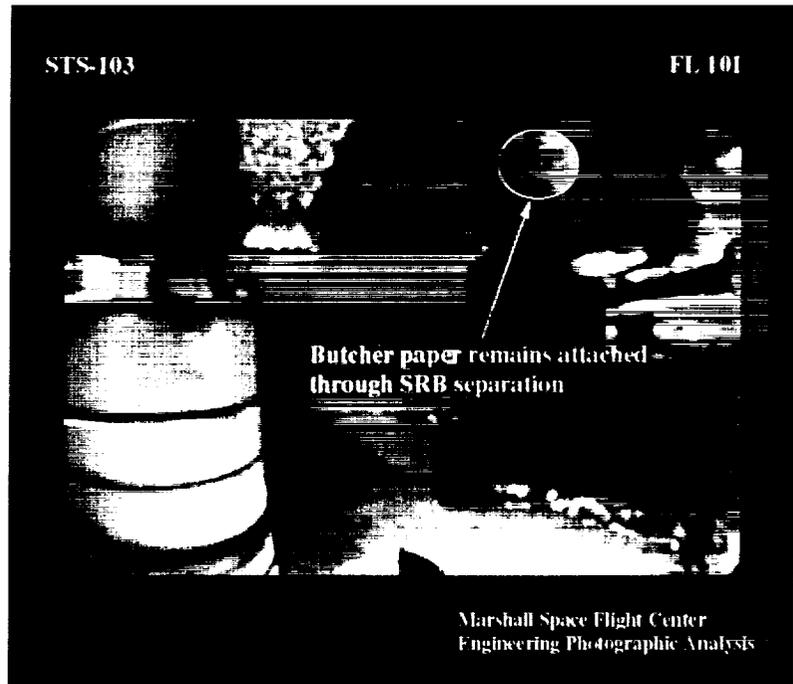


Figure 8. Butcher Paper Observed by FL-101

6.9 LH2 Umbilical Well Camera FL-101

A strand of purge barrier material tape was observed flapping prior to separation. The purge barrier tape also remained attached through SRB separation.

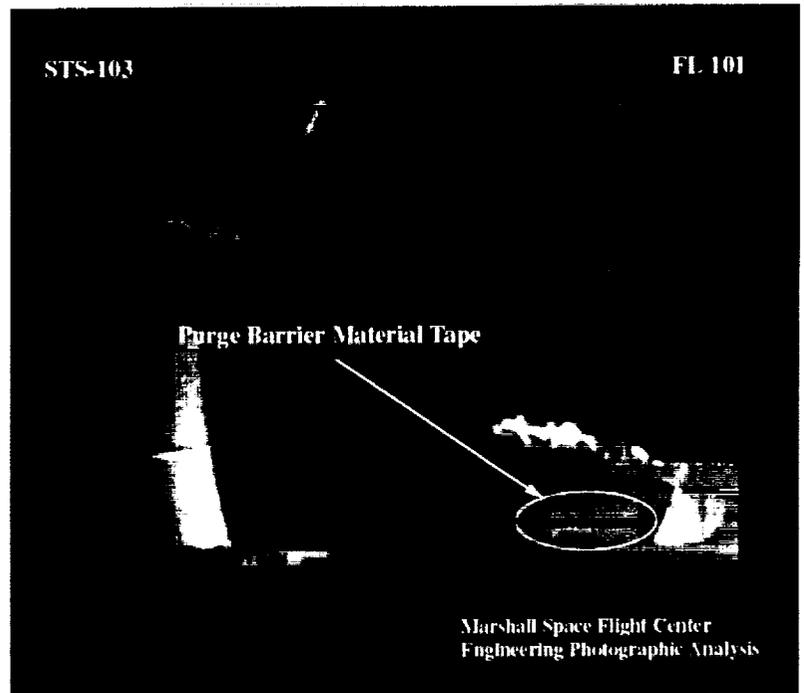


Figure 9. Purge Barrier Material Tape Observed by FL-101

7. SSME Streak Time-Line

The following table is a timeline of SSME plume streaking as recorded by camera E-19. These UTC times fall between mainstage and lift-off.

