Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-86

Gregory Katnik
Jill D. Lin
Process Engineering/Mechanical System Division/ET-SRB Branch,
Kennedy Space center, Florida

Technical Memorandum 113231 November 1997

DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-86

25 September 1997

Contributions By:

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

Prepared By:

Jill D. Lin
Shuttle Ice/Debris Systems
NASA/KSC/PK-H7

Approved:

James G. Tatum
Chief, ET/SRB Mech/TPS Systems
NASA/KSC/PK-H7

Gregory N. Katnik
Shuttle Ice/Debris Systems
NASA/KSC/PK-H7

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF PHOTOS

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.

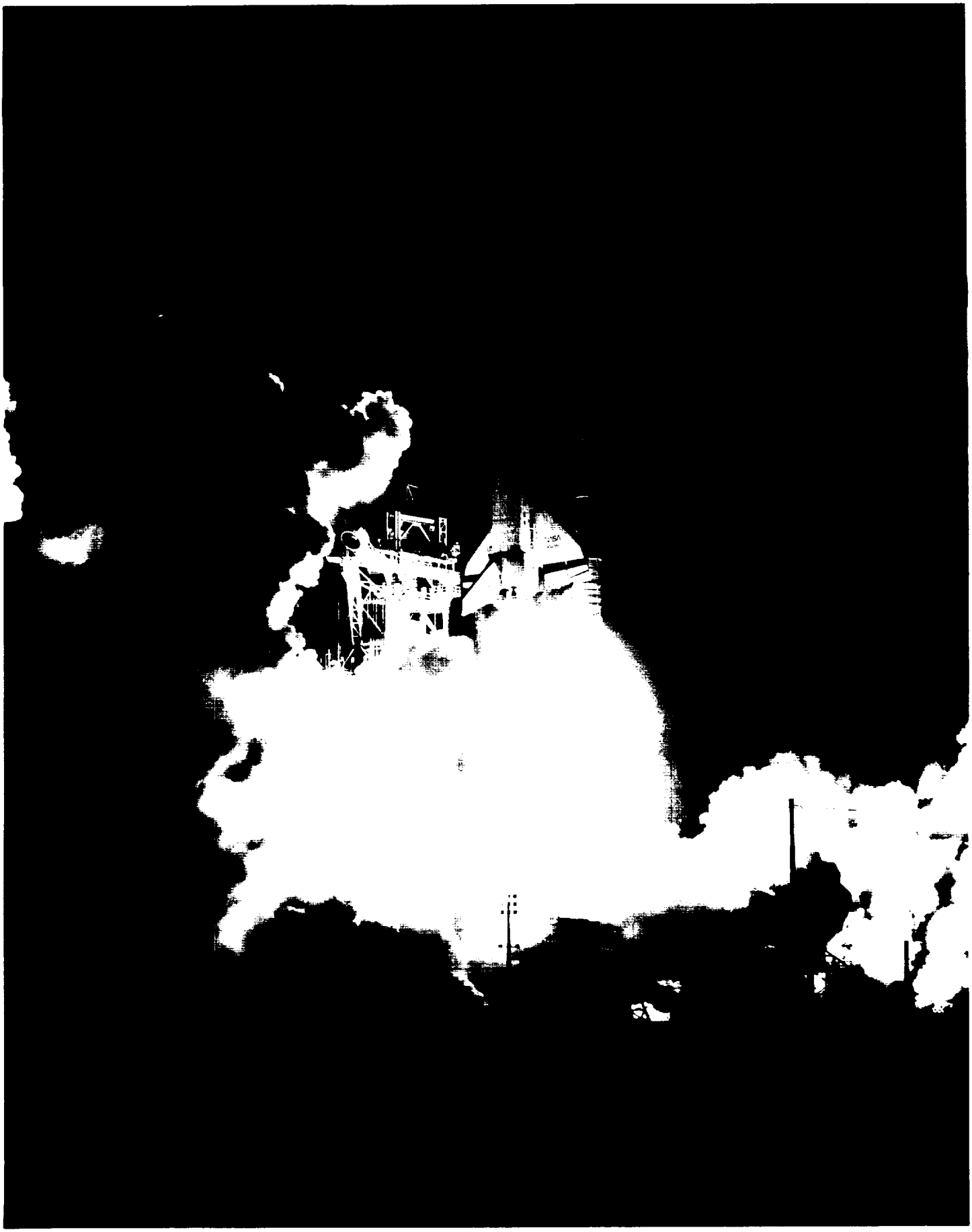


Photo 1: Launch of Shuttle Mission STS-86

1.0 SUMMARY

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 24 September 1997. The detailed walkdown of Pad 39A and MLP-2 also included the primary flight elements OV-104 Atlantis (20th flight), ET-88 (LWT 81), and BI-090 SRB's. There were no significant vehicle or launch pad anomalies.

The Final Inspection of the cryoloaded vehicle was performed on 25 September 1997 from 1815 to 1940 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Due to the warm weather conditions, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

The Final Inspection Team closely inspected the composite nose cone and perforated GOX vent seals due to the new configuration changes. The first observations at the beginning of the inspection revealed a considerable amount of dripping/running moisture in the nose cone area attributed to the recent rainfall. No ice was detected in this area and surface temperatures as measured by the portable STI averaged 61 degrees Fahrenheit. Vapors were visible exiting the -Z side of the southwest GOX vent seal. However, these vapors were relatively warm as imaged by the portable STI and were attributed to the heated nitrogen purge exiting some exposed seal perforations. A second inspection approximately an hour later revealed dry TPS with no ice or frost. The previously-observed moisture had probably been removed by the heated nitrogen purge in the GOX vent hood.

At T-2 minutes 30 seconds, the GOX vent seals were deflated. As soon as the hood was raised and the seals retracted, more-than-expected frost was visible on the ET louvers. A 2-inch wide band of frost was also present around the louvers on the composite nose cone. However, no ice was detected and frost is not a constraint for launch. But the presence of the frost raised concerns that moisture, most likely from the rain out of the west (260 degrees driven by 33 knot winds), had been somehow entrapped inside the seal.

After the 10:34 p.m. (local) launch on 25 September 1997, a debris walk down of Pad 39A was performed. No flight hardware or TPS materials were found. All the T-0 umbilicals operated properly. Overall, damage to the launch pad was minimal.

A total of 109 films and videos were analyzed as part of the post mission data review. No vehicle damage or lost flight hardware was observed that would have affected the mission.

A stud hang-up occurred on HDP #3. The stud "twanged" briefly after clearing the aft skirt before dropping into the holddown post. The stud abraded metal from the aft skirt bore and the resulting semi-circular piece was observed falling past the HDP shoe. No stud hang-ups were observed on the other seven holddown posts. No ordnance debris or frangible nut pieces fell from the DCS/stud holes. New configuration of SRB aft skirt thermal curtains without thermal curtain tape exhibited no anomalies during liftoff.

A light-colored object first appeared from an area behind the left SRB exhaust plume somewhat near the GH2 dispersal system (stovepipe) at 02:34:20.516 UTC. A second object appeared in the same general vicinity at 02:34:20.850 UTC above the stovepipe. Both objects were irregularly shaped, moved generally in a +Y direction away from the vehicle, and did not have vapor or smoke trails.

A third light-colored object first appeared from an area near the left SRB exhaust plume generally above the LH2 TSM at 02:34:21.264 UTC and moved in a -Y direction away from the vehicle. The object was semi-rigid with dimensions estimated to be 30-inches long by 4-inches wide by an inch thick. The object exhibited a curved shape when viewed in plan form. Reversing the trajectory revealed the object passing the aft skirt thermal curtains on the north side of the SRB and possibly originating generally from the HDP #7 area.

A more detailed debris inspection was conducted at the pad. Four pieces of white RTV, the largest of which was curved in shape and measured 18.5-inches long by 2.25-inches wide by 1.5-inches thick, were found west of the MLP. Examination of holddown post #7 revealed approximately 40 linear inches of protective white RTV was missing along the base circumference.

OV-104 was equipped with umbilical cameras. There were no anomalies during separation of the SRB's from the External Tank. However, ET separation from the Orbiter was not visible due to the dark conditions of a night launch.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. Both frustums were in excellent condition. No TPS was missing and no debonds/unbonds were detected over fasteners. All eight BSM aero heat shield covers had locked in the fully opened position though the attach ring on the left frustum upper left position had been bent by parachute riser entanglement. Seven of the holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally. The HDP #3 stud bore was broached. Stud thread impressions were visible in the bore. Post launch film analysis confirmed the stud hang-up occurred on HDP #3.

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

A post landing inspection of OV-104 Atlantis was conducted after the 5:55 p.m. touchdown on 6 October 1997 at the Kennedy Space Center on SLF runway 15. The Orbiter TPS sustained a total of 129 hits, of which 31 had a major dimension of 1-inch or larger. A comparison of these numbers to statistics from 71 previous missions of similar configuration indicates the total number of hits was greater than average and the number of hits 1-inch or larger was significantly greater than average.

The Orbiter lower surface sustained a total of 100 hits, of which 27 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the left glove and measured 6.5-inches long by 1.25-inches wide by 0.25-inches maximum depth. This damage site was just one of 26 hits (with 13 larger than 1-inch) from an area to the left of the nose progressing aft almost to the left main landing gear door - an unusual occurrence. In order to investigate the cause of this damage, the ET/ORB umbilical films were reviewed, samples were taken from five tile damage sites for chemical analysis, and the data base for debris particles in an aerodynamic flow were utilized for trajectory analysis.

The trajectory analysis considered a variety of debris particle sizes, densities, and Mach numbers. The results indicated the tile damaging debris most likely originated from an area equivalent to the ET intertank, LO2 tank barrel section, or left SRB nose cap (the left SRB frustum was missing no material when inspected after flight). The Orbiter umbilical films yielded no information due to the dark conditions of a night launch. The tile damage sites were scoured clean by re-entry and samples taken for chemical analysis yielded no definitive traces. Therefore, the cause of the unusual tile damage is unexplained, though it should be noted the new ET composite nose cone is located too far forward on the vehicle to be considered a probable source.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted on 24 September 1997 at 1500 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
M. Valdivia	USA - SPC	Supervisor, ET/SRB Mechanical Systems
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
F. Foster	BNA - LSS	Systems Integration
C. Hill	BNA - LSS	Systems Integration
J. Cook	THIO - LSS	SRM Processing
S. Otto	LMSO - LSS	ET Processing
J. Ramirez	LMSO - LSS	ET Processing
D. Maxwell	USA - Safety	

3.0 LAUNCH

STS-86 was launched at 97:269:02:34:19.000 UTC (10:34 p.m. local) on 25 September 1997.

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 24 September 1997. The detailed walkdown of Pad 39A and MLP-2 also included the primary flight elements OV-104 Atlantis (20th flight), ET-88 (LWT 81), and BI-090 SRB's. There were no significant vehicle or launch pad anomalies.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed on 25 September 1997 from 1815 to 1940 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC), OMRS, or NSTS-08303 criteria violations. No Ice, Debris, or TPS IPR's were taken. Due to the warm weather conditions, there were no acreage icing concerns. There were also no protuberance icing conditions outside of the established data base.

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

3.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster covers were intact though three of the covers on thrusters F3F, R1R, and L4L were tinted green indicating slight internal vapor leaks. 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 80 degrees F, which was within the required range of 44-86 degrees F.

3.2.3 EXTERNAL TANK

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

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 71 degrees F. The composite nose cone and perforated GOX vent seals were closely inspected due to the new configuration changes. The first observations at the beginning of the inspection revealed a considerable amount of dripping/ running moisture in the nose cone area attributed to the recent rainfall. No ice was detected in this area and surface temperatures as measured by the portable STI averaged 61 degrees Fahrenheit. Vapors were visible exiting the -Z side of the southwest GOX vent seal. However, these vapors were relatively warm as imaged by the portable STI and were attributed to the heated nitrogen purge exiting some exposed seal perforations. A second inspection approximately an hour later revealed dry TPS with no ice or frost. The previously-observed moisture had probably been removed by the heated nitrogen purge in the GOX vent hood.

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

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LH2 tank acreage. TPS surface temperatures averaged 68 degrees F on the +Z side and 58 degrees F on the -Z side. The 10 degree difference between the two sides was expected and attributed to the new "thick/thin" TPS configuration. All TPS repairs on the +Z side of the LH2 tank were intact with no visible frost lines.

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

No visible stress relief crack had formed on the -Y vertical strut forward facing TPS.

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

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

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

3.2.4 FACILITY

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

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

3.3 TERMINAL COUNT

By T-2 minutes 30 seconds, the GOX vent seals were deflated. As soon as the hood was raised and the seals retracted, more-than-expected frost was visible on the ET louvers. A 2-inch wide band of frost was also present around the louvers on the composite nose cone. This condition was documented on Anomaly 003 in OMI S6444. However, no ice was detected and frost is not a constraint for launch. But the presence of the frost raised concerns that moisture, most likely from the rain out of the west (260 degrees driven by 33 knot winds), had been somehow entrapped inside the seal. A plan to install lights and cameras for the purpose of observing the louvers during cryoload is being worked.

Photo 2: STS-86 Ready for Launch

OV-104 Atlantis (20th flight), ET-88 (LWT 81), and BI-090 SRB's. The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LO2 tank acreage. TPS surface temperatures averaged 71 degrees F.

Photo 3: LH2 Tank After Cryoload

The Final Inspection Team observed light condensate, but no ice or frost accumulations, on the LH2 tank acreage. Typical amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side and forward surface. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents.

Photo 4: Overall View of SSME's

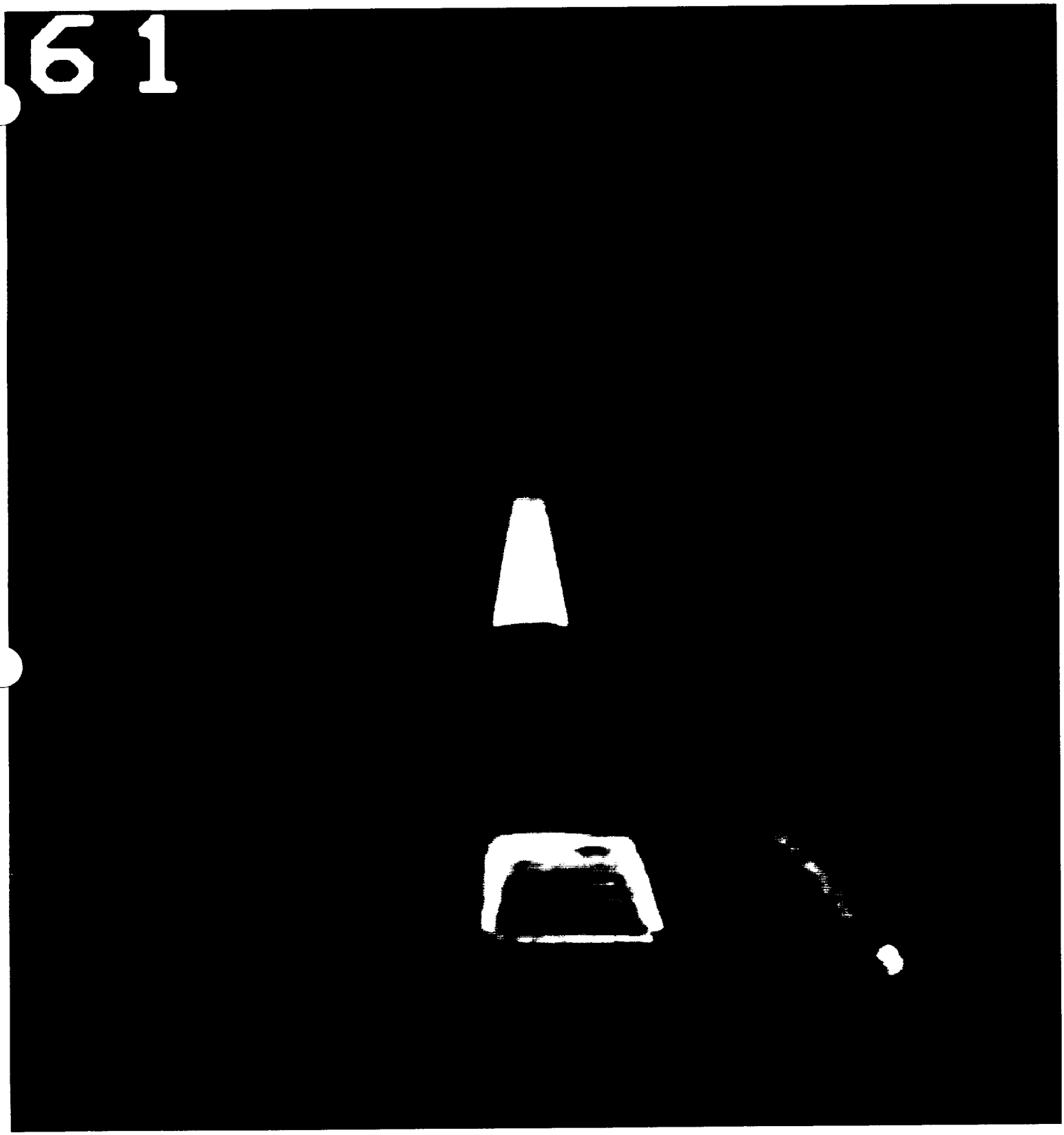


Photo 5: Frost on Composite Nose Cone

By T-2 minutes 30 seconds, the GOX vent seals were deflated. As soon as the hood was raised and the seals retracted, more-than-expected frost was visible on the ET louvers. A 2-inch wide band of frost was also present around the louvers on the composite nose cone. This condition was documented on Anomaly 003 in OMI S6444. However, no ice was detected and frost is not a constraint for launch.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of MLP 2, Pad A FSS and RSS was conducted on 25 September 1997 from Launch + 2 to 3.5 hours.

