Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-104

Armando Oliu

Technical Memorandum – 2005 – 211536 **January 2005**

DEBRIS/ICE/TPS ASSESSMENT and INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-104

Armando Oliu
Process Engineering/Mechanical System Division/ET-SRB Branch,
Kennedy Space Center, Florida

Technical Memorandum – 2005 – 211536 **January 2005**

DEBRIS/ICE/TPS ASSESSMENT
AND
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF
SHUTTLE MISSION STS-104

July 12, 2001

Contributions By:

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

Approved:

Armando Oliu
Shuttle Ice/Debris Systems
NASA - KSC
Mail Code: PH-H2

Peter Chitko
Chief, ET/SRB Mechanical Branch
NASA - KSC
Mail Code: PH-H2

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-104

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-104 consisted of OV-104 Atlantis (24th flight), ET-109, and BI-108 SRB's on MLP-2 and Pad 39B. Atlantis was launched at 05:03:59 EDT on 12 July 2001. Landing was at 11:39 p.m. local/eastern time on 24 July 2001.

Post landing inspection of Orbiter tiles showed a total of 126 hits, of which 26 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 108 total hits, of which 24 had a major dimension of 1-inch or larger. Approximately 39 damage sites (with eight larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. More damage occurred on the right-hand side of the vehicle than on the left-hand, with a typical pattern, some of these hits may be attributed to impacts from ice in the LO2 feedline bellows.

In summary, both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were somewhat less than the family average. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 0730 on 11 July 2001. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

A.Oliu	NASA - KSC	Shuttle Ice/Debris Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
R. Speece	NASA - KSC	ET Thermal Protection Systems
B. Nguyen	NASA - KSC	SRB Mechanical Systems
M. Payne	NASA - KSC	SRB Mechanical Systems
R. Page	NASA - KSC	SSP Integration
K. Leggett	USA - SFOC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC	ET Mechanical Systems
W. Richards	USA - SFOC	ET Mechanical Systems
M. Wollam	USA - SFOC	ET Mechanical Systems
T. Ford	USA - SFOC	ET Mechanical Systems
R. Seale	USA - SFOC	ET Mechanical Systems
R. Brewer	USA - SFOC	ET Mechanical Systems
R. Oyer	Boeing	Systems Integration
D. Leggett	Boeing	Systems Integration
B. Atkinson	Boeing	Systems Integration
T. Wilson	Boeing	Systems Integration
S. Otto	LMMSS	ET Processing
J. Ramirez	LMMSS	ET Processing
A. Khodaoust	Boeing	Shuttle Aerodynamics
M. Eastwood	Thiokol-LSS	SRM Processing

3.0 LAUNCH

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 11 July 2001. The walkdown of Pad 39B and MLP-2 included the flight elements OV-104 Atlantis (24th flight), ET-109, and BI-108 SRB's. There were no significant SSV discrepancies. Four facility items were documented in Appendix K of S0007VL4:

- Three loose bolts on plate cover on the East side of the raised deck of the MLP.
- Six holding fixtures for handrails on South side of SRB exhaust holes need to be removed.
- Six loose caps found on feed-through pipes adjacent to SRB exhaust holes at the MLP 0-level.
- Missing and loose bolts on blast diverter in front of camera (E4) on Northwest corner of MLP deck.

All facility items were in work by Pad crew at the conclusion of the debris inspection for resolution prior to cryoload.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 2300 hrs on 11 July 2001 to 0030 hrs on 12 July 2001 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database. One facility pipe end cap was found on the LH2 TSM during the walkdown. This debris was removed and an entry was made in Appendix M of S0007.

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. The RCS thruster paper covers were intact but two covers (F3L and F2U) were discolored, with no liquid indications observed. Ice/frost had formed on all the way around the SSME #2 heat shield-to-nozzle interface.

3.2.2 SOLID ROCKET BOOSTERS

SRB case temperatures measured by the STI radiometers were close to ambient temperatures, 78 degrees F. All measured temperatures were above the minimum requirement.

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 temperatures above the 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown.

Ambient conditions – 1100hrs	SURFICE Predictions	IR Surface Readings
79 Degrees F.	LO2 ogive 64 Degrees F	LO2 Tank 62-66 Degrees F
85% RH	LO2 barrel 63 Degrees F	
6 knots	LH2 upper 55 Degrees F	LH2 Tank 58-68 Degrees F
214 degrees	LH2 lower 70 Degrees F	

The Final Inspection Team observed no condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. No cracks were observed in the intertank stringer valley TPS. Ice and frost accumulations on the GUCP were typical.