STS-103 Camera E-19 Streak Timeline

Time (UTC)	Engine	Note
354:00:49:57.672	SSME #1	
354:00:49:57.769	SSME #3	
354:00:49:57.849	SSME #1	
354:00:49:58.058	SSME #3	
354:00:49:58.123	SSME #2	
354:00:49:58.130	SSME #1	
354:00:49:58.140	SSME #2	
354:00:49:58.163	SSME #2	
354:00:49:58.177	SSME #1	Faint with red color
354:00:49:58.294	SSME #2	
354:00:49:58.307	SSME #1	
354:00:49:58.419	SSME #2	
354:00:49:58.600	SSME #2	
354:00:49:58.707	SSME #2	
354:00:49:58.926	SSME #2	
354:00:49:59.088	SSME #2	
354:00:49:59.120	SSME #1	
354:00:49:59.190	SSME #1	Faint green color
354:00:49:59.459	SSME #2	
354:00:49:59.498	SSME #1	red color
354:00:49:59.506	SSME #1	
354:00:49:59.583	SSME #2	
354:00:49:59.595	SSME #1	
354:00:49:59.787	SSME #2	
354:00:49:59.804	SSME #1	faint red color
354:00:49:59.964	SSME #1	
354:00:50:00.026	SSME #1	
354:00:50:00.175	SSME #1	

8. SRB Camera Assessment

Foam loss event counts from both $-Y$ and $+Y$ thrust panels were greatly diminished on this mission.

8.1 $T+90.0$ and $T+120.0$ second images for $-Y$ Thrust Panel

The extent of foam loss on the $-Y$ thrust panel is shown in the following two pictures.

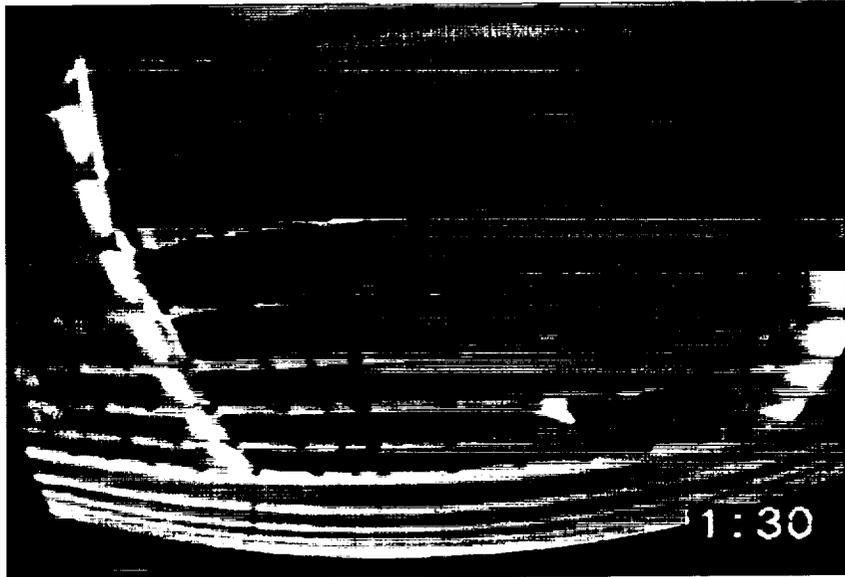


Figure 10. ET Surface at $T+90.0$ seconds on $-Y$ Thrust Panel

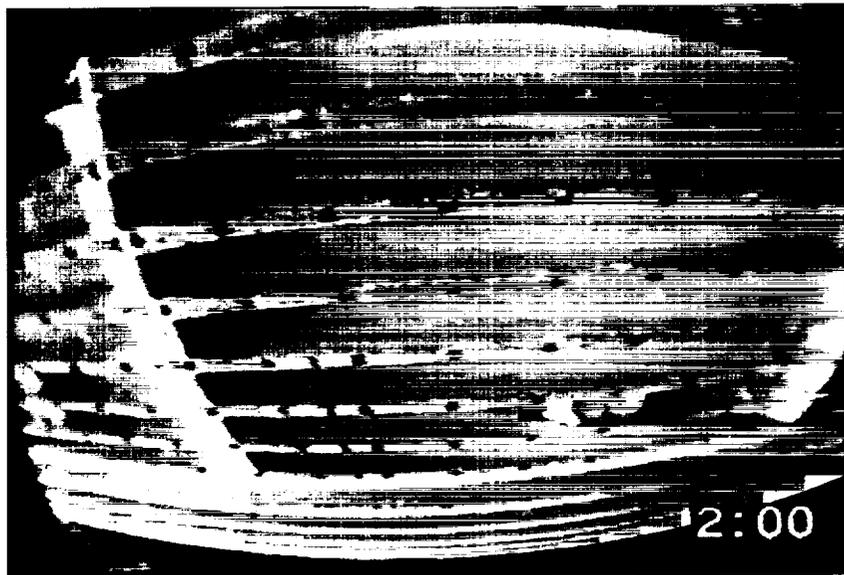


Figure 11. ET Surface at $T+120.0$ seconds on $+Y$ Thrust Panel

8.2 STS-103: -Y Thrust Panel Photographic Analysis

There were 39 total foam loss events recorded. The following table compares counts from vented and non-vented areas.

Table 3. STS-103 -Y Thrust Panel: Vented and Non-Vented Foam Loss Events

Category	Count
Vented	38
Non-Vented	1
Total	39

The following table shows the final count of foam loss events in each category.