SRB hold down post erosion generally was typical. Boeing - Downey reported an Orbiter liftoff lateral acceleration of 0.3 g's, which is above the 0.14 g threshold when stud hang-ups occur. Preliminary observations of the south holddown posts from the MLP deck revealed no obvious signs of a stud hang-up. Launch films confirmed the stud hang-up occurred on HDP #3. North holddown posts, aft skirt purge lines, and T-0 umbilicals exhibited typical exhaust plume damage.

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

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 from the static retract lanyard. All evidence indicated a nominal retraction and latchback.

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

These inspections noted minimal overall damage to the pad.

5.0 FILM REVIEW

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

5.1 LAUNCH FILM AND VIDEO SUMMARY

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

Due to the dark conditions of a night launch, atmospheric haze, and overexposure (white-out) of some films, vehicle detail was sometimes difficult to discern.

SSME ignition appeared normal. Noticeable amounts of free burning hydrogen drifted up to the OMS pods and under the body flap during start-up before being drawn into the plume by aspiration. The Mach diamonds formed in the expected sequence (E-76; OTV-051, 070, TV-7). Three debris-induced streaks occurred in the SSME #1 exhaust plume during start-up (E-2, -3, -5, -19, -20).

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. Condensate and small pieces of ice falling from the LH2 feedline bellows contacted the LH2 recirculation line, but no damage to TPS was visible (OTV-009).

Tile surface coating material was lost during ignition from two places on the aft surface of the LH OMS pod and one place on the aft surface of the LH RCS stinger (E-20). Three light spots on the base heat shield outboard of SSME #3 may be areas of missing tile surface coating material (OTV 070).

No structural or icing anomalies were detected on the new External Tank composite nose cone. Frost covered several fastener heads, a 2-3 inch wide band around each louver, and several louver vanes. Some residual GOX vapors exited the louvers, but no ice was present (OTV 013, 060, 061, 062).

A white particle originating from the Orbiter LH2 8-inch line T-0 interface at liftoff is believed to be a piece of ice (OTV 050).

A stud hang-up occurred on HDP #3. The stud "twanged" briefly after clearing the aft skirt before dropping into the holddown post. The stud abraded metal from the aft skirt bore and the resulting semi-circular piece was observed falling past the HDP shoe (E-10). No stud hang-ups were observed on the other seven holddown posts. No ordnance debris or frangible nut pieces fell from the DCS/stud holes. The north HDP blast covers closed normally.

New configuration of SRB aft skirt thermal curtains without thermal curtain tape exhibited no anomalies during liftoff (OTV 049, 050).

A white particle originated from the upper LH2 TSM area (02:34:16.542 UTC) and moved toward the vehicle before falling aft along side SSME #3 (E-18).

A debris object, believed to be a piece of SRB throat plug material, was ejected upward out of the LH SRB exhaust hole in the vicinity of HDP #8 at 02:34:20.336 UTC (E-16).

A light-colored object first appeared from an area behind the left SRB exhaust plume somewhat near the GH2 dispersal system (stovepipe) at 02:34:20.516 UTC. A second object appeared in the same general vicinity at 02:34:20.850 UTC above the stovepipe. Both objects were irregularly shaped, moved generally in a +Y direction away from the vehicle, and did not have vapor or smoke trails (E-76).

A third light-colored object first appeared from an area behind the left SRB exhaust plume generally above the LH2 TSM (in this field of view) at 02:34:21.264 UTC and moved in a -Y direction away from the vehicle. The object was semi-rigid with dimensions estimated to be 30-inches long by 4-inches wide by an inch thick. The object exhibited a curved shape when viewed in plan form. The object did not exhibit a dark side, which might be a candidate for SRB throat plug RTV, while tumbling (E-76, -222).

However, the white objects described above are also visible in film item E-4 from a camera in the northwest corner of the MLP deck. A white object moving upward and then arcing eastward at 02:34:20.642 UTC followed by a second object ejected vertically at 02:34:20.760 UTC appeared to originate from the HDP #7 area. Shortly afterwards, a curved object first appeared near the LH SRB aft skirt at 02:34:21.230 UTC moving westward. Reversing the trajectory revealed the object passing the aft skirt thermal curtains on the north side of the SRB and possibly originating generally from the HDP #7 area. (Note: data from film item E-1 in the northeast corner of the MLP deck would have been instrumental in the identification and trajectory analysis of these objects had not the camera failed due to an internal film jam). A fourth white debris object falling vertically from the FSS/RSS area at 02:34:21.464 UTC was unrelated to these objects. None of these objects was observed contacting the flight hardware.

A more detailed debris inspection was conducted at the pad. Four pieces of white RTV, the largest of which was curved in shape and measured 18.5-inches long by 2.25-inches wide by 1.5-inches thick, were found west of the MLP. Examination of holddown post #7 revealed approximately 40 linear inches of protective white RTV was missing along the base circumference.

Film items E-60 and E-62 provided additional views of the white debris objects near the left SRB aft skirt shortly after liftoff.

Five large pieces of the ET/ORB umbilical purge barriers fell aft during the roll maneuver. This is an expected occurrence (E-207, -212, -213, -222).

Debris-induced streaks appeared in the SSME exhaust plume nine times during ascent (E-213, -222, -223, -224).

Movement of the body flap in flight was very pronounced. Twisting of the body flap appeared visually to be somewhat more than usual compared to previous recent flights (E-207, -212, -213, -223).

SRB separation appeared normal. Numerous pieces of slag fell from the exhaust plume just before, during, and after separation (E-207, -208; TV-13).

Photo 6: HDP #3 Stud Hang-Up

Enhanced digital view of a stud hang-up on HDP #3. The stud "twanged" briefly after clearing the aft skirt before dropping into the holddown post.

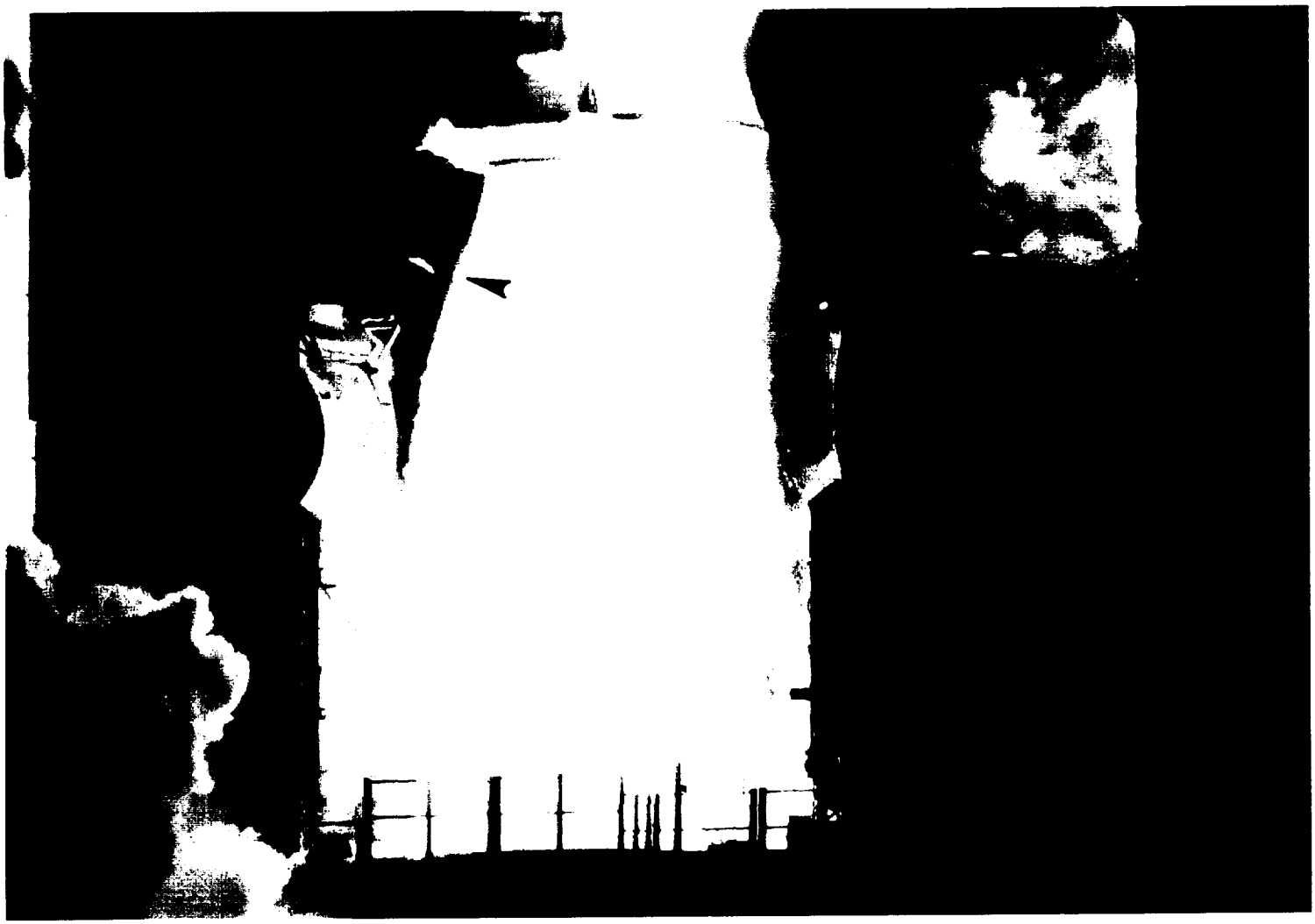


Photo 7: HDP #7 White RTV Debris

Enhanced digital view of a light-colored object first appearing from an area behind the left SRB exhaust plume generally above the LH2 TSM at 02:34:21.264 UTC and moving in a -Y direction away from the vehicle. The object was semi-rigid with dimensions estimated to be 30-inches long by 4-inches wide by 1- inch thick. The object exhibited a curved shape while tumbling.

Photo 8: HDP #7 White RTV Debris

Enhanced digital view shows piece of RTV moving away from the vehicle. The day after launch, a more detailed debris inspection was conducted at the pad. Four pieces of white RTV, the largest of which was curved in shape and measured 18.5-inches long by 2.25-inches wide by 1.5-inches thick, were found west of the MLP. Examination of holddown post #7 revealed approximately 40 linear inches of protective white RTV was missing along the base circumference.

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

OV-104 was equipped to carry umbilical cameras: 16mm motion picture with 5 mm lens; 16mm motion picture with 10mm lens; 35mm still views. The 35mm images from the LO2 umbilical were dark. Hand-held photography by the flight crew, which consisted of thirty-seven still 35mm images and a 20 second video, showed the ET too distant and small in size for detail.

SRB separation from the External Tank appeared nominal.

Very thin, charred layers of TPS were observed falling away from the aft surface of the -Y upper strut fairing closeout just before SRB separation. This is a normal occurrence. Charring and erosion of TPS from the LH2 ET/ORB umbilical cable tray and -Y vertical strut was also typical.

ET-88 separation from the Orbiter was not visible due to the dark conditions of a night launch.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 24 films and videos, which included nine 35mm large format films, one 16mm film, and twelve videos, were reviewed.

The landing gear extended properly. The infrared scanners showed no debris falling from the Orbiter during final approach. The main landing gear contacted the runway almost simultaneously straddling the centerline. Touchdown of the nose landing gear was smooth. The Orbiter rolled west of the centerline before being steered back onto the centerline.

Drag chute operation appeared nominal though deployment was delayed until after nose gear touchdown to counteract the effects of the cross wind. Both reefing cords could be seen falling from the drag chute to the runway. Rollout and wheel stop were uneventful.

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

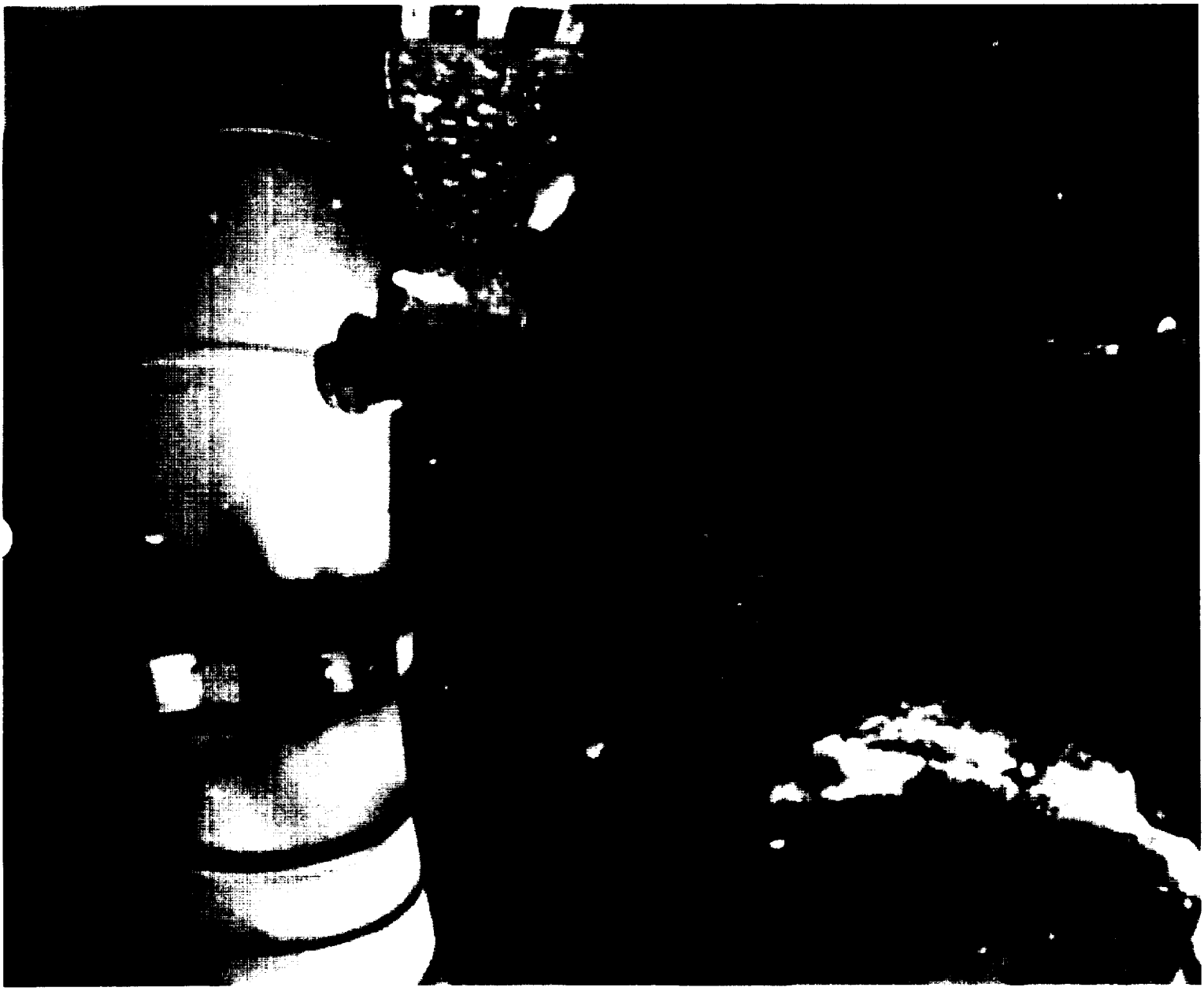


Photo 9: SRB Separation from External Tank

SRB separation from the External Tank appeared nominal. Very thin, charred layers of TPS fell away from the aft surface of the -Y upper strut fairing closeout just before SRB separation. This is a normal occurrence. Charring and erosion of TPS from the LH2 ET/ORB umbilical cable tray and -Y vertical strut was also typical.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-090 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAS Hangar AF on 29 September 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 ring on the left frustum upper left position had been bent by parachute riser entanglement.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. The +Z antenna base plates on both SRB's exhibited two delaminated phenolic layers. 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 though the right upper strut fairing -Z side was dented. Instafoam aft of the SRB stiffener rings had shrunk causing separation from the trailing edge of the stiffener rings as well as fissures in the foam. This is the second flight exhibiting this phenomenon.

