Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-87

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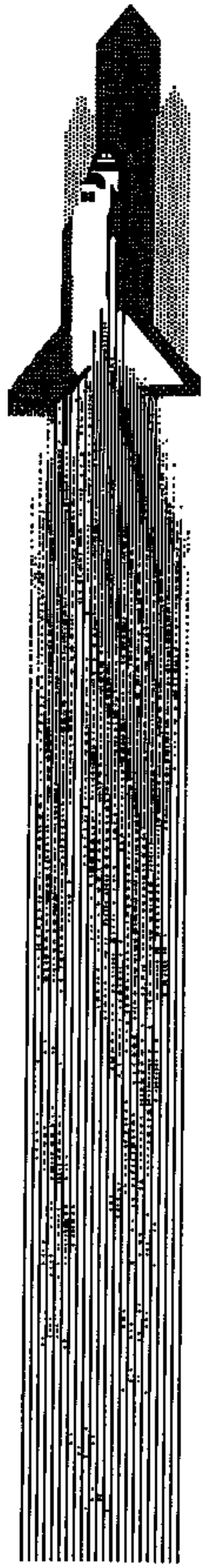
APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

<u>Space Science Branch</u>
Image Science and Analysis Group



STS-87 Summary of Significant Events

January 30, 1998

Space Shuttle
Image Science and Analysis Group
STS-87 Summary of Significant Events

Project Work Order - SN5CA

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Table and Figures

1. STS-87 (OV-102): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-87 launch of Columbia (OV-102) from pad B occurred on Wednesday, November 19, 1997 (day 323) at 19:46:00.001 Coordinated Universal Time (UTC), as seen on camera E9. Solid Rocket Booster (SRB) separation occurred at 19:48:03.7 UTC, as seen on camera ET212.

On launch day, 24 of the 24 expected videos were received and screened. Following launch day, 21 films were screened. Twenty-one additional films were received for contingency support and anomaly resolution, but were not screened. A Dome Mounted Heat Shield (DMHS) closeout blanket was seen to detach at the 5 o'clock position of SSME #1 during ascent. With the possible exception of the detached DMHS blanket, no anomalies that could threaten vehicle safety were seen on the launch imagery.

Photography of the left SRB and the LSRB/ET aft attach and the external tank aft dome was acquired using umbilical well camera films. Handheld still photography of the ET was acquired. During post-flight analysis of the handheld photography of the ET, extensive damage to the TPS on the left and right ET intertank thrust panels was observed. A handheld video of the ET following separation was also acquired. Venting from the ET intertank was clearly visible on the handheld video. The tumbling and rolling motion of the ET appeared greater than typically seen on previous missions.

Numerous pieces of debris (probably ice) are visible throughout the video sequence.

1.1.2 On-Orbit

Accidental rotation rates were imparted to the Spartan satellite when the grapple attempt failed on November 21, 1997. At the request of the MER manager, the rotation rates of the Spartan satellite around each of the primary axes were determined using downlinked video from the end effector camera. These rates were used in the planning for the EVA to capture Spartan. After Spartan had been successfully captured, the MER manager made a follow-up request that the Spartan rotation rates be determined just prior to the EVA capture. Using downlink video from Payload Bay camera D, the rotation rates about each of Spartan's primary axes were again determined. The second set of rotation rate data was used in the planning for a possible re-deploy of Spartan. Section 2.5.1 contains the results of the Spartan rotation rate analysis.

1.1.3 Landing

Columbia made an early morning landing on runway 33 at the KSC Shuttle Landing Facility on December 5, 1997. Twelve videos were received and screened. Following landing, ten films were screened.

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

The drag chute deployment appeared normal.

1.1.4 Post Landing

More than typical instances of Orbiter tile damage on the left and right outboard sections of the Orbiter underbody were seen on the post landing walk around inspection video. Tile damaged areas observed include: a forward to aft, linear tile damage pattern on the left Orbiter underbody from a point aft of the nose RCS thrusters to a point aft of the left wing root, tile damage on the inboard sections of the leading edges of both wings, and several possible instances of tile damage on the top surface of the left wing immediately aft of leading edge. Other tile damage included damage on the forward surface of both the left and right OMS pods, near the LH2 umbilical well, near Orbiter window #4, on the starboard main landing gear door, near the LH2 umbilical well, on the upper surface of the body flap, and on aft surface of the left RCS stinger. A missing section of closeout blanket panel was visible at the five o'clock position of the SSME #1 Dome Mounted Heat Shield (DMHS). Normal tile erosion was visible on the base heat shield. An area of brown discoloration was visible on the forward upper edge of left payload bay door. The tires appeared to be in good condition.

1.1.5 STS-87 Orbiter Damage Investigation

The MA/Manager, Space Shuttle Program requested that the Space Shuttle Systems Integration Office conduct an expedited investigation of all potential contributors to the in excess of 300 damage locations found on Orbiter tiles during the post-landing inspection. The investigation was to review the findings, most probable cause, and provide recommendations for corrective action prior to the STS-89 Flight Readiness Review.

Section 2.6 contains a summary of the image analysis support provided to the STS-87 Orbiter damage investigation by SN3/Image Science and Analysis Group, Space Science Branch.

1.2 TIMING ACTIVITIES

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.

Event Description	Time (UTC)	Camera
Landing Gear Doors Opened	339:12:19:44.119	EL30
Left Main Wheel Touchdown	339:12:20:03.908	EL2
Right Main Wheel Touchdown	339:12:20:04.041	EL9
Drag Chute Initiation	339:12::20:07.436	EL9
Pilot Chute at Full Inflation	339:12:20:08.290	EL12
Bag Release	339:12:20:08.957	EL2
Drag Chute Inflation in Reefed Configuration	339:12:20:10.019	EL9
Drag Chute Inflation in Disreefed Configuration	339:12:20:13.314	EL9
Nose Gear Touchdown	339:12:20:14.376	EL12
Drag Chute Release	339:12:20:37.627	EL1
Wheel Stop	339:12:21:00.869	EL4

Table 1.2 Landing Events Timing

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION THROUGH LIFTOFF

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

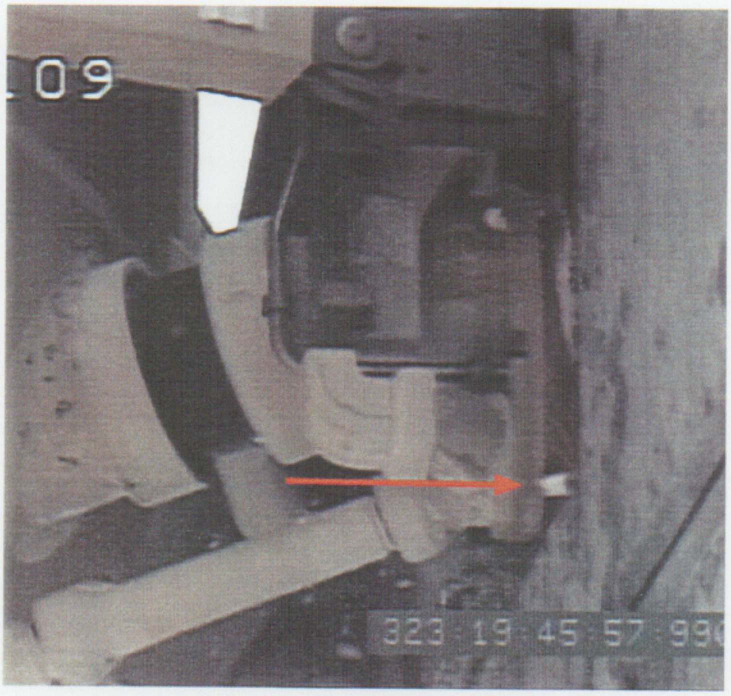

Figure 2.1 (A) Umbilical Ice Striking LH2 Umbilical Door Sill

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals during SSME ignition. An ice/frost finger from a LH2 umbilical purge vent fell aft and contacted the LH2 press line (~19:45:56.6 UTC) and then struck the LH2 umbilical door sill. Three other pieces of umbilical ice debris were seen to strike the ET/Orbiter LH2 umbilical door sill (~19:45:56.4 through 19:45:58.0 UTC). A single piece of umbilical ice debris was seen to strike the LH2 four-inch recirculation line at ~19:45:56.65 UTC. No damage to the press line, the door sill, or the four-inch recirculation line was visible. (Cameras OTV109, OTV163, E31)

Multiple of pieces of light colored debris were seen near the RSRB at SRB ignition. These debris were not seen to contact the vehicle. (Camera E5)

A large piece of light-colored debris (probably instafoam) was seen near the RSRB aft skirt moving toward the FSS during lift off (~19:46:02.8 UTC). A rope like piece of debris (probably water baffle material) was seen in the exhaust cloud after liftoff (~19:46:03 UTC). (Cameras E1, E4)

A single piece of light-colored debris (possibly metallic) was seen in the exhaust cloud after lift off (~19:46:10.7 UTC). (Camera E76)

2.2 DEBRIS DURING ASCENT

Multiple pieces of debris (probably umbilical ice and RCS paper) fell aft of the launch vehicle after liftoff, through the roll maneuver, and beyond. The debris appeared similar to that seen on previous missions. The debris seen was not in sufficient concentration to have been from the damaged ET or to have caused the Orbiter tile damage seen post-flight (see Section 2.6). None of the debris was seen to contact the vehicle. Intermittent clouds obscured the tracking camera views of the launch vehicle during ascent. No follow-up action was requested. (Cameras E1, E5, E52, E207, E212, E222, E223, E224).

Several pieces of light colored debris were noted falling aft of the body flap after the roll maneuver (~19:46:15.8 UTC). A debris induced flash was seen in the SSME exhaust plume during ascent (19:46:16.950 UTC). (Camera E52).

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

The SSME Mach diamonds did not appear to form in the expected sequence as seen on Camera E19 and recorded in Table 2.3. No follow-up action was requested.

SSME	TIME (UTC)
SSME #2	19:45:56.844
SSME #3	19:45:56.905
SSME #1	19:45:57.036

Table 2.3 Mach Diamond Formation

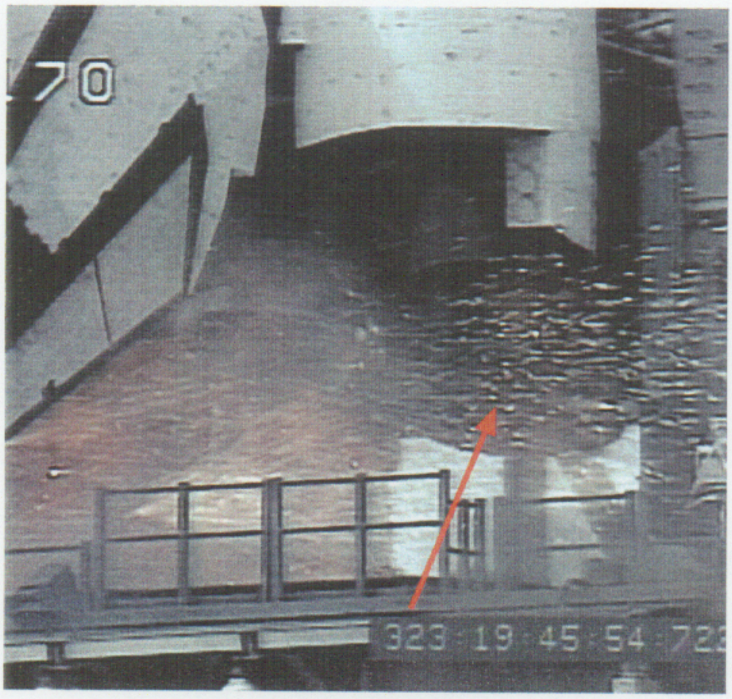

Figure 2.3 (A) Orange Vapor During SSME Ignition

2.0 Summary of Significant Events

Orange vapor, probably free burning hydrogen, was seen forward of the SSME rims and near the base heat shield during SSME ignition (~19:45:54.7 UTC). Orange vapors have been seen on previous missions. (E2, E5, E17, E19, E20, OTV170)

Several small areas of TPS erosion on the base shield were noted near SSME # 2 and SSME #3 after SSME ignition. (Cameras E17, E18).

2.4 ASCENT EVENTS

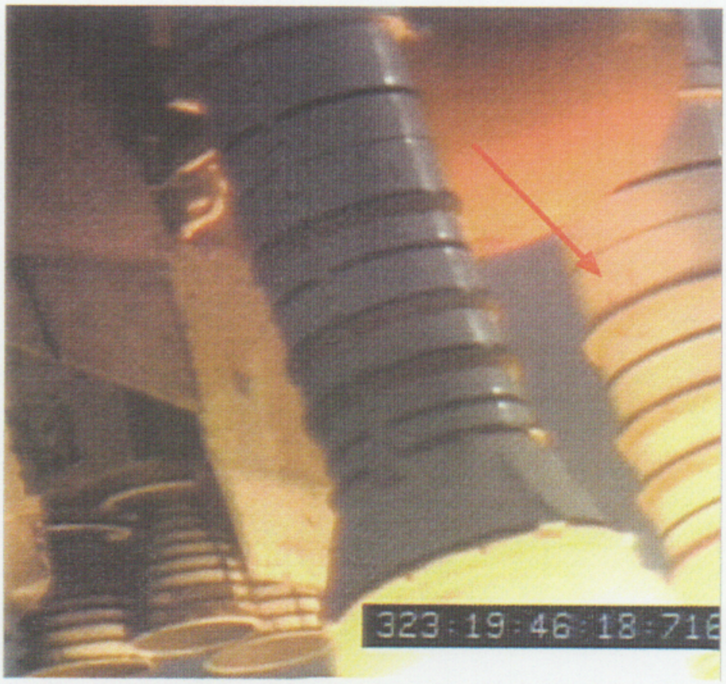

Figure 2.4 (A) Umbilical Purge Barrier Material

A piece of umbilical purge barrier material was seen to detach and travel toward the LSRB before falling aft (~19:46:18.7 UTC).

Figure 2.4 (B) Umbilical Purge Barrier Material Adhered to Base Heat Shield

A single piece of debris (possibly umbilical purge barrier material) first seen near the body flap, moved laterally into the SSME exhaust plume, broke into multiple pieces, and fell aft (19:46:24.189 UTC). (Camera ET207)

After the roll maneuver, a single piece of umbilical purge barrier material, first seen aft of SSME #2, traveled forward and adhered to the base heat shield outboard of SSME #2. No base heat shield tile damage at this location was reported in the STS-87 KSC Orbiter Post Landing Inspection Debris Assessment report.

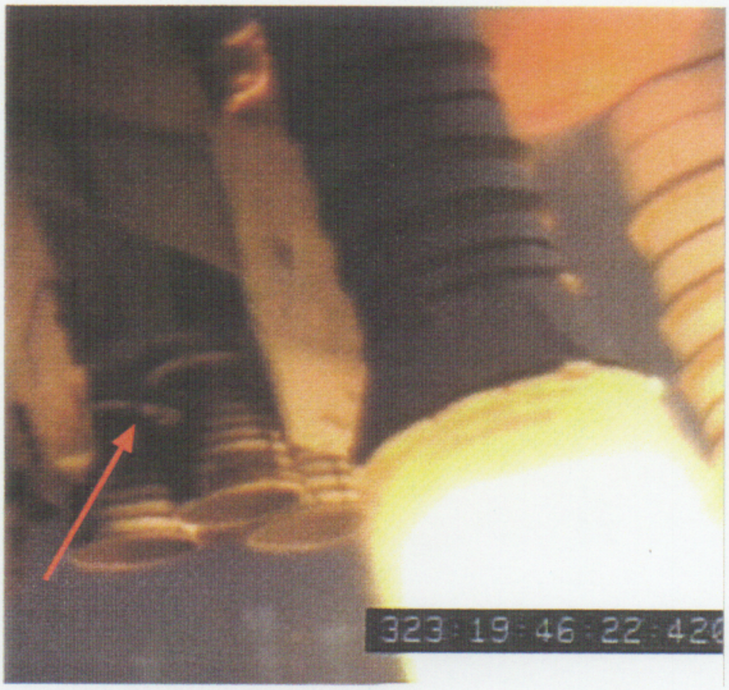

Figure 2.4 (C) Partially Detached Dome Mounted Heat Shield (DMHS) Closeout Blanket

A Dome Mounted Heat Shield (DMHS) closeout blanket was seen to partially detach at the 5 o'clock position of SSME #1 at ~19:46:20.7 UTC.

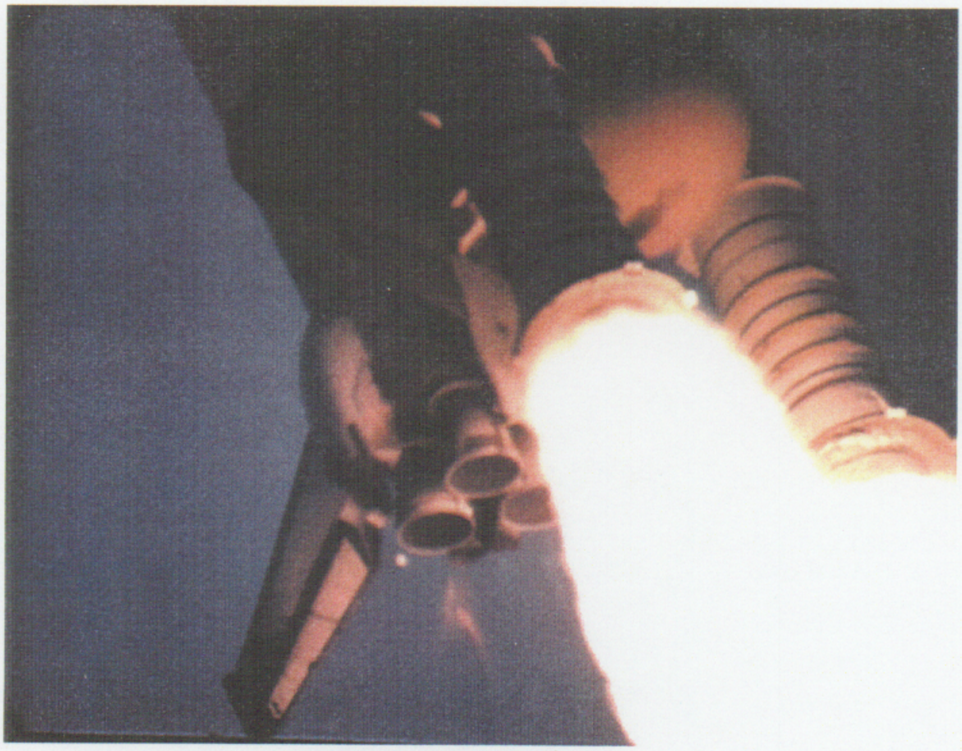

Figure 2.4 (D) Detached DMHS Closeout Blanket

The DMHS blanket tore loose and fell aft at approximately ~19:46:39 UTC. The falling blanket induced orange-colored streaks in the SSME exhaust plume. (KTV4B, KTV21B, ET204, ET207, E207, E213, E222, E223).

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

2.5 ON-ORBIT EVENTS

2.5.1 Spartan Rotation Rates

When the on-orbit attempt to grapple the Spartan satellite failed, accidental rotations were imparted to it. Using downlinked video from the end effector camera, an analysis of the rotation rates about each of Spartan's primary axes was performed. The rotation rates were derived using six digitized video frames with known relative times. Figure 2.5.1 and Table 2.5.1 (A) summarizes the findings of the analysis (a positive rotation is defined as a clockwise motion as viewed from the origin looking in the direction of the positive axis). The accuracy of these numbers was estimated to be approximately +/-0.02 deg/sec.

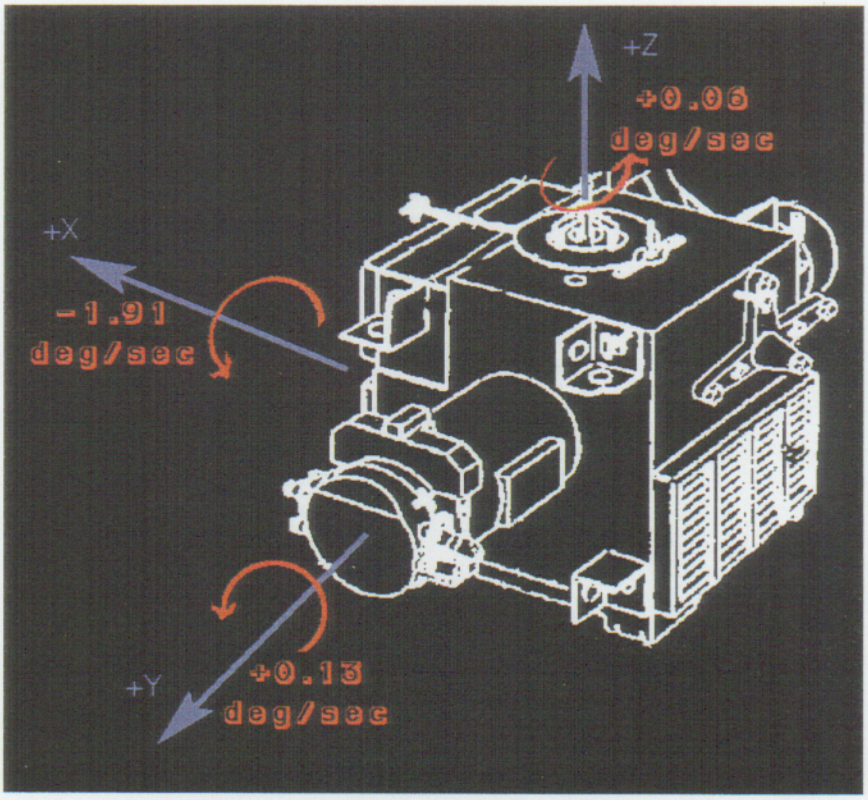

Figure 2.5.1 Spartan Rotation Rates after Failed Grapple

Axis	Rotation Rate (deg/sec)
X	-1.91
Y	+0.13
Z	+0.06

Table 2.5.1(A) Spartan Rotation Rates after Failed Grapple

The Spartan rotation rates were also determined just prior to the EVA capture. Using downlink video from Payload Bay camera D, the rotation rates about each of Spartan's primary axes were determined. This second set of rotation rate data was used in the planning for a possible re-deploy of Spartan. Table 2.5.1(B) contains the rotation rates that were determined just prior to the EVA capture.

Axis	Rotation Rate (deg/sec)
X	+0.02
Y	-0.06
Z	+0.03

Table 2.5.1 (B) Spartan Rotation Rates Prior to EVA Capture

2.6 OV-102 DAMAGE INVESTIGATION

This section is a summary of the image analysis tasks performed by SN3/Image Science and Analysis Group, Space Science Branch in support of the investigation of the source of the STS-87 Orbiter tile damage found during the post-landing inspection.

The investigation board was provided with imagery products, image enhancements, and imagery analysis support of: (1) the Space Shuttle (OV-102) during launch from ground tracking camera films, (2) the post-separation ET (from the Orbiter umbilical well and the crew handheld cameras), (3) umbilical camera views of the SRBs at separation, (4) crew acquired on-orbit images of the OMS pods, (5) timelines of the ET venting seen on the handheld ET imagery, and (6) a summary of the observed ET tumble rates. A preflight meteoroid/orbital debris risk assessment prepared by SN3 Space Science Branch was also provided to the board.

The damage to the ET thrust panel TPS seen on the crew handheld photography was ultimately determined by the investigation board to be the probable cause of a significant portion of the Orbiter fuselage tile damage.

2.6.1 Onboard Photography of the External Tank

2.6.1.1 Analysis of the Umbilical Well Camera Films

Three rolls of umbilical well camera films from mission STS-87 were received at JSC on December 6, 1997: the 16mm film (5mm lens) and the 16mm film (10mm lens) from the LH2 umbilical, and the 35mm film from the LO2 umbilical well camera. The +X translation maneuver was performed on STS-87.

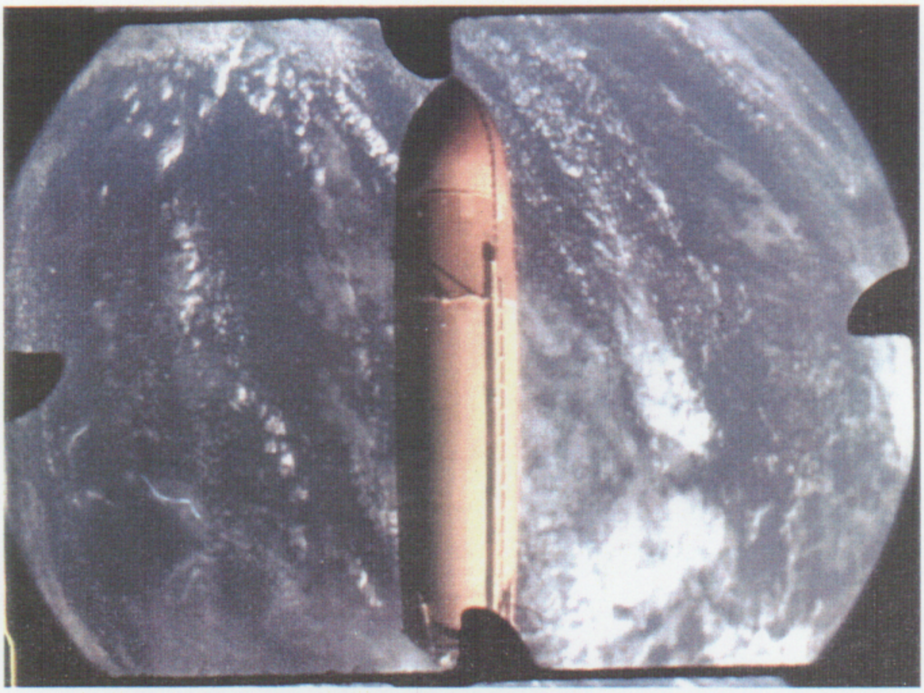

Figure 2.6.1.1 (A) 16mm Umbilical Well Camera Film (5mm Lens) of ET

16mm films:

No damage to the Orbiter side of the ET (+Z) or the visible forward portion of the SRBs was seen on the 16mm umbilical well films that would account for the tile damage found on the Orbiter after landing. No indications of vapor were seen on the ET film sequence. Although the GH2 vent on the ET intertank was not visible from the umbilical well camera perspective, it appeared that if venting similar to that seen on the downlink video had been present it should have been detected (see section 2.6.1.3). No unusual motions of the ET could be discerned during the 16mm film separation sequence when compared to identical views acquired on previous missions.