Table 4. STS-103 -Y Thrust Panel: Foam Loss Events by Category

Category	Count
Valley	1
Stringer	10
Longitudinal Rib	28
Circumferential Rib	0
Hi-Lock	0
Ramp	0
Total	39

The first graphic illustrates the total count of foam loss events for the STS-103 -Y Thrust Panel. Bright red areas on the image highlight foam loss events.

In the first chart, the frequency and cumulative number of events recorded during each 0.5 second time interval from approximately T+90.0 seconds are shown. Using a fourth order polynomial approximation to trend the count data, the maximum foam loss activity appears to peak just after T+ 110.0 seconds. The maximum number of events recorded during any 0.5 second time interval was four.

The second and third charts illustrate the timeline of events for vented/non-vented, and ET surface categories of foam loss events.

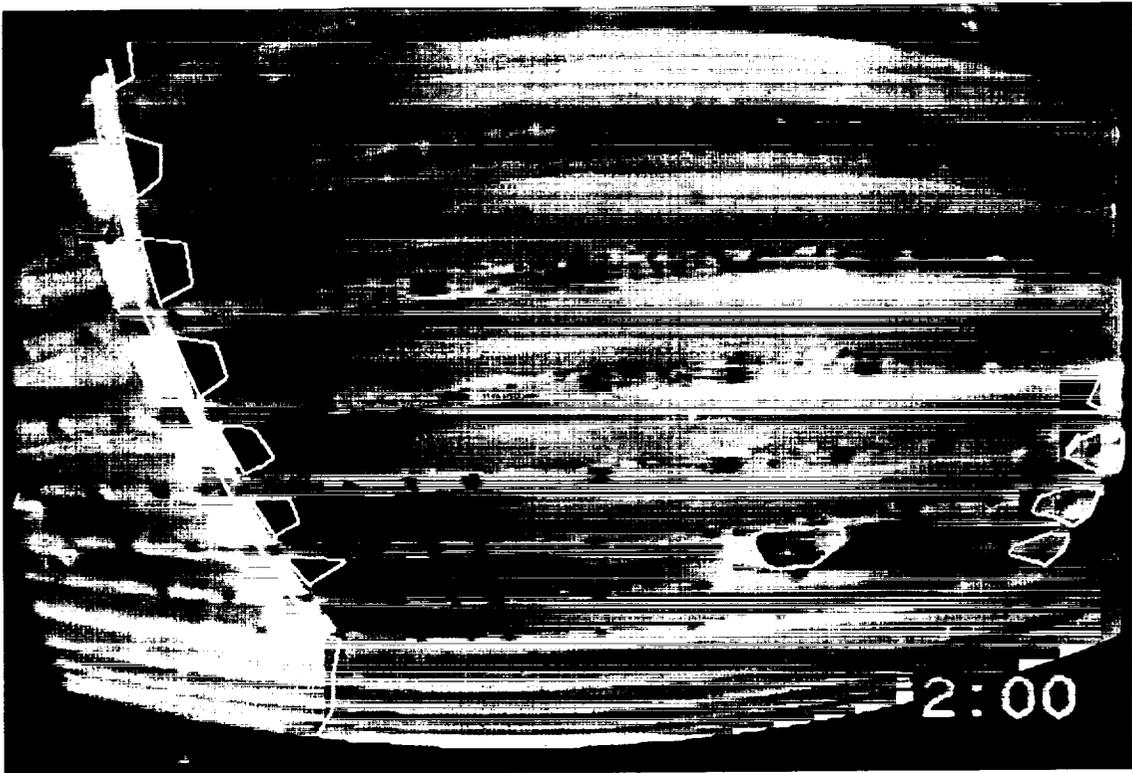


Figure 12. STS-103 -Y Thrust Panel (White lines in the figure are boundaries to vented areas.)