TPS on the external surface of both aft skirts was intact and in good condition. A 2-inch long by 1-inch wide piece of red tape was discovered between the cluster and single aft BSM on the RH SRB. The tape had been covered by Hypalon during the aft skirt buildup process.

Most of the instafoam between HDP #1 to HDP #4 on the right SRB and between HDP #6 to HDP #8 on the left SRB was missing.

Seven of the holddown post Debris Containment Systems (DCS) plungers were seated and appeared to have functioned normally. The HDP #1 DCS plunger was not fully seated and appeared to be partially offset by frangible nut debris. The HDP #3 stud bore was broached. Stud thread impressions were visible in the bore. Post launch film analysis confirmed the stud hang-up occurred on HDP #3.

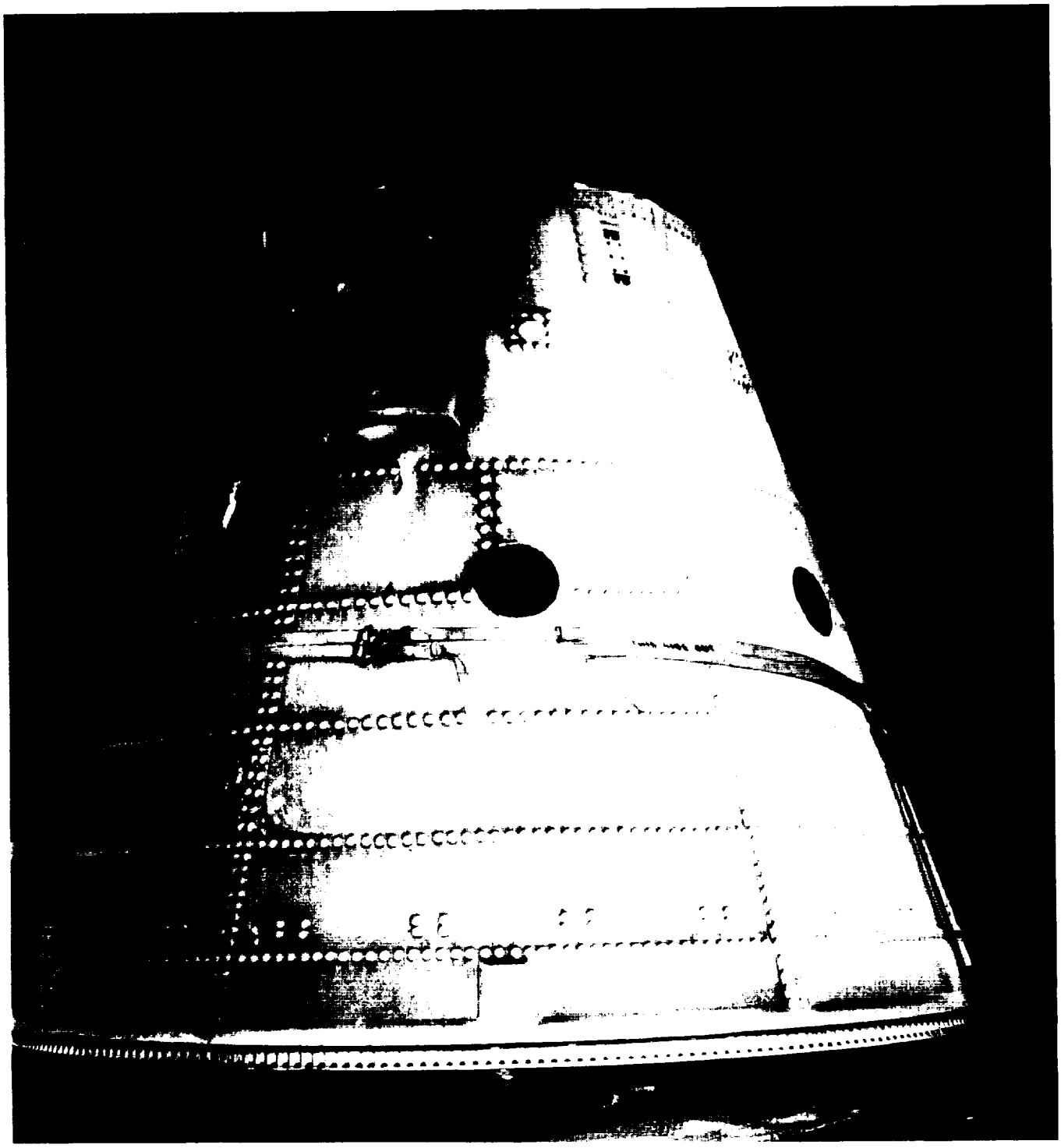


Photo 10: Frustum Post Flight Condition

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 ring on the left frustum upper left position had been bent by parachute riser entanglement.

Photo 11: Forward Skirt Post Flight Condition

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

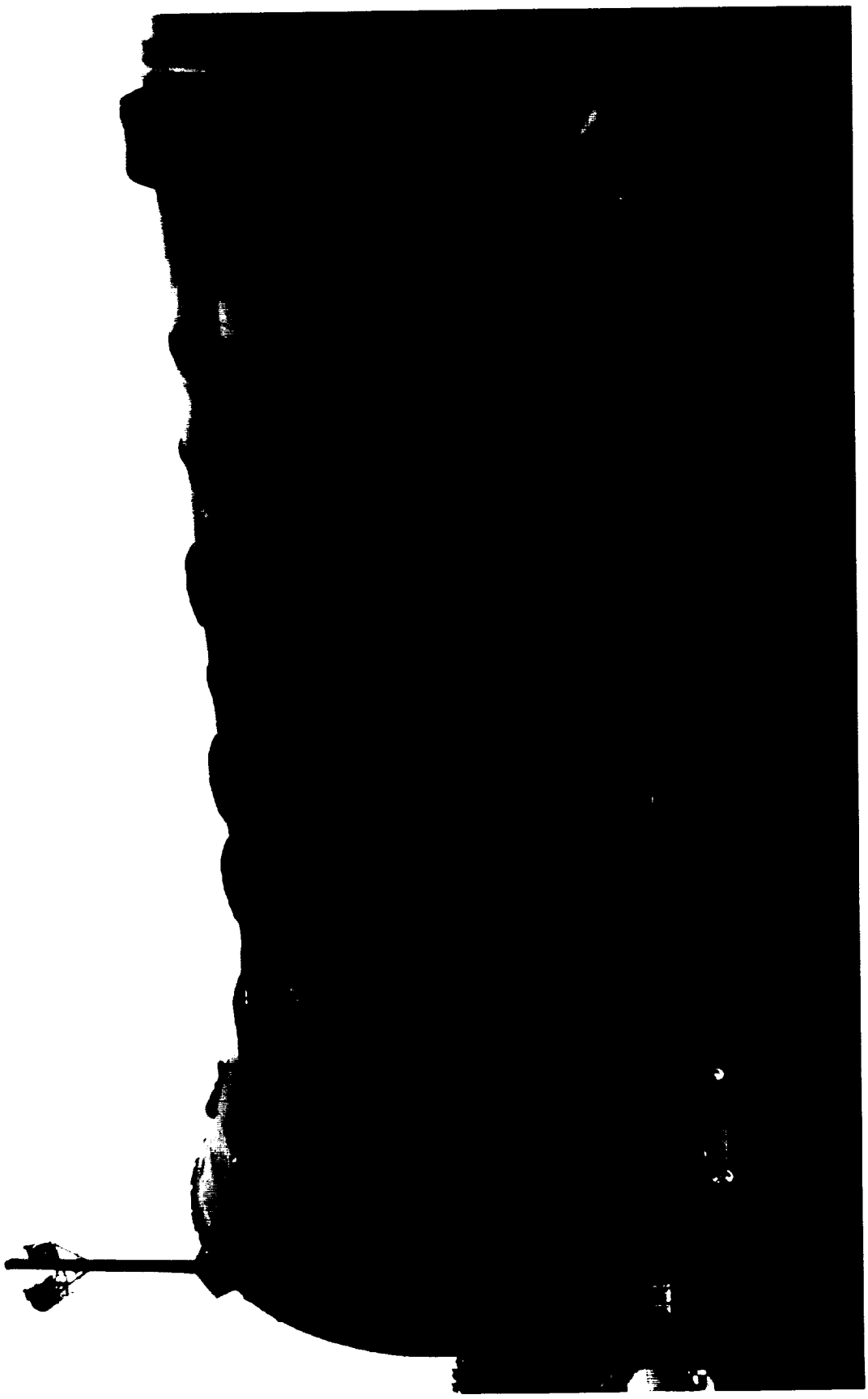


Photo 12: Aft Booster/Aft Skirt Post Flight Condition

Separation of the aft ET/SRB struts appeared normal. The stiffener rings, ETA rings, and IEA's appeared undamaged by water impact though the right upper strut fairing -Z side was dented.

Photo 13: Stiffener Ring Foam Shrinkage

Instafoam aft of the SRB stiffener rings had shrunk causing separation from the trailing edge of the stiffener rings as well as fissures in the foam. This is the second flight exhibiting this phenomenon.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing inspection of OV-104 Atlantis was conducted after the 5:55 p.m. touchdown on 6 October 1997 at the Kennedy Space Center on SLF runway 15 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 129 hits, of which 31 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 71 previous missions of similar configuration (excluding missions STS-23, 24, 25, 26, 26R, 27R, 30R, and 42, which had damage from known debris sources), indicates the total number of hits was greater than average and the number of hits 1-inch or larger was significantly greater than average (Reference Figures 1-3. Note: no hits were recorded on the right side of the Orbiter, so the corresponding figure was omitted).

The following table breaks down the STS-86 Orbiter debris damage by area:

	HITS > 1"	TOTAL HITS
Lower surface	27	100
Upper surface	2	21
Right side	0	0
Left side	0	3
Right OMS Pod	0	2
Left OMS Pod	2	3
TOTALS	31	129

The Orbiter lower surface sustained a total of 100 hits, of which 27 had a major dimension of 1-inch or larger. The largest lower surface tile damage site was located on the left glove and measured 6.5-inches long by 1.25-inches wide by 0.25-inches maximum depth. This damage site was just one of 26 hits (with 13 larger than 1-inch) from an area to the left of the nose progressing aft almost to the left main landing gear door - an unusual occurrence. In order to investigate the cause of this damage, the ET/ORB umbilical films were reviewed, samples were taken from five tile damage sites for chemical analysis, and the data base for debris particles in an aerodynamic flow were utilized for trajectory analysis.

The trajectory analysis considered a variety of debris particle sizes, densities, and Mach numbers. The results indicated the tile damaging debris most likely originated from an area equivalent to the ET intertank, LO2 tank barrel section, or left SRB nose cap (the left SRB frustum was missing no material when inspected after flight). The Orbiter umbilical films yielded no information due to the dark conditions of a night launch. The tile damage sites were scoured clean by re-entry and samples taken for chemical analysis yielded no definitive traces. Therefore, the cause of the unusual tile damage is unexplained, though it should be noted the new ET composite nose cone is located too far forward on the vehicle to be considered a probable source.

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

One lower surface damage site (tile V070-391034-648) may have been caused by a micrometeorite or on-orbit debris impact. The 1-inch diameter damage site featured a 0.25-inch diameter by 0.25 inch deep cavity perpendicular to the tile outer mold line.

The tires, which exhibited no ply undercutting, were reported to be in good condition for a cross wind 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 retainer springs appeared to be in nominal configuration. Two clips were missing from the EO-2 fitting "salad bowl". Virtually no umbilical closeout foam or white RTV dam material adhered to the umbilical plate near the LH2 recirculation line disconnect.

The SSME Dome Mounted Heat Shield (DMHS) closeout blankets were generally in good condition. However, a blanket panel on SSME #1 at the 5-6 o'clock position was torn/frayed.

The thermal insulators on both FES vents were undamaged.

Although the drag chute was deployed after the nose wheel was on the runway, vertical stabilizer "stinger" tiles sustained no damage from the reefing lines.

No ice adhered to the payload bay door. No unusual tile damage occurred on the leading edges of the OMS pods or vertical stabilizer.

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles was noticeably less than usual in quantity and size, though a piece of a forward RCS thruster paper cover was wedged between window #5 and the perimeter tiles.

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

In summary, the total number of Orbiter TPS debris hits was greater than average when compared to previous missions. The number of hits 1-inch or larger was significantly greater than average (reference Figure 4).