The LH2 tank was wet with light condensate on the upper portion and significantly more condensation at the aft end. There were no acreage TPS anomalies.

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

A 1 to 1 ½ inch long and .25 inch wide stress relief crack was observed in the –Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

There were no TPS anomalies on the LO2 ET/ORB umbilical. Ice and frost in the LH2 recirculation line bellows and on both burst disks was typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. 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. One facility pipe end cap was found on the west side of the LH2 TSM during the walkdown. This debris was removed and an entry was made in Appendix M of S0007. All MLP facility stub-ups were inspected to assure that the end cap was not missing from them. All end caps were verified to be in place and secured.

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. All frost formation on the acreage TPS had dissipated by T-0. At T-0 there were no OMRS or LCC violations related to ice conditions. At T-2:30, the GOX vent seals were deflated and the GOX vent hood lifted. Although frost covered some of the ET nose cone louvers - an expected condition - no ice was detected. When the heated purge was removed by retraction of the GOX vent hood, frost continued to form on the louvers until liftoff. At the time of launch, there were no ice accumulations in the “no ice zone”.

STS-104 was launched at 05:03:59 EDT on 12 July 2001.

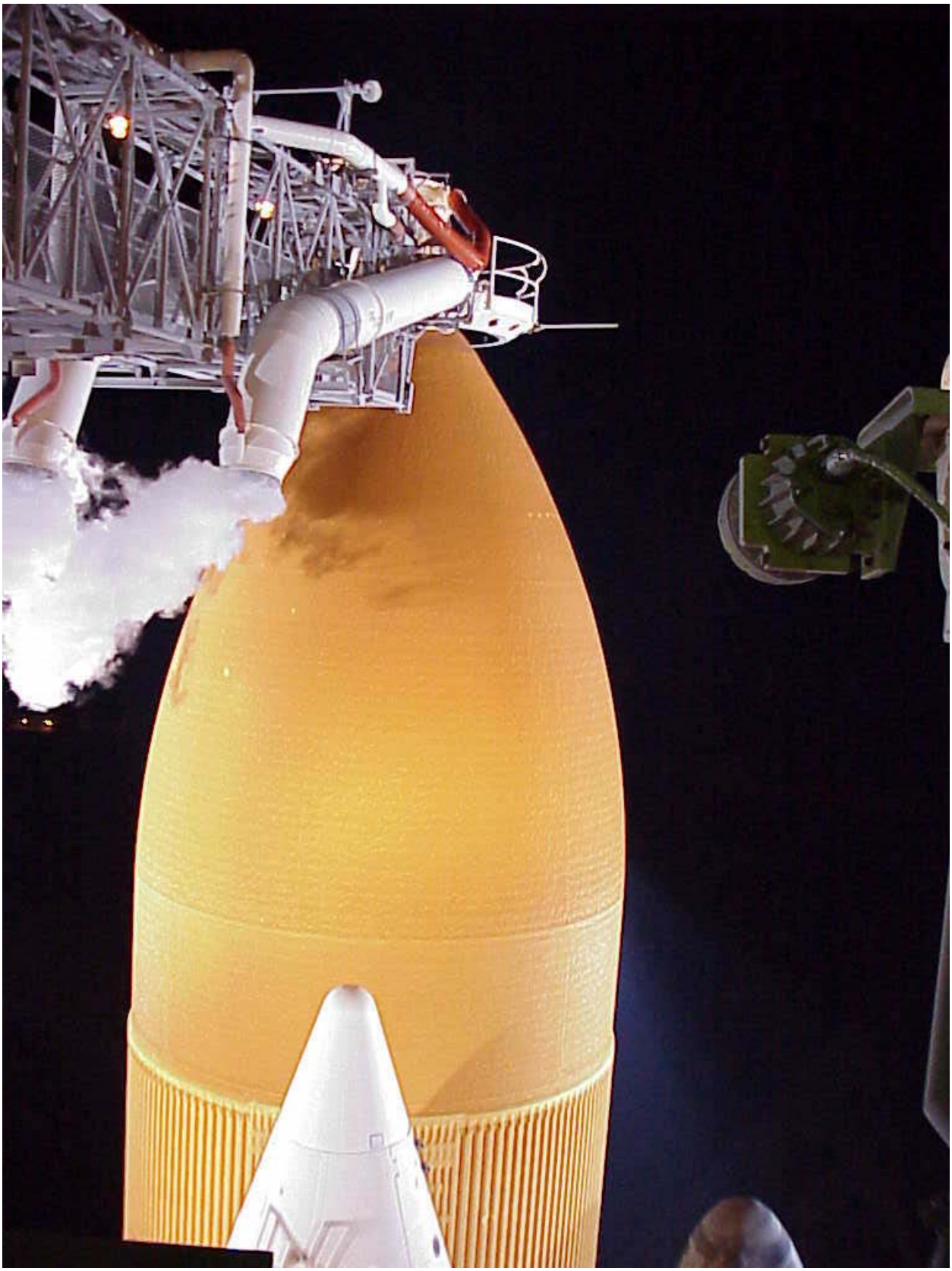


Photo 2: LO2 tank acreage.

No condensate was present on the LO2 tank acreage. Surface temperature ranged from 62 to 66 degrees Fahrenheit. There were no acreage TPS anomalies.