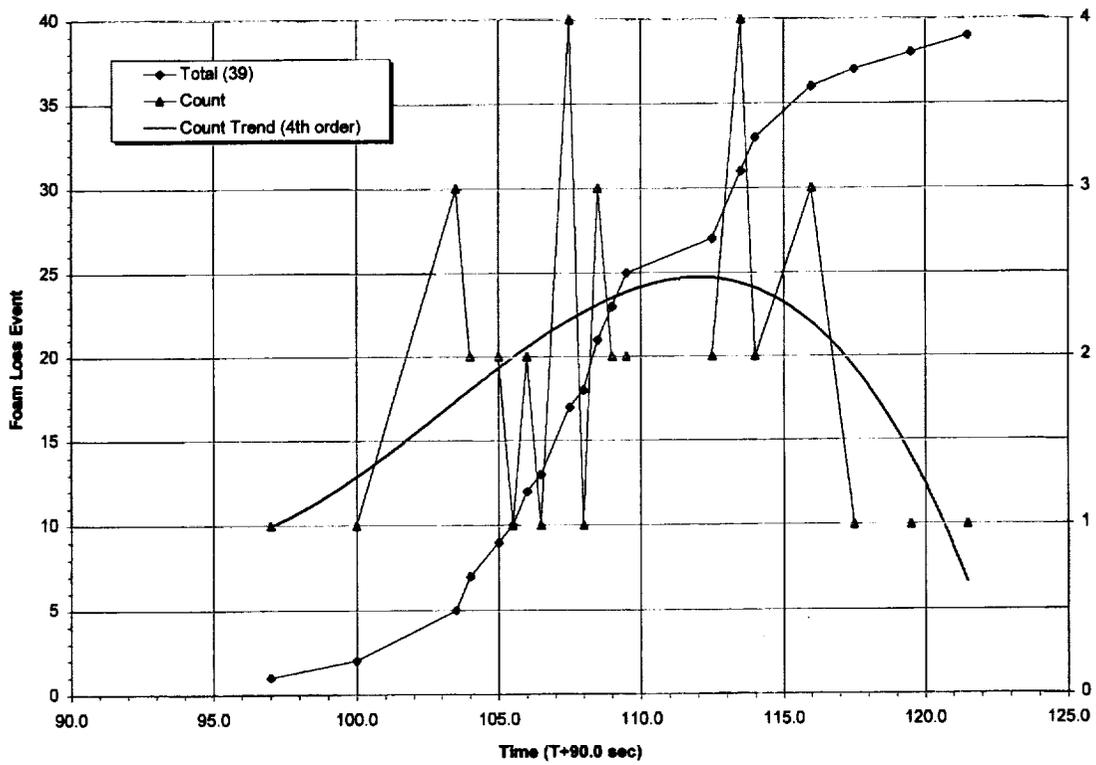


Figure 13. STS-103 -Y Thrust Panel: Foam Loss Event Timeline

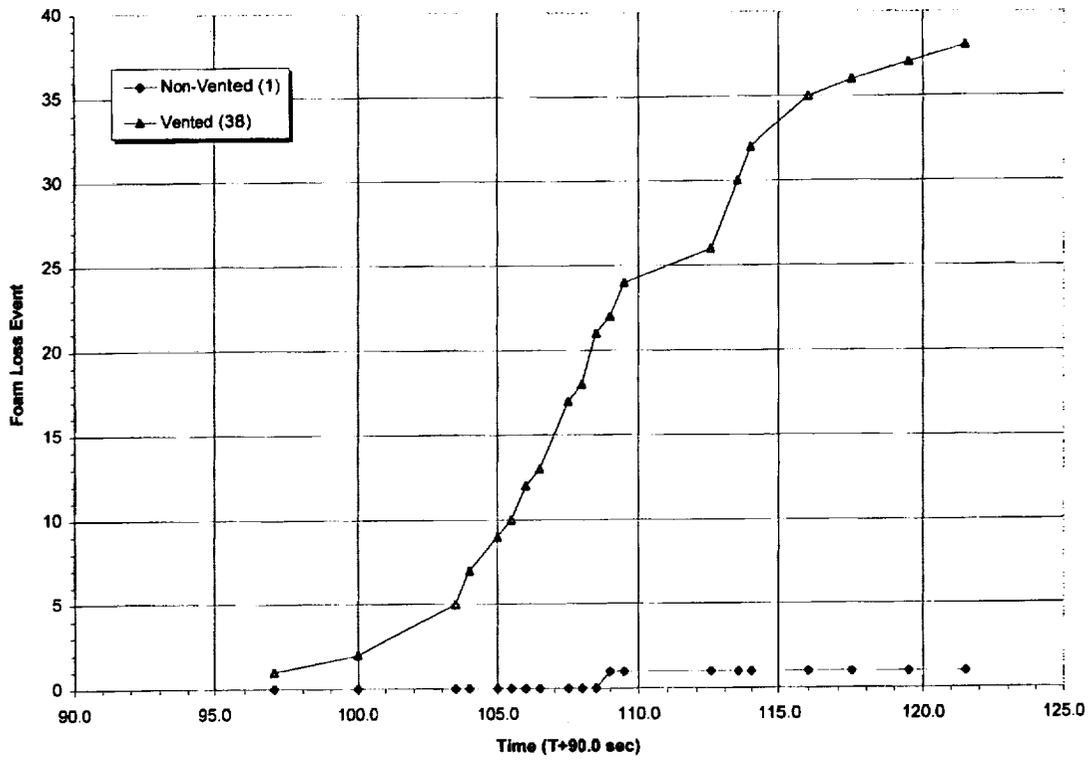


Figure 14. STS-103 -Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas

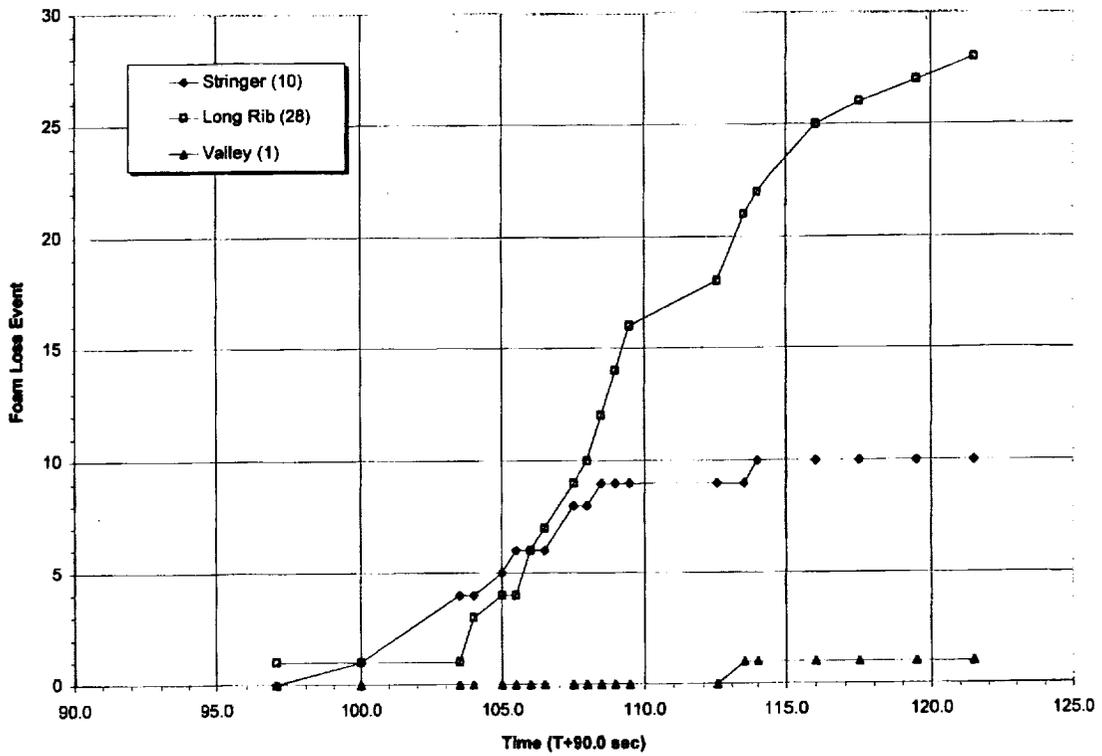


Figure 15. STS-103 -Y Thrust Panel: Foam Loss Timeline for Categories of Events

8.3 *T+90.0 and T+120.0 second images for +Y Thrust Panel*

The extent of foam loss on the +Y thrust panel is shown in the following two pictures.