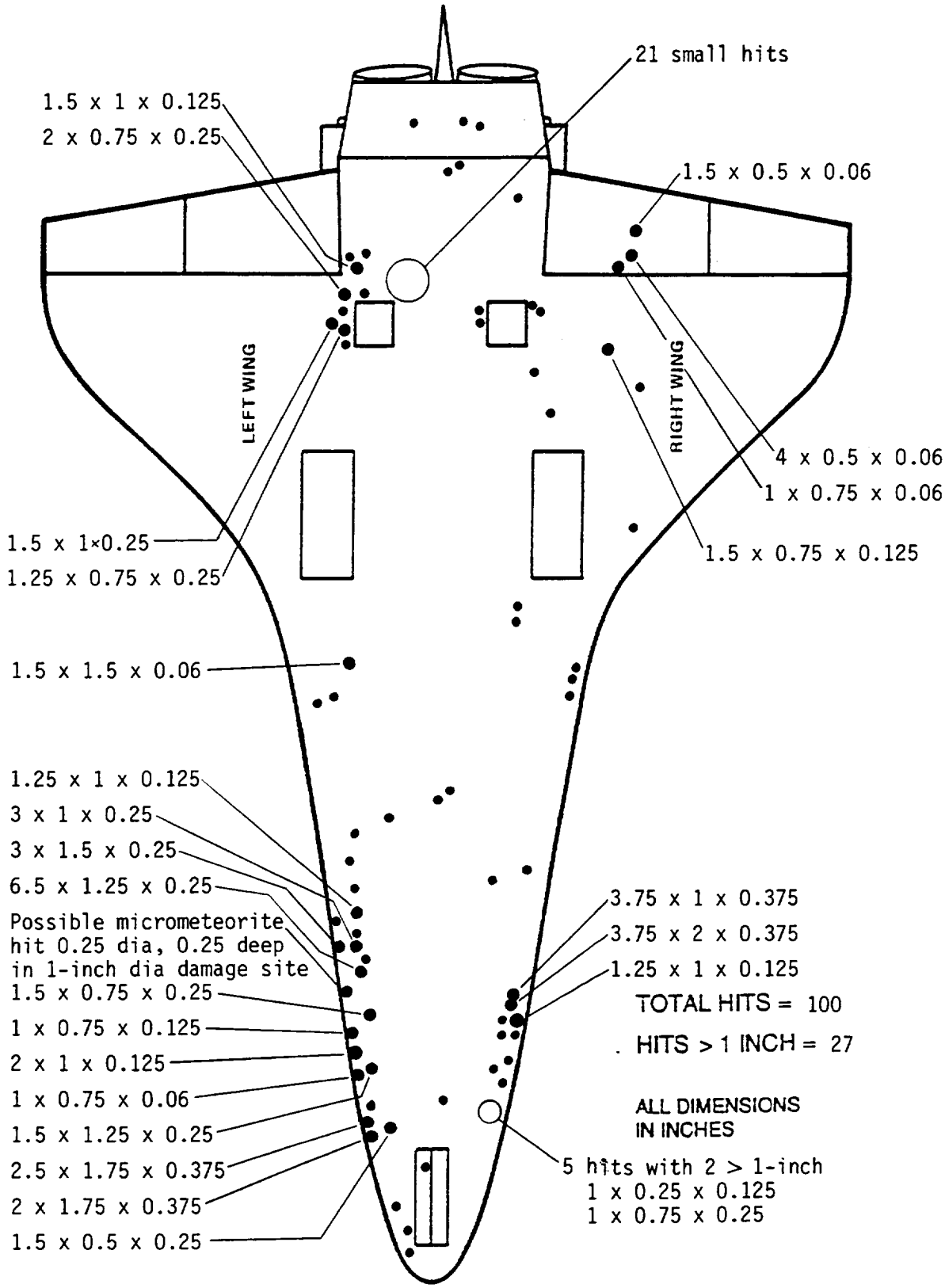


Figure 1: Orbiter Lower Surface Debris Damage Map

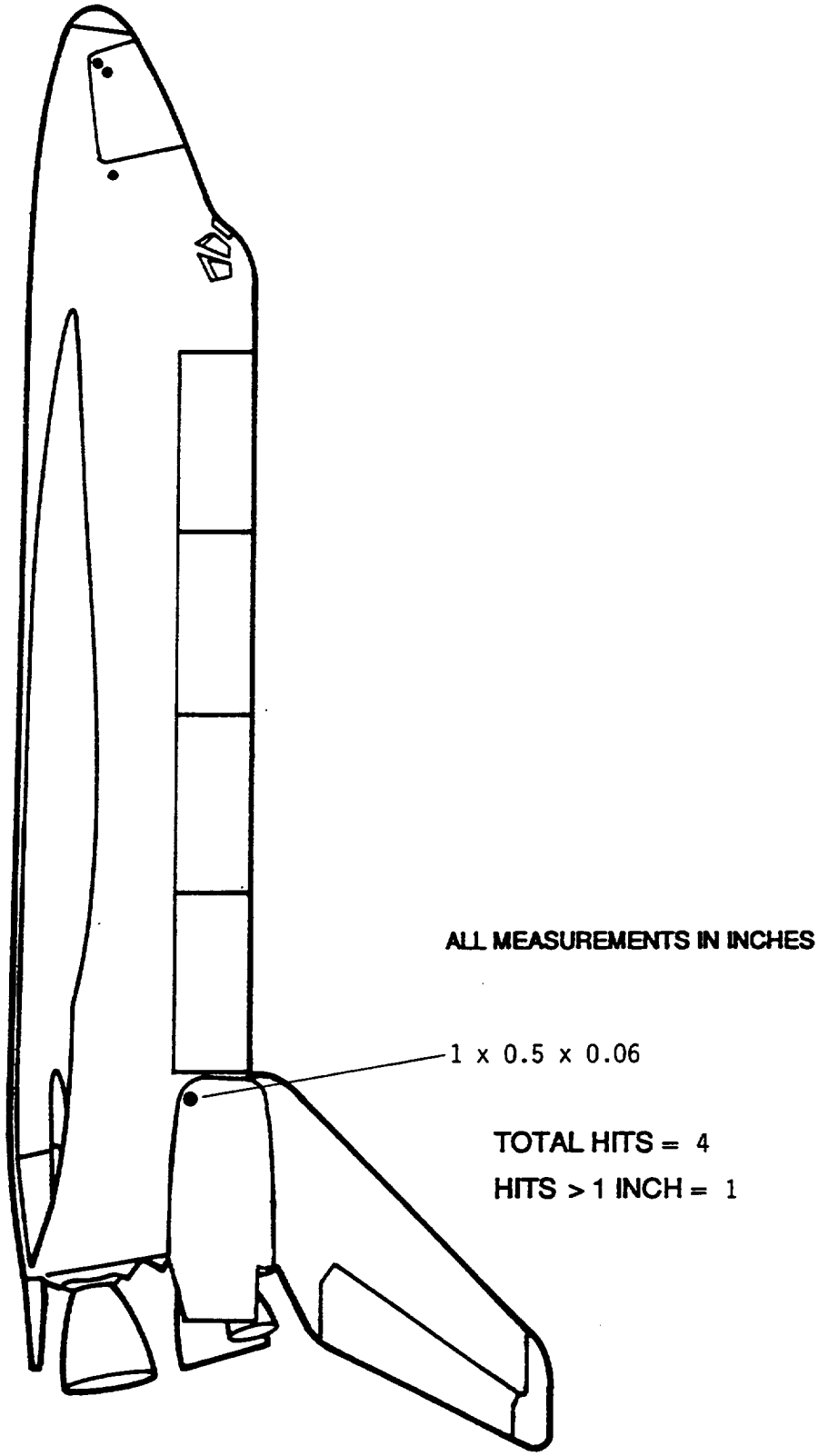


Figure 2: Orbiter Left Side Debris Damage Map

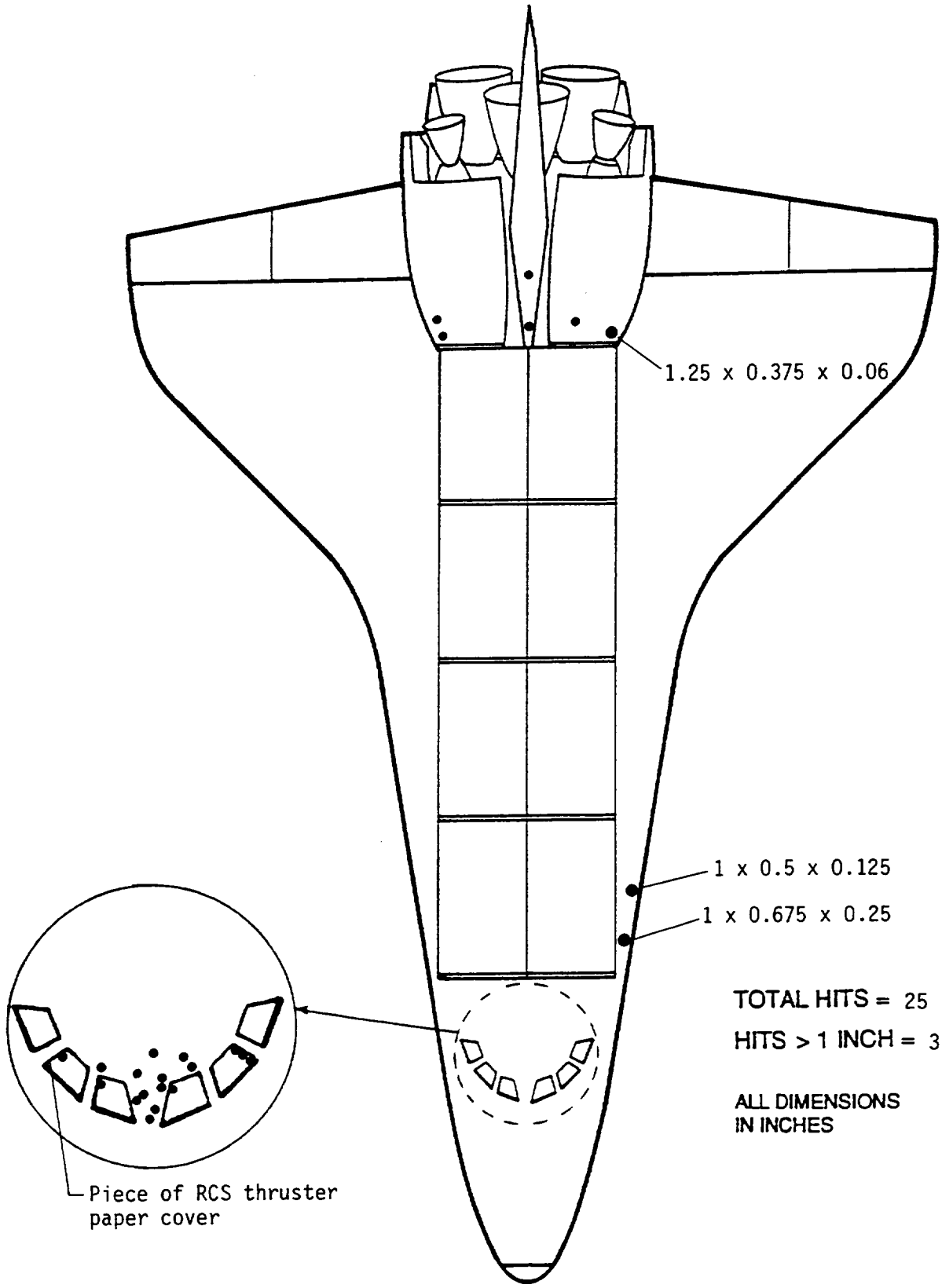


Figure 3: Orbiter Upper Surface Debris Damage Map

	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-86	27	100	31	129

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

Figure 4: Orbiter Post Flight Debris Damage Summary

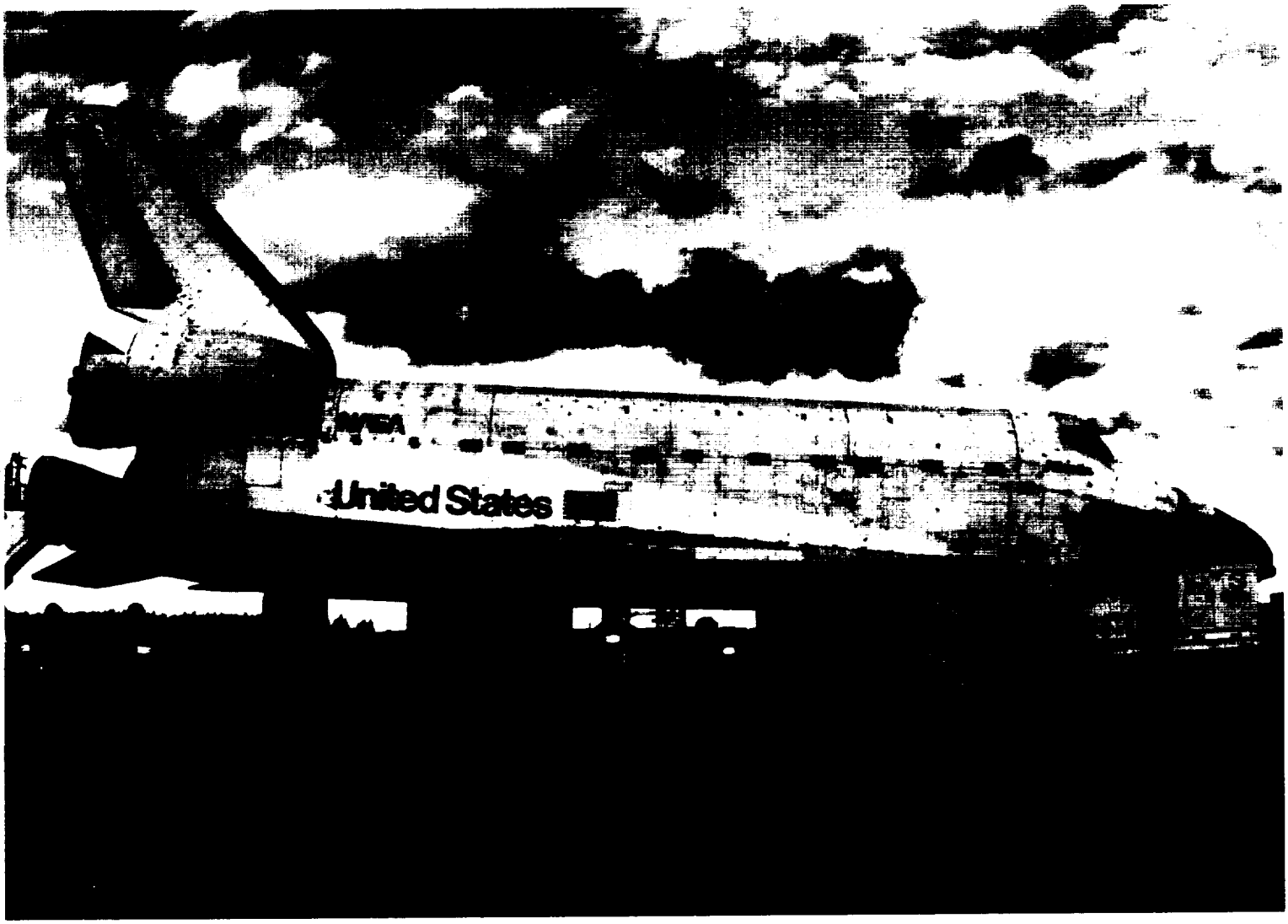


Photo 14: Overall View Orbiter Right Side

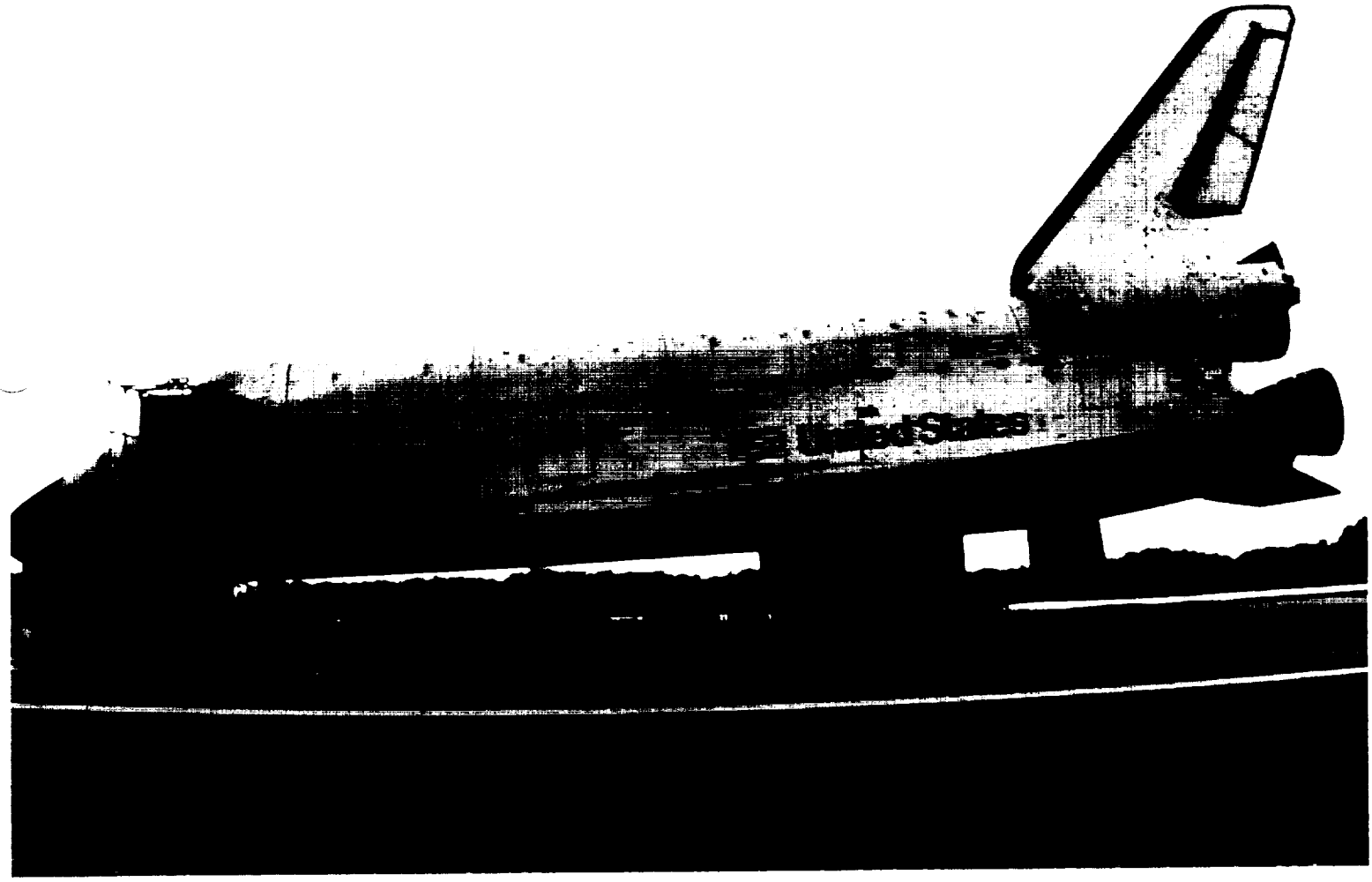


Photo 15: Overall View Orbiter Left Side

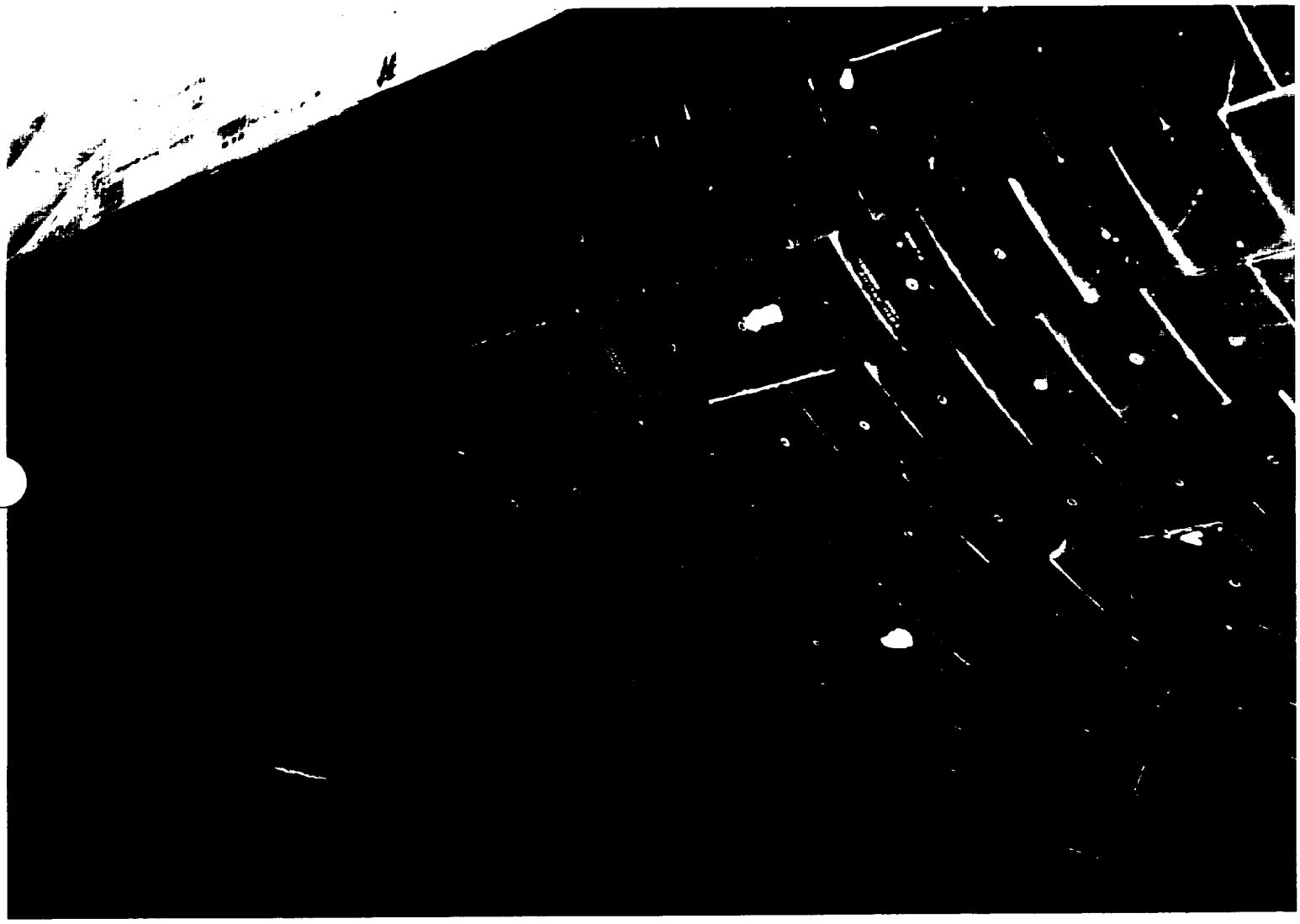


Photo 16: Lower Surface Tile Damage

The Orbiter lower surface sustained a total of 100 hits, of which 27 had a major dimension of 1-inch or larger.