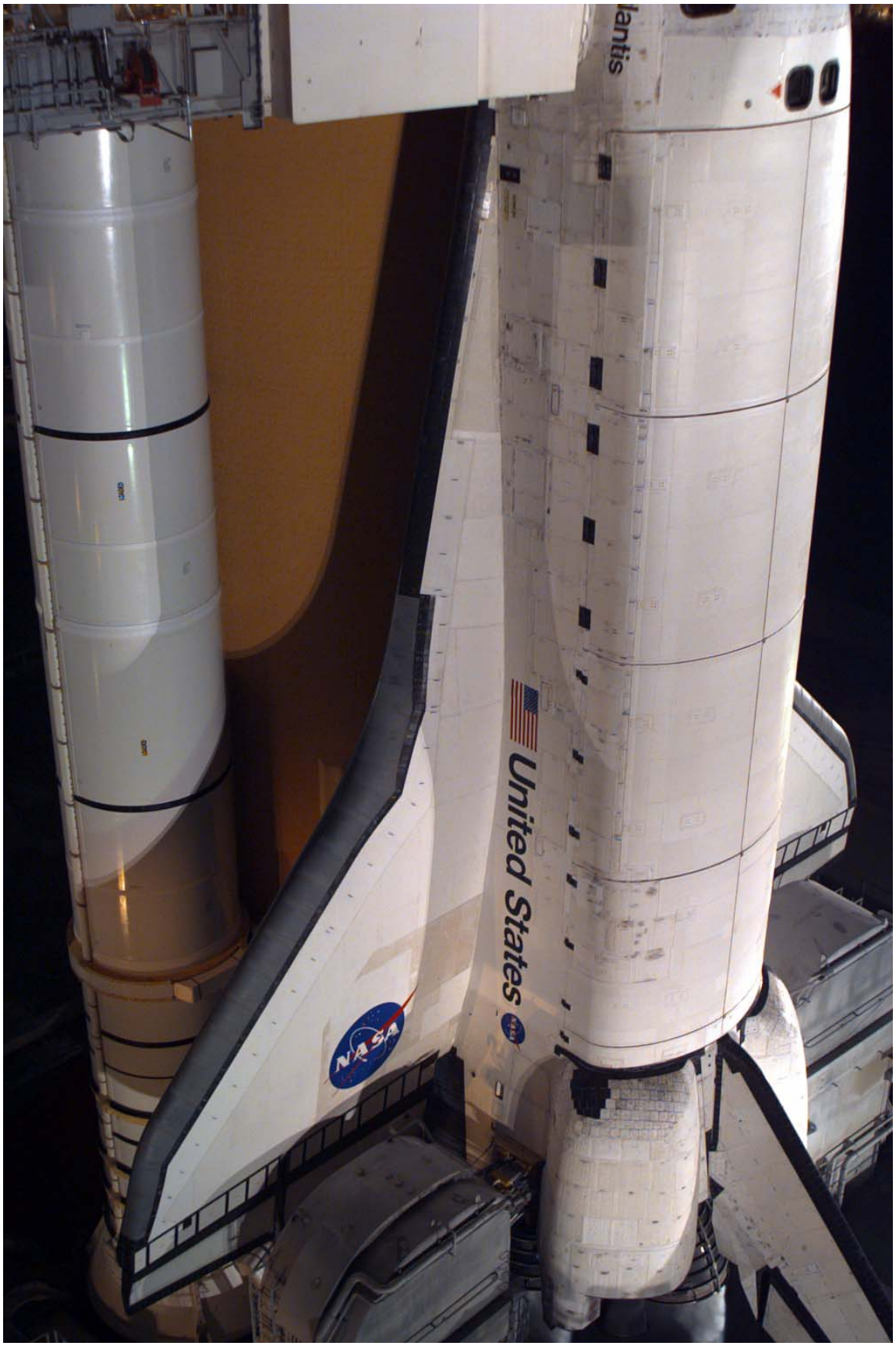


Photo 3: LH2 tank acreage.

No condensate was present on the LH2 tank acreage. Surface temperature ranged 58 to 68 degrees Fahrenheit. There were no acreage TPS anomalies.