Less than usual divots were seen on the ET surface areas. Two light colored marks (possibly divots) were seen on the intertank acreage between the +Z aero vent and the RSS antenna. Small erosion marks or divots were seen on the LO2 aft feedline flange closeouts. A light area (possibly a divot) was seen on the -Y limb of the intertank near the LSRB forward attach fitting. Several divots were seen on the -Y thrust strut and flange closeout. Numerous light colored pieces of debris (probably insulation and frozen hydrogen) were seen throughout the ET separation sequence. No anomalies were noted on the face of the LH2 umbilical after ET separation (the LH2 umbilical interface plate appeared similar to previous mission views). As typically seen on previous missions, frozen hydrogen was noted on the orifice of the LH2 17 inch connect.

Good coverage of the LSRB separation and the tip of the RSRB was acquired on the 16mm films. Numerous light-colored pieces of debris (insulation and frozen hydrogen) and dark debris (probably charred insulation) were seen throughout the 16mm film sequence. Numerous irregularly-shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. Charred TPS was seen on the aft surface of the -Y upper strut fairing prior to SRB separation. Typical ablation of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the horizontal section of the -Y ET/SRB vertical strut was seen. 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. TPS ablation or small aero-heating erosion marks on the ET aft dome may be slightly more than typically seen.

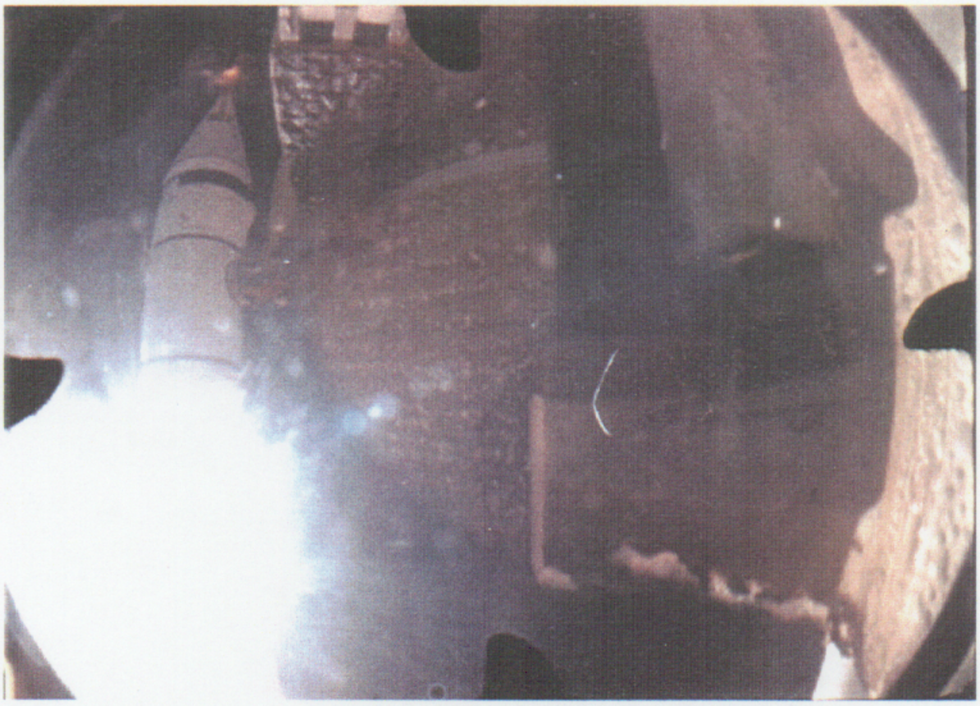

Figure 2.6.1.1 (B) 16mm Umbilical Well Camera Film (5mm Lens) View of SRB Separation

The LSRB separation appeared normal. The SRB nose caps were visible during SRB separation.

STS-87 was the first flight where the umbilical well cameras imaged the external tank from the roll-to-heads-up position. The film exposure of external tank is dark while the ET is in the shadow of the Orbiter. After ET separation, the ET comes into sunlight and the exposure is good. The film quality of the SRB separation sequence on the 16mm films is good until after SRB separation when the exposure becomes dark. The 16mm umbilical well films have good focus. OV-102 is not configured for timing data on the 16mm umbilical well cameras.

35mm Umbilical Well Camera Film:

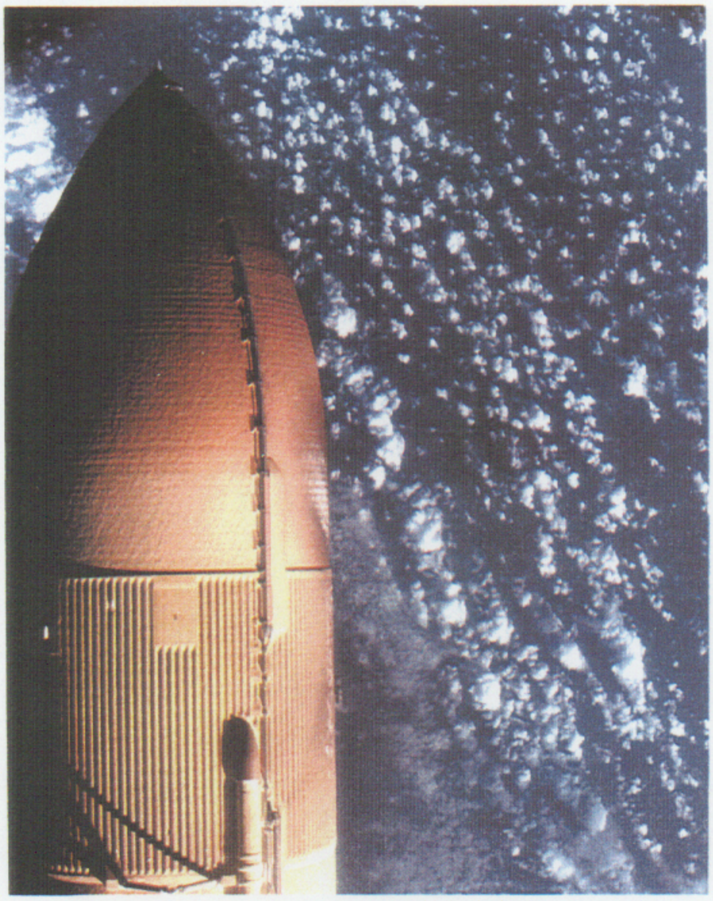

Figure 2.6.1.1 (C) 35mm Umbilical Well Camera Film View of Forward ET

The 35mm STS-87 umbilical well camera film of the external tank from the Orbiter LO2 umbilical well was reviewed at JSC on December 7, 1997.

Excellent quality views of the ET from the LO2 umbilical forward to the tip of the ET nose were acquired. As planned, a total of 59 image frames were recorded. Overall, the +Z ET TPS appeared to be in good condition. No anomalies were noted on the face of the LO2 umbilical (the LO2 umbilical interface plate appeared similar to previous mission views). The ET/Orbiter attach bipod closeouts appeared normal. The LO2 feedline, cable tray, PAL ramps, press lines, and ET nose cone appeared in good condition.

Multiple white-colored marks (TPS damage), including several divots, were seen on the on the 35 mm umbilical well film on the +Y ET thrust panel near the RSRB forward attach. Better views of this damage were acquired with the crew handheld photography. The investigation team concluded that the thrust panel damage near the RSRB forward attach accounted for the damage found on the fuselage tiles along the right side of Orbiter after landing. (The -Y ET thrust panel near the LSRB forward attach was not imaged on the 35mm umbilical well camera film). No indications of vapor were seen on the 35mm film. No unusual motions of the ET could be discerned on the 35 mm film when compared to identical views acquired on previous missions.

Other items noted on the 35mm umbilical well camera film, although not consider anomalous, include:

- Approximately 60 to 70 percent of the visible ET aft dome TPS surface area was covered with small, white-colored "popcorn" divots.
- Several small divots were seen on the +Y vertical section of the electrical cable tray adjacent to the LO2 umbilical.
- A divot, approximately 3 inches in length, was seen just above the LO2 umbilical between the +Y ends of the diagonal strut and the cross beam.
- Multiple small divots (less than 1 inch in size) were seen on the LO2 aft feedline flange closeouts.
- On frames 14 -17, a thin white-colored string-like debris object (estimated to be approximately 30 inches in length) was seen near the base of the LO2 feedline just forward of the cross beam. A similar string-like object was previously seen on the STS-78 35mm umbilical well film.
- Several small shallow appearing divots (approximately 1 inch in size) were seen on the base and the forward-end of the +Y thrust strut.
- Multiple very small white-colored "popcorn" aero heating or erosion marks were seen on the lower LH2 tank TPS. These marks were not visible on the pre-launch close-out photography.
- A shallow divot, approximately 3 inches in size, was seen on the LH2 / intertank closeout flange in the +Y direction from the LO2 feedline.
- Approximately seven small shallow divots (approximately 1 inch in size) were seen on the intertank stringer heads just forward of the ET / Orbiter attach bipod.
- A divot, approximately 1 to 2 inches in size, was seen near the +Z aero vent.
- A divot, approximately 8 inches in length, was seen on a forward intertank stringer head between the +Z aero vent and the RSS antennae (approximate station XT 750).

The 35mm umbilical well film is of excellent quality, with good exposure and focus.

2.6.1.2 Analysis of the Handheld Photography of the ET

Fifty-three images of the ET were acquired using the handheld 70 mm Hasselblad camera with the 250mm lens images (magazine 705). The exposure and focus of the photography is good. However on many of the images, a substantial portion of the ET is in shadow (detail not visible) because of the sun angle. Views of the sides, nose and aft dome of the ET were acquired. Timing data is not present on the handheld film. The normal SRB separation burn scars and aero-heating marks were noted on the ET TPS. The ET was measured to be 1.1 km distance from the Orbiter on the first picture. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows (STS-87 was the first flight with the roll-to-heads-up maneuver).

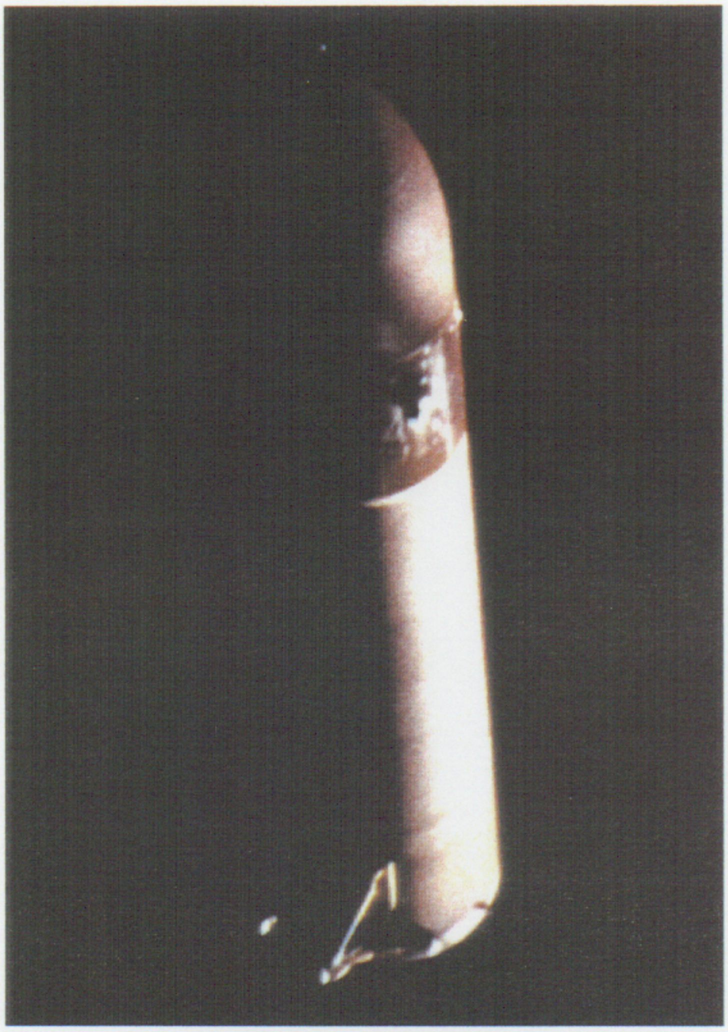

Figure 2.6.1.2 (A) Damage to the ET +Y Intertank Thrust Panel

Damage to the ET intertank TPS was noted. The damaged areas are visible on both the +Y and -Y intertank thrust panels near the forward left and right SRB attach fittings and extend forward and aft from the attach points for almost the entire width of the intertank.

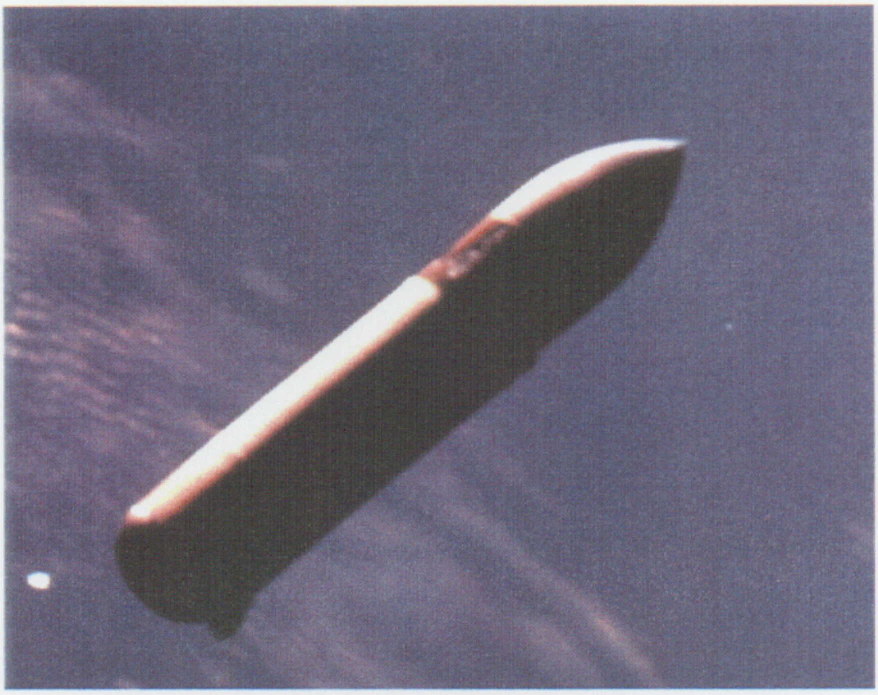

Figure 2.6.1.2 (B) Damage to the ET -Y Intertank Thrust Panel

The damaged areas appeared to consist of multiple white-colored divots. A separate large, bright, light-blue-colored area estimated to be approximately 100 inches in length, was noted on the ET intertank -Y/-Z axis. The presence of exposed substrate in the damaged area could not be confirmed from the imagery. No indication of structural damage was noted.

2.6.1.3 Analysis of the ET Venting Seen on the Crew Handheld Imagery

Figure 2.6.1.3 (A) ET Venting Seen on the Hasselblad Camera Film

Venting from the intertank in the vicinity of the GH2 vent (-Y axis) is visible on the Hasselblad film. The venting is present on two separate sequences of frames. After a close review of the STS-87 ET film it was determined that the first sign of ET venting was evident in the ninth frame (image reference S87-705-009). The distance to the ET was calculated to be 5336 feet on this image. This estimate was based on the measured image/object scale and the 250 mm lens used for the photography. The expected error is approximately ±4 %.

2.6.1.4 Analysis of the Camcorder Video of the ET

One minute and forty-three seconds of post-separation downlink video of the ET taken by the astronauts were received on November 21, 1997. Vapor venting from the intertank region near the GH2 vent of the STS-87 external tank (ET) is visible in the video. Numerous pieces of debris (more than typically seen) are visible throughout the video sequence. Some of the debris (probably ice) is out of focus suggesting a close proximity to the Orbiter window. The tumbling and rolling motion of the ET was greater than typically seen on previous missions (see section 2.6.1.6). Timing data is not present on the downlink video but is present on the on-board video received after landing.

2.6.1.5 Analysis of STS-87 External Tank Separation Distances

To assist in the investigation of the STS-87 ET venting and tumbling observed post-ET separation, measurements of the ET separation distances in relation to the observed intertank GH2 venting were made. The imagery used for this analysis was the Orbiter umbilical well film (16 mm film with 10 mm lens), the crew handheld photography (Hasselblad roll STS-87-705), and the onboard camcorder video tape (STS-87 #001). The MET times of the ET imagery acquisitions are shown in Figure 2.6.1.5 (A).

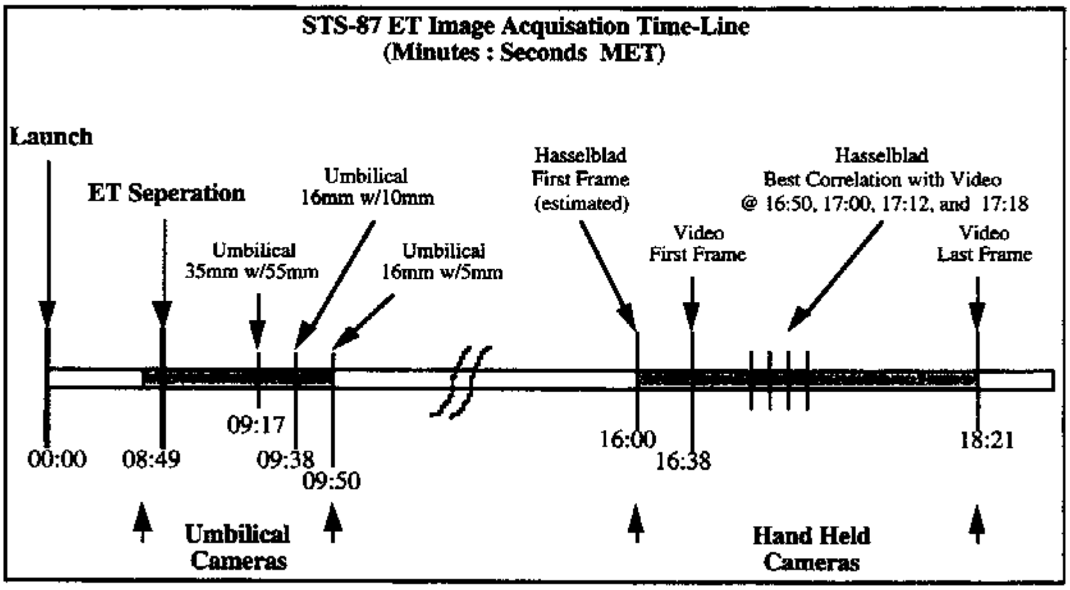

Figure 2.6.1.5 (A) ET Image Acquisition Timeline

The ET separation distance versus time was measured from the 16 mm umbilical well film using the ET intertank diameter as the scale reference. The first reliable ET diameter measurement in the film sequence was at 9 seconds post-separation, and the last reliable ET diameter measurement was at 42 seconds.

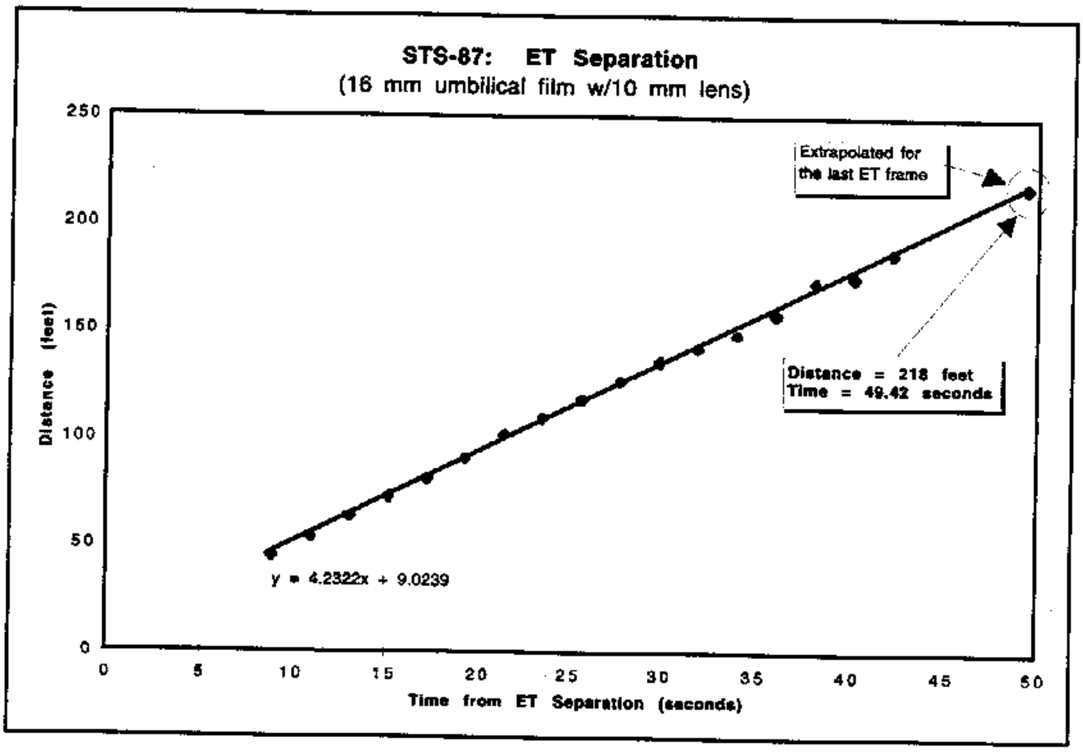

Figure 2.6.1.5 (B) Distance of ET vs. Time on 16 mm Umbilical Well Camera Film (10mm Lens)

The ET distance from the Orbiter versus time from separation is shown in Figure 2.6.1.5 (B). The ET separation rate was approximately constant over the film sequence at 4.4 feet per second. At 49 seconds post-separation, only the tip of the ET nose cap was visible before the ET moved out of the field of view. By extrapolation (see Figure 2.6.1.5 (B)), the ET was at a distance from the Orbiter of 218 feet +/- 3 feet when last viewed by the umbilical well camera.

ET venting was not observed in the umbilical well film sequence, nor do there appear to be ET tumble or roll rates that would suggest venting occurred from the GH2 intertank vent. Therefore it was concluded that there was no significant ET GH2 intertank venting within the first 49 seconds (218 feet) post-ET separation. Table 2.6.1.5 (A) provides the ET separation distance, time, and rate of separation for the umbilical well films.

Umbilical Film Camera	Focal Length (mm)	Frame Rate (frames/sec)	Time (sec)	Maximum Range (ft)	Separation Rate (ft/sec)
16 mm	10	240	49.42	218	4.4
35 mm	55	2.1	28.10	125	4.4

Table 2.6.1.5 (A) ET Separation Distance on 16mm and 35mm Umbilical Well Film.

The use of handheld photography, although of good quality, was limited for this analysis due to the lack of timing data on the film. An indirect method of obtaining handheld photography timing was partially successful. This method involved correlating the handheld photography frames with the camcorder video frames (with timing), but was hampered by a combination of poor video quality and poor ET lighting conditions. The ET distances from the Orbiter were measured from the handheld photography using the diameter of the ET intertank as the scale reference.

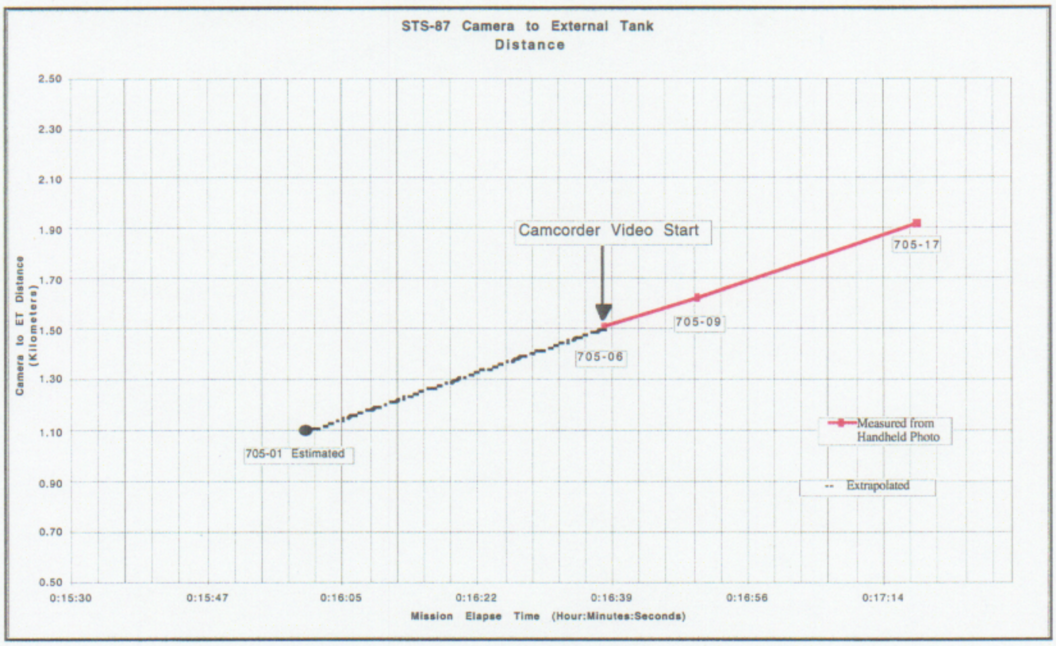

Figure 2.6.1.5 (C) Measured ET Distances from the Orbiter vs. Time

The ET distance was measured from four frames of handheld photography (705-01, 705-06, 705-09, 705-17). Three of these frames (705-06, 705-09, 705-17) were also successfully correlated with camcorder video frames to obtain timing. The measured ET distances from the Orbiter versus time in MET are shown in Figure 2.6.1.5 (C). Handheld photography frame 705-06 was taken at about 16:38 MET, corresponding to the time that the camcorder video of the ET begins. At this time, the ET was at a distance of approximately 1.5 km (4900 feet), separating from the Orbiter at 33 feet per second. The first handheld frame of the ET, 705-01, was taken prior to the video start, therefore its timing using the camcorder video is not possible. The ET distance for frame 705-01 was measured to be 1.1 km (3600 feet). Using the measured separation rate from handheld frames 705-06, 705-09, and 705-17 and extrapolating forward in time yields an estimated time for the first handheld frame, 705-01, of about 16:00 MET, as shown in Figure 2.6.1.5 (C)

In her post-flight debrief statements, astronaut Chawla recalls that the ET "tumbling and venting were unusual" when she first observed and photographed the ET. Therefore, it was inferred that the first visual observation by the crew of ET venting was at about the time of handheld frame 705-01; 16:00 MET (3600 feet). However, ET venting is not evident in the first eight handheld frames and is first observed in handheld frame 705-09 (MET 16:50, 5250 feet). ET venting is observed at the beginning of the camcorder video sequence (16:38 MET, 4900 feet). Therefore the first observation of venting in any imagery is with the camcorder video. Also, there is indirect evidence from the observed ET tumble rate (see section 2.6.1.6) that venting began prior to 16:38 MET.