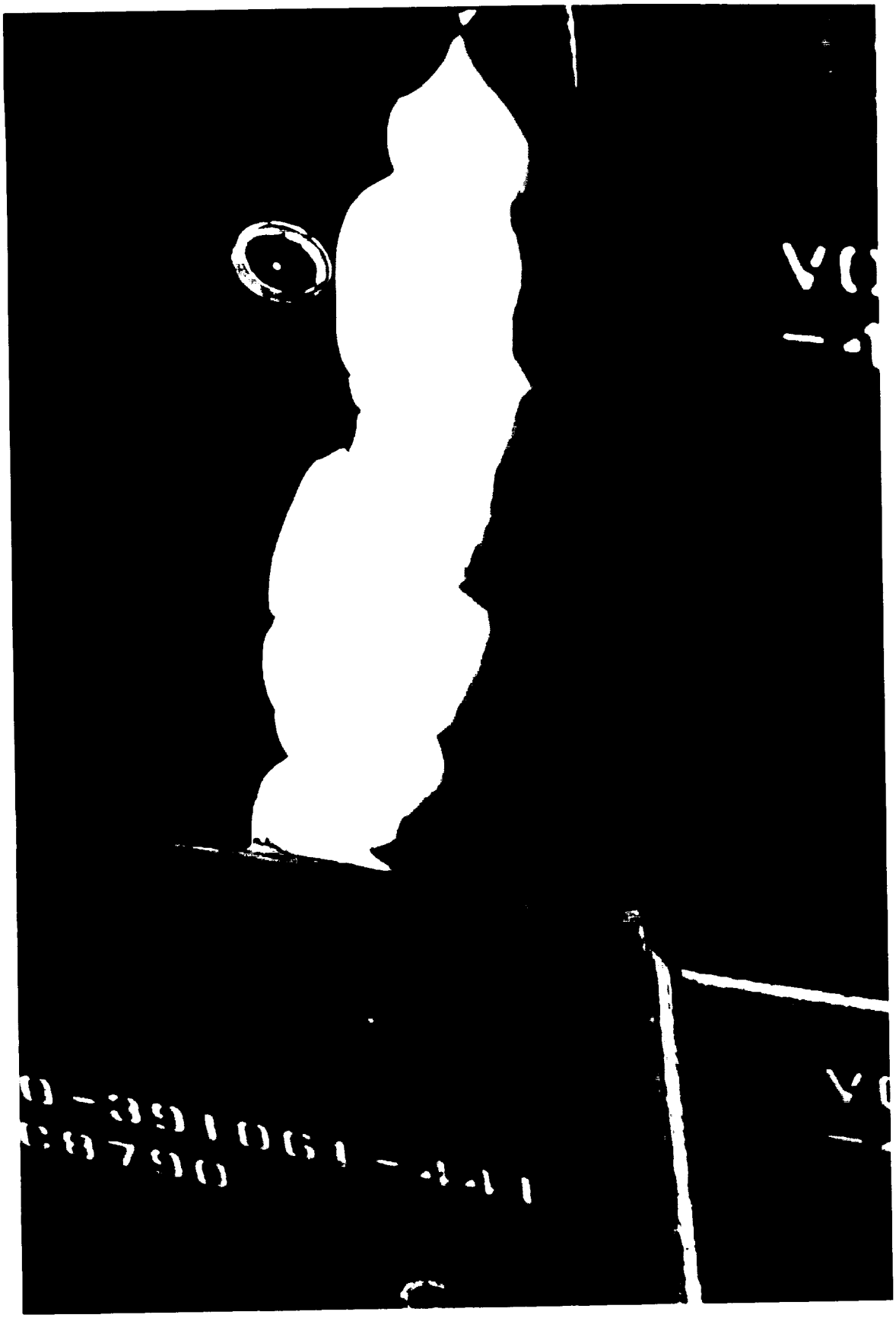


Photo 17: Lower Surface Tile Damage

The largest lower surface tile damage site was located on the left glove and measured 6.5-inches long by 1.25-inches wide by 0.25-inches maximum depth.

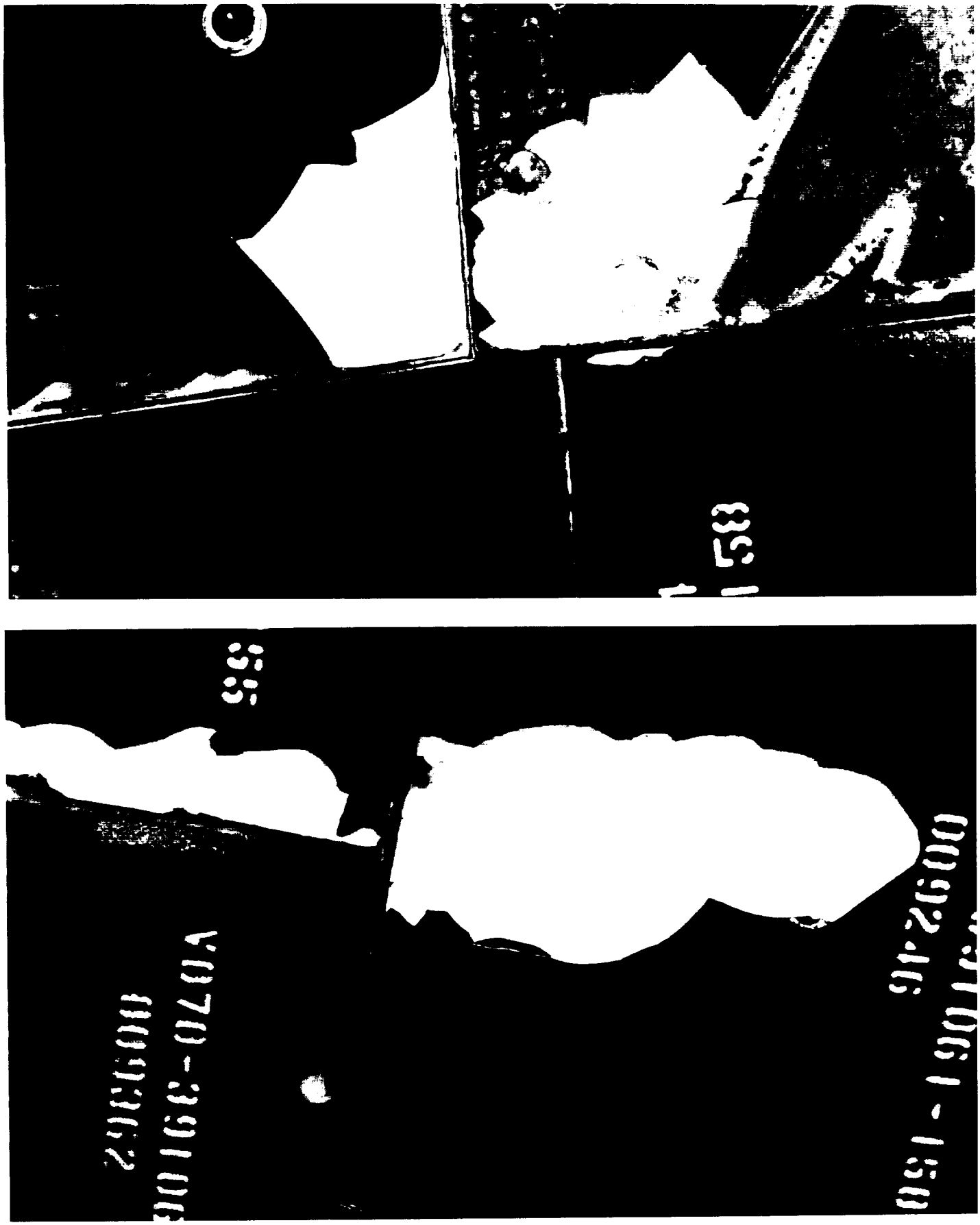


Photo 18: Lower Surface Tile Damage

This damage sites are just some of 26 hits (with 13 larger than 1-inch) from an area to the left of the nose progressing aft almost to the left main landing gear door - an unusual occurrence.