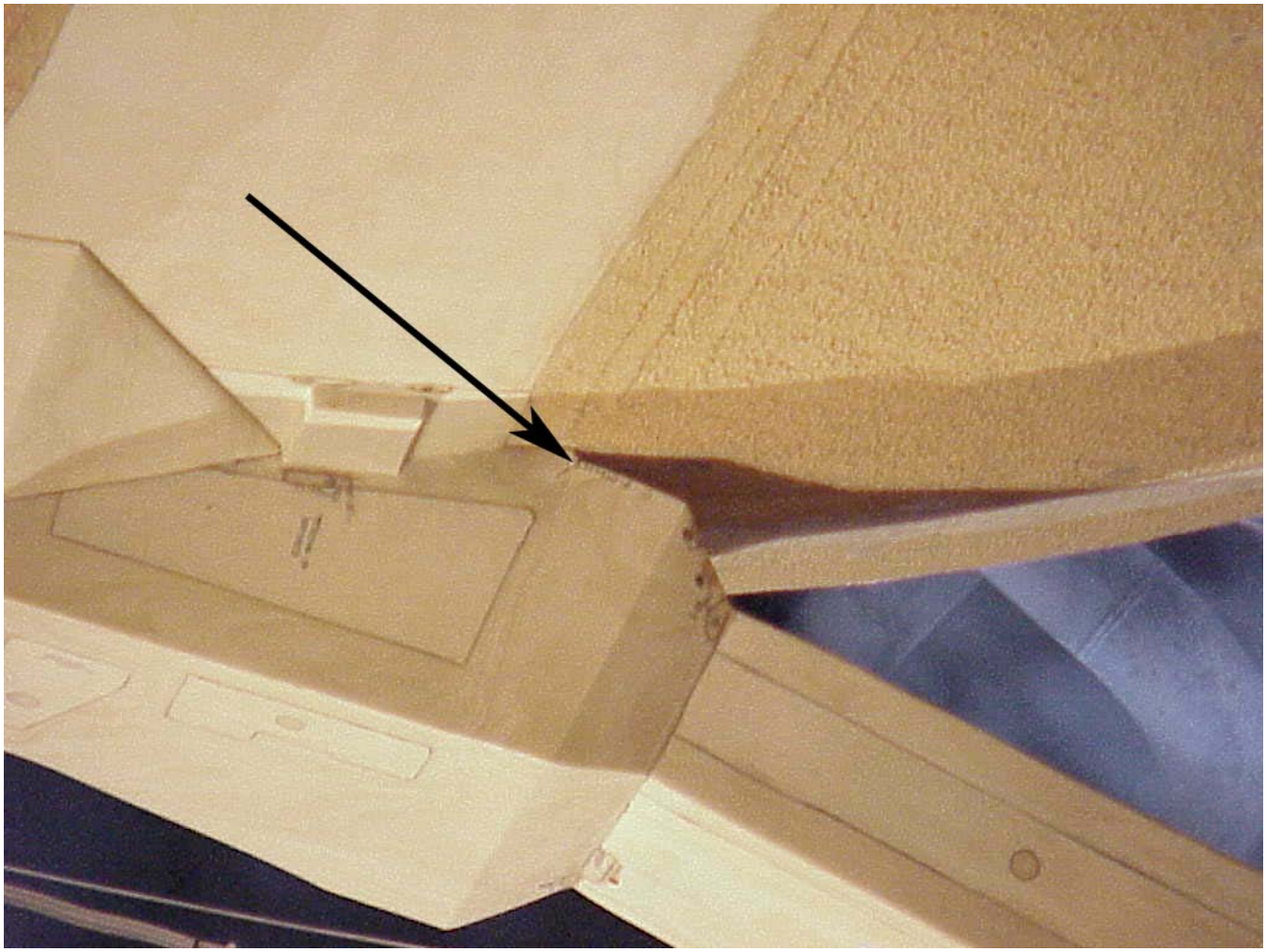


Photo 4: Crack in –Y Vertical Strut TPS

A 1 to 1-1/2 inch long and 0.25 inch wide stress relief crack was observed in the –Y vertical strut TPS with no offset. This condition has been observed