In conclusion, from the available imagery, it was not possible to determine the time or ET distance for when the ET GH2 intertank venting began. However, based upon the available imagery and crew recollections, it was concluded that venting began after 9:24 MET (distance of 218 feet) and before 16:00 MET (distance of about 3600 feet).

2.6.1.6 Video Analysis of STS-87 ET Tumble Rates

To assist in the investigation of the STS-87 ET venting and tumbling observed post-ET separation, measurements of the ET tumble rates were made.

The rate of ET tumble, i.e., the end-to-end rotation of the ET about its center of mass, was measured using camcorder video recorded onboard by the crew. The video tape used in this task was onboard tape STS-87 #001 (Reference Master 615161). The ET was in view in the video beginning at 00:16:38 MET. The ET was out of view at 00:18:21 MET as it entered into the terminator darkness. The ET was observed to tumble approximately 2.5 cycles over the entire video sequence. The axis of rotation was approximately the Z axis. No significant roll about the X axis was observed. Intermittent venting from the intertank GH2 vent was observed throughout the sequence. From the observed orientation of the venting relative to the tumble motion, one can infer that the vent force was perpendicular to the axis of rotation and would have increased the angular rotation rate.

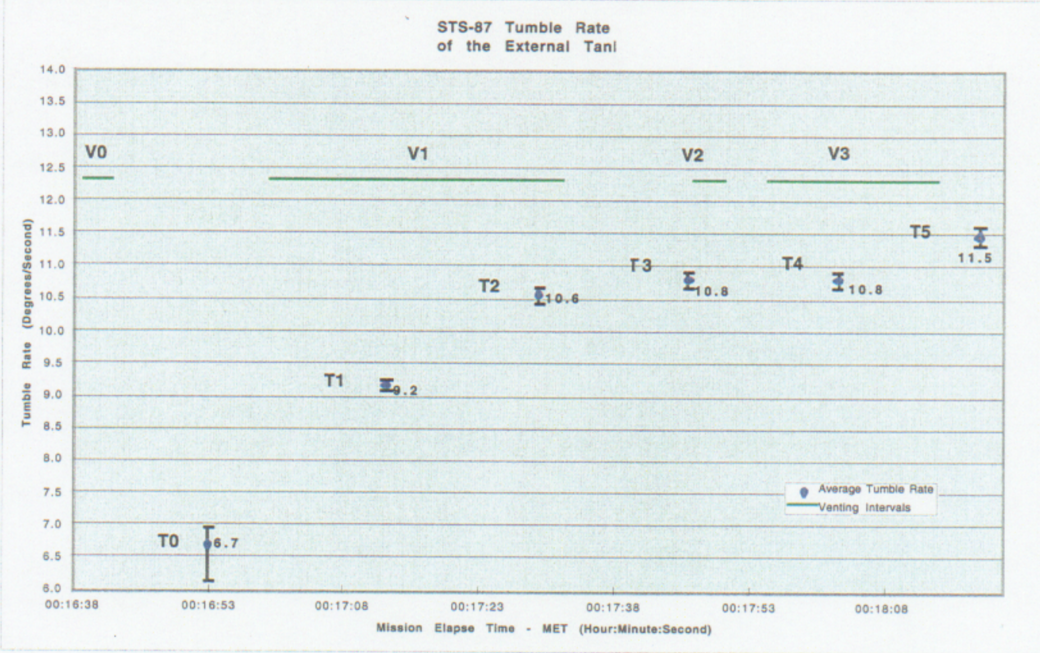

Figure 2.6.1.6 (A) ET Venting and Tumble Rates vs. MET

Figure 2.6.1.6 (A) shows the measured ET tumble rate versus MET. Each data point represents the average tumble rate over the preceding half cycle of ET tumble (180 degrees of rotation), denoted by T1 through T5. For example, for the first full half cycle, T1, the ET tumbled 180 degrees over the time interval from MET 16:52.8 to 17:12.4, for an average tumble rate of 9.2 degrees per second over that interval. The uncertainty in each of the T1 through T5 rates is +/-0.1 degrees per second. The initial average rate, T0, was measured over one quarter cycle of ET rotation, beginning about when the ET was first in view. The larger error bars for T0 (+0.3, -0.6) are due to the relatively poor quality of video at the start of the sequence.

Also shown on Figure 2.6.1.6 (A) are the four observed intervals of near-continuous venting, denoted by events V0 through V3. The most pronounced venting , V1, spans all of T2 and the majority of T1 and coincides with the observed ET angular acceleration over those intervals.

The major venting event, V1 began with an intense burst at 17:00 MET. The intense venting was continuous for at least 20 seconds, then the venting slowly tapered off and ends at MET 17:32. This event accounts for the observed increase in ET tumble rate from an average of approximately 6.7 degrees per second to 10.6 degrees per second, as shown in Figure 2.6.1.6 (A).

Table 2.6.1.6 is a timeline summary of the venting events, showing their correlation with the rate measurement intervals and with time (MET and time relative to the time the ET was first in view). The qualitative properties of the events are in the comments. Of note is the intermittent nature of the venting, as indicated by several very short duration (1 second or less) venting bursts.

2.0 Summary of Significant Events

Half Cycles	MET HRS:MIN:SEC	Relative time (Seconds)	Comments	
	00:16:38	0.0	ET image Acquisition Of Vehicle (AOV) I Film/Video Sync S87-705-	
	00:16:39	1.1	Venting noted (activity noted preceding first ET nose forward	V0
T0 1/4 cycle	00:16:39	1.4	Start of T0 1/4 cycle (ET approximately 90 degrees to the next half	
	00:16:40	2.4	Venting burst to 34:08 then die down	
	00:16:41	3.4	Small burst (3 or 4 frames)	
	00:16:42	3.7	Small burst (3 or 4 frames)	
	00:16:42	4.0	Small burst (2 or 3 frames)	
	00:16:42	4.1	No venting noted	
	00:16:50	12.0	Film/Video Sync S87-705-09	
	00:16:53	14.8	Tip Forward (No Venting)	
T1	00:16:53	14.8	Tip Forward (No Venting)	
	00:17:00	21.6	Major Venting Burst (along camera	V1
	00:17:00	22.0	Film/Video Sync S87-705-12	
	00:17:00	22.2	Big burst dies down but venting	
	00:17:00	22.2	Another big burst(Burst continuous after this)	
	00:17:12	34.0	Film/Video Sync S87-705-15	
	00:17:12	34.4	Aft forward (Large amount of continuous	
T2	00:17:12	34.4	Aft forward (Large amount of continuous	
	00:17:17	39.0	Camera -ET Separation	
	00:17:18	40.0	Film/Video Sync S87-705-17	
	00:17:19	41.0	Camera -ET Separation	
	00:17:25	46.8	Venting lower but continuous	
	00:17:29	51.4	Tip forward (venting at low	
T3	00:17:29	51.4	Tip forward (venting at low	
	00:17:32	54.3	Venting ends	
	00:17:35	57.1	Venting starts	
	00:17:35	57.3	Large Burst	
	00:17:36	58.0	Camera -ET Separation	
	00:17:36	58.3	No Venting observed	
	00:17:37	58.8	ET image Loss of Vehicle (LOV) No venting	
	00:17:43	65.2	ET image AOV (No venting	
	00:17:46	68.1	No venting observed	
T4	00:17:46	68.1	No venting observed	
	00:17:47	68.7	Large venting burst	V2
	00:17:47	68.9	Venting ends	
	00:17:47	69.5	ET image LOV	
	00:17:48	69.6	ET image AOV Large venting	
	00:17:48	69.8	Venting at low level	
	00:17:48	70.1	ET image LOV (Venting observed preceding and following	
	00:17:48	70.3	ET image AOV (venting	
	00:17:49	71.0	ET image LOV	
	00:17:50	71.5	ET image AOV (little to no	
	00:17:50	72.1	No venting	
	00:17:54	75.5	Venting starts	
	00:17:54	76.3	Ventings ends	
	00:17:55	77.0	Venting starts (Large burst) I Camera -ET Separation	V3
	00:17:56	77.9	Ventings ends	
	00:17:56	78.4	Venting starts (Large burst)	
	00:17:57	79.4	Venting reduced but still	
	00:17:58	80.0	Venting (Large burst)	
	00:17:59	81.0	Venting reduced but still	
	00:17:59	81.2	Large burst	
	00:18:00	81.6	Dies down	
	00:18:00	81.8	Burst	
	00:18:00	82.1	Dies down to steady stream-like	
	00:18:03	84.7	Tip forward (Stream	
T5	00:18:03	84.7	Tip forward (Stream	
	00:18:08	90.1	Venting ends	
	00:18:08	90.4	Venting noted (low)	
	00:18:12	94.5	Large burst	
	00:18:14	95.9	Venting ends	
	00:18:14	96.1	Quick puff 3 frames then no	
	00:18:18	100.4	Aft Forward (No venting)	
	00:18:21	103.4	ET loss due to darkness	

Table 2.6.1.6 ET Venting Timeline

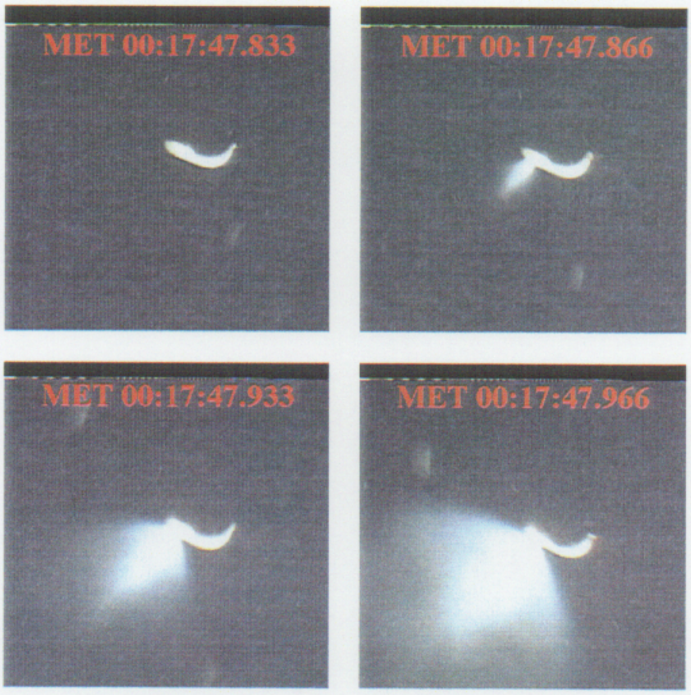

Figure 2.6.1.6 (B) ET Venting

Figure 2.6.1.6 (B) shows venting sequences, that are separated by 1/30th of a second (0.033 seconds). This venting event was identified as a large burst that lasted less than six video frames from MET 17:47.833 through 17:48.033. In Table 2.6.1.6, this venting event was identified in the V2 region.

2.6.1.7 Review of Previous Missions with ET Venting

A review of previous mission records showed that venting from the ET intertank region was previously seen on STS-45 (the intertank venting on STS-45 was insignificant compared to that seen on STS-87). Also, venting from the aft umbilical area of the ET was previously seen on STS-45, STS-53, STS-66, and STS-68. The following is the launch times and inclinations for the missions where ET venting was seen:

STS-45 Launch 08:13 EST, 57 degree inclination.
STS-53 Launch 08:24 EST, 57 degree inclination.
STS-66 Launch 12:00 EDT, 57 degree inclination.
STS-68 Launch 07:16 EDT, 57 degree inclination.
STS-87 Launch 14:46 EST, 28 degree inclination.

2.6.2 On-Orbit Imagery of OMS Pod Damage

On-orbit imagery of the payload bay was screened for views of the OMS pods. The purpose was to document the earliest time the damage found post-landing on the OMS pods was imaged.

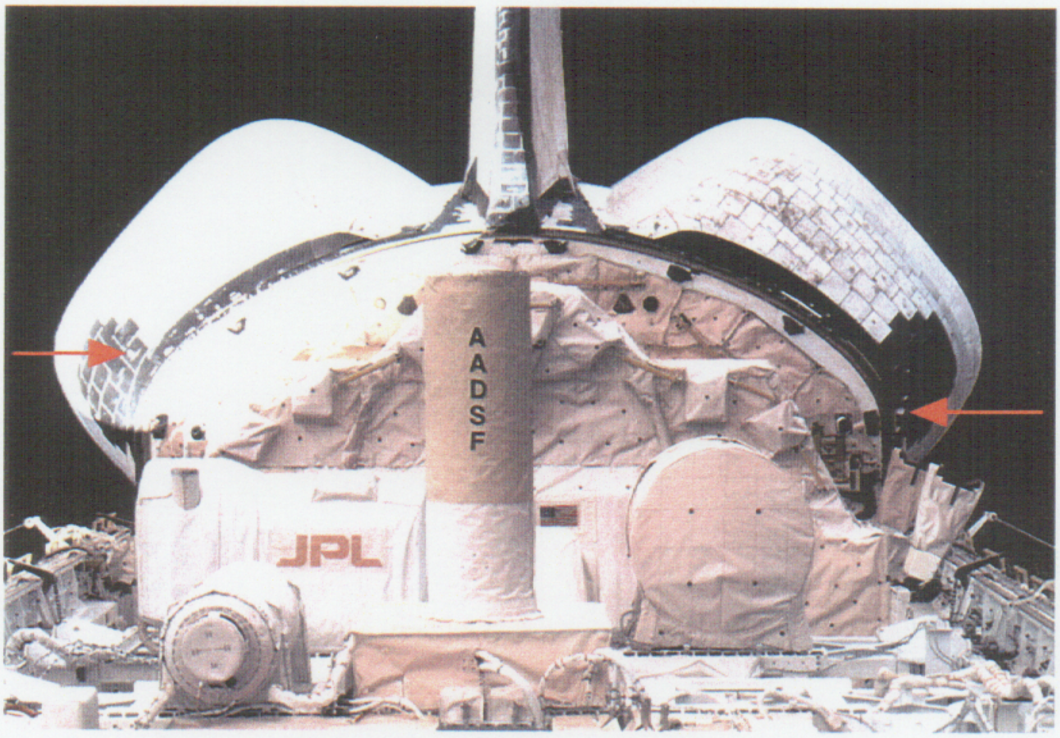

Figure 2.6.2 On-Orbit View of OMS Pod Damage

The OMS pod damage seen post-landing is clearly visible on STS-87 Hasselblad Roll 752, frame 19. This photograph was taken two days prior to landing (December 3, 1997) and confirms that the OMS pod damage did not occur during late on-orbit flight, re-entry, or landing. The on-orbit video taken after launch did not provide an adequate view of the OMS pod for tile damage assessment.

2.6.3 Ground Camera Tracking Views of Shuttle Launch Vehicle

The STS-87 ground based long range tracking camera screening sheets and selected films and videos were reviewed for debris or other evidence that could be related to the damage seen to the ET intertank on the on-board ET handheld photography. None was found. However, clouds intermittently obscured the Shuttle Launch Vehicle during ascent after approximately 57 seconds MET.

2.6.3.1 Intermediate Range Tracking Camera Views of the ET Intertank Region

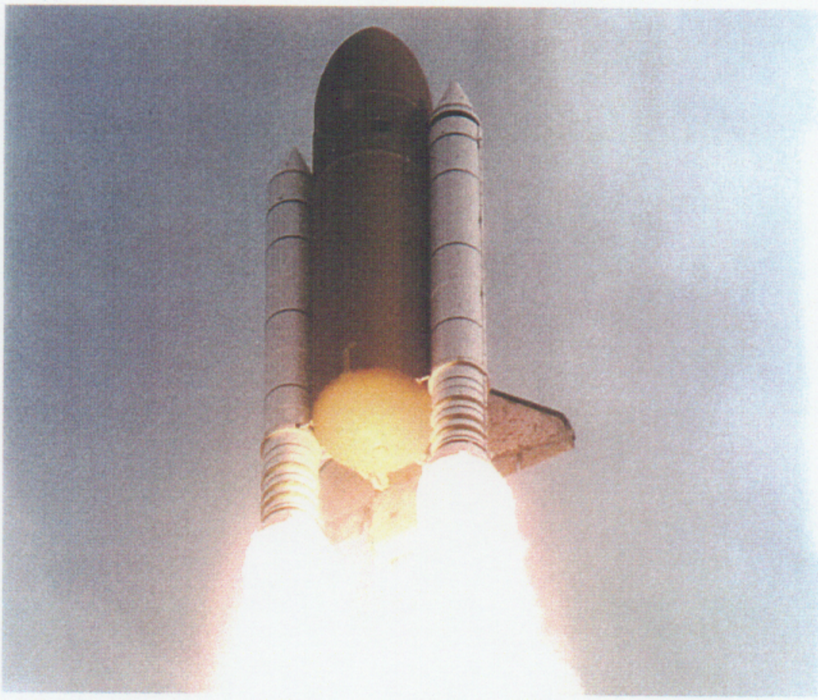

Figure 2.6.3.1 View of ET Intertank after Liftoff

Excellent quality views of the left and right ET intertank thrust panel regions were acquired on the perimeter cameras E54 and E57 at approximately 12 seconds MET. The left and right ET intertank thruster panels were confirmed to be undamaged at approximately 12 seconds MET from these views.

2.6.3.2 Long Range Tracking Camera View of the ET Intertank Region

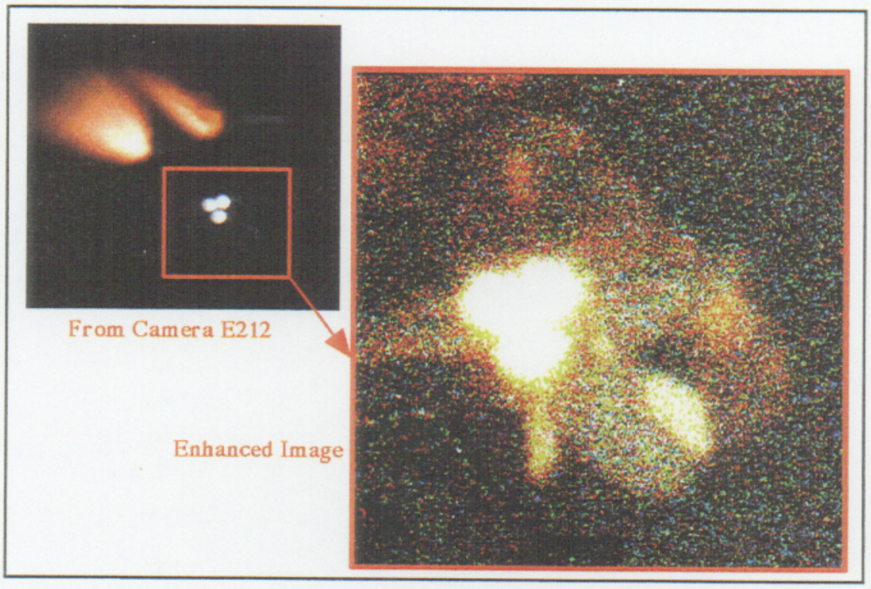

Figure 2.6.3.2 Post SRB Separation View of ET Intertank

The long range tracking camera E212 film imaged the ET intertank region just after SRB separation. However the image resolution was not sufficient to confirm the presence or absence of the intertank thrust panel damage.

2.7 LANDING EVENTS

2.7.1 Landing Sink Rate Analysis

Film camera EL9 was used to determine the landing sink rate of the Orbiter main gear and camera film EL1 was used to determine the nose gear sink rate. The sink rates of the Orbiter were determined over a one-second time period prior to main and nose gear touchdown.

The measured main gear sink rate values were found to be below the maximum allowable values of 9.6 ft/sec for a 211,000 lb vehicle and 6.0 ft/sec for a 240,000 lb vehicle (the landing weight of the STS-87 Orbiter was reported to be 233,089 lb). The sink rate measurements for STS-87 are given in Table 2.7.1. In Figure 2.7.1(A), and 2.7.1(B), the trend of the measured data points for the image data is illustrated.

Sink Rate Prior to Touchdown (1 Second)	
Main Gear	1.1 ft/sec.
Nose Gear	3.1 ft/sec.

Table 2.7.1 Sink Rate Measurements

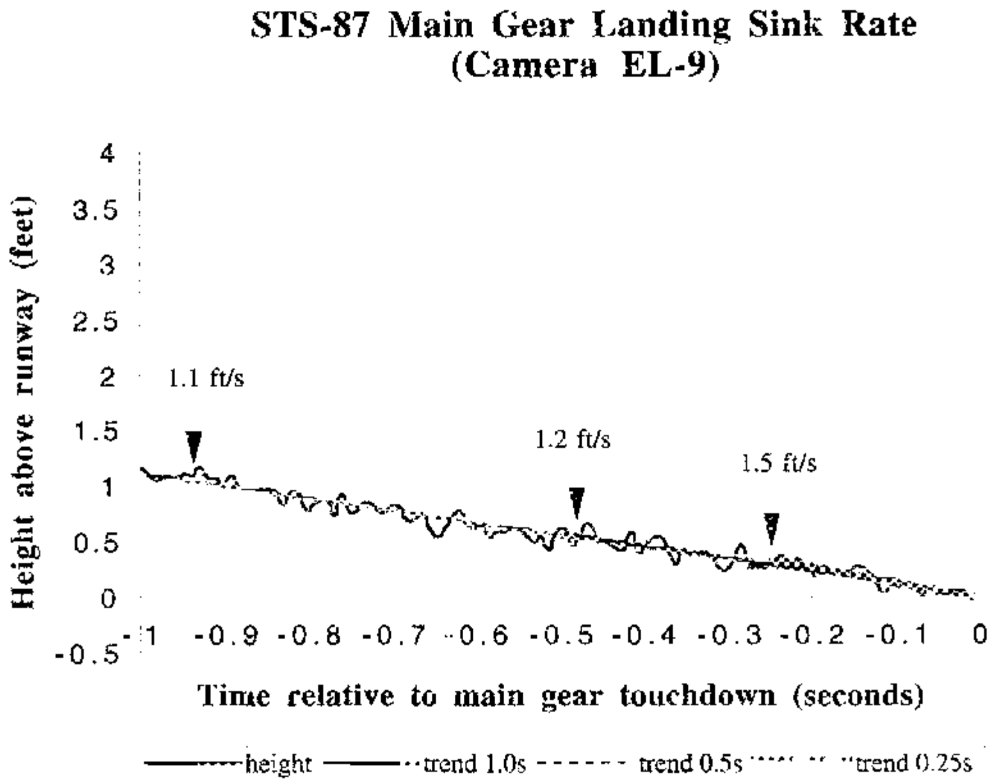

Figure 2.7.1 (A) Main Gear Height versus Time Prior to Touchdown

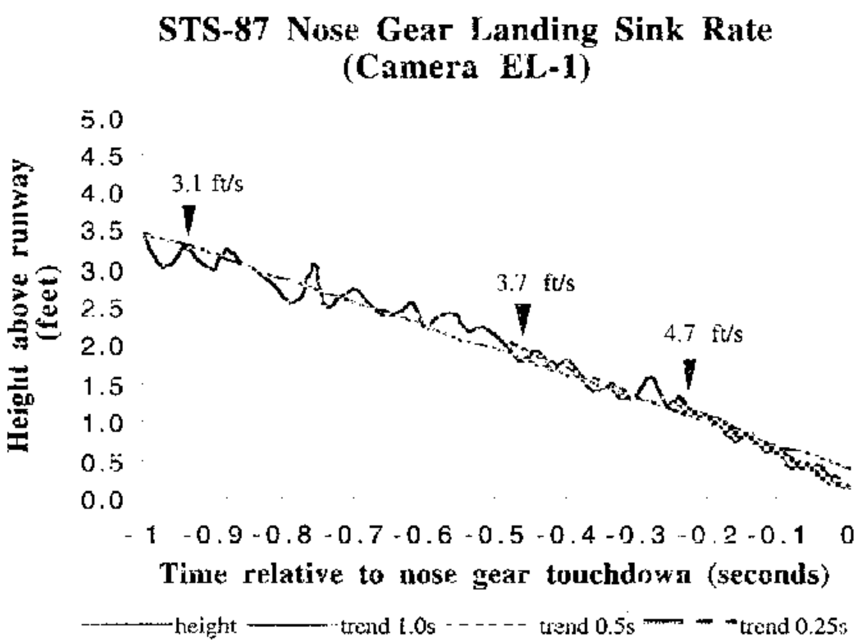

Figure 2.7.1 (B) Nose Gear Height versus Time Prior to Touchdown

2.8 OTHER

2.8.1 Normal Events

Other normal events observed included: ice and vapor from the ET/Orbiter umbilical areas during SSME ignition, elevon motion at SSME ignition, RCS paper debris prior to liftoff, ET twang, multiple pieces of light-colored debris falling from the LH2 and LO2 TSM T-0 umbilicals at disconnect, acoustic waves after liftoff, debris in the exhaust cloud after liftoff, vapor off the SRB stiffener rings, roll maneuver, contrails from the Orbiter wing tips, condensation around the Shuttle Launch Vehicle, ET aft dome outgassing and charring of the ET aft dome, linear optical effects, recirculation, SRB brightening prior to SRB separation, SRB separation, and slag debris during and after SRB separation.