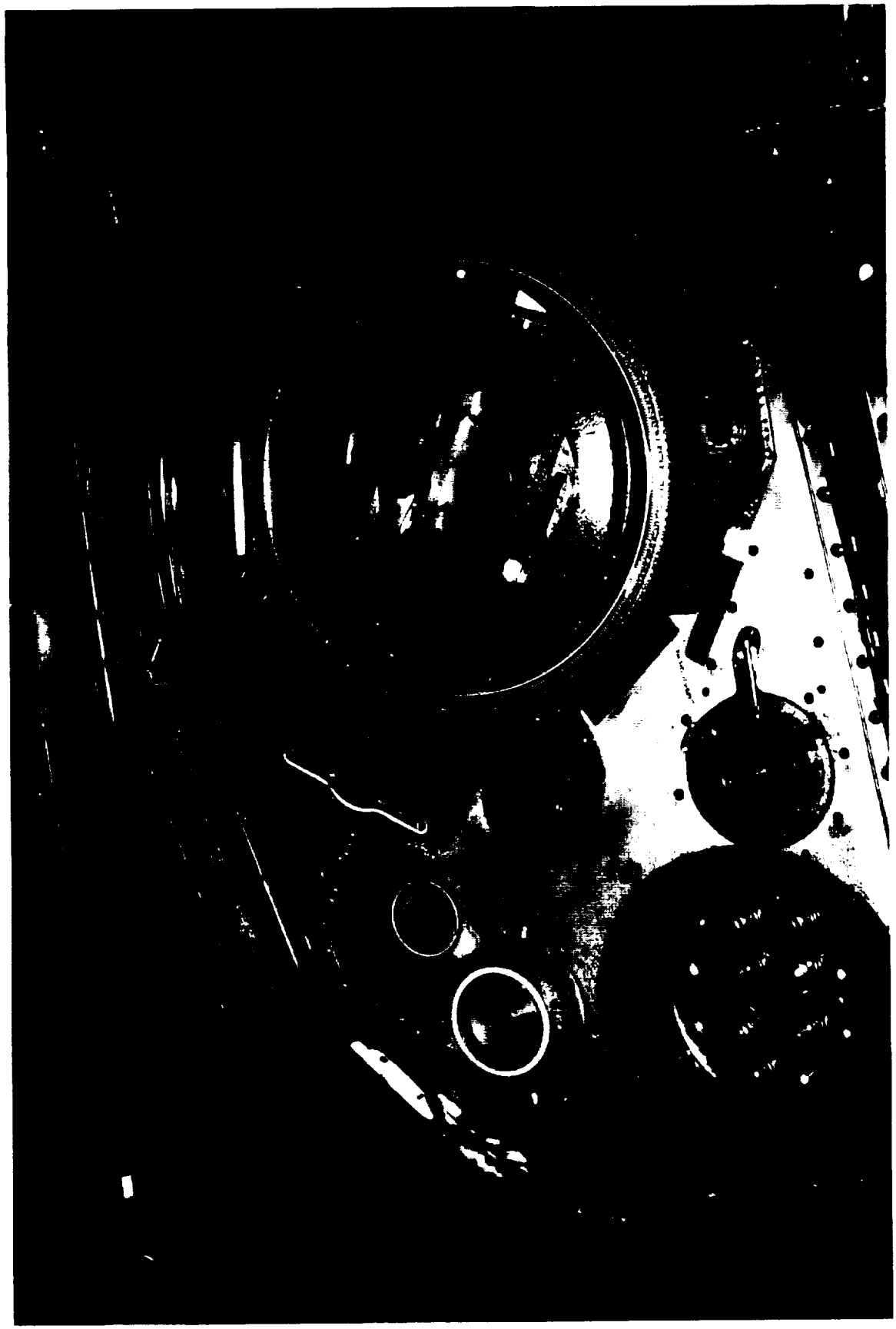


Photo 19: LH2 ET/ORB Umbilical

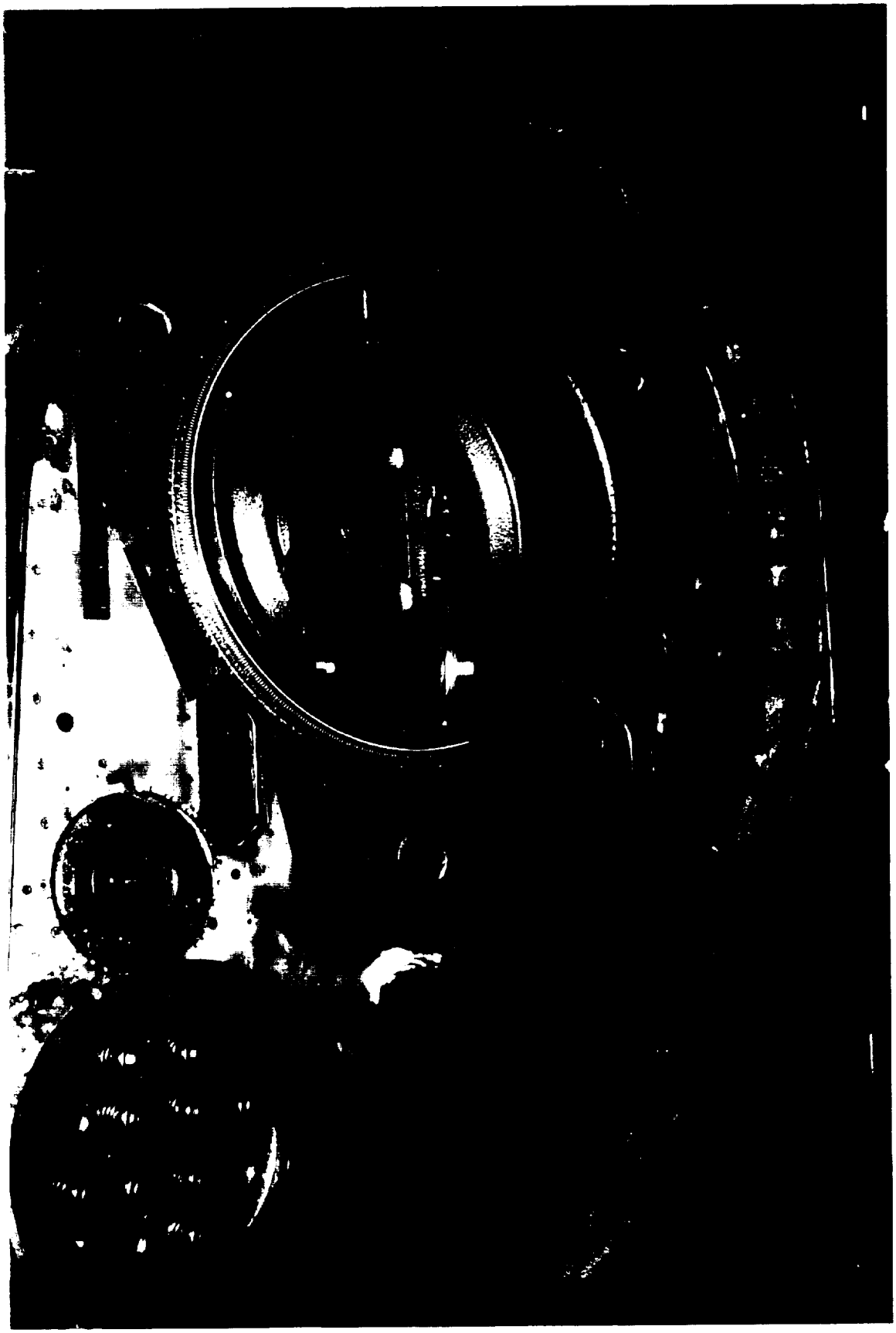


Photo 20: LO2 ET/ORB Umbilical

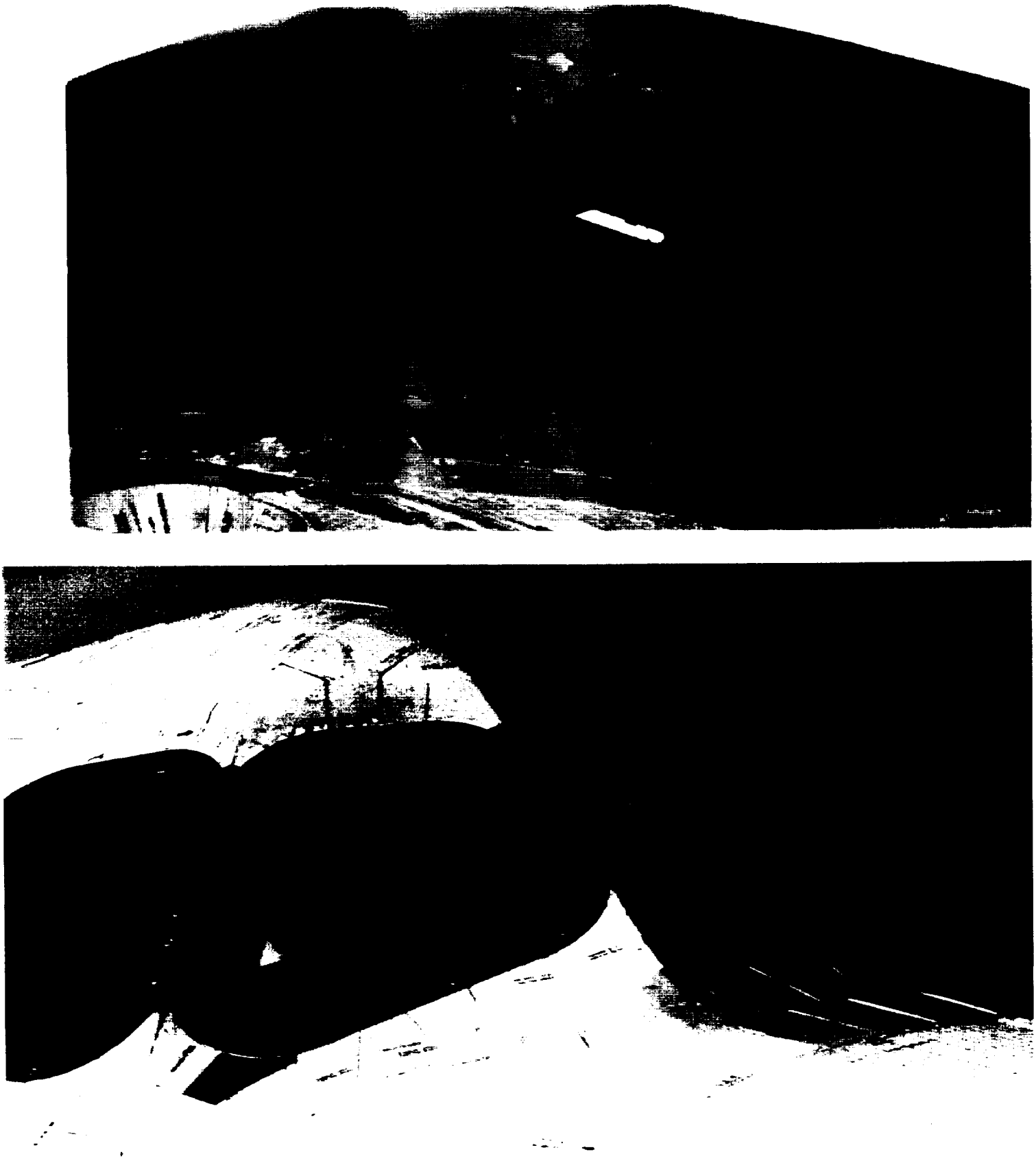


Photo 21: Windows and Perimeter Tiles

Hazing and streaking of forward-facing Orbiter windows was typical. Damage sites on the window perimeter tiles was noticeably less than usual in quantity and size, though a piece of a forward RCS thruster paper cover was wedged between window #5 and the perimeter tiles.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

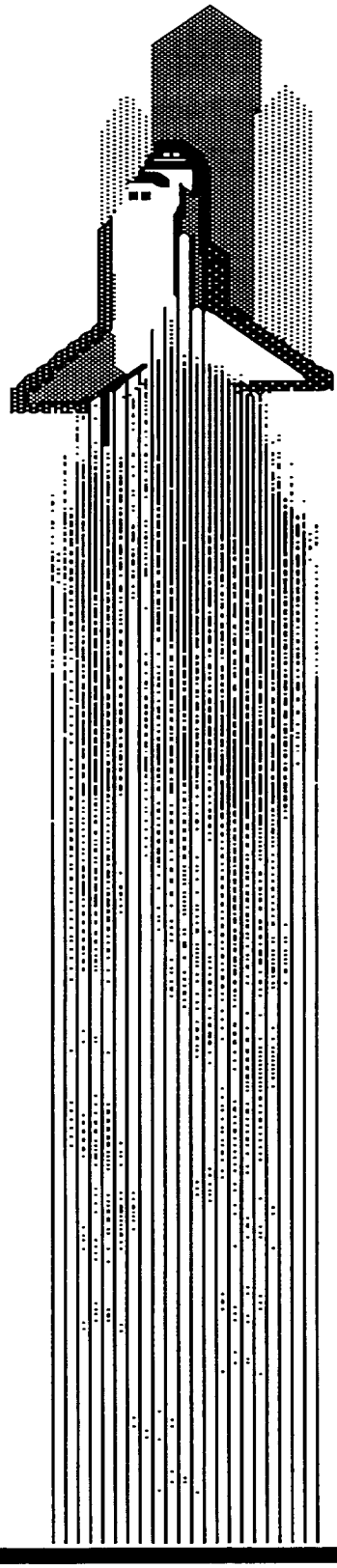
Space Shuttle

Earth Science Branch

Image Science and
Analysis Group

STS-86 Summary of Significant Events

November 13, 1997



Space Shuttle Image Science and Analysis Group

STS-86 Summary of Significant Events

Project Work Order - SN-5CA

Approved By

Lockheed Martin

E. R. Magness, Project Analyst
Image Science and Analysis Group

for M. H. Trenchard, Project Manager
Image Analysis Projects

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

NASA

Michael Gaunce, Mission Lead
Image Science and Analysis Group
Earth Science Branch

Prepared By

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

Table of Contents

List of Tables and Figures

1. STS-86 (OV-104): FILM/VIDEO SCREENING AND TIMING SUMMARY

1.1 SCREENING ACTIVITIES

1.1.1 Launch

The STS-86 launch of Atlantis (OV-104) from pad A occurred on Thursday, September 25, 1997 (day 269) at 02:34:19.011 Coordinated Universal Time (UTC) as seen on camera E9. Solid Rocket Booster (SRB) separation occurred at 02:36:22.025 UTC as seen on camera E207.

On launch day, 24 of the 24 expected videos were received and screened. Following launch day, 19 films were screened. Twenty-two additional films were received for contingency support and anomaly resolution, but were not screened since there were no major launch/ascent issues. 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 ET aft dome was acquired using umbilical well camera film (Method 1). Handheld still photography of the ET was acquired (Method 4). A handheld video of the external tank following separation was also acquired.

1.1.2 On-Orbit

No unplanned on-orbit analysis support was requested. Analysis support was provided to the Mir station photographic and television external survey (Detailed Test Objective 1118).

1.1.3 Landing

Atlantis made a late afternoon landing on runway 15 at the KSC Shuttle Landing Facility on October 6, 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 was delayed until after nose wheel touchdown because of crosswinds. The drag chute deployment appeared normal.

1.1.4 Post Landing

The following items were seen on the post landing walk-around inspection video: a thin, jagged streak or line on the mid-section of the right side of the rudder, three possibly damaged tiles beneath the forward edge of the left wing, a partially torn close-out blanket panel at the six o'clock position of the SSME #1 Dome Mounted Heat Shield (DMHS), a small area of tile damage near the left aft RCS thrusters, slight discolorations on the leading edge of the right OMS pod, normal tile erosion of the base heat shield and body flap, an area of brown discoloration in the LO2 umbilical, a small amount of white material (possibly RTV) in the LO2 umbilical well, and a red/brown-colored streak on the nose gear strut (possibly hydraulic fluid). The tires appeared to be in good condition. Tile damage around the Orbiter windows appeared to be less than normal.

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	279:21:54:48.735	EL30
Right Main Wheel Touchdown	279:21:55:08.547	EL7
Left Main Wheel Touchdown	279:21:55:08:567	EL7
Nose Gear Touchdown	279:21:55:18.560	EL4
Drag Chute Initiation	279:21:55:22.048	EL17IR
Pilot Chute at Full Inflation	279:21:55:23.077	KTV15L
Bag Release	279:21:55:24.445	KTV15L
Drag Chute Inflation in Reefed Configuration	279:21:55:26.414	KTV15L
Drag Chute Inflation in Disreefed Configuration	279:21:55:29.218	KTV11L
Drag Chute Release	279:21:55:56.647	EL2
Wheel Stop	279:21:56:29.945	KTV11L

Table 1.2 Landing Events Timing

2. SUMMARY OF SIGNIFICANT EVENTS

2.1 DEBRIS FROM SSME IGNITION TO LIFTOFF

As on previous missions, multiple pieces of debris were seen near the time of SSME ignition until 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

A single piece of umbilical ice debris was seen to strike the ET/Orbiter LH2 umbilical door sill during SSME ignition at 02:34:15.585 UTC. Another piece of umbilical ice was seen to strike the LH2 four-inch recirculation line at 02:34:16.419 UTC (Camera OTV009). No damage to the door sill or the four-inch recirculation line was visible.

A dark-colored piece of debris was seen near the RSRB aft skirt during SSME ignition (02:34:15.704 UTC) (Camera E2).

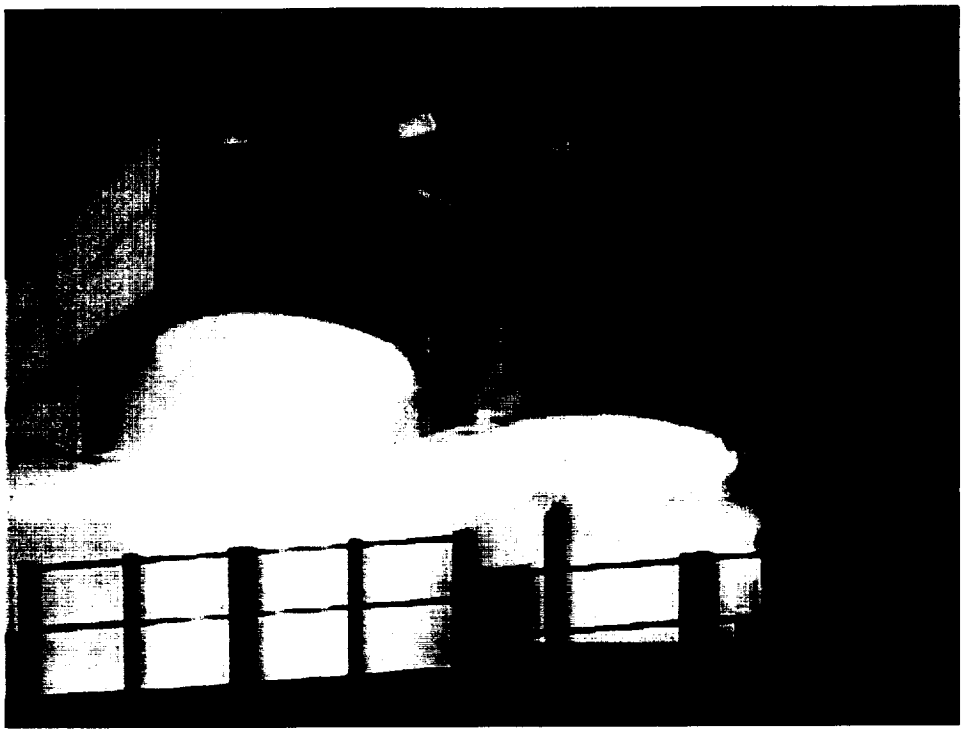


Figure 2.1 (B) Probable Ice Debris near Vertical Stabilizer

A single piece of white-colored debris (probably ice) was seen near the trailing edge of the vertical stabilizer during SSME ignition at 02:34:15.686 UTC. This debris may have been ice from the LH2 TSM T-O umbilical disconnect area (Cameras OTV050, OTV070).

A single piece of dark-colored debris, first seen near the RSRB aft skirt, was seen to arc upward before falling aft along the body flap at liftoff (02:34:19.3 through 02:34:20.4 UTC) (Cameras E2, E5). The debris was not seen to contact the vehicle.

A dark piece of debris of unknown origin was seen near the LSRB aft skirt traveling upward toward the ET/Orbiter umbilicals during liftoff. The debris was not seen to contact the vehicle (02:34:19:431 UTC) (Camera E31).

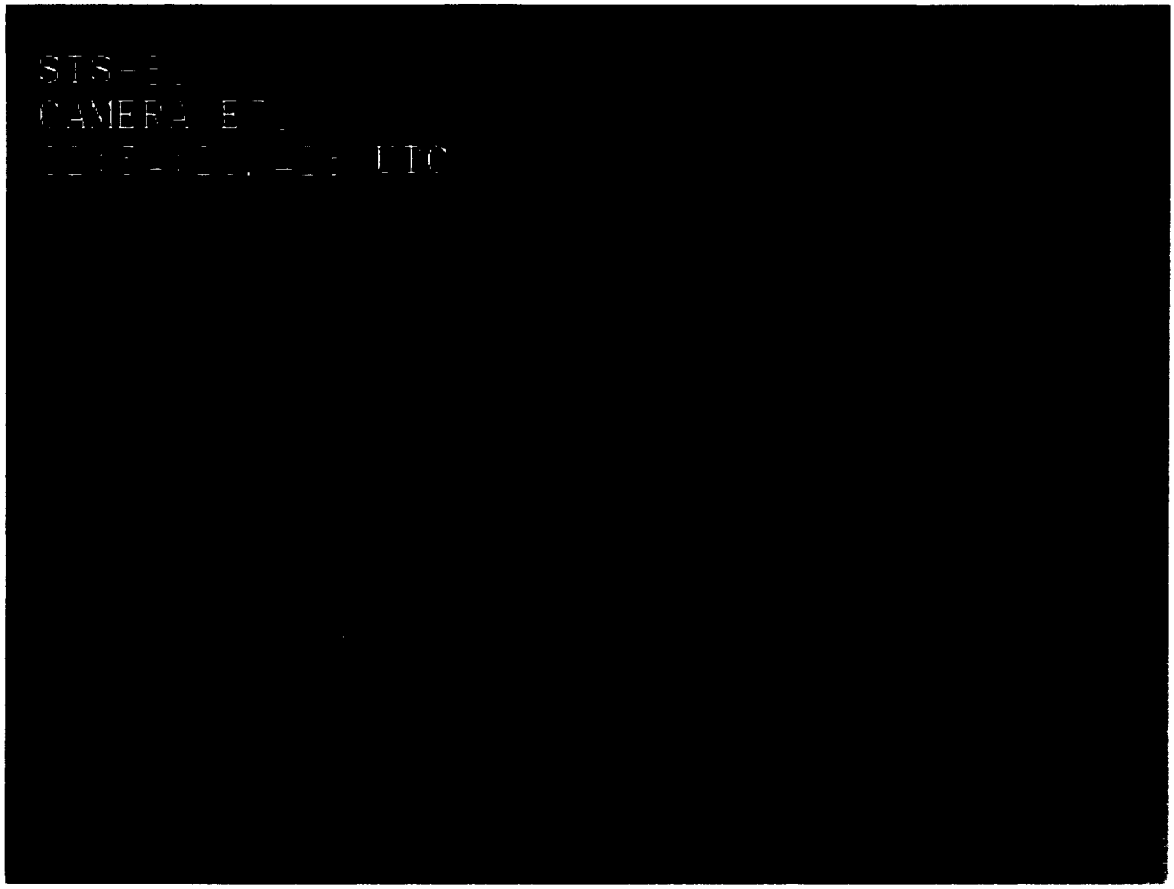


Figure 2.1 (C) Debris near LSRB Aft Skirt

On camera film E76, a long, curved, light-colored piece of debris was seen near the LSRB aft skirt traveling in an upward direction toward the FSS during liftoff (02:34:21:426 UTC). Three pieces of debris, first seen over the gaseous hydrogen dispersal system (stovepipe), traveled upward on the right side of the LSRB (02:34:20.536 and 02:34:20.991 UTC). None of the debris were seen to contact the launch vehicle.