on previous vehicles and found acceptable for flight per the NSTS-08303 criteria.

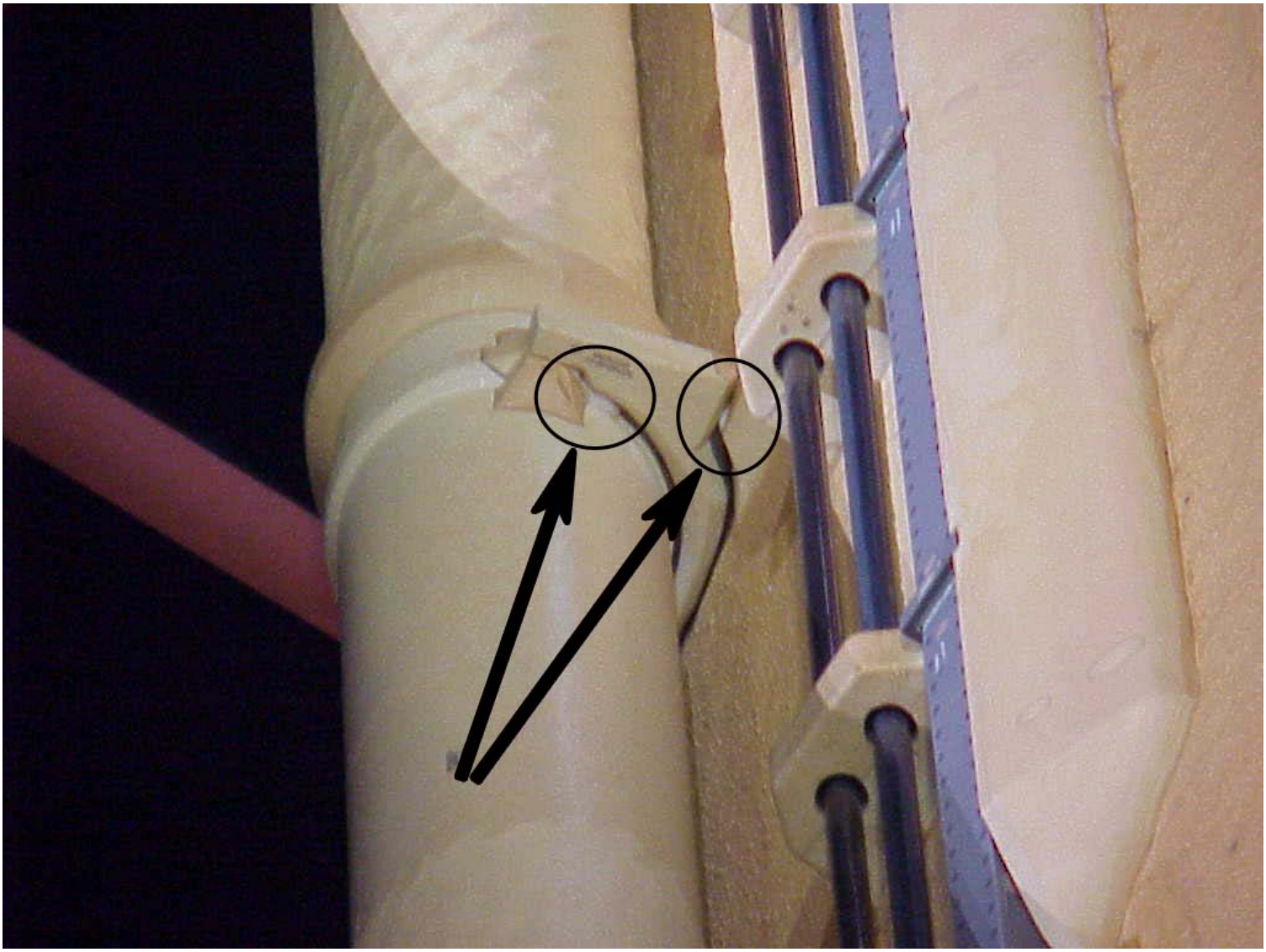


Photo 5: Ice/Frost on LO2 F/L bracket

Typical ice/frost on the LO2 feedline support bracket attachments.