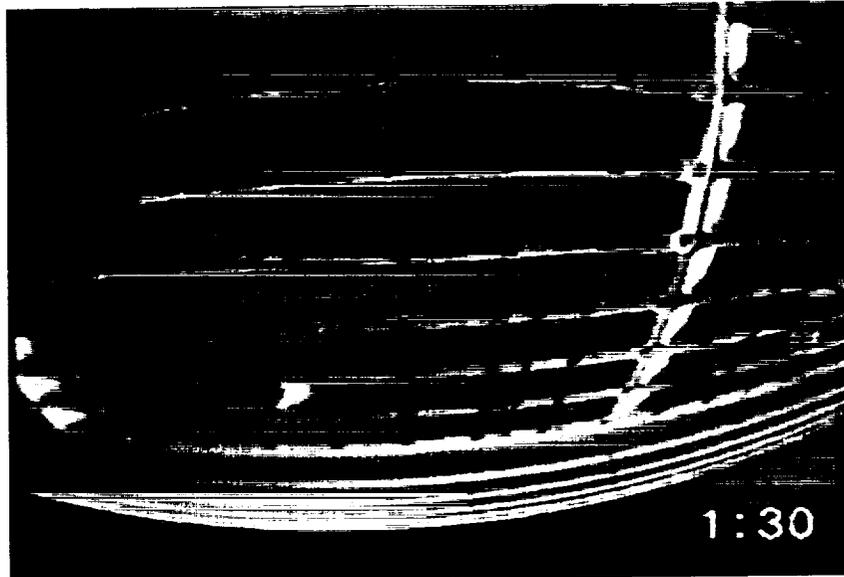


Figure 16. ET Surface at T+90.0 seconds on +Y Thrust Panel

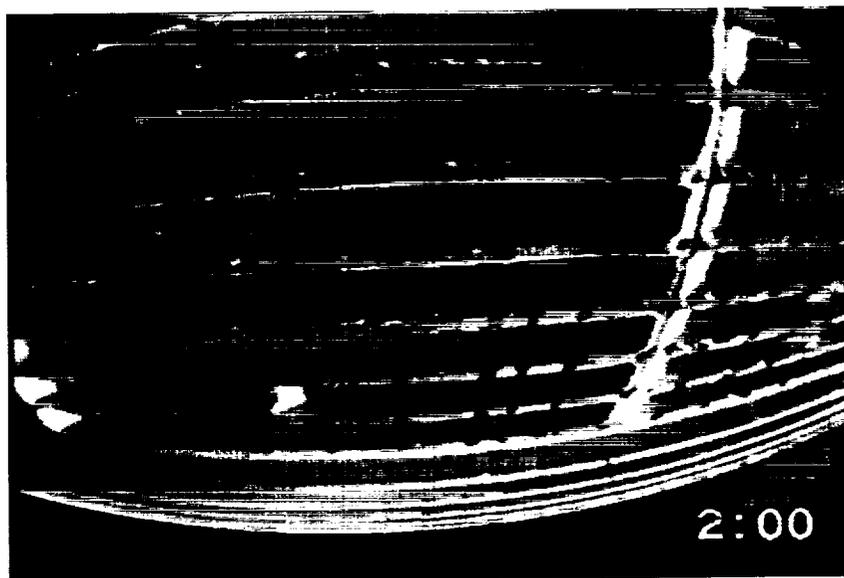


Figure 17. ET Surface at T+120.0 seconds on +Y Thrust Panel

8.4 STS-103: +Y Thrust Panel Photographic Analysis

There were 63 total foam loss events recorded. The following table compares counts from vented and non-vented areas.

Table 5. STS-103 +Y Thrust Panel: Vented and Non-Vented Foam Loss Events

Category	Count
Vented	13
Non-Vented	50
Total	63

The following table shows the final count of foam loss events in each category.

Table 6. STS-103 +Y Thrust Panel: Foam Loss Events by Category

Category	Count
Valley	2
Stringer	6
Longitudinal Rib	55
Circumferential Rib	0
Hi-Lock	0
(Indeterminate)	0
Total	63

The first graphic illustrates the total count of foam loss events for the STS-103 +Y Thrust Panel. Bright red areas on the image highlight foam loss events.

In the first chart, the frequency and cumulative number of events recorded during each 0.5 second time interval from approximately T+90.0 seconds are shown. Using a fifth order polynomial approximation to trend the count data, the maximum foam loss activity appears to peak just before T+ 110.0 seconds. The maximum number of events recorded during any 0.5 second time interval was six.

The second and third charts illustrate the timeline of events for vented/non-vented, and ET surface categories of foam loss events.