Several pieces of white-colored debris (probably umbilical ice) were noted falling aft of the Orbiter body flap at liftoff (02:34:20.557 UTC) (Camera OTV049).

Multiple pieces of light-colored debris were seen north of the MLP during liftoff (02:34:20.614 UTC) (Camera KTV7A). The debris appeared to move away from the vehicle.

2.2 DEBRIS DURING ASCENT

Multiple pieces of debris (probably umbilical ice) fell aft of the launch vehicle after liftoff through the roll maneuver. None of the debris was seen to contact the vehicle. No follow-up action was requested. (Cameras E207, E212, E222, E223, E224).

Debris, first seen near the LSRB forward of the aft skirt, was seen falling aft of the vehicle during ascent at 02:34:35.128 UTC (Camera E223).

Debris, first seen near the LSRB forward of the aft skirt, was seen falling aft of the vehicle during ascent at 02:34:35.128 UTC (Camera E223).

Multiple pieces of light-colored debris (possibly forward RCS paper) were seen falling aft of the vertical stabilizer after the roll maneuver between 02:34:36.9 and 02:34:39.6 UTC (Cameras E222, E223, E224, ET212).

A single piece of debris was seen in the SSME exhaust plume after the roll maneuver at 02:34:41.75 UTC. A single piece of light-colored debris (possibly umbilical purge barrier material) was seen just aft of the body flap at 02:34:52.4 UTC (Camera ET207).

Light-colored debris (probably ET/Orbiter umbilical purge barrier material) were seen falling aft of the launch vehicle during early ascent (02:34:52.453 UTC) (Camera E223).

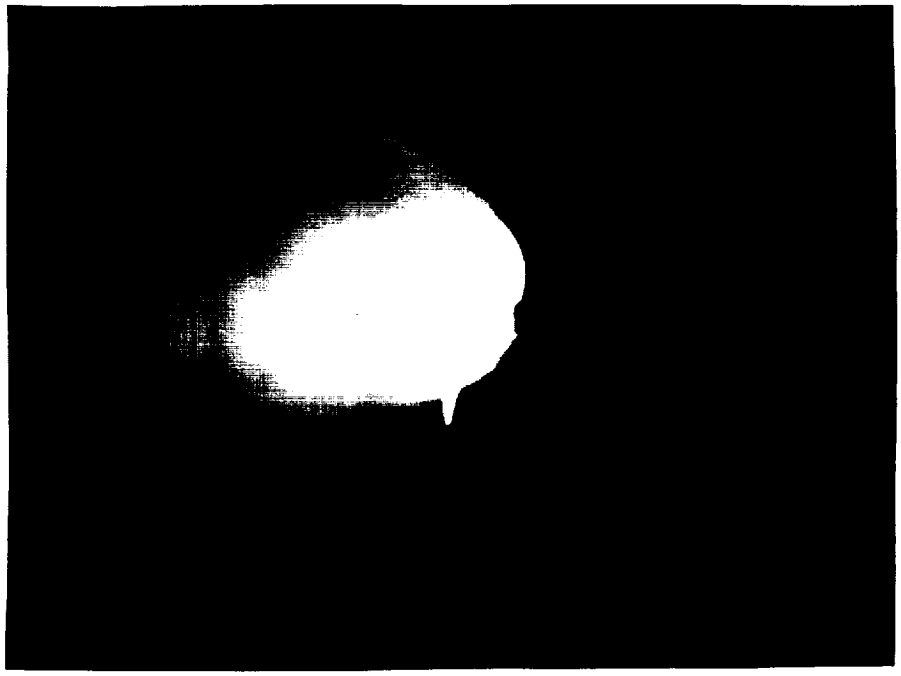


Figure 2.2 (A) Debris before SRB Separation

Two pieces of SRB slag debris were seen immediately prior to SRB separation. Numerous pieces of slag debris were noted during and after SRB separation on imagery from the long range tracking cameras.

2.3 MOBILE LAUNCH PLATFORM (MLP) EVENTS

The SSME Mach diamonds formed in the expected sequence as seen on Camera E19 and recorded in Table 2.3 (A). No follow-up action was requested. The times of the Mach diamond formation are provided in Table 2.3.

SSME #3	02:34:15.728 UTC
SSME #2	02:34:15.872 UTC
SSME #1	02:34:15.937 UTC

Table 2.3 (A) Mach Diamond Formation

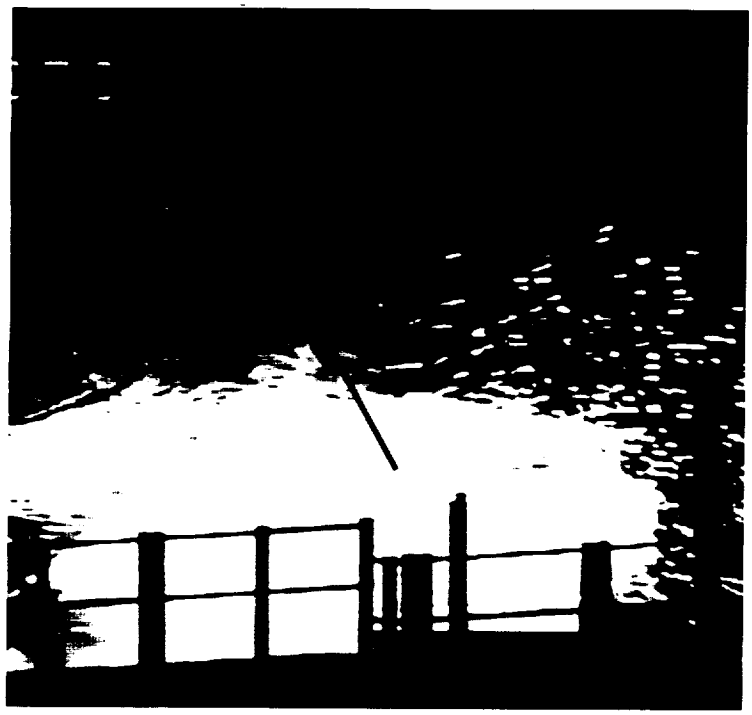


Figure 2.3 (A) Orange Vapor during SSME Ignition

Orange vapor, probably free burning hydrogen, was seen above the SSME rims and near the base heat shield during SSME ignition (Cameras E2, E5, E17, E18, E19, E20, E36, E52, E63, E76, OTV070). Similar orange vapors have been seen on several previous missions.

A small area of possible base heat shield erosion was noted at the base of SSME #3 during SSME ignition. A similar area of tile erosion was also visible on the outboard edge of the right RCS stinger. (Camera E19)

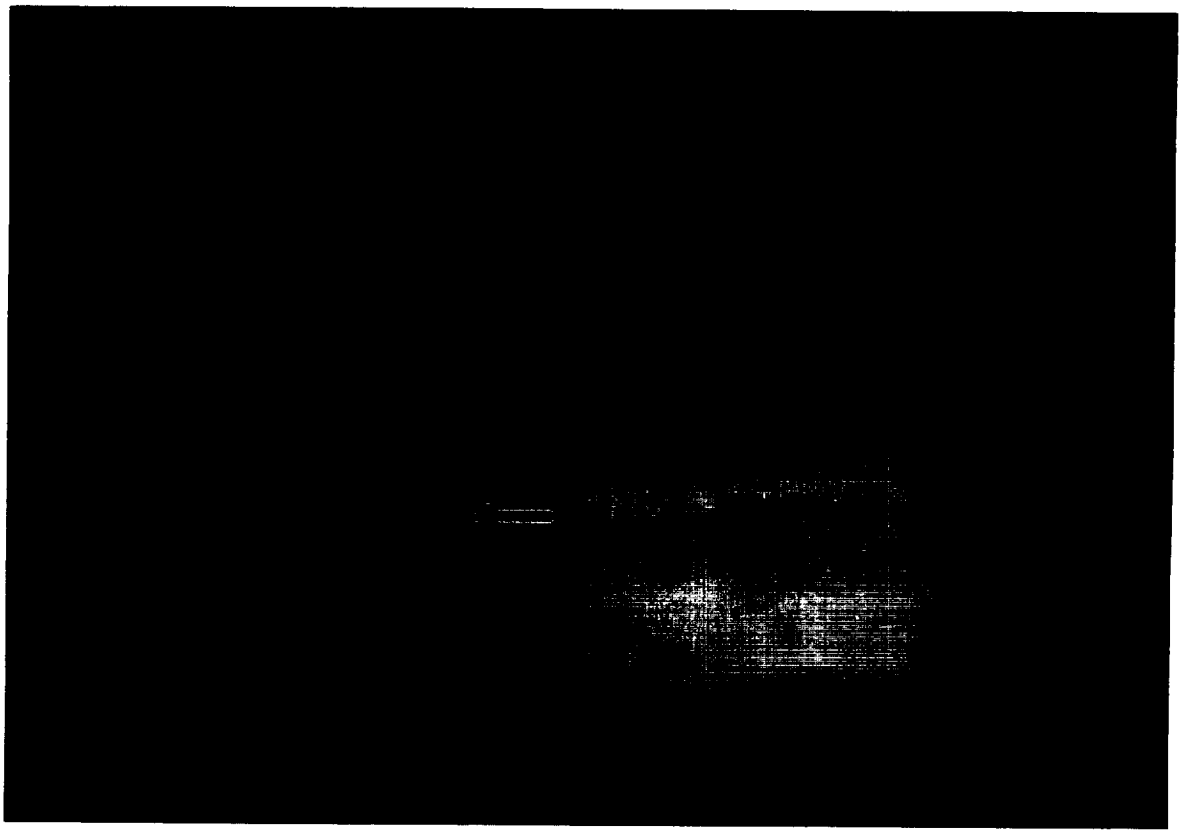


Figure 2.3 (B) Bolt Hang-up on RSRB HDP M-3

A bolt hang-up was seen at RSRB holddown post M-3 at liftoff (02:34:19.579 UTC) (Camera E10). No debris fragments were seen near the DCS during the hang-up and bolt release. SRB holddown bolt hang-ups have been seen on seven of the last fifteen previous missions. See Table 2.3 (B). No follow-up action was requested.

MISSION	LOCATION OF HANG-UP
STS-34	RSRB holddown post M-2
STS-33	RSRB holddown post M-3
STS-39	RSRB holddown post M-1
STS-43	LSRB holddown post M-7
STS-45	RSRB holddown post M-4
STS-50	RSRB holddown post M-4
STS-46	LSRB holddown post M-7
STS-53	RSRB holddown post M-1
STS-73	RSRB holddown post M-2
STS-75	LSRB holddown post M-5
STS-76	LSRB holddown post M-5
STS-78	LSRB holddown post M-5
STS-79	RSRB holddown post M-3
STS-83	LSRB holddown post M-7
STS-86	RSRB holddown post M-3

Table 2.3 (B) Table of Holddown Post Bolt Hang-ups

2.4 ASCENT EVENTS

2.4.1 Flares in SSME Exhaust Plume

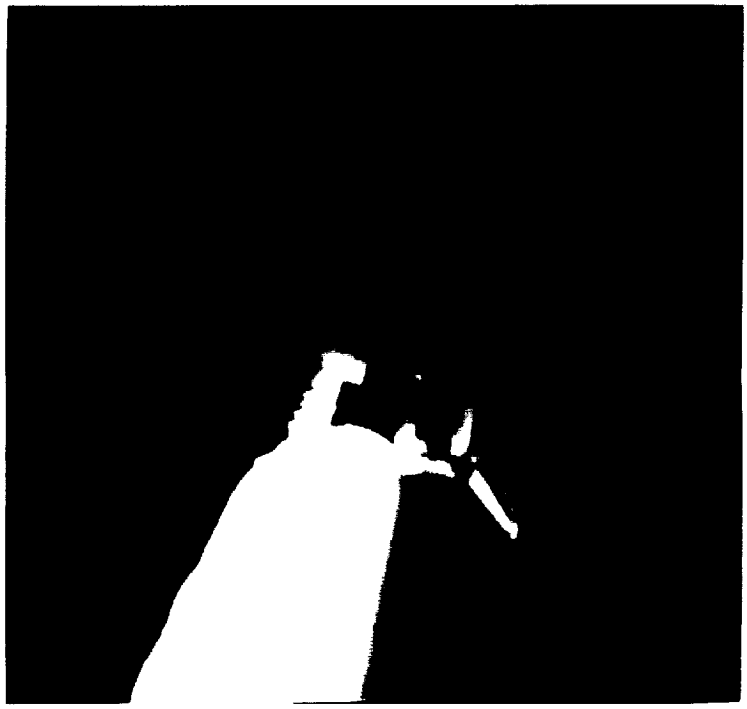


Figure 2.4.1 Orange-colored Flare in the SSME Exhaust Plume

Eleven orange-colored flares (probably debris-induced) were seen in the SSME exhaust plume between 02:34:47.3 and 02:35:03 UTC (Cameras E207, ET212, E222, E223).

Linear optical effects were seen along the launch vehicle at 02:36:02.869 and at 02:36:22.025 UTC (Cameras ET207 and E207).

2.4.2 Body Flap Motion Analysis (Task #6)

Figure 2.4.2 (A) Body Flap Motion during Ascent

Orbiter body flap motion was seen on STS-86 during ascent on the long range tracking camera views. The apparent torsion or twisting motion of the Orbiter body flap was reviewed with engineers from the ES/Structure and Dynamics Branch on October 1, 1997. At this review, IS&AG was tasked to make quantitative measurements of the motion to support a possible post landing modal test of the body flap at KSC.

Measurements of the body flap motion were made on the launch tracking camera imagery. Film E207 was screened to determine the sequence of frames for analysis. Frames 2300 through 2700 were analyzed in the study (from 34.8-41.3 seconds MET). To verify that errors were not introduced in the data collection process, measurements of the body flap motion were made using two independent methods. The first method was manual using a duplicate master film and a film motion analyzer. The second method was automated using a video conversion of the E207 film and a recently-developed point tracking program. The raw data sets for each technique were examined. The data from the automatic procedure had a higher signal-to-noise ratio and, therefore, was used for the remainder of the analysis.

Measurements of the body flap tip locations (Figure 2.4 (B), points 1 and 2) in each frame were made using both the manual and the automatic procedure. Reference/scale points (Figure 2.4 (B), points 3 through 8) were also measured for all analysis frames using both procedures. The reference points were used to remove the overall launch vehicle motion from the body flap motion and to remove camera tracking motion. The reference points were also used to define the scale factor. A noise reduction algorithm was applied to enhance the dominant frequencies of the automatic data. The frequency analysis results are shown in Figure 2.4 (C).

Measurements of the body flap motion showed an average peak-to-peak deflection of the starboard body flap tip to be approximately of 1.4 inches. The average peak-to-peak deflection of the port body flap tip was measured to be 1.5

inches. The maximum peak-to-peak deflection measured approximately 4 inches on both the port and starboard tips of the body flap. Both the port and starboard data revealed frequency peaks at 8 Hz (global rotation) and 13 Hz (torsion rotation).