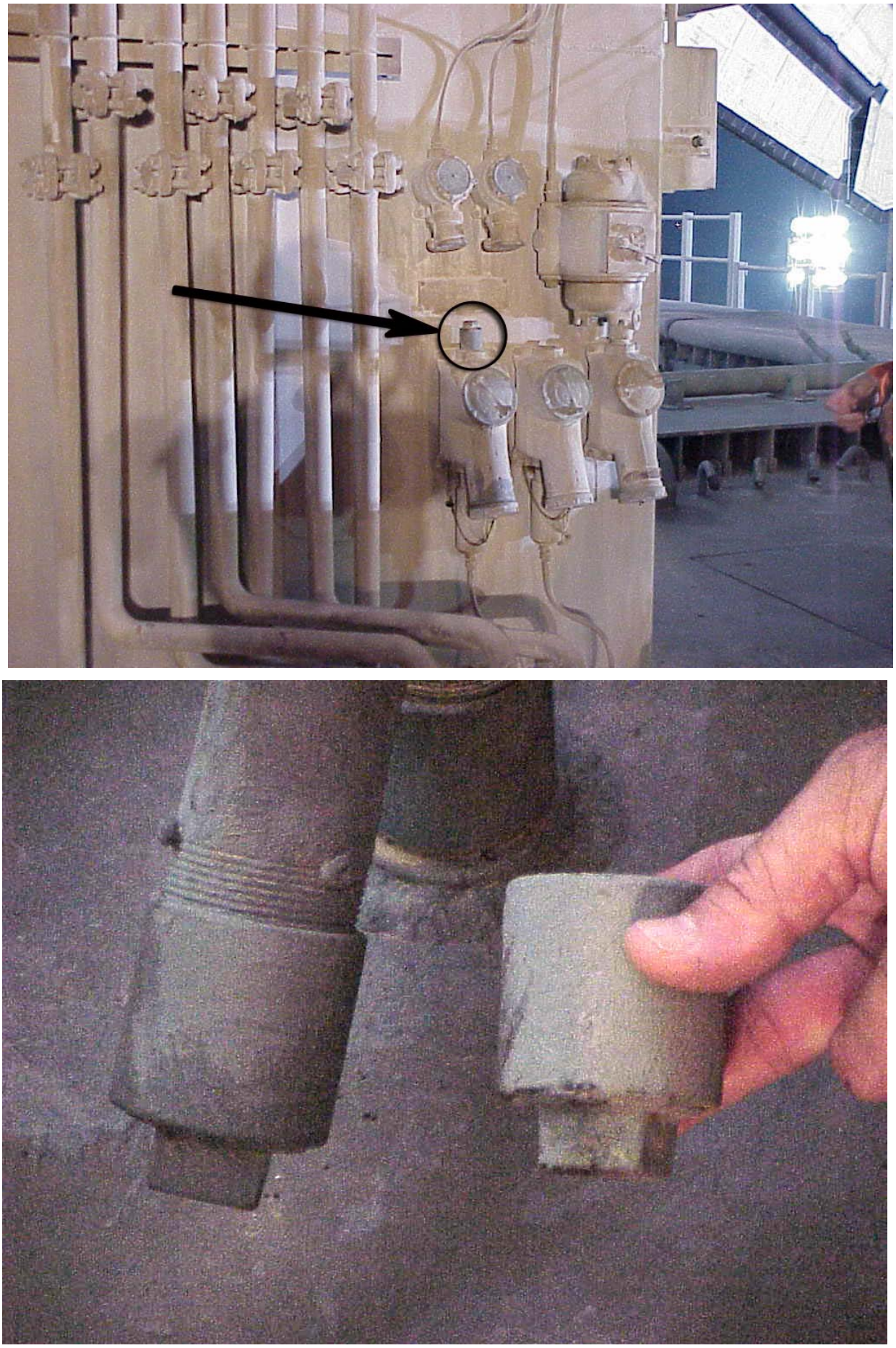


Photo 6: Facility pipe-end cap.