2.8.2 Normal Pad Events

Normal Pad events observed were: Hydrogen ignitor operation, FSS deluge water operation, MLP deluge water activation, sound suppression system water operation, TSM T-O umbilical operations, and GH2 vent arm retraction.

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-87

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

Technical Memorandum-1998 - 206642 February 1998

DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-87

19 November 1997

Contributions By:

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

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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.

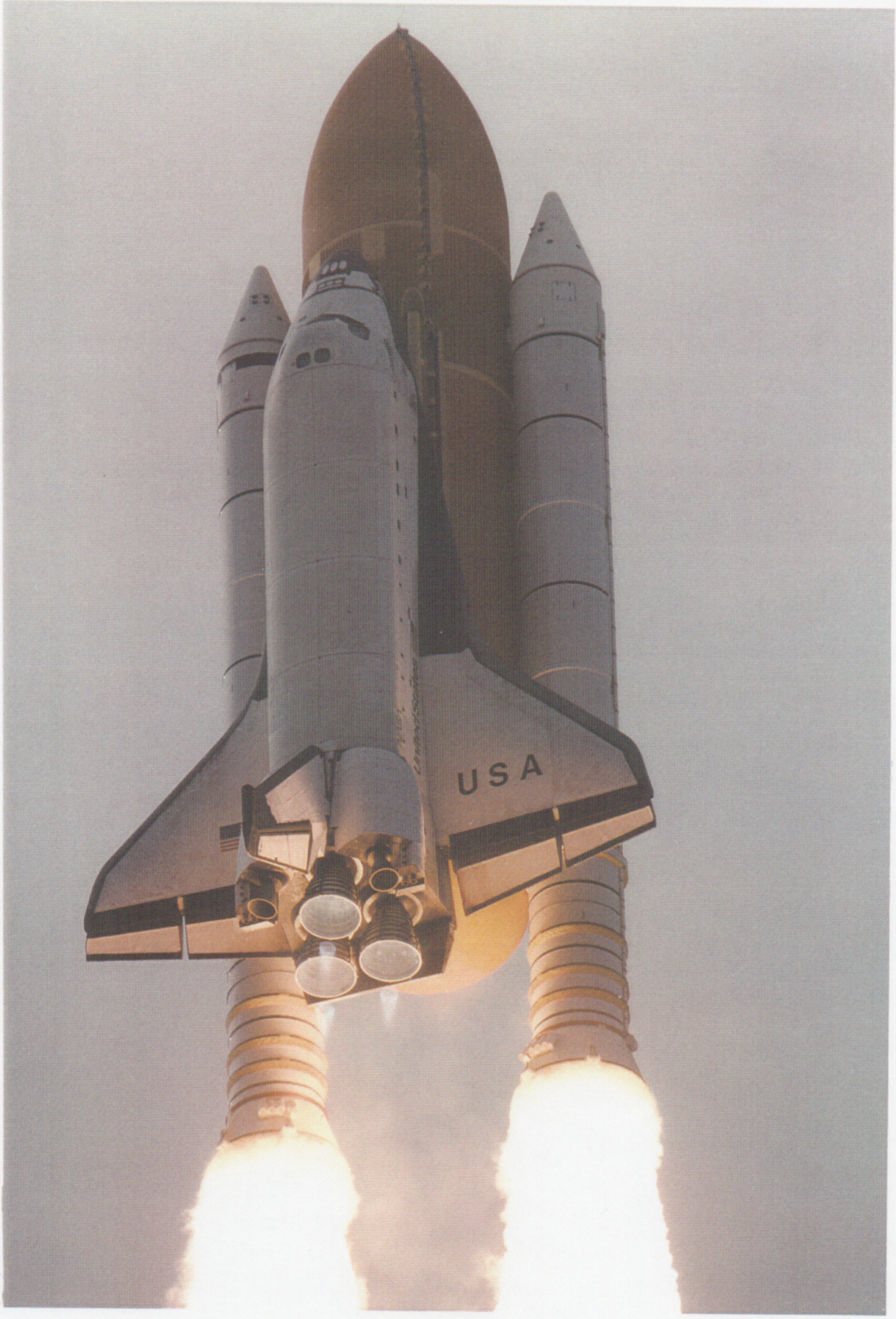


Photo 1: Launch of Shuttle Mission STS-87

1.0 SUMMARY

STS-87, which included the flight elements of OV-102 Columbia (24th flight), ET-89 (LWT 82), and BI-092 SRB's, launched from Pad 39B/MLP-1 on 19 November 1997 at 2:46 p.m. eastern time. Several anomalies and debris issues were documented on this mission.

Post launch inspection of Pad 39B revealed both left and right SRB aft skirt GN2 purge lines were missing approximately 12 inches of tube and flex-line. Typically, the purge lines are bent or deformed by SRB exhaust plume impingement. This was the first occurrence of missing hardware and was considered to be an "out-of-family" condition. The remaining, or lower, part of the line was still attached to the MLP GN2 standpipe supporting structure adjacent to holddown posts #2 and #6. The right flex-line was recovered in an area just north of the SRB flame trench. This flex-line measured 10.5-inches long by 2.25-inches maximum width. The left flex-line was subsequently discovered on or near a holddown post haunch during MLP refurbishment operations. All four rigid components of the GN2 purge lines were recovered, though approximately 90 percent of the stainless steel braided portion of the flex-line was not recovered.

Review of the MLP high speed camera films after launch showed both purge lines extracted smoothly from the SRB aft skirts at liftoff. The lines appeared undamaged and in the upright position for 2.1 seconds, at which time the SRB exhaust plume smoke obscured the view.

Analysis of the recovered components revealed a failure due to the effects of heat damage (melting) from SRB exhaust plume impingement and led the investigation team to conclude the design capability did not withstand the thermal environment. As a result, the GN2 purge line will be redesigned.

During ascent, film and video provided views of a Dome Mounted Heat Shield (DMHS) closeout blanket at the 5:00 o'clock position of SSME #1 starting to tear and unstitch at T+20.5 seconds MET. Air flow and plume recirculation eventually caused the blanket to come loose at T+38.5 seconds MET. The blanket appeared to be lifted in the +Z direction and passed between the SSME #1 nozzle and the drag chute door before falling aft. The streaks aft of the Orbiter in this same time frame are attributed to the blanket passing through the SSME exhaust plumes.

In orbit, still images of the ET after separation from the Orbiter were obtained by the crew. The ET was approximately 1.1 kilometers away when the first still frame was taken. These images showed that substantial amounts of TPS were missing from both ET thrust panels forward and aft of the ET/SRB attach fittings.

The still images and almost two minutes of video footage taken with a camcorder also provided rarely seen views of gaseous hydrogen venting from the 7-inch QD in the intertank. Venting from this location had been observed only once before on STS-45. Since the venting was not visible in the 16mm ET/ORB umbilical films (distance of 200+ feet and time of 49 seconds after separation), this event and any associated debris were judged to have no affect on the Orbiter or be associated with any tile damage. The venting itself is not considered anomalous.

During left SRB aft skirt disassembly at Hangar AF, an Insta-Foam spray nozzle was found embedded in the aft ring foam mid way between the actuators. Technicians recalled the missing nozzle occurrence while performing the spraying operation, but did not find the nozzle after an extensive search. This problem has since been corrected by changing the foam application procedures and devising a nozzle tie-wrap retention system.

A post landing inspection showed the Orbiter tiles sustained a total of 308 hits, of which 132 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 72 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was "out of family".

The Orbiter lower surface sustained at least 244 significant hits, of which 109 had a major dimension of 1-inch or larger. Virtually all of this unusual damage was concentrated in the area between the nose landing gear and the main landing gear more or less symmetrically divided between left and right outboard sides. The largest lower surface tile damage site was located on the left glove. The site measured 15-inches long by 2-inches wide by 0.25-inches deep. The deepest lower surface tile damage site was located just forward of the left main landing gear well. It measured 4-inches long by 2-inches wide by 1.5-inches deep. Tile material in the damage sites showed signs of glazing and heat effects from re-entry. The damage sites with significant depth appeared to be generally aligned in a fore to aft direction. Many of these sites were affected by re-entry aerodynamic erosion.

Unusual tile damage occurred on the lower outboard leading edges of both OMS pods. There were 33 total hits, of which 14 were larger than 1-inch in size.

In order to determine the cause of this damage, the on-orbit films (ET/ORB umbilical cameras and crew hand-held still photographs) were reviewed, and as stated previously, revealed significant loss of TPS from both ET thrust panels - an NSTS-7700 violation and In-Flight Anomaly.

Since the same damage pattern occurred on STS-86, a trend was established that may involve the change to NCFI 24-124 used on the thrust panels. An investigation team is also examining TPS density and strength, structural loads and flexing of the thrust panels, aerodynamic loading, and the flight environment.

As a result of this investigation, plug pull tests to verify material strength were performed on the ET-90 (STS-89) thrust panels. All of the test results were within specification. Nevertheless, the panels were then modified. The foam was machined/sanded to minimum drawing requirements above the rib tops and the rind was removed in the rib valleys to improve the stress/strain capability, eliminate a denser material layer, reduce the amount of potential debris material, and reduce the foam height above the panel ribs to decrease the cross-flow air loading on the foam. All of these measures were designed to eliminate or reduce the amount of TPS loss from the thrust panels, and in turn reduce the amount of damage to Orbiter tiles.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 18 November 1997 at 1400 hours. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

J. Tatum	NASA - KSC	Chief, ET/SRB Mechanical Systems
G. Katnik	NASA - KSC	Shuttle Ice/Debris Systems
J. Lin	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
B. Davis	NASA - KSC	Digital Imaging Systems
R. Page	NASA - KSC	SSP Integration
J. Blue	USA - SPC	ET Mechanical Systems
R. Seale	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	Mechanical Systems
F. Foster	BNA - LSS	Systems Integration
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
J. Burney	USA - Safety	

3.0 LAUNCH

STS-87 was launched at 97:323:19:45:59.993 UTC (2:46 p.m. local) on 19 November 1997.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 18 November 1997. The detailed walkdown of Pad 39B and MLP-1 also included the primary flight elements OV-102 Columbia (24th flight), ET-89 (LWT 82), and BI-092 SRB's. There were no significant vehicle or launch pad anomalies. There were no problems with Orbiter tiles or External Tank TPS.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 19 November 1997 from 0930 to 1055 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Due to the mid-afternoon launch time and warm ambient weather conditions, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

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

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster covers were intact though the cover on thruster F4R was tinted green indicating a slight internal vapor leak. Typical ice/frost and 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.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature supplied by THIO was 68 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. Given the warm, ambient conditions (58-67 degrees Fahrenheit, 78-87 percent relative humidity, winds 6-12 knots at 330 degrees), the program predicted condensate with no ice or frost on the ET acreage TPS.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures ranged from 53 to 57 degrees F.

The intertank acreage exhibited no TPS anomalies. No cracks were visible in the intertank acreage TPS or thrust panels. Foam surface temperatures averaged 65 degrees F. Ice/frost accumulation on the GUCP was less than usual.

The Final Inspection Team observed very light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures ranged from 51 to 58 degrees F. All TPS repairs on the +Z side of the LH2 tank were intact with no visible frost lines.

Ice/frost accumulations in the LO2 feedline bellows and support brackets were characterized as less than usual.

The stress relief crack in the -Y vertical strut forward facing TPS was estimated to be 10-inches long by 3/8-inches wide. The presence of this stress relief crack was expected and acceptable for flight 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 somewhat longer in length than usual. Ice 5-inches long by 3-inches wide by 1-inch thick had formed on the aft pyro can closeout. The presence of this ice was acceptable for launch per the NSTS-08303 criteria.

Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows appeared to be dry.

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

3.2.4 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. No leaks were observed on the GUCP or the LO2 and LH2 Orbiter T-0 umbilicals.

3.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No ice or frost on the acreage TPS was detected. Protuberance icing did not increase noticeably. With the rise 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.

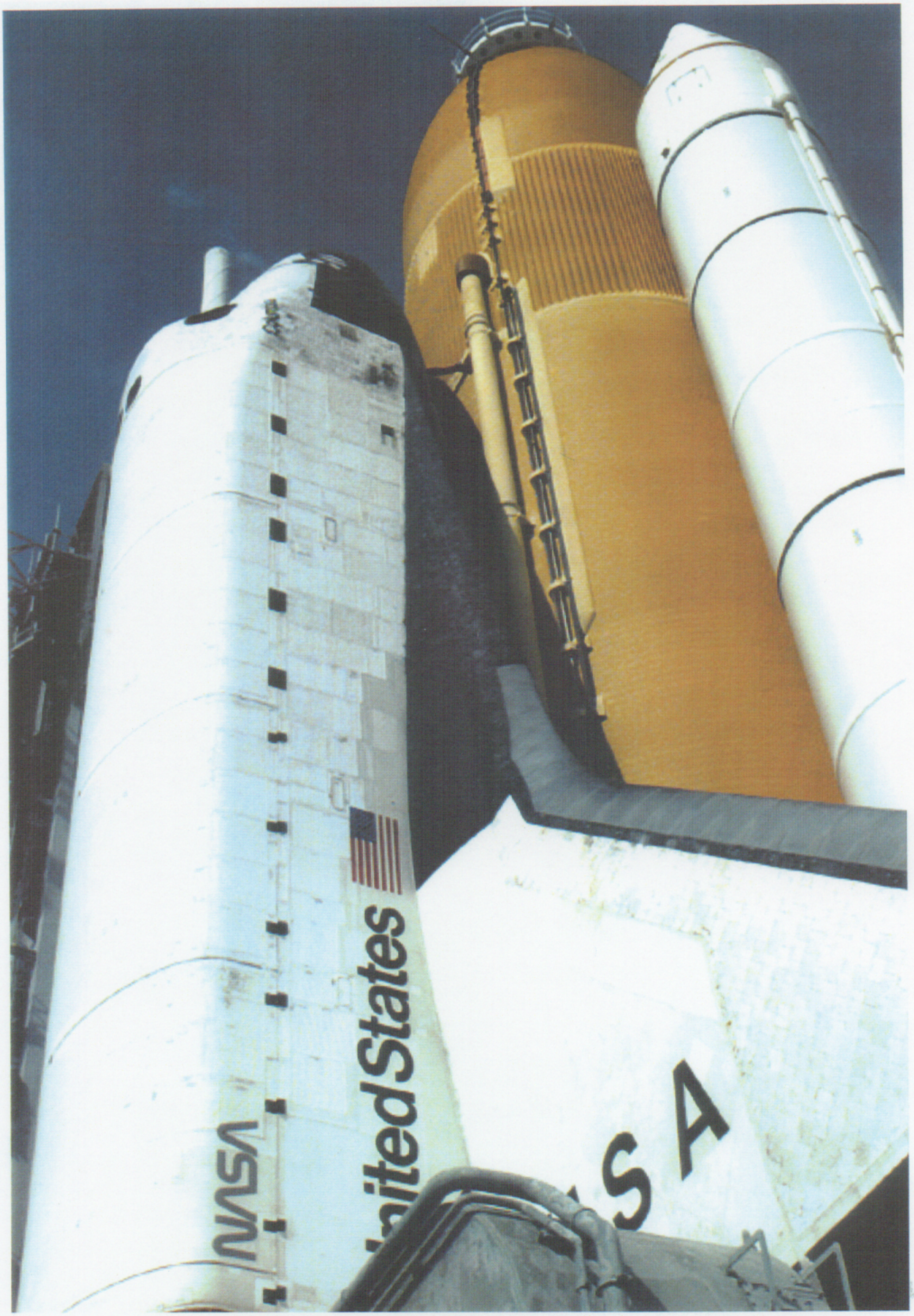


Photo 2: STS-87 Ready for Launch

OV-102 Columbia (24th flight), ET-89 (LWT 82), and BI-092 SRB's

Photo 3: LO2 Tank After Cryoload

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures ranged from 53 to 57 degrees F. No damage to either -Y or +Y ET intertank thrust panel TPS was observed prior to launch.

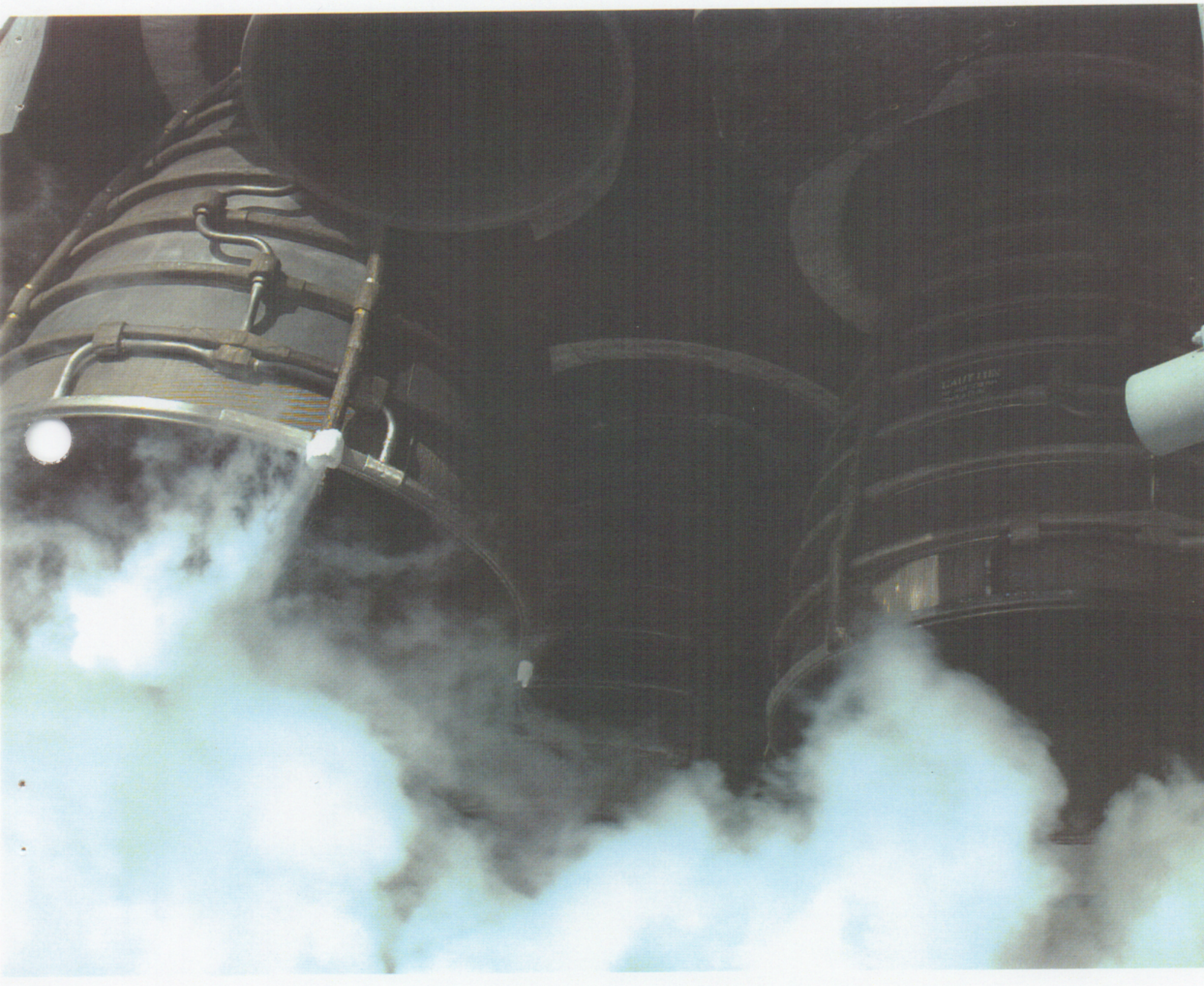


Photo 4: Overall View of SSME's

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 1, Pad B FSS, RSS, and pad apron was conducted on 19 November 1997 from Launch + 1 to 3 hours.

No stud hang-ups occurred on this launch. Boeing - Downey had reported an Orbiter liftoff lateral acceleration of 0.06 g's, which is below the threshold (0.14 g's) for stud hang-ups. SRB hold down post erosion was less than usual. North holddown post blast covers and T-0 umbilicals exhibited typical exhaust plume damage. White RTV was missing from the bases of holddown posts #3, #7, and #8.

Both left and right SRB aft skirt GN2 purge lines (P/N 10185-0018-101) were missing approximately 12 inches of tube and flex-line. Typically, the purge lines are bent or deformed by SRB exhaust plume impingement. This was the first occurrence of missing hardware and was considered to be an "out-of-family" condition (PR PV6332972/D-BI-092L-0003). The remaining, or lower, part of the line was still attached to the MLP GN2 standpipe supporting structure adjacent to holddown posts #2 and #6. The right flex-line was recovered in an area just north of the SRB flame trench. This flex-line measured 10.5-inches long by 2.25-inches maximum width. The left flex-line was subsequently discovered on or near a holddown post haunch during MLP refurbishment operations. All four rigid components of the GN2 purge lines were recovered, though approximately 90 percent of the stainless steel braided portion of the flex-line was not recovered.

Review of the MLP high speed camera films after launch showed both purge lines extracted smoothly from the SRB aft skirts at liftoff. The lines appeared undamaged and in the upright position for 2.1 seconds, at which time the SRB exhaust plume smoke obscured the view.

Analysis of the recovered components revealed a failure due to the effects of heat damage (melting) from SRB exhaust plume impingement and led the investigation team to conclude the design capability did not withstand the thermal environment. As a result, the GN2 purge line will be redesigned.

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

The GH2 vent line was latched in the sixth of eight teeth of the latching mechanism. No damage was apparent on the GUCP 7-inch QD surface from contact with the static retract lanyard. All observations indicated a nominal retraction and latchback, though the GH2 vent line exhibited heat effects/damage from the SRB exhaust plume.

The GOX vent seals were in excellent shape with no indications of plume damage. No topcoat from the External Tank nose cone adhered to the seals. Several pieces of thin sheet metal from the GOX vent arm heated purge ducts were found on the MLP deck and pad surface.

Debris findings were numerous. Nuts, bolts, washers, signs, placards, parts tags, brackets, pieces of fiberglass, RTV, and concrete chips were scattered on the pad surface and in the SSME flame trench. A 7-foot long by 1-foot wide cable tray cover lay in the acreage just east of the pad apron. On the FSS, fire extinguishers lay on the floor of the elevator, the new plastic elevator push buttons were melted, a 2-foot by 1-foot cable tray cover lay on the 135 foot level deck, and white plastic pieces from lighting fixtures were found on many of the levels. A 2-inch spring was found in the MLP west side gutter.

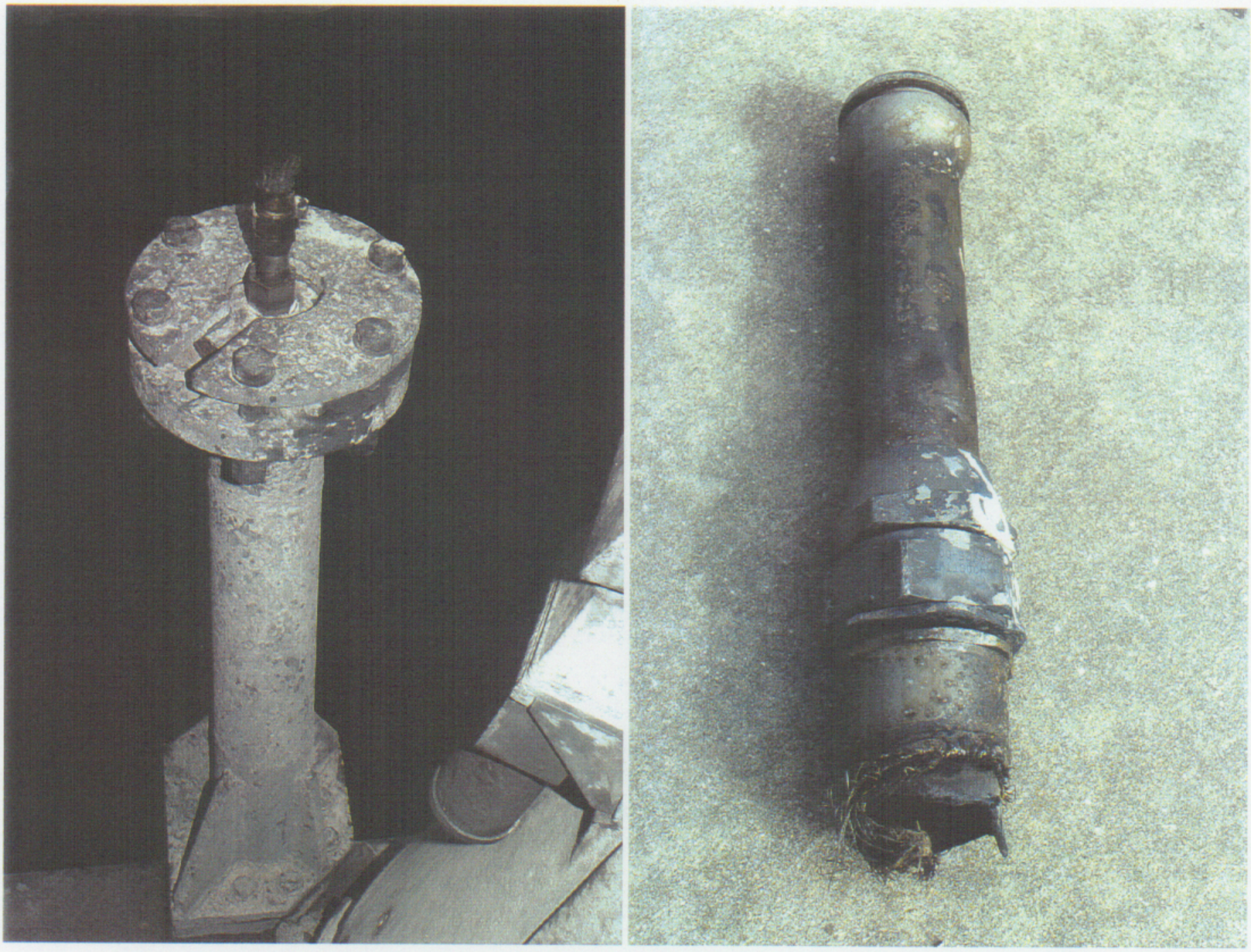


Photo 5: SRB Aft Skirt GN2 Purge Lines

Both left and right SRB aft skirt GN2 purge lines were missing approximately 12 inches of tube and flex-line. Typically, the purge lines are bent or deformed by SRB exhaust plume impingement. This was the first occurrence of missing hardware and was considered to be an "out-of-family" condition. The remaining, or lower, part of the line was still attached to the MLP GN2 standpipe supporting structure adjacent to holddown posts #2 and #6 (left photo). The right flex-line was recovered in an area just north of the SRB flame trench. This flex-line measured 10.5-inches long by 2.25-inches maximum width (right photo). The left flex-line was subsequently discovered on or near a holddown post haunch during MLP refurbishment operations.