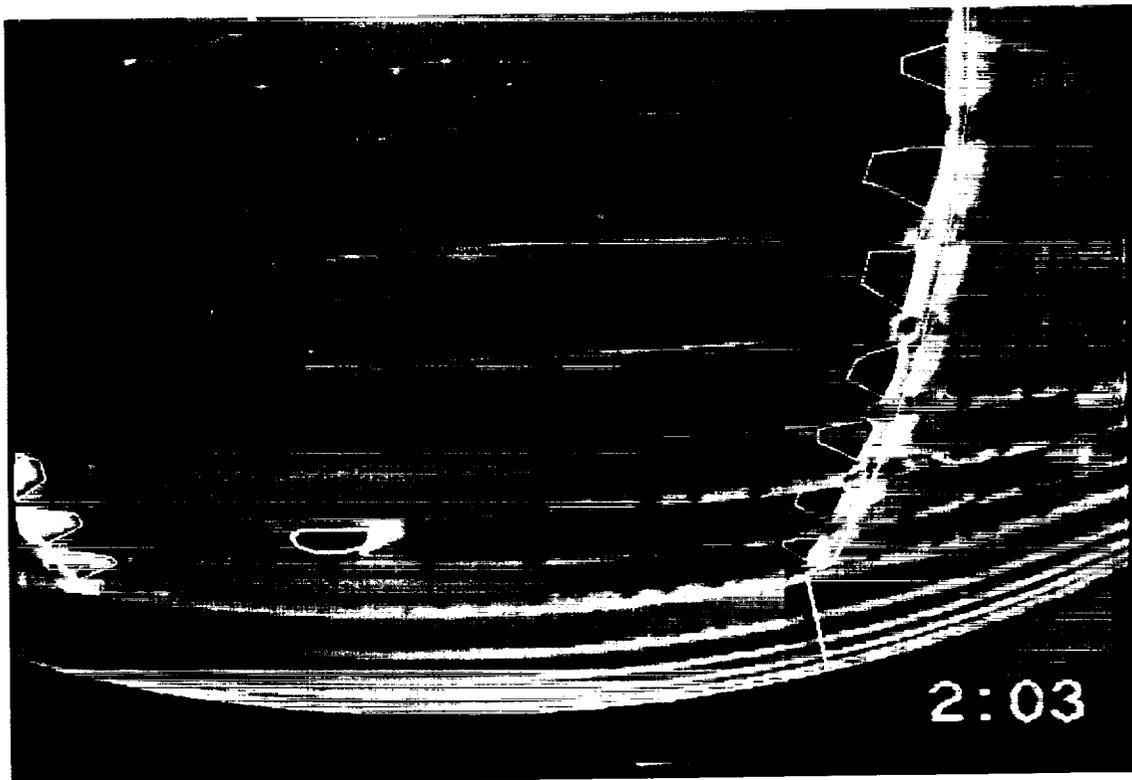


Figure 18. STS-103 +Y Thrust Panel (White lines in the figure are boundaries to vented areas.)