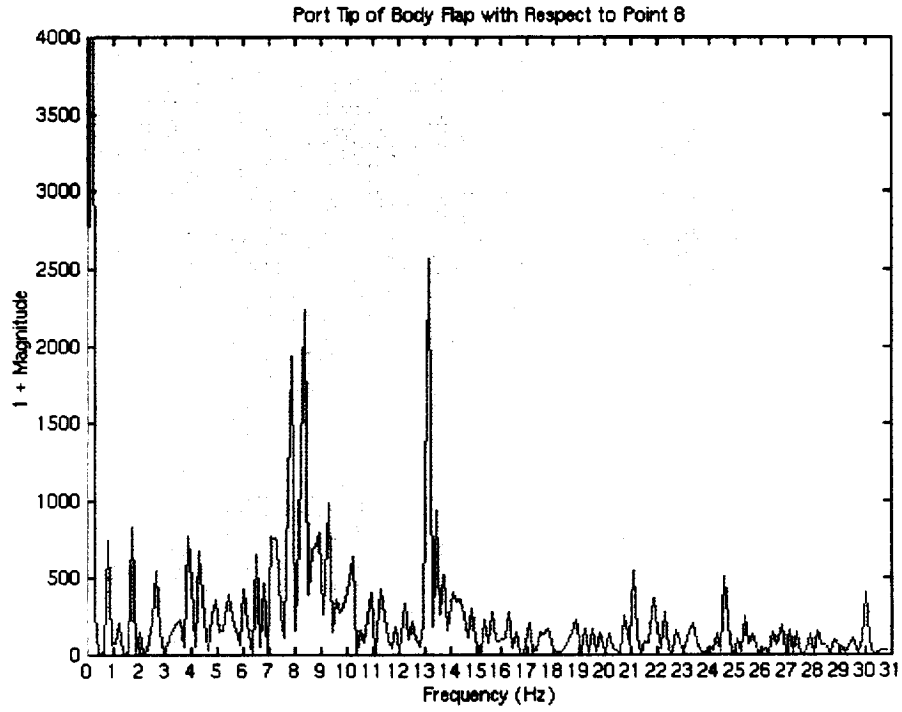


Figure 2.4.2 (B) Frequency Plot of STS-86 Body Flap Motion (Port Tip)

Measurements of the body flap motion were also made on STS-84 imagery using identical procedures for comparison to the STS-86 data. The body flap motion seen on STS-84 was similar to STS-86 in frequency except that the 13 Hz frequency peak seen on STS-86 was not evident on STS-84 (torsion rotation). Both the port and starboard data revealed frequency peaks at 8 Hertz (global). On STS-84, an average peak-to-peak deflection of both the port and starboard body flap tips was measured to be approximately 1.9 inches. The maximum peak-to-peak deflection measured approximately 6 to 8 inches on the starboard tip of the body flap and 8 inches on the port side. Table 2.4 is a summary of the body flap motion image measurements from STS-84 and STS-86.

Low frequency, low amplitude peaks of 1 through 7 Hz are present in both the STS-84 and STS-86 motion data, but are not attributed to independent body flap motion. These lower frequency motions are variable, depending on the reference points, and are not considered dominant frequencies. They may be attributed to a combination of noise, vehicle vibration, atmospheric effects, and/or point measurement variations.

Body flap maximum displacement (inches):	STS-84	STS-86
Starboard tip	6-8	4
Port tip	8	4
Body flap average displacement (inches):		
Starboard tip	1.9	1.4
Port tip	1.9	1.5
Frequency:		
Global Frequency	8	8
Torsional Frequency	Not dominant	13

Table 2.4.2 Comparison of STS-84 and STS-86 Body Flap Motion Measurements

The point tracking error for the automatic procedure was calculated to be +/- 0.01 inches. The standard deviation after smoothing the data showed that the maximum displacement error of the body flap was +/- 1.0 inches. The frequency uncertainty calculated from the full half width of the dominant frequency peaks was +/- 0.6 Hz for 8 Hz and +/- 0.4 Hz for 13 Hz.

A more detailed description of the STS-86 body flap motion imagery analysis is available under separate documentation.

2.5 ONBOARD PHOTOGRAPHY OF THE EXTERNAL TANK

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

Two rolls of umbilical well camera films from mission STS-86 were received: the 16mm film (5mm lens) and the 16mm film (10mm lens) from the LH2 umbilical. The 35mm film from the LO2 umbilical well camera was unusable due to darkness and was not printed. The +X translation maneuver was not performed.

The LSRB separation appeared normal. Numerous light-colored pieces of debris (insulation and frozen hydrogen), and dark debris (probably charred insulation) were seen throughout the 16mm SRB separation film sequence. One large piece of debris was noted near the base of the LSRB electric cable tray after SRB separation. Both white and charred-appearing debris (probably insta-foam) were seen near the LSRB attach point after SRB separation. Two pieces of white debris (probably TPS) appeared to strike the left aft LSRB attach brace (no damage was visible). Late in the LSRB separation film sequence, a large, piece of debris (probably insta-foam) was seen falling aft. Chipping of the ET aft dome TPS was visible. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the horizontal section of the -Y ET/SRB vertical strut was seen.

As in the case of the 35mm umbilical well camera film, the post-separation ET was not imaged on the 16mm films. The ET separation film sequence of both of the 16mm films were dark and unusable due to the nighttime conditions.

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

Post-separation handheld photography (method 4) of the STS-86 ET was acquired. A Nikon 35mm camera with a 400mm lens was used for the ET photography. In accordance with a decision made prior to flight, the 2X extender was not used . The OMS-2 attitude pitch maneuver was performed to assist the crew members in acquiring the ET visually.

Thirty-six views of the external tank were acquired (roll 328). Views of the sides, nose and aft dome of the ET were acquired. Timing data is present on the handheld film. The first ET picture was taken on September 26, 1997 at 03:19:53 UTC (approximately 45.5 minutes after liftoff), and the last picture was taken at 03:25:57 UTC.

The size of the ET is very small on the film (0.22 mm), which hindered the visual analysis of the ET condition. No anomalies were seen on the handheld photography of the ET. The normal SRB separation burn scars and aero-heating marks were noted on the ET TPS.

The ET was measured to be approximately 14.1 kilometers from the Orbiter on the first usable image of the ET. The separation velocity was not calculated due to the small size of the ET image. The tank tumble rate was determined to be approximately 4.7 degrees/second. The ET roll rate was not determined.

In addition to the handheld photography, approximately 20 seconds of video of the ET was acquired with a Canon L1 camcorder. The quality of the video was excellent. The same aspects of the ET imaged on the still views were imaged on the video. Like the film, the size of the ET image was very small on the video.

2.6 LANDING EVENTS

2.6.1 Landing Sink Rate Analysis (Task #1)

Film camera EL7 was used to determine the landing sink rate of the Orbiter main gear and camera film EL4 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-86 Orbiter was reported to be 214,726 lbs). The sink rate measurements for STS-86 are given in Table 2.6.1. In Figure 2.6.1 (A), and 2.6.1 (B), the trend of the measured data points for the image data is illustrated.

Sink Rate Prior to Touchdown (1 Second)	
Main Gear	3.0 ft/sec.
Nose Gear	4.5 ft/sec.

Table 2.6.1 Sink Rate Measurements

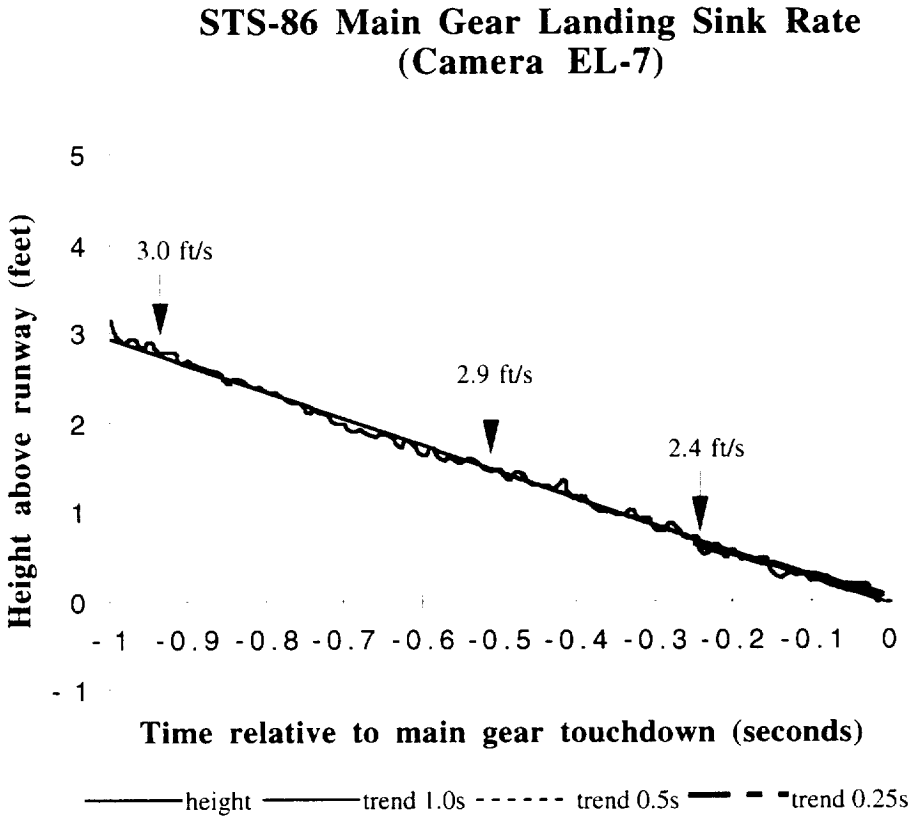


Figure 2.6.1 (A) Main Gear Height versus Time Prior to Touchdown

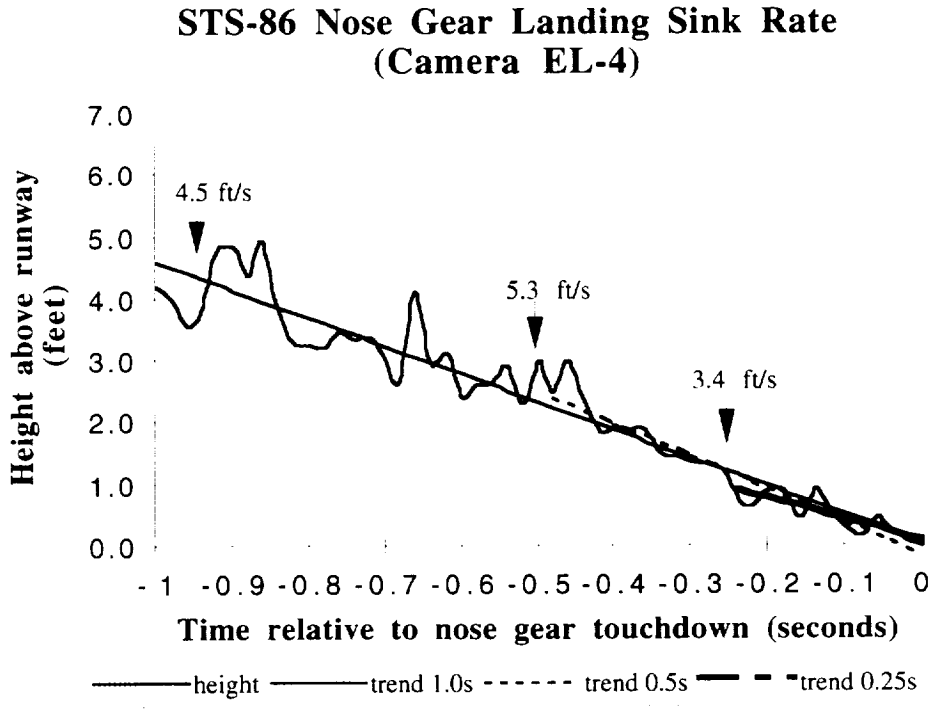


Figure 2.6.1 (B) Nose Gear Height versus Time Prior to Touchdown

2.6.2 Drag Chute Analysis (Task #7)

JSC Structures and Mechanics Division/ES engineers requested photographic measurements of the drag chute angles after deployment to support the evaluation of the crosswind landing performance Detailed Test Objective (DTO-805). This task is in work and the results will be reported under separate documentation.

2.7 OTHER

2.7.1 Normal Events

Other normal events observed included: ice and vapor from the ET/Orbiter umbilical areas during SSME ignition, elevon motion at SSME ignition, 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.

2.7.2 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

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

Reply to Attn of: EP11(97-026)

TO: Distribution

FROM: EP42/Thomas J. Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-86

The launch of Space Shuttle Mission STS-86, the 20th flight of the Orbiter Atlantis, occurred on September 25, 1997, at approximately 9:34 p.m., Central Daylight Time (CDT) from Launch Complex 39A (LC-39A), Kennedy Space Center (KSC), Florida. Launch time was reported as 97:269:02:34:19.000 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team. Photographic and video coverage has be evaluated to determine proper operation of the flight hardware.

The tracking coverage of the vehicle was degraded due to cloud coverage and moisture content in the atmosphere. All ground-based cameras operated properly except for Items E1 and E57, which failed to run; Item E212 which provided a short track of the vehicle during ascent. The umbilical well cameras that record the Solid Rocket Booster (SRB) and External Tank (ET) separation events only provided data during the SRB separation due to insufficient lighting at ET separation. The astronauts photographed the ET approximately 37 minutes after separation using the hand-held 35mm Nikon camera with a 400mm lens. The image size was too small for any detail analysis.

Holddown post M3 experienced a stud hangup at liftoff. A debris particle was observed exiting the post when the stud cleared the hold.

The typical events such as pad debris from the SRB blast holes at ignition, RCS cover paper and purge barrier material falling aft during ascent, debris-induced streaks in the Space Shuttle Main Engine (SSME) plumes, and glowing debris particles from the Solid Rocket Motor (SRM) plumes were observed. An apparent nozzle cold wall leak was visible at the beginning of SSME Number 1 start. The leak appeared to originate near the Number 1 coolant line interface to the manifold. However, a post-flight leak check indicated no cold wall leak in this area. Orbiter body flap motion during ascent was pronounced as viewed from camera E207.

The following event times were acquired.

EVENT	TIME (UTC)	DATA SOURCE
M-1 PIC Firing	02:34:19.007	Camera E9
M-2 PIC Firing	02:34:19.008	Camera E8
M-5 PIC Firing	02:34:19.009	Camera E12
M-6 PIC Firing	02:34:19.008	Camera E13
SRB Separation	02:36:22.02	Camera E205

This report and additional information are available on the World Wide Web at URL:
http://photo4.msfc.nasa.gov/STS/sts86/sts86.html

For further information concerning this report, call Tom Rieckhoff, NASA/MSFC, at (205) 544-7677 or Jeff Hixson, Boeing North American, at (205) 971-3082.

Thomas J. Rieckhoff

Distribution:
CR01/Ms. Harris
EA01/Mr. Jobe
ED01/Dr. Humphries
ED31/Mr. Bianca
EE11/Mr. Rudolphi
EE12/Mr. Pung
EE21/Mr. Worlund
EE31/Mr. Harsh
EE31/Mr. Moye
EE31/Mr. Pessin
EE51/Mr. Nichols
EP01/Mr. Saucier
EP11/Mr. Pratt
EP12/Mr. Schafer
ZA06/Mr. Bruce
ZA12/Mr. Crowder
ZA15/Ms. Owens
ZA16/Ms. Simmons
USB-SYS/USBI-KSC/Mr.Lafleur
KSC-BICO-/Mr. Hoover
KSC-BICO-/Mr. Harland
KSC-MK-SIO-2/Mr. Martin

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	November 1997	Final Sept 24 - Oct 8, 1997

4. TITLE AND SUBTITLE
Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle Mission STS-86

5. FUNDING NUMBERS
OMRS00U0

6. AUTHOR(S)
Gregory N. Katnik
Jill D. Lin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
John F. Kennedy Space Center, NASA
Process Engineering/ Mechanical Systems Division
ET/SRB Branch, Mail Code: PK-H7
Kennedy Space Center, Florida 32899

8. PERFORMING ORGANIZATION REPORT NUMBER

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

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-113231

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Blanket Release

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-86. 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 anonalies. This report documents the ice/debris/thermal protection system conditions and integrated photographic analysis of Space Shuttle mission STS-86 and the resulting affect on the Space Shuttle Program.

14. SUBJECT TERMS
SUBJECT CATEGORY: 15, 16
STS-86 Thermal Protection System (TPS)
Ice Debris Photographic Analysis

15. NUMBER OF PAGES

16. PRICE CODE

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

KSC DEBRIS/ICE/TPS ASSESSMENT AND INTEGRATED PHOTOGRAPHIC ANALYSIS
REPORT DISTRIBUTION LIST 10/97

NASA - KSC

AA-C/L. J. Shriver
MK/D. McMonagle
MK-SIO/R. W. Page
PK-D2/R. Harrison
PK-H/C. Stevenson
PK-H7/G. Katnik (7)
RO-OMP/T. L. Smith
RO-PAD/A. Willett
PZ-C2/C. Brown
SK/F. Kienitz
USK-321/R. S. Herman
USK-437/M. Valdivia
ZK-86/F. J. Foster
BICO-RVITS/R. B. Hoover
MMC-15/D. S. Otto
USBI-LSS/L. Clark

NASA - HQ

QSO/W. Comer

NASA - JSC

Johnson Space Center
Houston, Texas 77058

EP2/P. Cota
ES3/J. Kowal
MV3/D. Camp
SN3/E. Christiansen
SN5/M. Gaunce

NASA - MSFC

Marshall Space Flight Center
Huntsville, AL 35812

ED31/D. Andrews
EE31/M. A. Pessin
EE31/M. G. Harsh
EP42/T. J. Rieckhoff

Rockwell - Downey

Rockwell International
12214 Lakewood Blvd
Downey, CA 90241

AE21/J. McClymonds
FA44/R. Ramon

Martin Marietta

P. O. Box 29304
New Orleans, Louisiana 70189

Dept. 3571/S. Copsey
MAF Technical Library