5.0 FILM REVIEW

Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. One IFA (STS-87-T-1) was generated as a result of the film review.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 82 films and videos, which included twenty-eight 16mm films, eighteen 35mm films, and thirty-six videos, were reviewed starting on launch day. Due to clouds and atmospheric haze, vehicle detail was sometimes difficult to discern.

Free burning hydrogen drifted up to the OMS pods during start-up before being drawn into the plume by aspiration (OTV-170, TV-7). Film items E-76 and E-63 showed SSME Mach diamonds forming in a 2-3-1 sequence.

SSME ignition caused pieces of ice to fall from the ET/ORB umbilicals. Several pieces of ice contacted the umbilical cavity sills and were deflected outward. No tile damage was visible. Small pieces of ice falling from the LH2 feedline bellows contacted the LH2 recirculation line, but no damage to TPS was visible (OTV-109).

One dark and two light pieces of debris appeared to originate from the right SRB ETA platform on the RSS at 19:45:56.490 UTC. The debris fell south of the MLP and was not near the vehicle (E-63).

Tile surface coating material was lost during ignition from four places on the base heat shield adjacent to and outboard of the SSME #2 engine mounted heat shield (E-18) and two places on the body flap +Z side outboard of SSME #3 (E-76).

No ice or anomalies were detected on the External Tank nose cone (OTV 113, 160, 162).

Numerous small, black pieces of debris (possibly pieces of mud from a wasp nest), appeared to originate from the aft edge of the GUCP just after GH2 vent line disconnect from the ET (E-33). There was no apparent damage to ET TPS.

There were no stud hang-ups. No ordnance debris or frangible nut pieces fell from the DCS/stud holes. The north holddown post blast covers closed normally.

The post launch pad inspection revealed the loss of both left and right SRB aft skirt GN2 purge lines. The left purge line was last visible at T+2.22 seconds MET before being obscured by smoke and exhaust plume (E-8). The right purge line appears to be discernible through smoke until T+2.369 seconds MET (E-13). Note: at T+2.2 seconds, the aft ring of the SRB aft skirt appears to have an altitude of 40-50 feet above the MLP deck. No debris objects that could be associated with the missing purge lines were observed in any of the launch films.

Film item E-213 showed a piece of the ET/ORB umbilical purge barrier fall aft just after completion of the roll maneuver, get caught in air flow recirculation, and travel forward where it contacted and adhered to the base heat shield just outboard of SSME #2. This piece of material fluttered in the air flow the entire time this part of the vehicle was visible. As a result of this odd (and first time) occurrence, some minor tile damage may be expected.

A flash in the SSME exhaust plume occurred at T+17 seconds MET (E-52).

Film item E-207 and video item ET-207 provided the best views of a Dome Mounted Heat Shield (DMHS) closeout blanket at the 5:00 o'clock position of SSME #1 starting to tear and unstitch at T + 20.5 seconds MET. Air flow and plume recirculation eventually caused the blanket to come loose at T + 38.5 seconds MET. The blanket appeared to be lifted in the +Z direction and passed between the SSME #1 nozzle and the drag chute door before falling aft. The streaks aft of the Orbiter in this same time frame are attributed to the blanket passing through the SSME exhaust plumes. Other views of this event were obtained from film items E-213, -220, -222; TV-5, TV-21

Typical movement of the body flap in flight was visible in film items E-207 and E-213.

SRB separation appeared normal (E-212, TV-21).

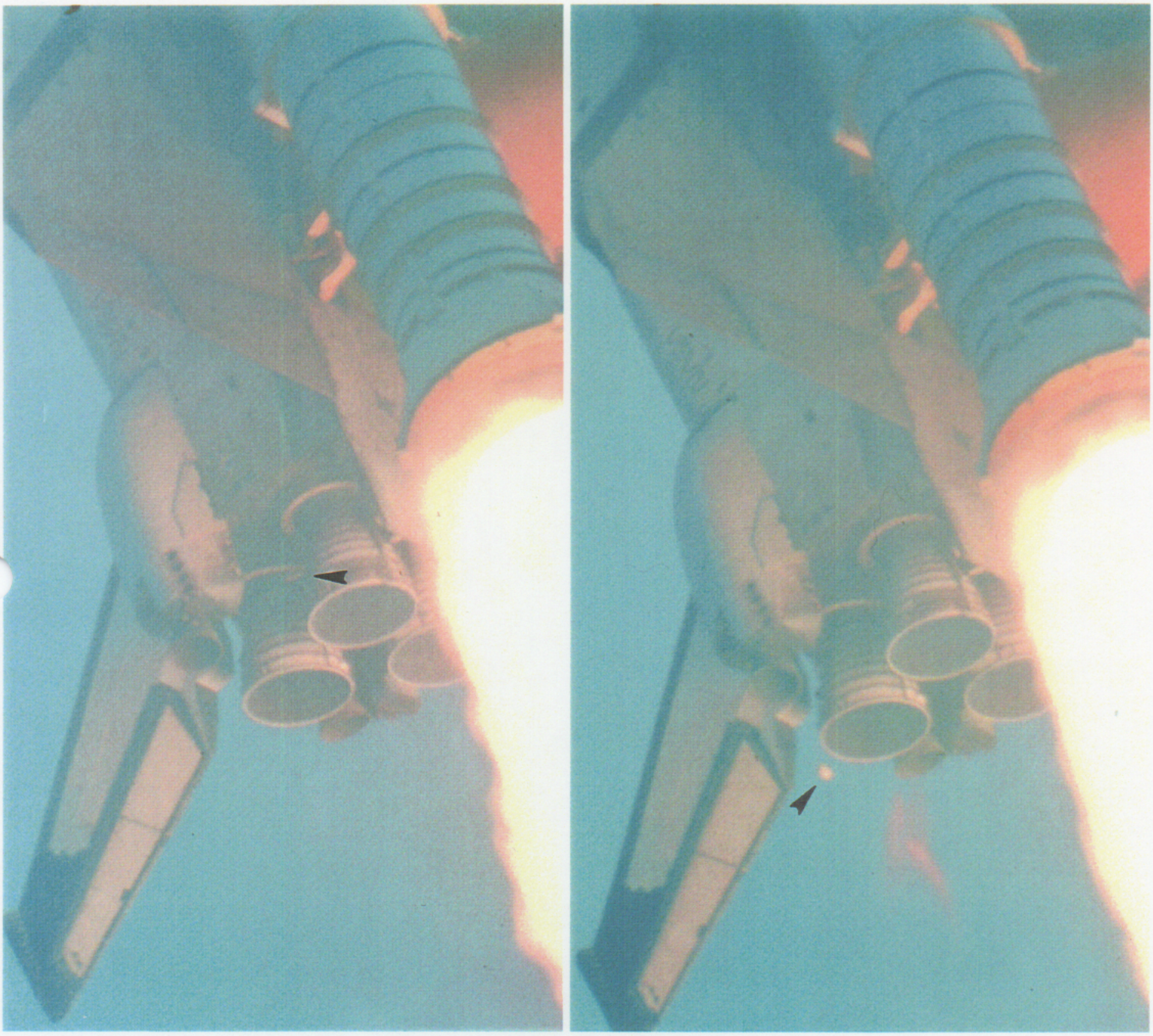


Photo 6: SSME Heat Shield Blanket

Film item E-207 and video item ET-207 provided the best views of a Dome Mounted Heat Shield (DMHS) closeout blanket at the 5:00 o'clock position of SSME #1 starting to tear and unstitch at T + 20.5 seconds MET (left photo). Air flow and plume recirculation eventually caused the blanket to come loose at T + 38.5 seconds MET. The blanket appeared to be lifted in the +Z direction and passed between the SSME #1 nozzle and the drag chute door before falling aft (right photo).

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-102 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. Hand-held photography, which consisted of fifty-three 70mm still images and video footage, was taken by the flight crew. The +X translation was performed on this mission.

LH2 ET/ORB 16mm films

SRB separation from the External Tank appeared normal. The wide angle ET/ORB LH2 umbilical camera provided a view of both SRB forward skirts/frustums/nosecaps during separation. The nosecaps, which are not recovered for post flight inspection at Hangar AF, appeared to be intact and undamaged.

ET-89 separation from the Orbiter was normal. No venting from the GUCP/intertank area was observed in these two films. No significant divots were detected in the LO2, LH2, and intertank acreage. Small, bright spots on the upper LH2 tank near the bipods were associated with sanded repairs, which were documented in the prelaunch closeout photography.

No anomalies were detected on the ET nose cone. A bright spot on the LO2 tank XT-439 pressurization line mount aft of the nose cone was attributed to a large sanded area documented in prelaunch photographs.

Two divots were visible on adjacent intertank stringer heads between the +X aero vent and the RSS antenna. Primed substrate was not visible, indicating shallow divots. Prelaunch photos showed no repairs in this area.

No divots in the intertank splices or the jack pad standoff closeouts were detected in these films though there were seven very small "popcorn" divots on stringer heads forward of the bipods. A light area (lighter than the surrounding foam) could be seen in the shadowed area in the far -Y side of the intertank near the ET/SRB attach fitting and may be indicative of a divot. No such area was documented in prelaunch photos.

Foam on both thrust struts exhibited damage. Eight divots were detected on the -Y thrust strut and flange closeout. Some of these divots were fore-to-aft gouges and gave the appearance of being caused by debris impacts.

L02 ET/ORB 35mm film

The 35mm film from the LO2 ET/ORB umbilical camera consisted of 59 high resolution views of the ET +Z side. The details previously discussed in the 16mm films were verified. The bipod jack pad standoff closeouts were intact. However, numerous divots were visible in the +Y thrust panel TPS forward and aft of the ET/SRB forward attach point (the -Y thrust panel was in shadow and therefore not visible). One 8-inch diameter divot was detected in the LH2 tank-to-intertank flange closeout between the +Y thrust panel and the LO2 feedline. The BSM burn scar on the LO2 tank was typical.

Impact-type damage and fore-to-aft gouges were present in the TPS on the +Y thrust strut, LO2 feedline flange closeouts, and the pressurization line ramps.

The LO2 ET/ORB umbilical appeared to be undamaged, though erosion and divots were visible in the horizontal and vertical sections of the cable tray. "Popcorn" type divots were greater in number on the aft dome and the lower LH2 tank acreage - an expected occurrence with the new (NCFI) foam.

Crew Hand-Held Images

Fifty-three still images of the ET after separation from the Orbiter were obtained by the crew using the 70mm Hasselblad camera. The ET was approximately 1.1 kilometers away when the first still frame was taken. These images showed conclusive proof that substantial amounts of TPS were missing from both ET thrust panels forward and aft of the ET/SRB attach fittings. However, the images could not substantiate the appearance/presence of substrate with primer in the divots.

The still images and almost two minutes of video footage taken with a camcorder also provided rarely seen views of gaseous hydrogen venting from the 7-inch QD in the intertank. Venting from this location had been observed only once before on STS-45. Since the venting was not visible in the 16mm ET/ORB umbilical films (distance of 200+ feet and time of 49 seconds after separation), this event and any associated debris were judged to have no affect on the Orbiter or be associated with any tile damage. The venting itself is not considered anomalous.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 23 films and videos, which included nine 35mm large format films, two 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. The left main landing gear contacted the runway just before the right tire (east of the runway centerline). Touchdown of the nose landing gear was smooth. The Orbiter rolled east of the centerline before being steered back onto the centerline.

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

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

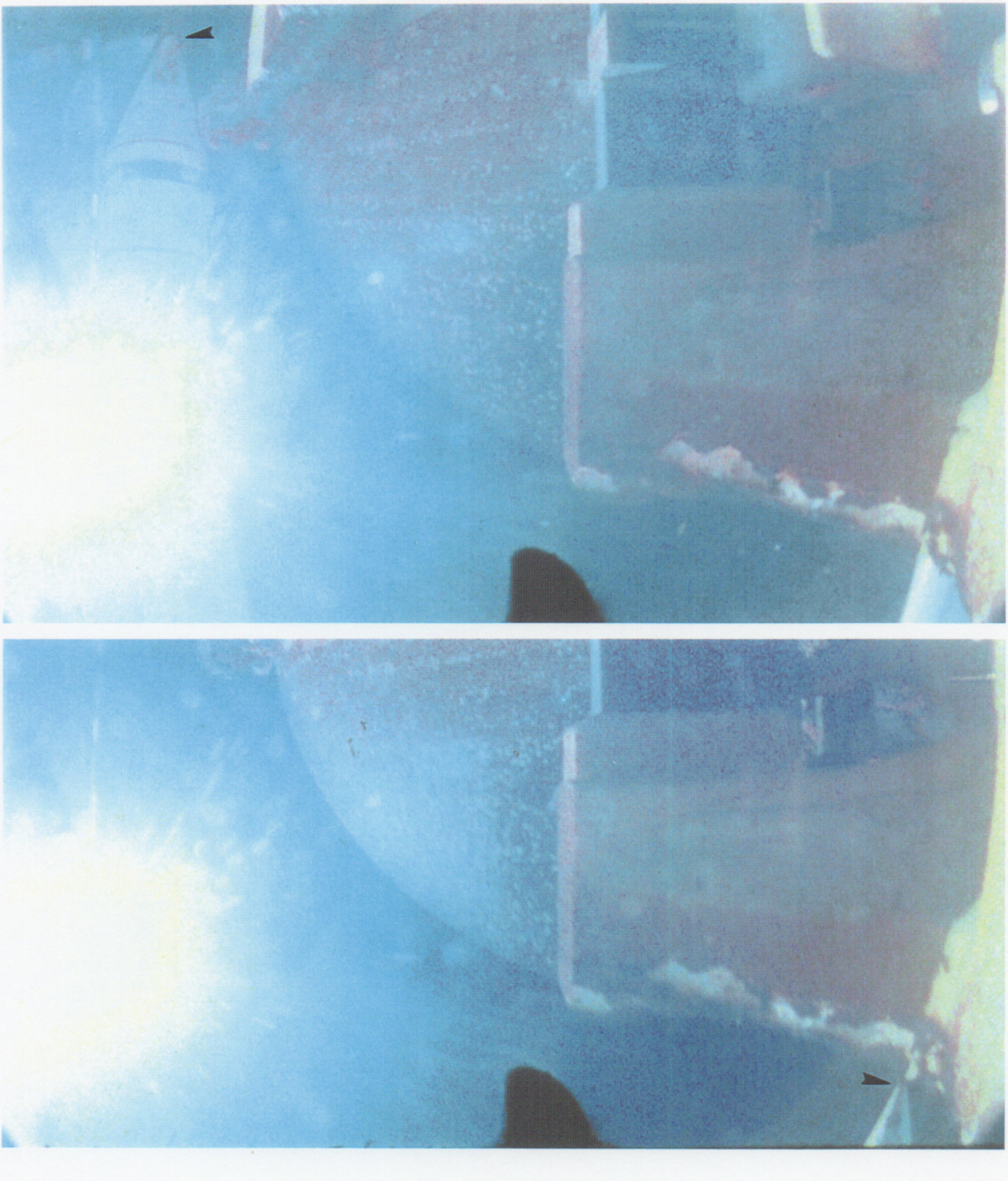


Photo 7: SRB Separation from External Tank

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

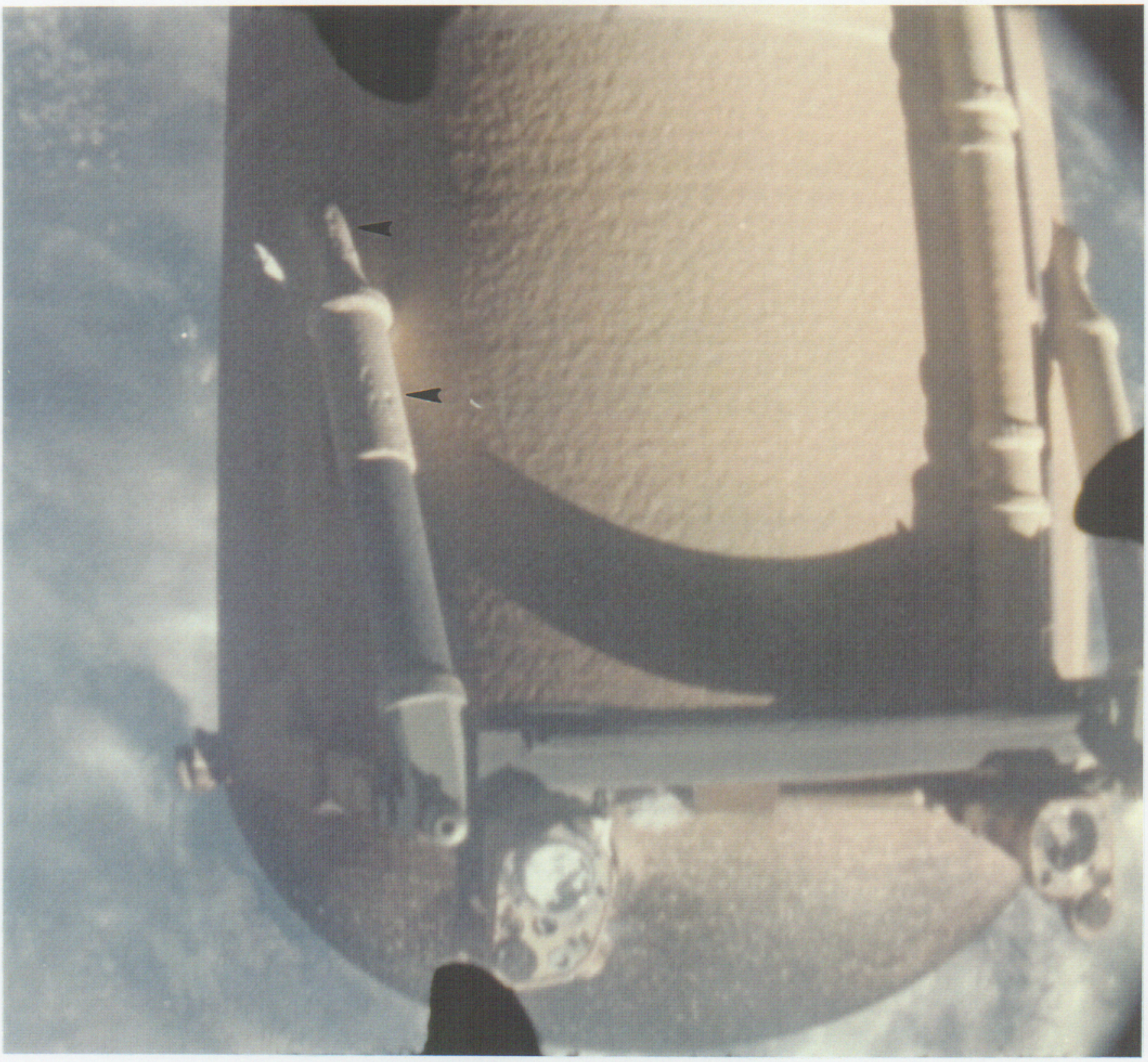


Photo 8: ET Separation from Orbiter

ET-89 separation from the Orbiter was normal. Foam on both thrust struts exhibited damage. Eight divots were detected on the -Y thrust strut and flange closeout. Some of these divots were fore-to-aft gouges and gave the appearance of being caused by debris impacts.

Photo 9: View from 35mm Umbilical Camera

Impact-type damage and fore-to-aft gouges were present in the TPS on the +Y thrust strut (1), LO2 feedline flange closeouts (2), and the pressurization line ramps (3). The LO2 ET/ORB umbilical appeared to be undamaged, though erosion and divots were visible in the horizontal (4) and vertical (5) sections of the cable tray. "Popcorn" type divots were greater in number on the aft dome and the lower LH2 tank acreage - an expected occurrence with the new (NCFI) foam.

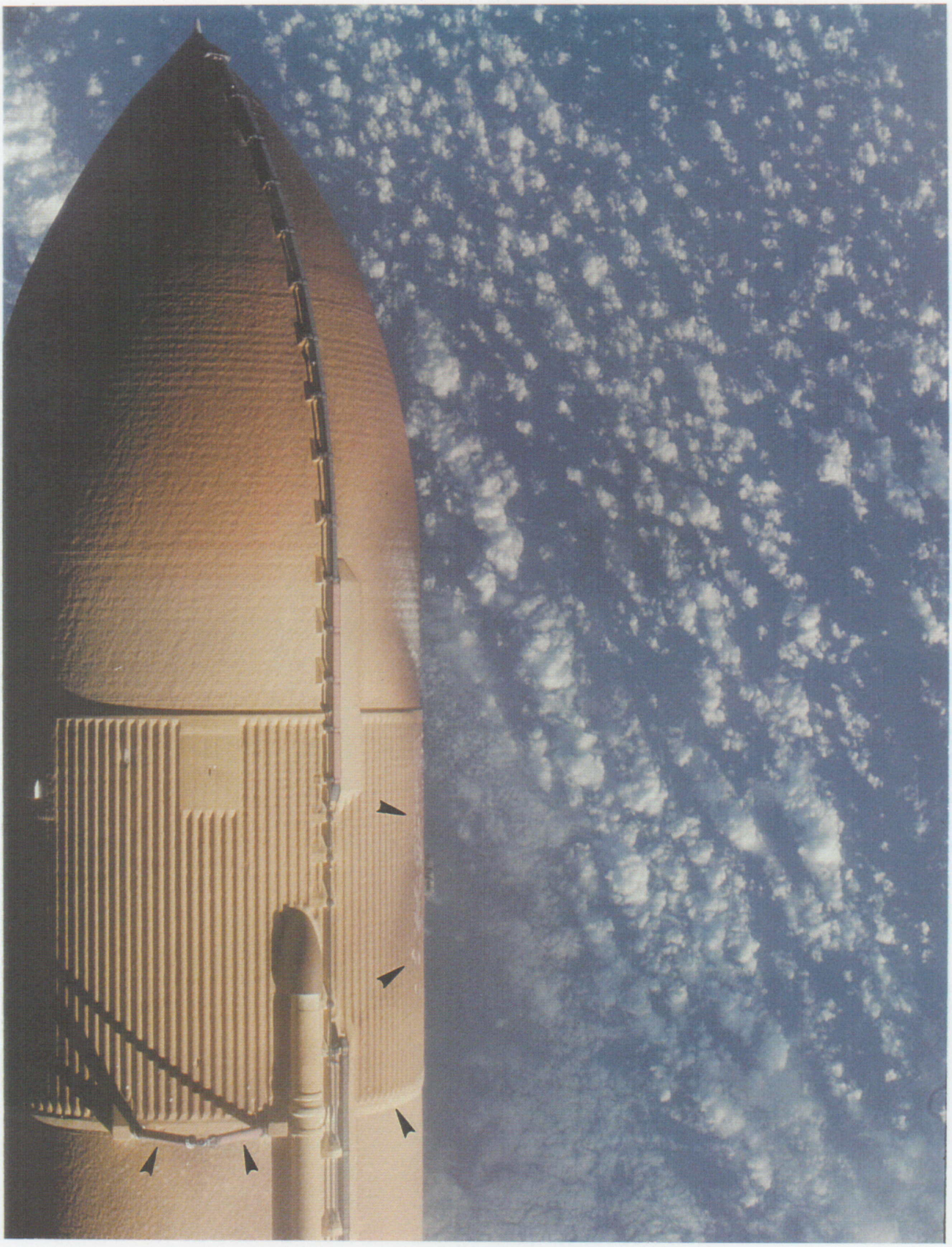


Photo 10: Thrust Panel Foam Damage

The bipod jack pad standoff closeouts were intact. However, numerous divots were visible in the +Y thrust panel TPS forward and aft of the ET/SRB forward attach point (the -Y thrust panel was in shadow and therefore not visible). One 8-inch diameter divot was detected in the LH2 tank-to-intertank flange closeout between the +Y thrust panel and the LO2 feedline. The BSM burn scar on the LO2 tank was typical.