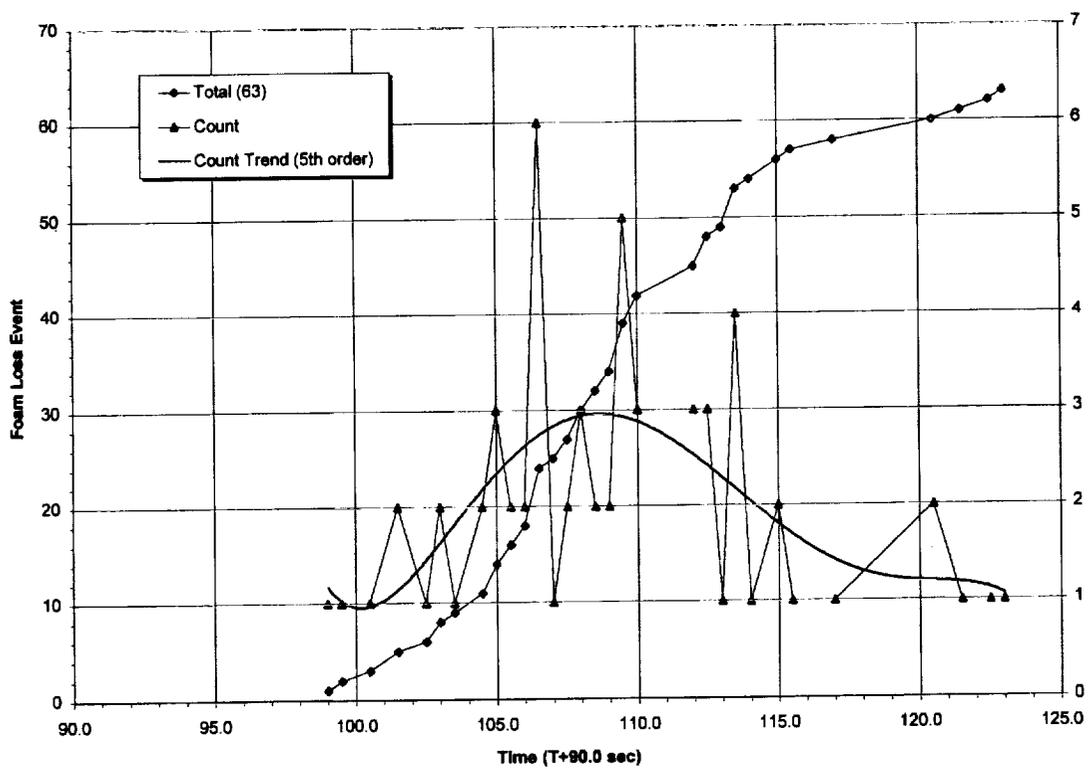


Figure 19. STS-103 +Y Thrust Panel: Foam Loss Event Timeline

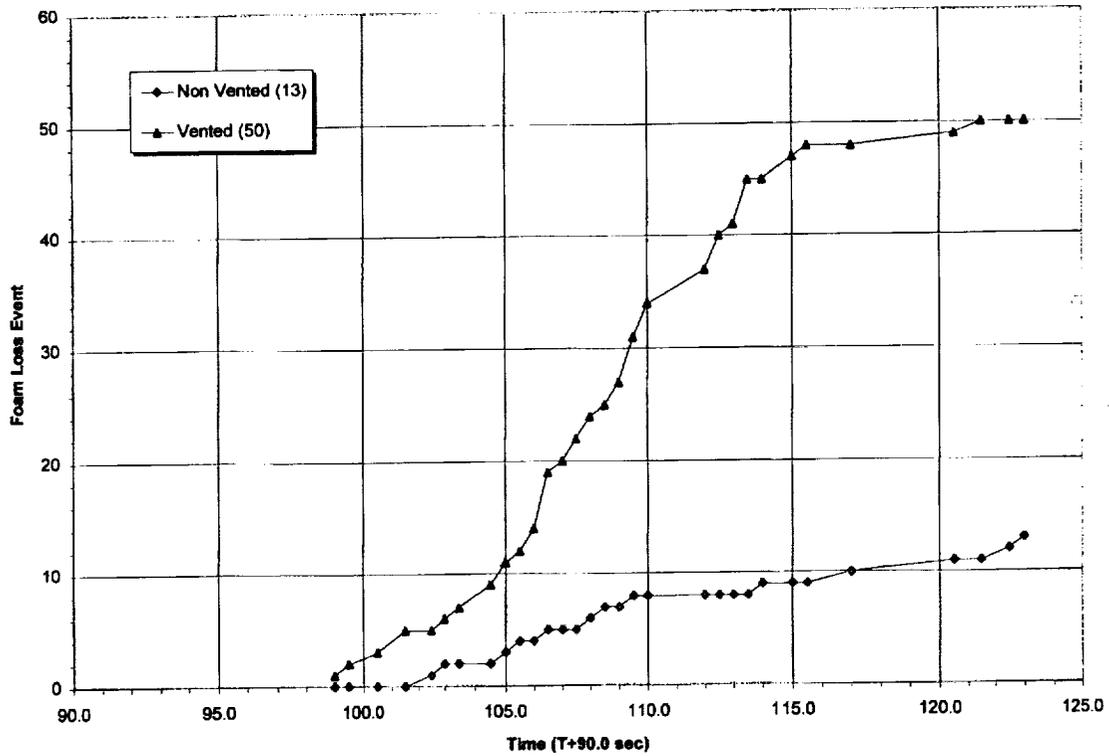


Figure 20. STS-103 +Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas

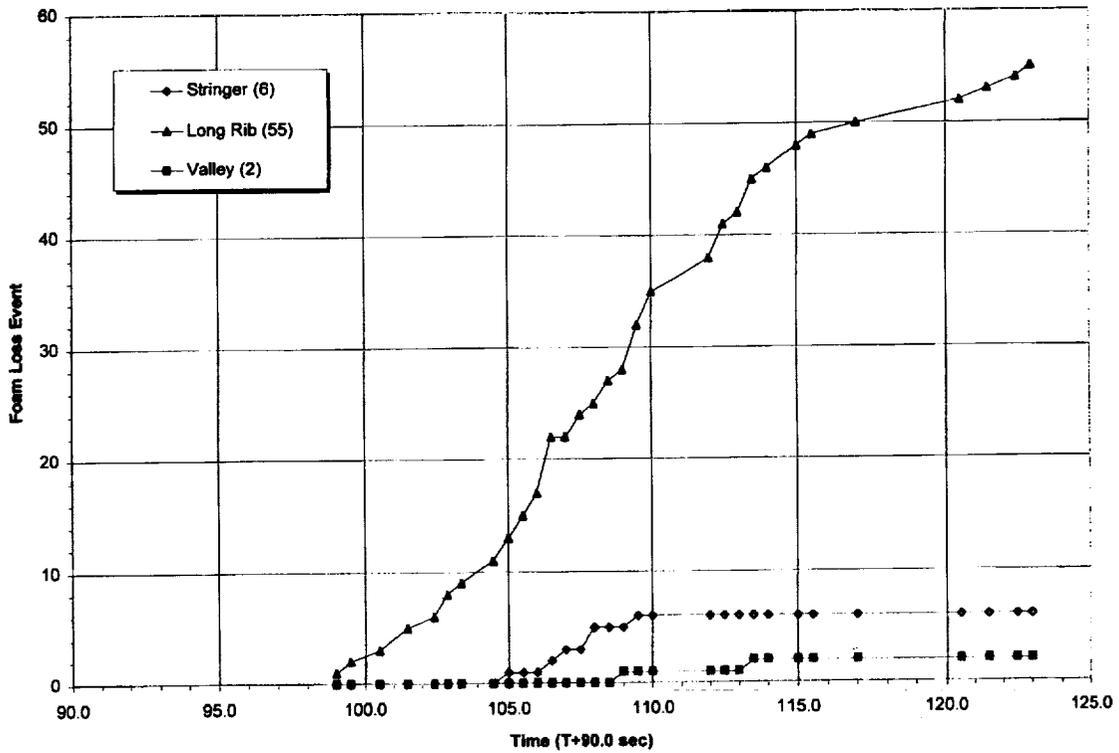


Figure 21. STS-103 +Y Thrust Panel: Foam Loss Timeline for Categories of Events

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Tom Rieckhoff/TD53

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13. ABSTRACT (Maximum 200 words) A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-103. 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-103 and the resulting effect on the Space Shuttle Program.				
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