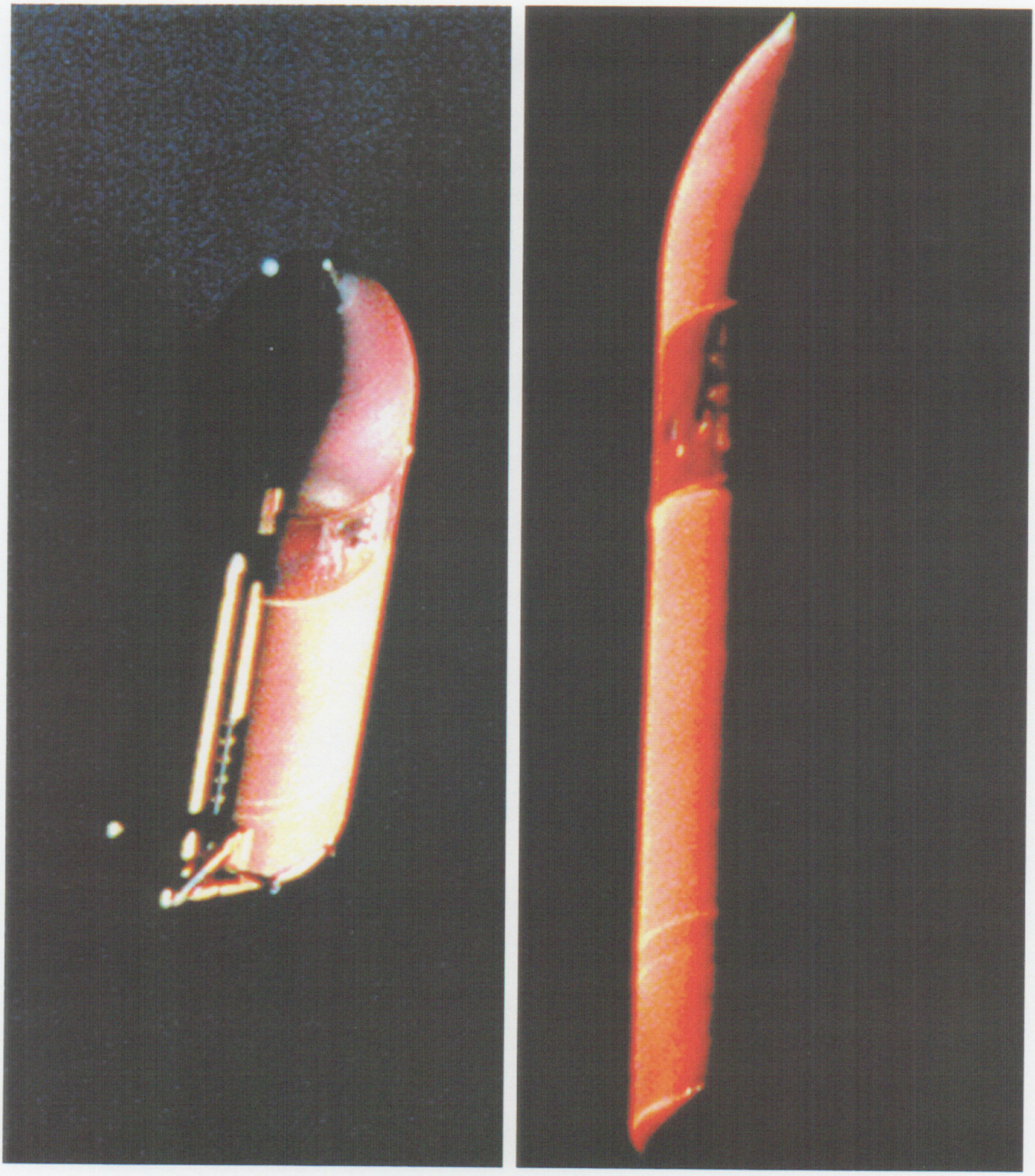


Photo 11: Crew Hand-Held Still Images

Still images of the ET after separation from the Orbiter were obtained by the crew using the 70mm camera. The ET was approximately 1.1 kilometers away when the first still frame was taken. These images showed conclusive proof that substantial amounts of TPS were missing from both ET thrust panels forward and aft of the ET/SRB attach fittings.

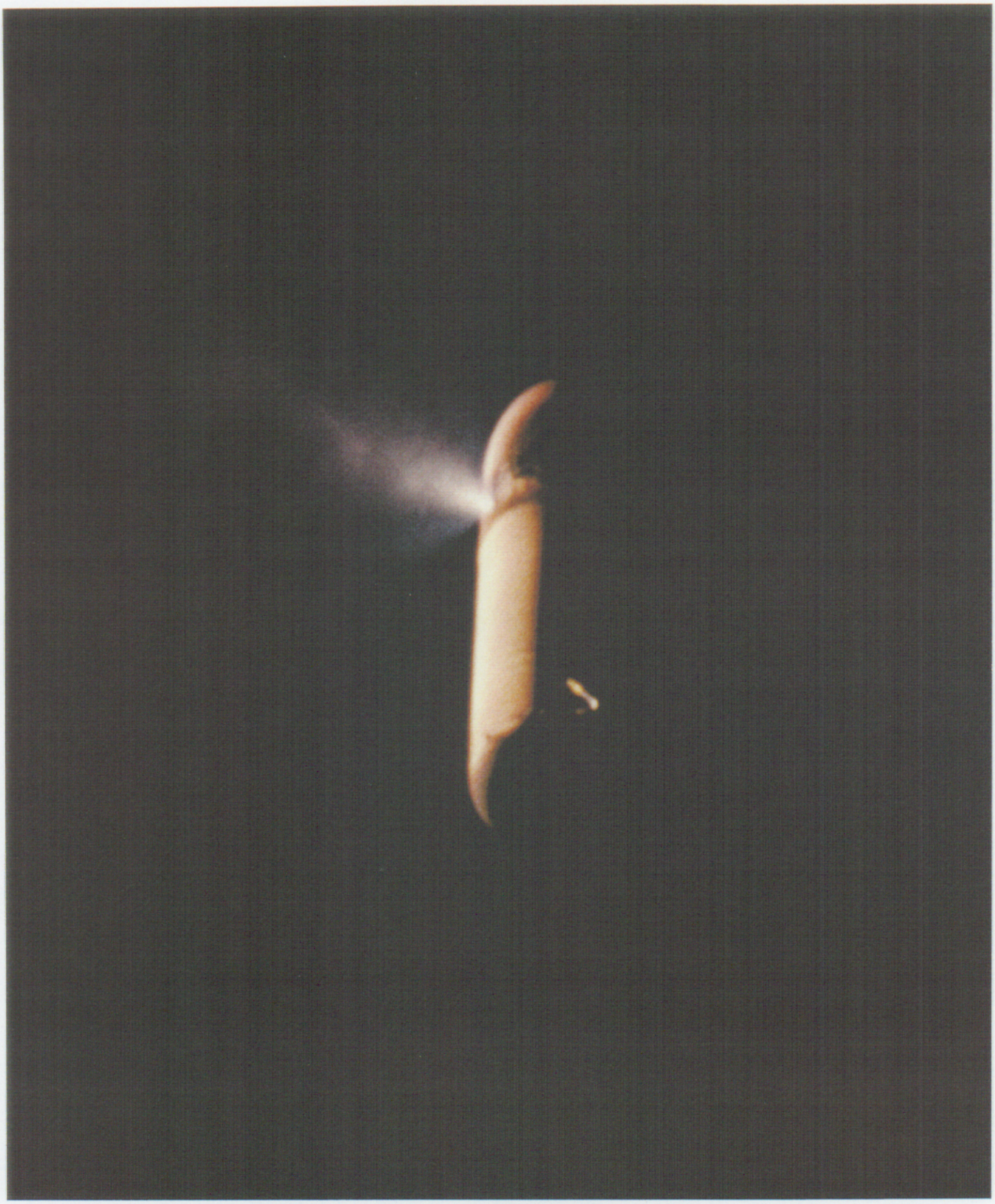


Photo 12: Gaseous Hydrogen Venting

A rarely seen view of gaseous hydrogen venting from the 7-inch QD in the intertank. Venting from this location had been observed only once before on STS-45. Since the venting was not visible in the 16mm ET/ORB umbilical films (distance of 200+ feet and time of 49 seconds after separation), this event and any associated debris were judged to have no affect on the Orbiter or be associated with any tile damage. The venting itself is not considered anomalous. Note damage to TPS on nearby intertank thrust panel.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-092 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 24 November 1997.

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners. Virtually none of the Hypalon paint had blistered. All eight BSM aero heat shield covers had locked in the fully opened position though the attach rings on three of the four covers on the left frustum had been bent to varying degrees by parachute riser entanglement. Note: a configuration change had been made to the right frustum. The PR-1422 sealant/cap closeouts had been eliminated from the majority of the fastener heads prior to the application of ablator. There were no debonds, unbonds, or missing TPS associated with this change.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. 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. The stiffener rings, ETA rings, and IEA's appeared undamaged by water impact. TPS on the external surface of both aft skirts was intact and in good condition. During left aft skirt disassembly at Hangar AF, an Insta-Foam spray nozzle was found embedded in the aft ring foam mid way between the actuators. Technicians recalled the missing nozzle occurrence while performing the spraying operation, but did not find the nozzle after an extensive search. This problem has since been corrected by changing the foam application procedures and devising a nozzle tie-wrap retention system.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally. However, the HDP #2 DCS plunger was not fully seated though there was no visible obstruction. The HDP #3 DCS plunger also was not seated and was obstructed by a frangible nut piece. There were no stud hang-ups on this launch.

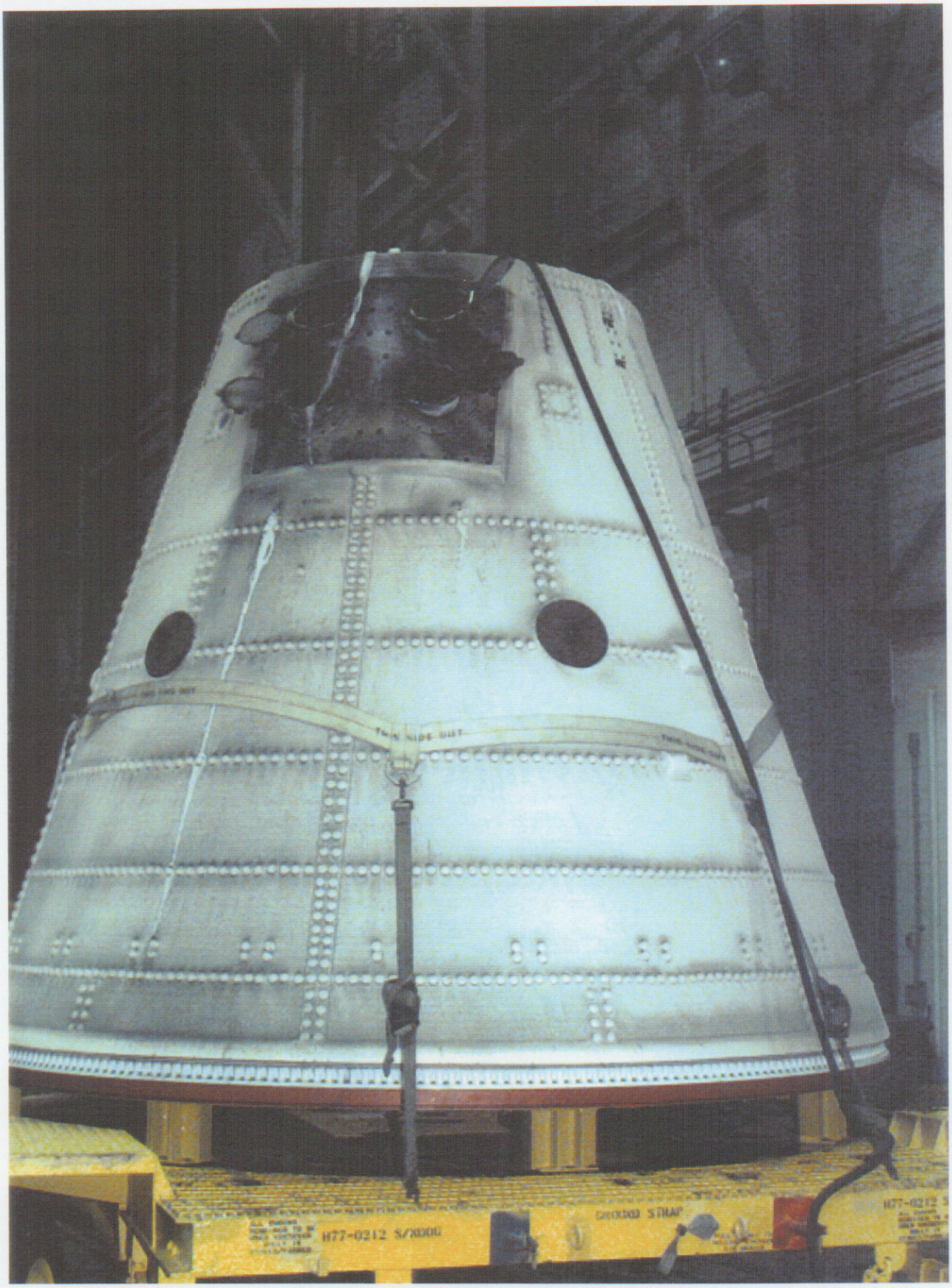


Photo 13: Frustum Post Flight Condition

Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners. Virtually none of the Hypalon paint had blistered. All eight BSM aero heat shield covers had locked in the fully opened position though the attach rings on three of the four covers on the left frustum had been bent to varying degrees by parachute riser entanglement.

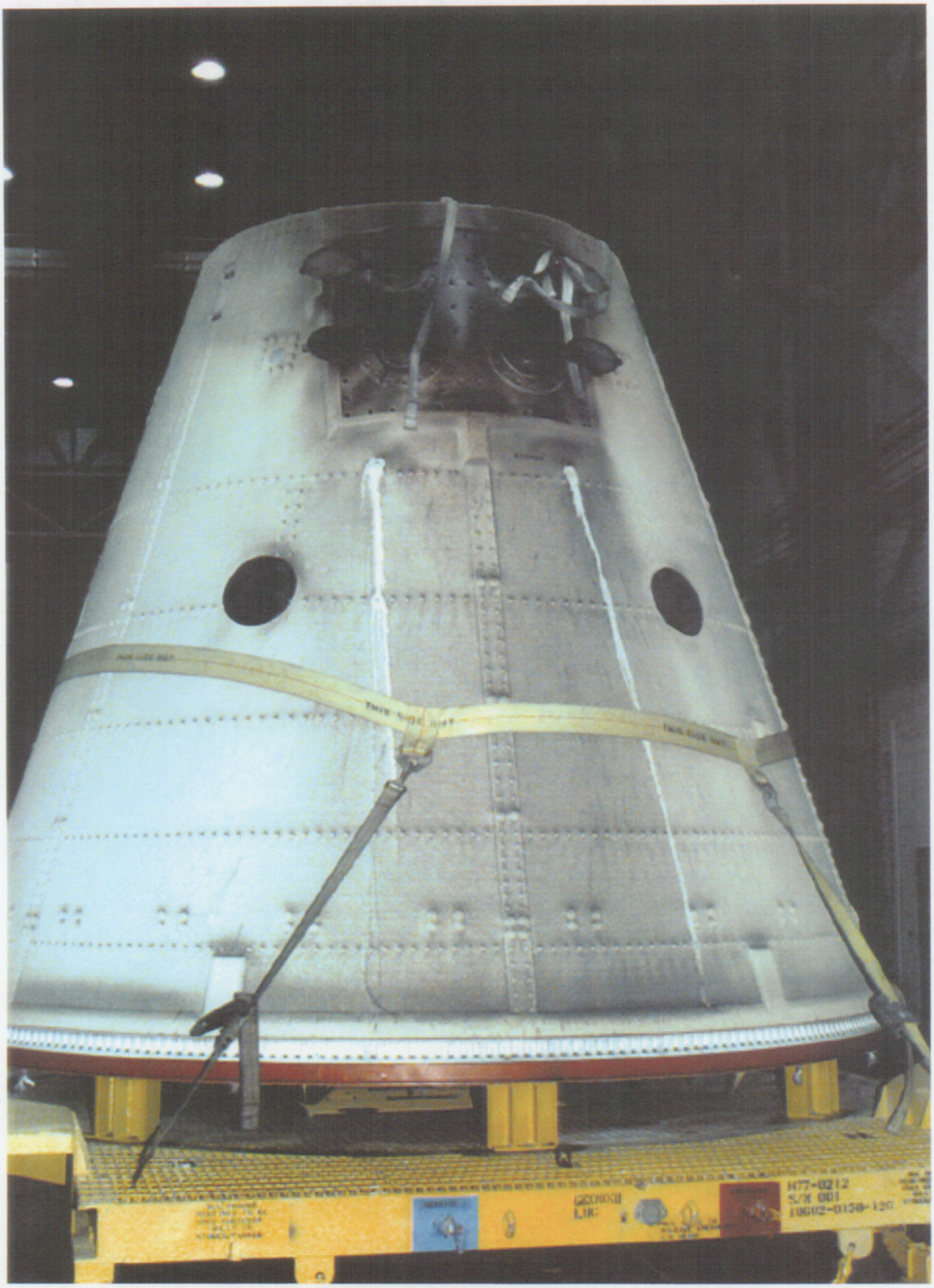


Photo 14: Frustum Configuration Change

A configuration change had been made to the right frustum. The PR-1422 sealant/cap closeouts had been eliminated from the majority of the fastener heads prior to the application of ablator. There were no debonds, unbonds, or missing TPS associated with this change.

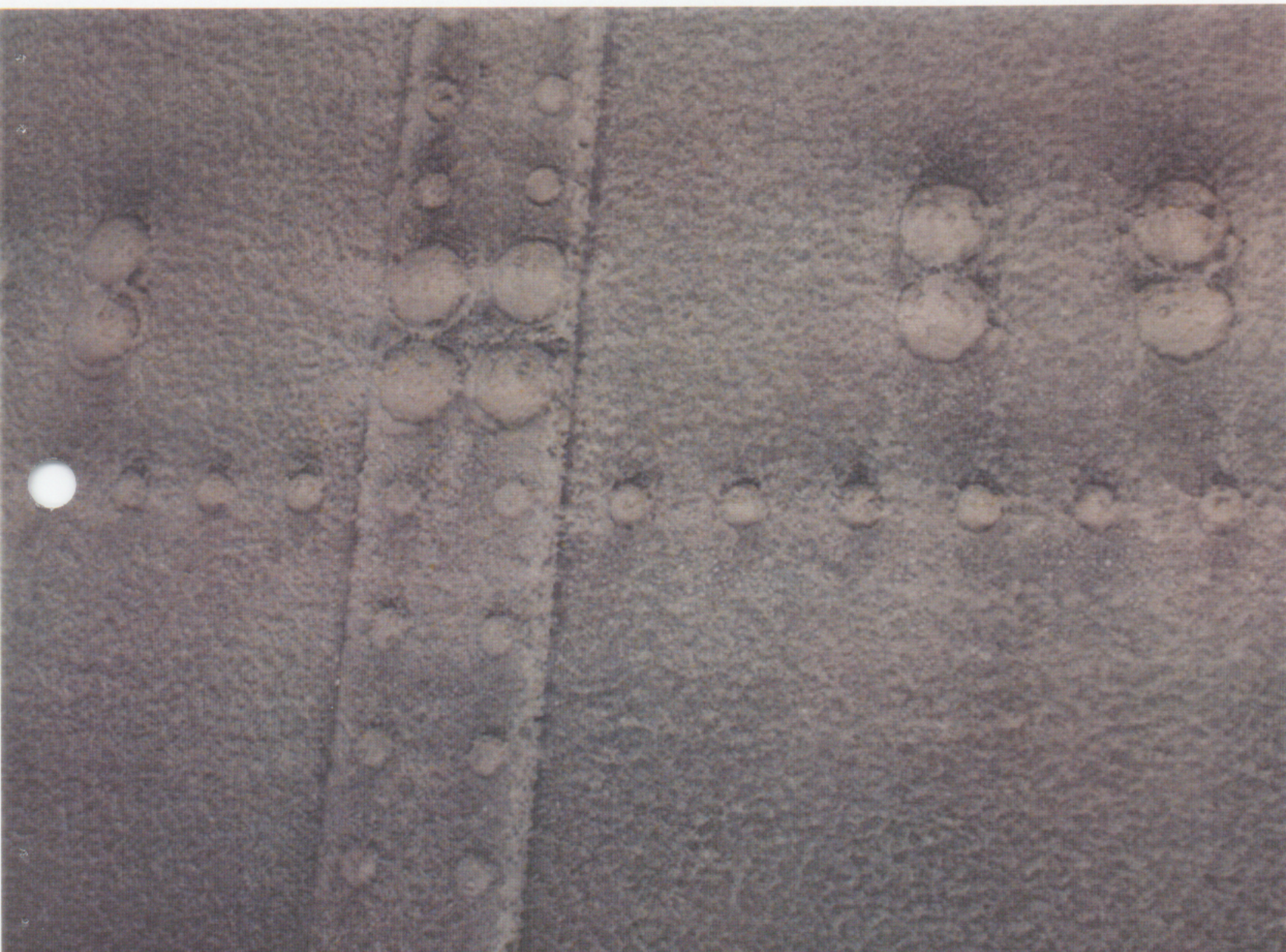


Photo 15: Elimination of Sealant/Cap Closeout

Close-up view of fastener heads covered by TPS.
Note ten PR-1422 sealant/cap closeouts for comparison.

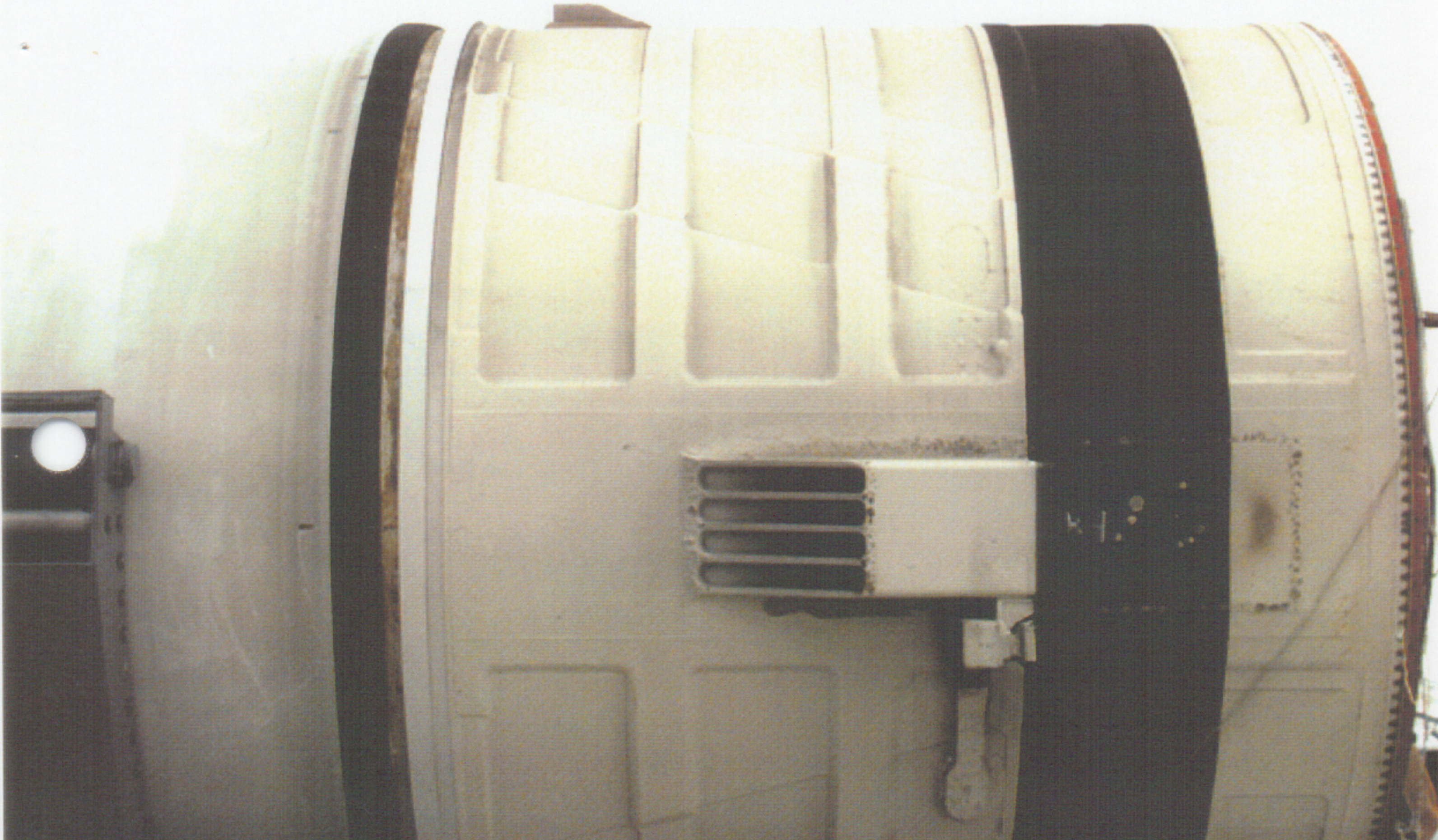


Photo 16: Forward Skirt Post Flight Condition

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. 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 17: Aft Booster/Aft Skirt Post Flight Condition

Separation of the aft ET/SRB struts appeared normal. The stiffener rings, ETA rings, and IEA's appeared undamaged by water impact. TPS on the external surface of both aft skirts was intact and in good condition.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-102 Columbia was conducted after the 7:20 a.m. eastern time landing 5 December 1997, on the Kennedy Space Center SLF runway 33 and in the Orbiter Processing Facility bay #3. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 308 hits, of which 132 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 72 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates both the total number of hits and the number of hits 1-inch or larger was "out of family" (reference Figures 1-4).

The following table breaks down the STS-87 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	109	244
Upper surface	0	7
Right side	5	6
Left side	3	4
Right OMS Pod	7	13
Left OMS Pod	7	20
Window Area	1	14
TOTALS	132	308

The Orbiter lower surface sustained at least 244 significant hits, of which 109 had a major dimension of 1-inch or larger. Virtually all of this unusual damage was concentrated in the area between the nose landing gear and the main landing gear more or less symmetrically divided between left and right outboard sides. The largest lower surface tile damage site was located on the left glove. The site measured 15-inches long by 2-inches wide by 0.25-inches deep. The deepest lower surface tile damage site was located just forward of the left main landing gear well. It measured 4-inches long by 2-inches wide by 1.5-inches deep. Tile material in the damage sites showed signs of glazing and heat effects from re-entry. The damage sites with significant depth appeared to be generally aligned in a fore to aft direction. Many of these sites were affected by re-entry aerodynamic erosion.

Unusual tile damage occurred on the lower outboard leading edges of both OMS pods. There were 33 total hits, of which 14 were larger than 1-inch in size. However, there was no significant tile damage on the leading edge of the vertical stabilizer.

In order to determine the cause of this damage, the on-orbit films (ET/ORB umbilical cameras and crew hand-held still photographs) were reviewed and revealed significant loss of TPS from both ET thrust panels - an NSTS-7700 violation and IFA (STS-87-T-1). Although numerous samples were taken from tile damage sites on the Orbiter lower surface and two sites on the OMS pods for chemical analysis, the results were inconclusive.

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

The tires, which exhibited some ply undercutting on the right main inboard tire, were reported to be in good 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 SSME #2 and #3 Dome Mounted Heat Shield (DMHS) closeout blankets were in good condition. However, the blanket panels on SSME #1 at the 4-6:00 o'clock position were missing. The underlying batting material was torn and frayed. Loss of this material in flight was detected in the launch tracking films at T+39 seconds MET.

Some very small holes, or damage sites, were detected on the leading edges of right wing RCC panels #11 and #19.

Hazing and streaking of forward-facing Orbiter windows was less than usual. Damage sites on the window perimeter tiles was noticeably less than usual in quantity and size.

The post landing walkdown of Runway 33 was performed immediately after landing. No debris concerns were identified. All drag chute hardware was recovered and appeared to have functioned normally. The 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 "out of family" when compared to previous missions (reference Figures 5 and 6). Since the same damage pattern occurred on STS-86, a trend was established that may involve the change to NCFI 24-124 used on the thrust panels. An investigation team is also examining TPS density and strength, structural loads and flexing of the thrust panels, aerodynamic loading, and the flight environment.

As a result of this investigation, plug pull tests to verify material strength were performed on the ET-90 (STS-89) thrust panels. All of the test results were within specification. Nevertheless, the panels were then modified. The foam was machined/sanded to minimum drawing requirements above the rib tops and the rind was removed in the rib valleys to improve the stress/strain capability, eliminate a denser material layer, reduce the amount of potential debris material, and reduce the foam height above the panel ribs to decrease the cross-flow air loading on the foam. All of these measures were designed to eliminate or reduce the amount of TPS loss from the thrust panels, and in turn reduce the amount of damage to Orbiter tiles.

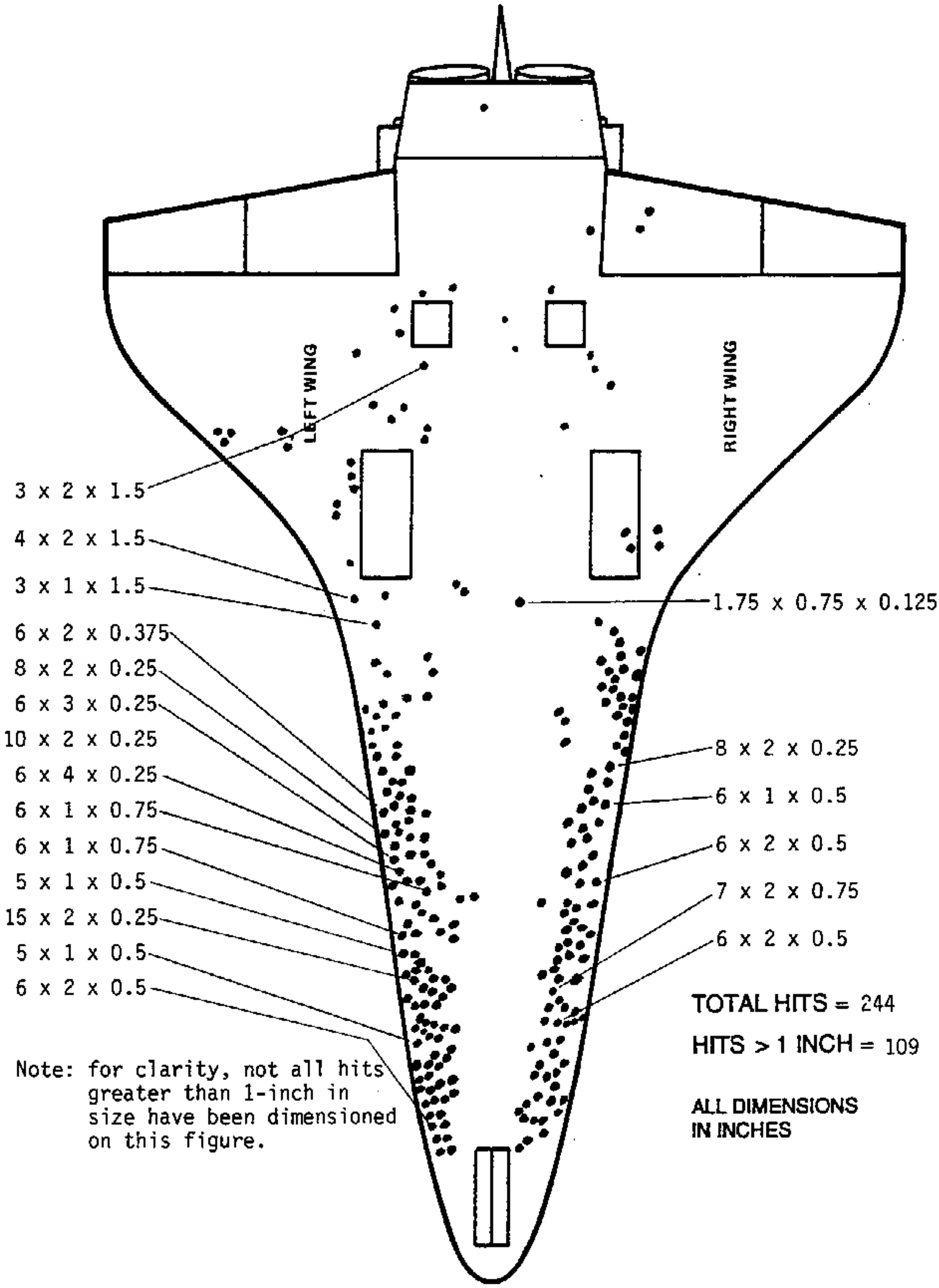


Figure 1: Orbiter Lower Surface Debris Damage Map

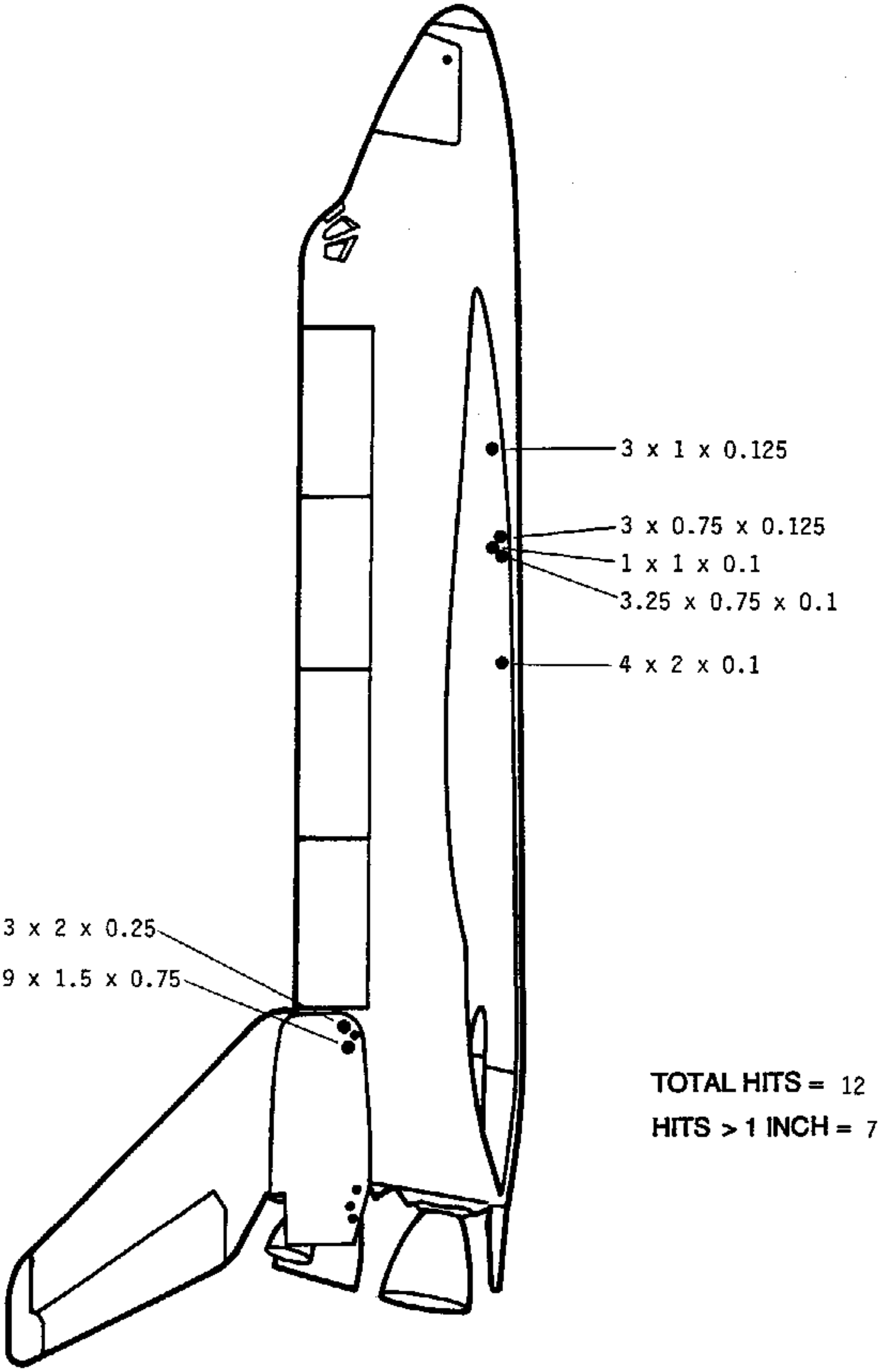


Figure 2: Orbiter Left Side Debris Damage Map

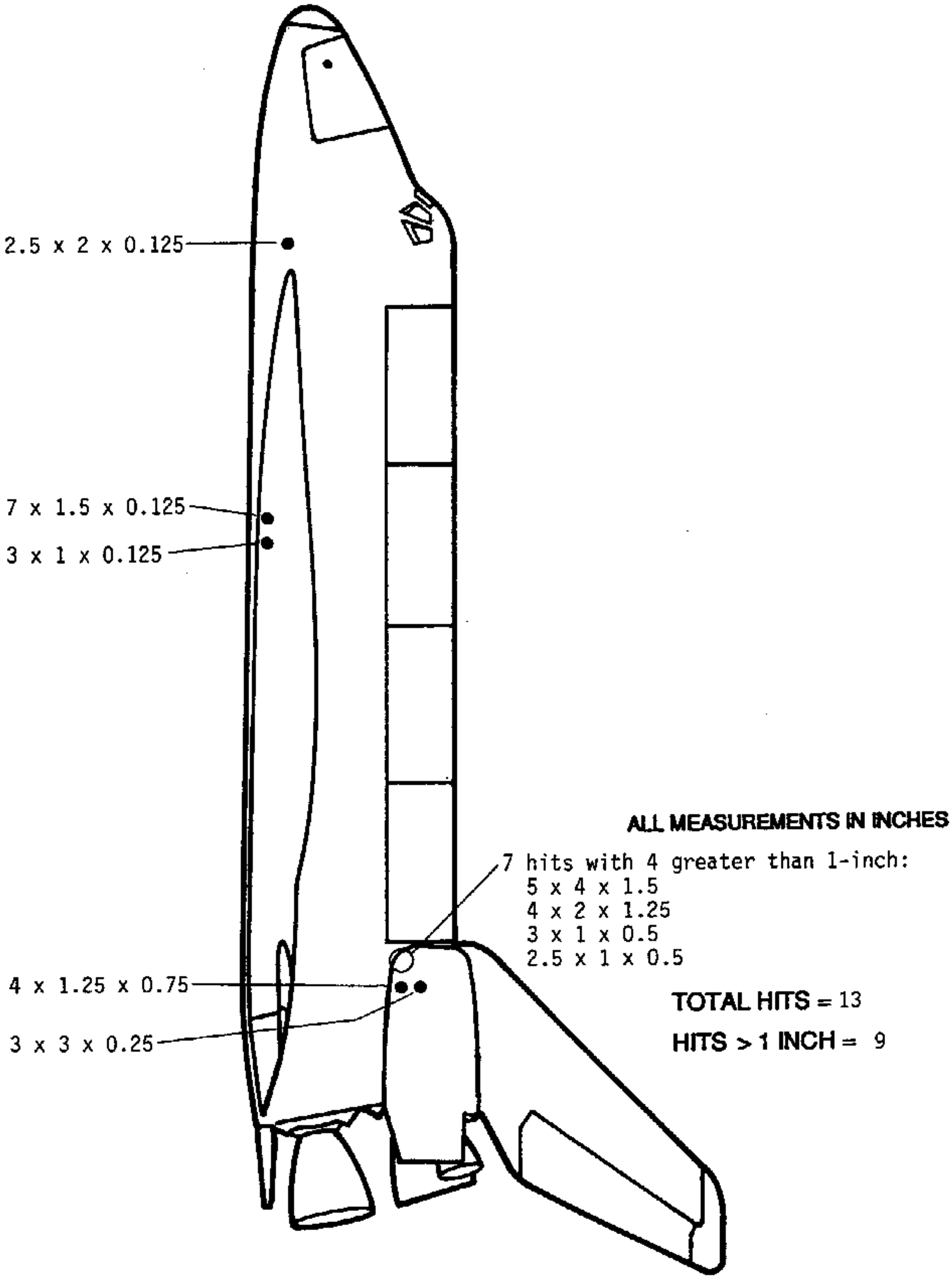


Figure 3: Orbiter Right Side Debris Damage Map

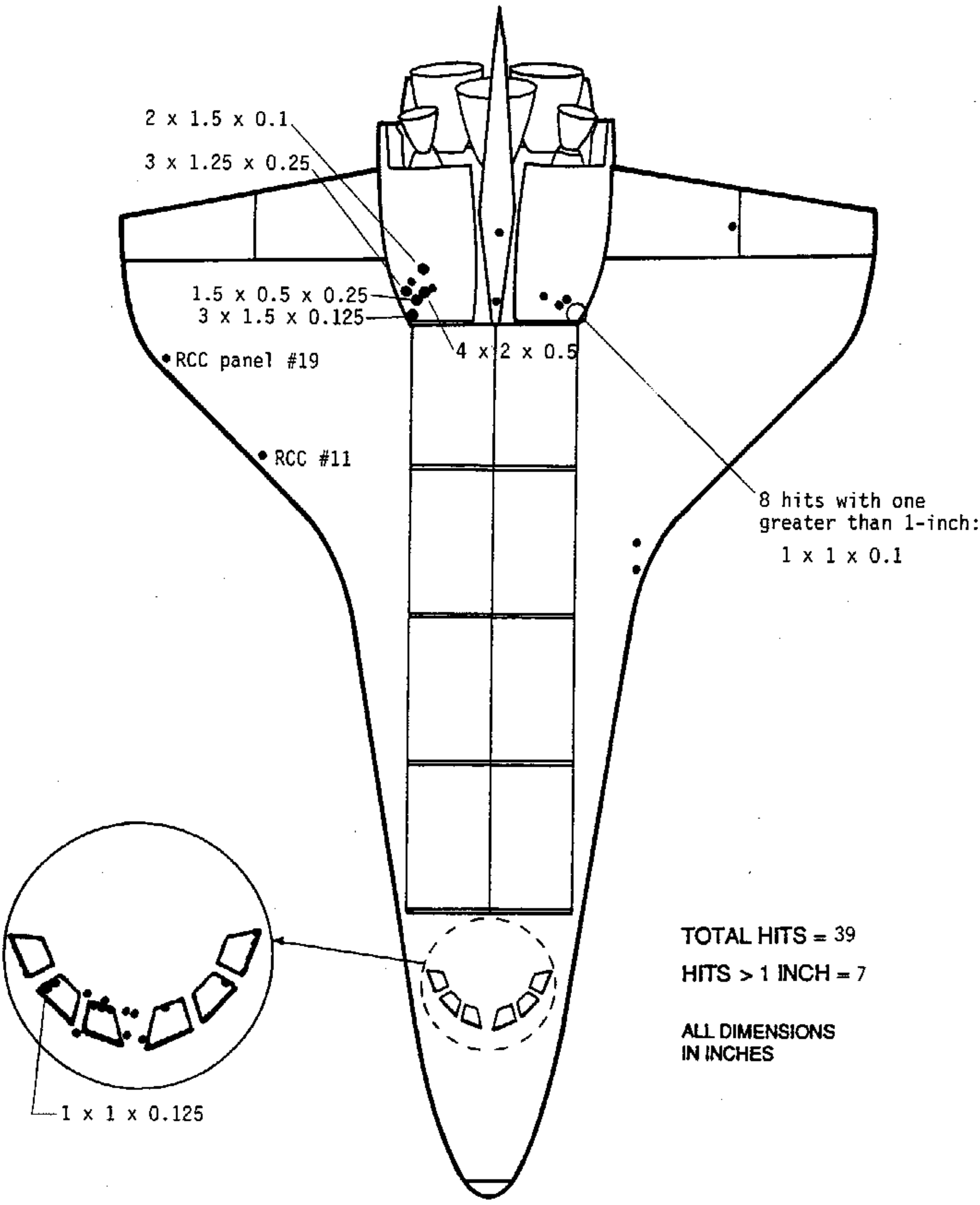


Figure 4: Orbiter Upper Surface Debris Damage Map

	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

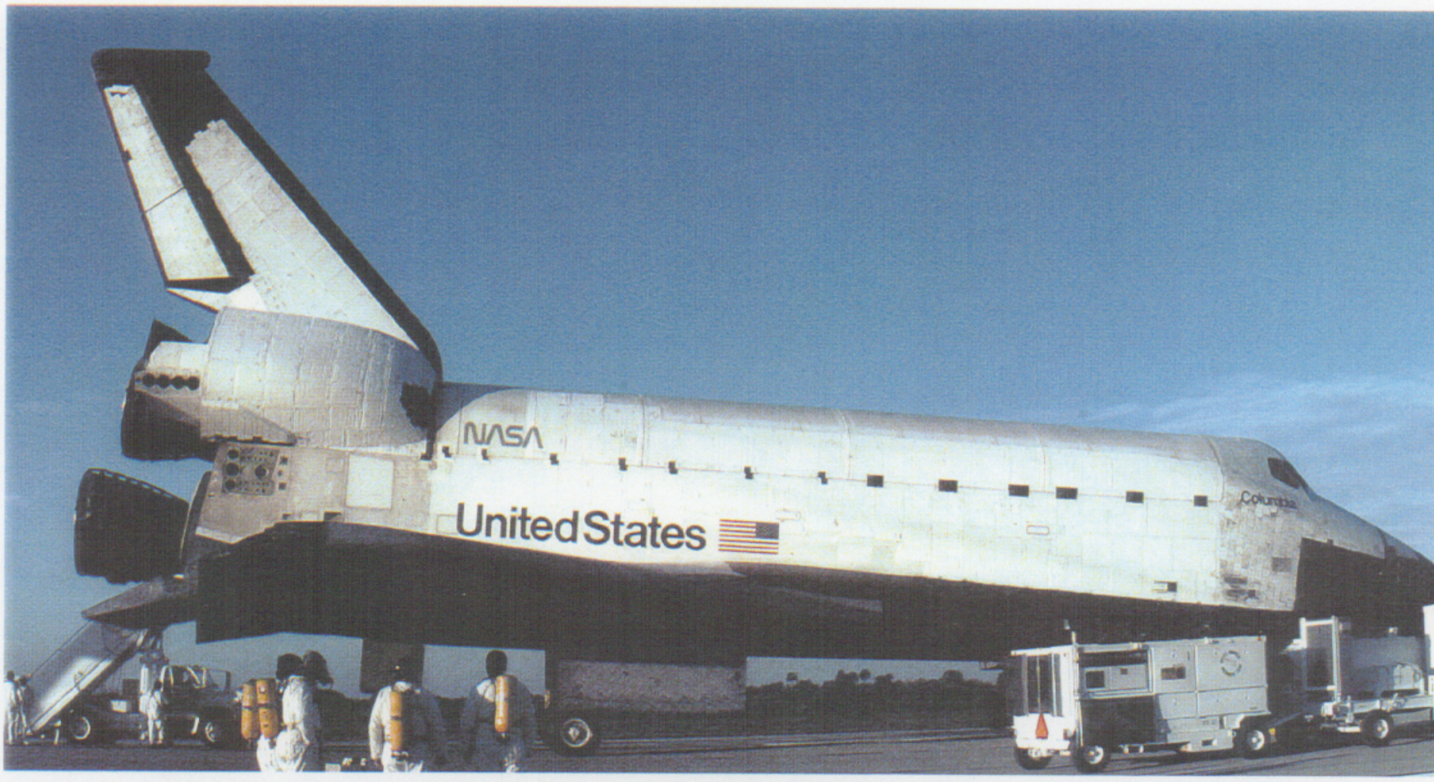
	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
STS-55	10	128	13	143
STS-57	10	75	12	106
STS-51	8	100	18	154
STS-58	23	78	26	155
STS-61	7	59	13	120
STS-60	4	48	15	106
STS-62	7	36	16	97
STS-59	10	47	19	77
STS-65	17	123	21	151
STS-64	18	116	19	150
STS-68	9	59	15	110
STS-66	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-87	109	244	132	308

MISSIONS STS-23,24,25,26,26R,27R,30R,42, AND 86 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 Pieces
STS-42	38	159	44	209	ET Intertank TPS
STS-86	27	100	31	129	ET Thrust Panel TPS

Figure 6: Orbiter Debris Exclusion Damage Summary



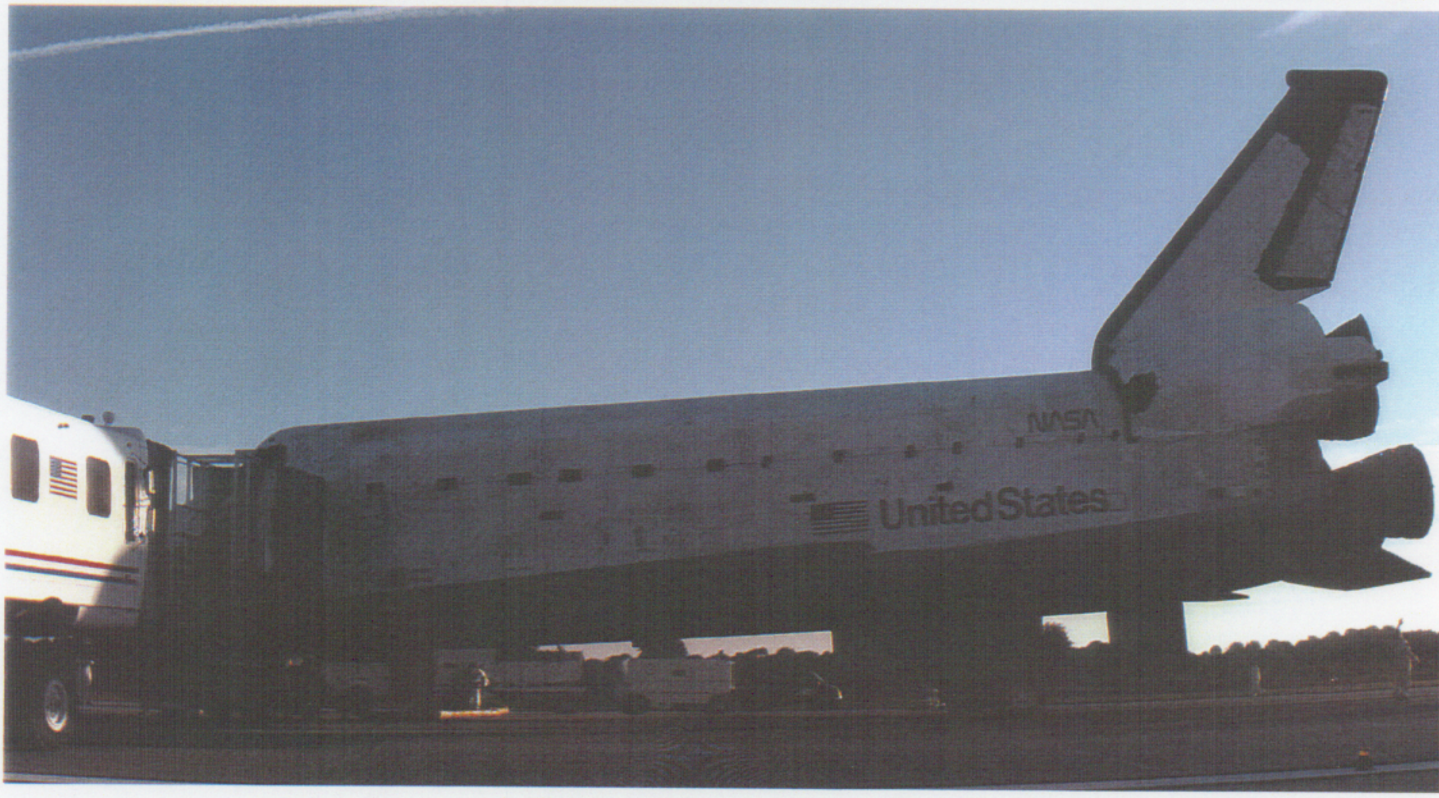


Photo 18: Overall View Orbiter Right/Left Sides

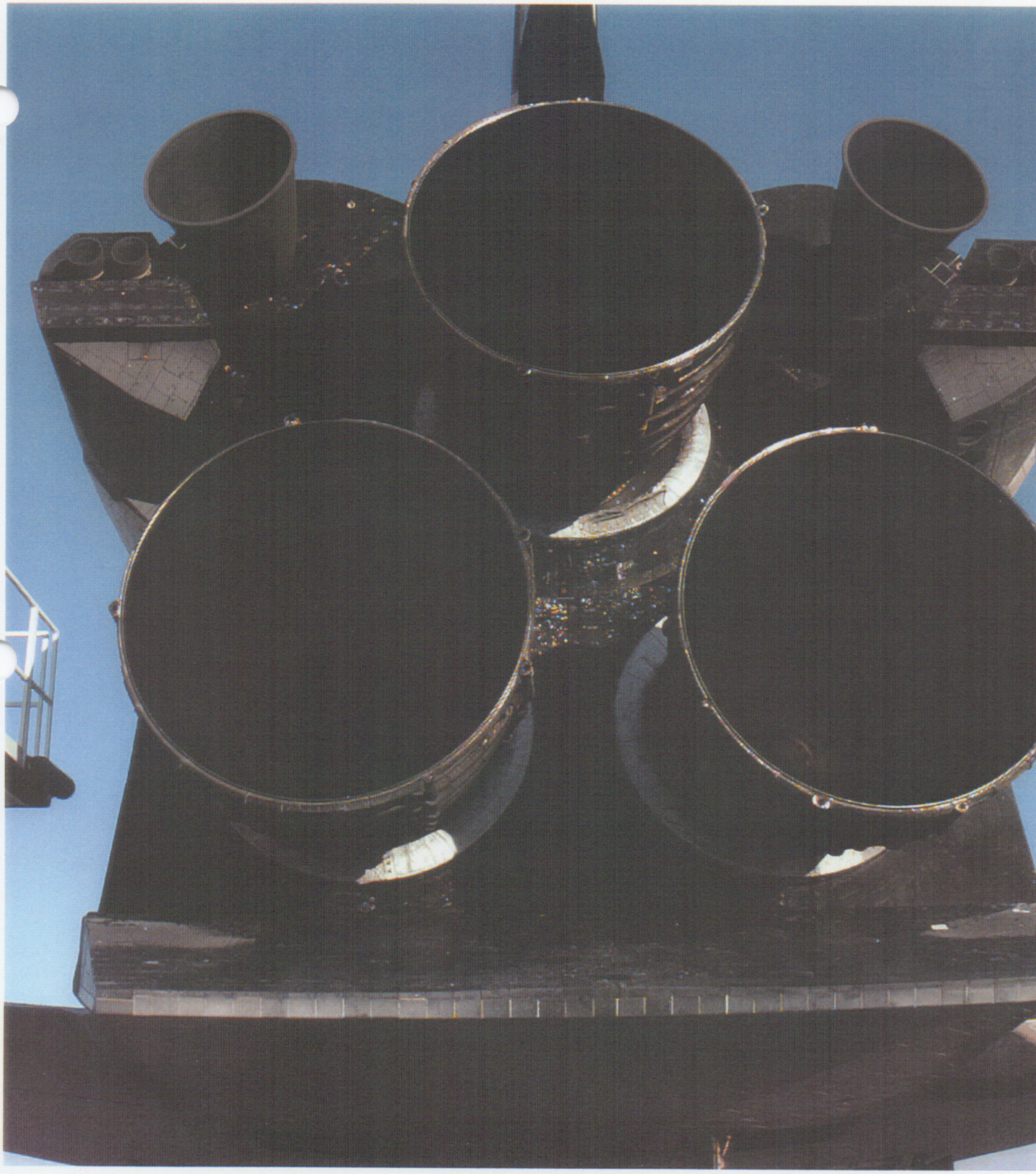


Photo 19: Overall View SSME's/Base Heat Shield

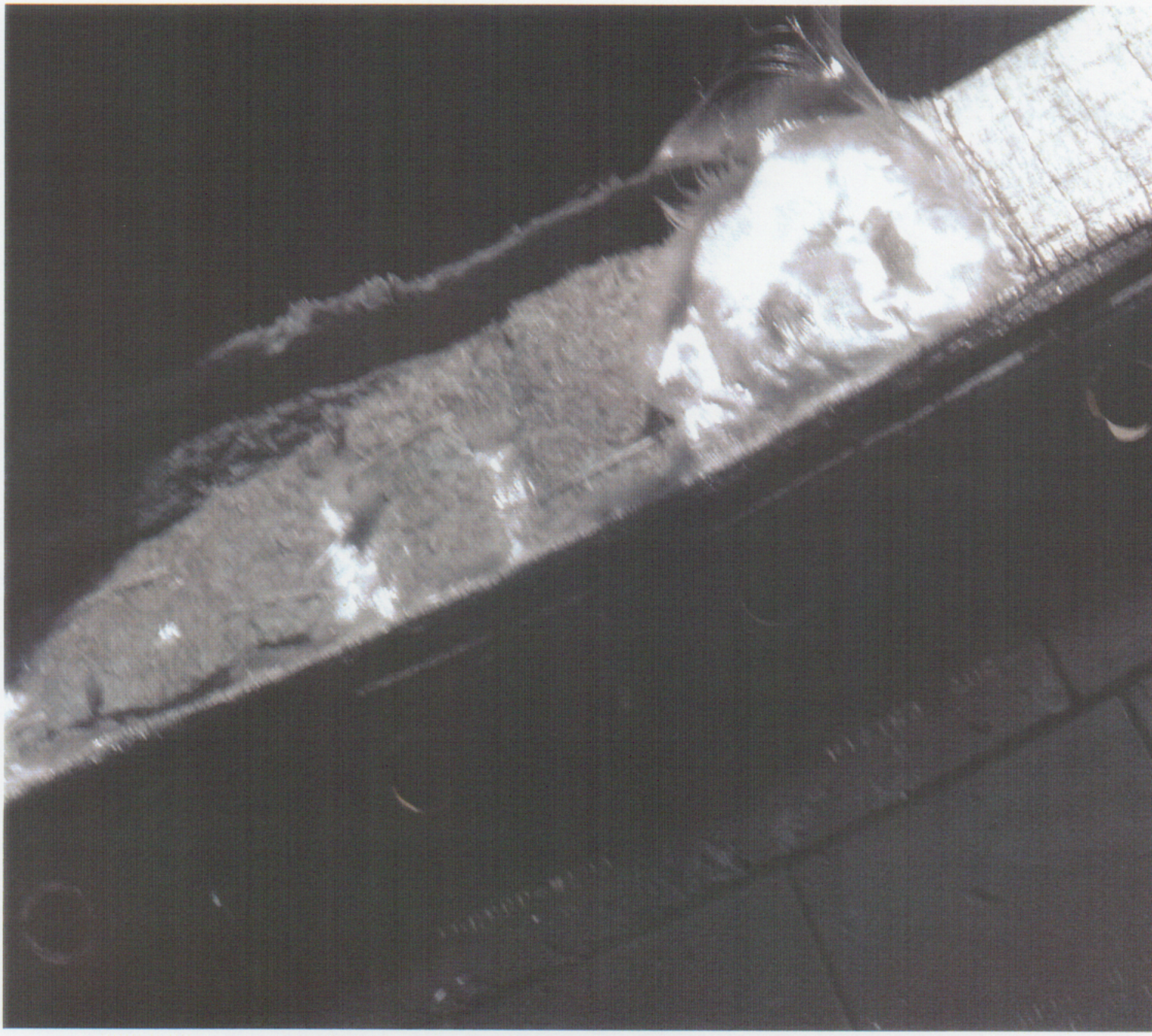


Photo 20: SSME #1 DMHS Blanket Damage

The blanket panels on SSME #1 at the 4-6:00 o'clock position were missing. The underlying batting material was torn and frayed. Loss of this material in flight was detected in the launch tracking films at T+39 seconds MET.

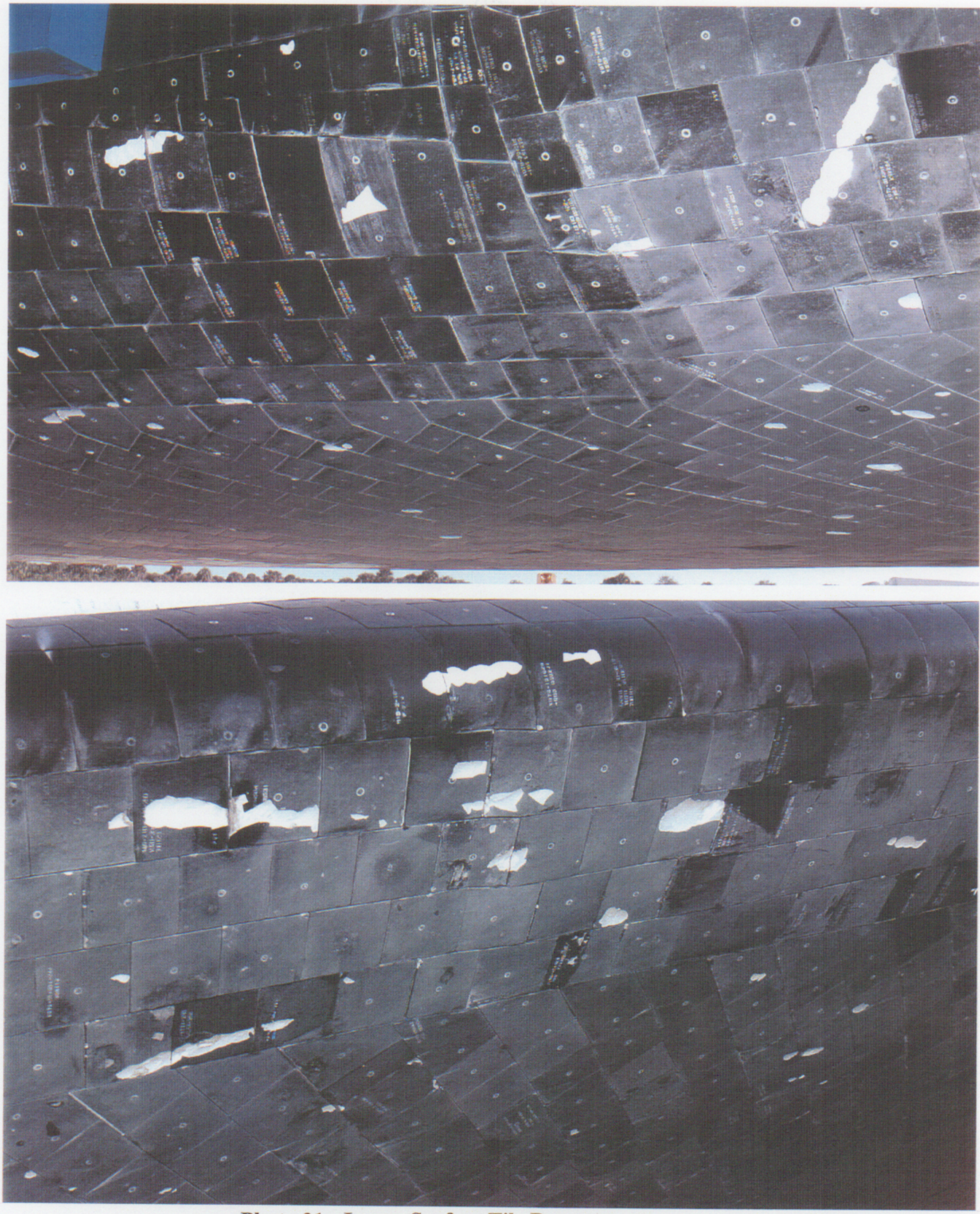


Photo 21: Lower Surface Tile Damage

The Orbiter lower surface sustained at least 244 significant hits, of which 109 had a major dimension of 1-inch or larger. Virtually all of this unusual damage was concentrated in the area between the nose landing gear and the main landing gear more or less symmetrically divided between left (top photo) and right (bottom photo) outboard sides. The largest lower surface tile damage site was located on the left glove. The site measured 15-inches long by 2-inches wide by 0.25-inches deep.

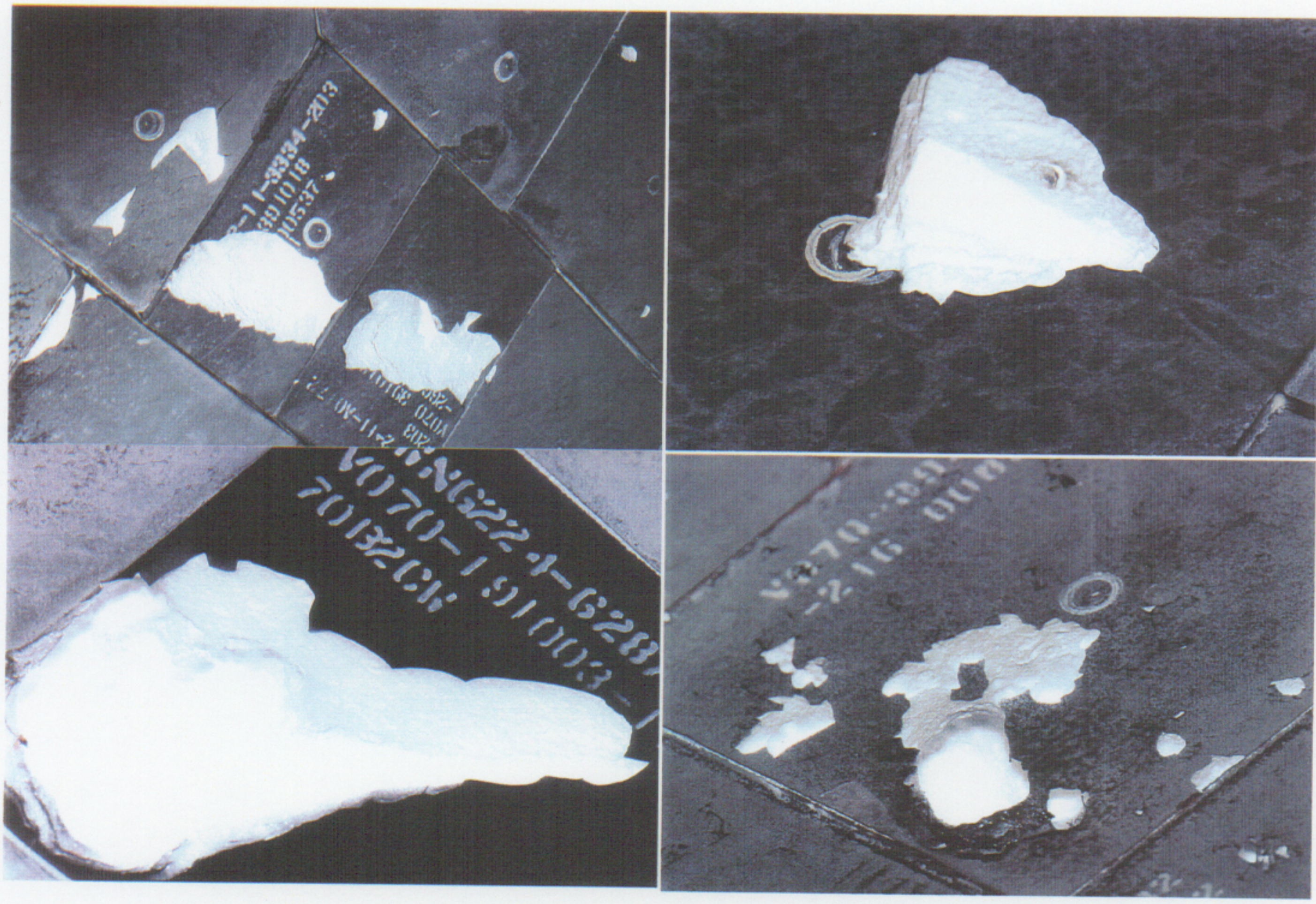
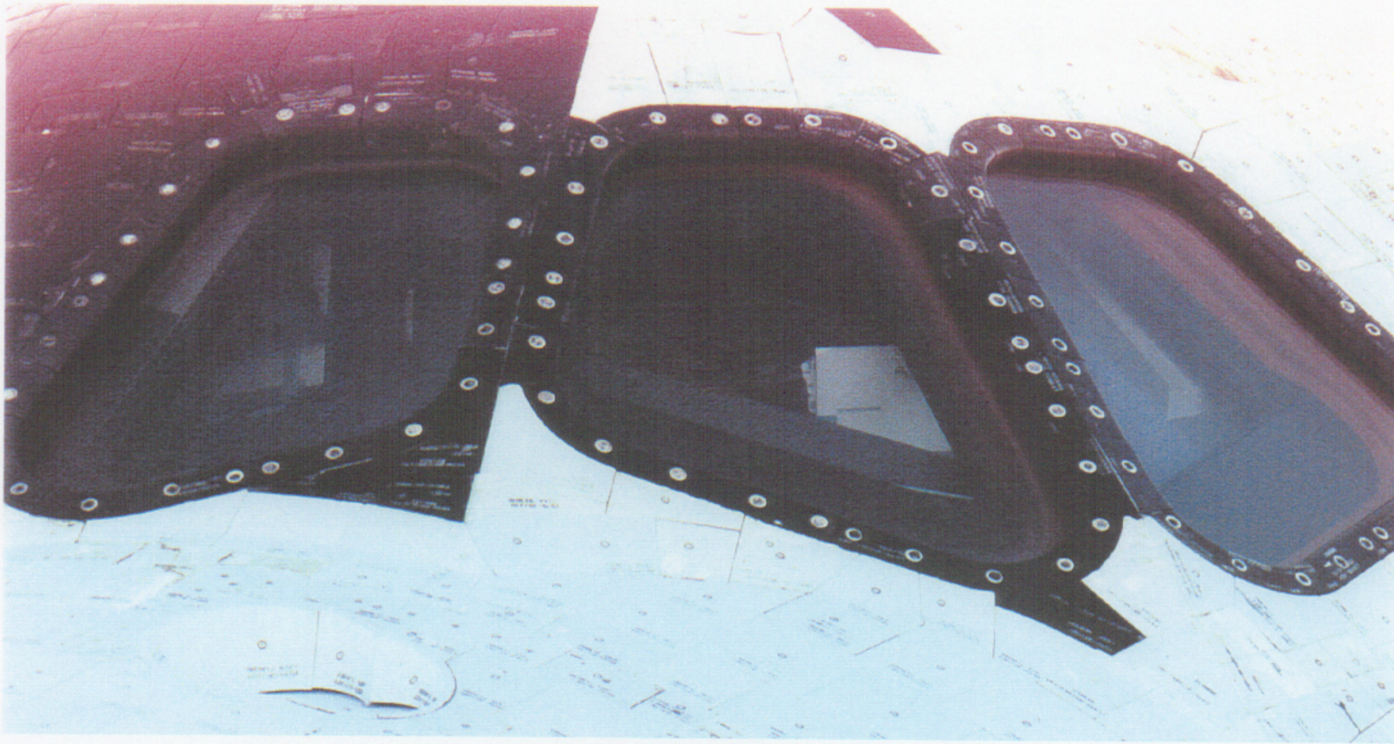


Photo 22: Lower Surface Tile Damage

The deepest lower surface tile damage site was located just forward of the left main landing gear well. It measured 4-inches long by 2-inches wide by 1.5-inches deep. Tile material in the damage sites showed signs of glazing and heat effects from re-entry. The damage sites with significant depth appeared to be generally aligned in a fore to aft direction. Many of these sites were affected by re-entry aerodynamic erosion.

Photo 23: OMS Pod Tile Damage

Unusual tile damage occurred on the lower outboard leading edges of both OMS pods. There were 33 total hits, of which 14 were larger than 1-inch in size.



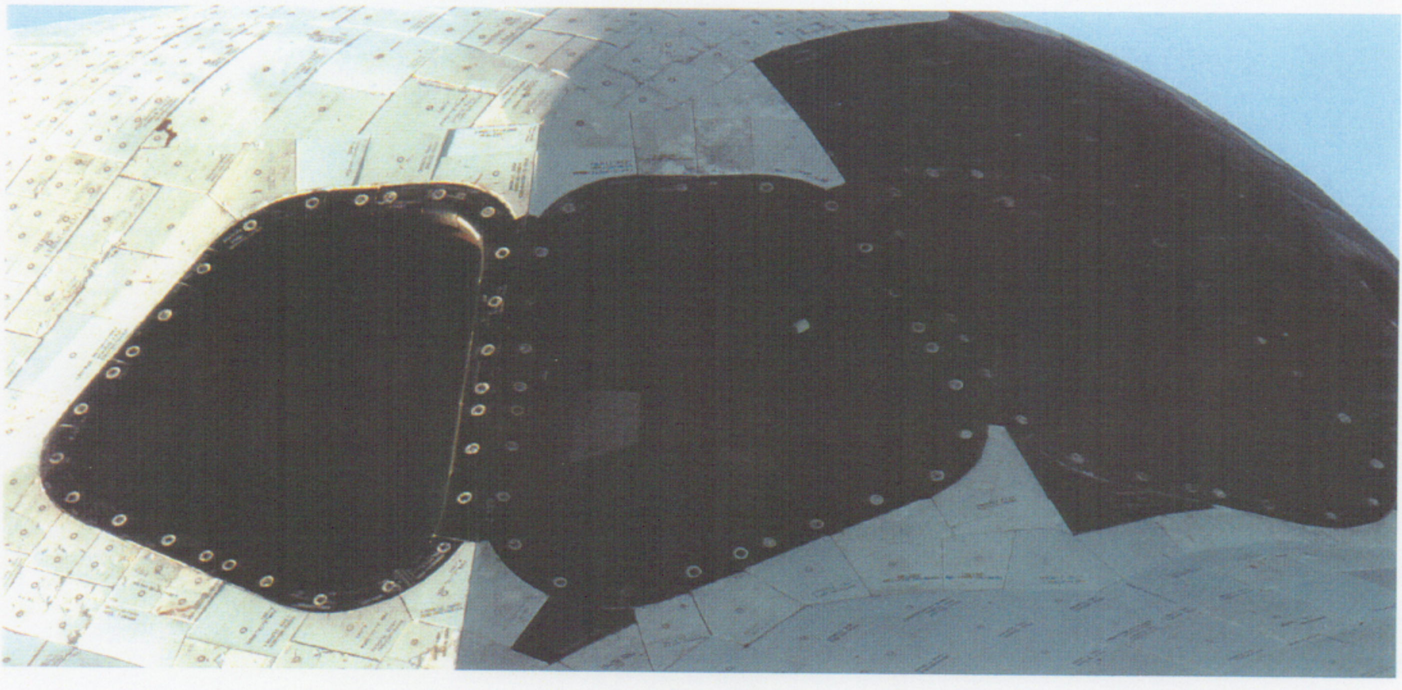


Photo 24: Windows and Perimeter Tiles

Hazing and streaking of forward-facing Orbiter windows was less than usual. Damage sites on the window perimeter tiles was noticeably less than usual in quantity and size.

National Aeronautics and
Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

Reply to Attn of: EP71(98-001) January 12, 1997

TO: Distribution

FROM: EP73/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-87

The launch of space shuttle mission STS-87, the 24th flight of the Orbiter Columbia occurred on November 19, 1997, at approximately 1:46 P.M. Central Standard Time from launch complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Launch time was reported as 97:323:19:45:59.993 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

Clouds obscured the vehicle from several of the tracking cameras approximately one minute after launch reducing the available data from photography. No ground based camera systems problems were reported. The onboard umbilical well films and the astronaut hand held 70mm and video data were received at MSFC. All onboard camera systems operated normally and provided excellent data.

Loss of TPS material was observed on the ET intertank thrust panels on both the +Y and -Y sides. The first evidence from photography of the TPS loss was after ET separation from the onboard cameras. Because of the cloud coverage and limited visibility due to moisture in the atmosphere details of the ET thrust panels were not visible from the grounds based cameras.

Frost was noted around the SSME #2 eyelid at liftoff. The typical observations of debris, consisting of butcher paper from the RCS motor covers and umbilical baggie material, falling aft during early ascent were noted.

A piece of the base heat shield thermal blanket around SSME #1, between the 4 and 5 o'clock positions, tore and fell from the vehicle. This event was recorded by tracking cameras ET207 and E207. Tearing of the blanket was first noted at 19:46:20.5 UTC. The particle fell from the vehicle at 19:46:38.52 UTC, creating a debris induced streak in the SSME plume. This streaking coincides with a plume streak noted from other tracking cameras.

Venting from the GH2 vent was recorded by the astronauts while photographing the ET. Venting from the GH2 vent has previously been recorded on STS-45. No venting was recorded on the umbilical well cameras. These cameras view the ET from separation to approximately 200 feet after separation.

The following event times were acquired.

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	19:46:00.001	Camera E9
M-2 PIC Firing	19:46:00.000	Camera E8
M-5 PIC Firing	19:46:00.001	Camera E12
M-6 PIC Firing	19:46:00.001	Camera E13
SRB Separation	19:48:03.73	Camera E212

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

http://photo4.msfc.nasa.gov/STS/sts87/sts87.html.

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

Tom Rieckhoff

Thomas J. Rieckhoff

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13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-87. 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-87 and the resulting effect on the Space Shuttle Program.

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