A pipe-end cap was found on the west side of the LH2 TSM.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP-2, Pad B FSS and RSS was conducted on 12 July 2001 from Launch + 1 to 4 hours(0600 to 0900 EDT). No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach indicated that no SRB holddown stud hang-up had occurred, the reported value was 0.095. Evaluation of the MLP 0-level was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for the north posts with some evidence of missing RTV at the HDP haunch interface. North holddown post blast covers and T-0 umbilical exhibited minimal exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, with no protective tape layering loss evident.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the bonnets were observed to have closed properly. The MLP deck was in generally good shape, no damage noted and minimal debris evident.

The GH2 vent line latched in the fourth of eight teeth of the latching mechanism and was off-center towards the north. The GUCP 7-inch QD sealing surface exhibited no damage. A 4-inch section of the peripheral seal was missing from the aft (bottom) location. The deceleration cable was in nominal configuration, and the vent line blanket was sooted and in generally good condition.

The OAA appeared to be intact with no evidence of plume impingement.

All slidewire baskets were secured with no evidence of damage.

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

Debris findings included:

- East elevator doors were damaged at the base (pushed in and off-track) at the 175, 235, and 255 foot levels.
- No flight debris was found on the Pad apron or adjacent grass.
- No unusual debris items were found on the FSS.
- On the west side SRB flame trench (north) deflector a piece (approx. 2’x6”x6”) of material was missing. Damage to metal grating 100 yards from flame deflector was noted and appeared to be inline with the missing material area.
- On the east side SRB flame trench floor, near (north) deflector, a piece (approx. 3’x3’x2”) of material was missing with metal banding reinforcement protruding from resultant hole.
- Control panel signs were noted on deck grating adjacent to corresponding panel mount locations, one at FSS 175 and other at 215 foot levels.
- Rubber grommets were noted on deck grating at 175 and 255 foot levels.

Overall, damage to the pad appeared to be minimal. Minimal debris was noted on pad apron and FSS.

5.0 FILM REVIEW

No significant anomalies were observed during the review of the STS-104 Films/videos that required notification to the Mission Management Team, Shuttle managers, vehicle systems engineers, and to Program Integration.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 68 films and videos, which included 16mm films, 35mm films, and Operational Television Video (OTV) camera videos, were reviewed starting on launch day.

Debris particle fell along the upper surface of LH wing, near the inboard/outboard elevon split. First seen at GMT 09:04:00.715 near the outboard edge of inboard elevon. There was no contact with flight hardware noted. (E-77)

SSME Mach diamond formation sequence was 3-1-2; normal sequence is 3-2-1. (E-76, -77)

Several flashes and streaks were observed in the SSME plume. (E-207, E-212)

Fraying of SSME #2 closeout blanket at 9 o'clock position visible during start-up sequence. (E-18, E-20)

Tile surface coating material was lost from several tiles on the Orbiter base heat shield as well as from right hand RCS stinger. This is a common occurrence due to SSME ignition acoustics.

Free-burning GH2 blown under body flap by wind. (E-36, E-52)

Particles of SRB aft-skirt instafoam fell along side the SRB plume. (E-207, E-212)

Body flap and elevon movement during ascent were typical. (E-207, E-212)

Facility debris observed passing through field of view well after the vehicle had cleared the tower. (E-34)

Base heat shield movement during SSME ignition was typical. (E-76, E-77)

Ice particles fell from ET/ORB umbilicals after lift-off. No impact to orbiter lower surface was noted. (E-36, E-40, E-52, E-54, E-63, E-76)

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

Charring on the ET aft dome was typical. (E-207)

Umbilical purge barrier baggy material fell during roll maneuver. (E-207, E-212)

Forward RCS paper covers were observed falling aft during early ascent.

Throat plug material ejected from SRB exhaust hole after T-0. No contact with vehicle. (E-52)

The lens ports on the protective boxes on cameras E-7 and E-10 were shattered approximately 4 to 5 seconds after T-0. The lens port stayed with the camera box and did not become dislodged.

5.2 ON-ORBIT FILM AND VIDEO SUMMARY

16mm film motion picture film from the LH2 umbilical cameras, as well as the 35mm still images from the LO2 ET/ORB umbilical camera and Crew Hand-Held Still Images, of the External Tank after separation from the Orbiter were received and reviewed at KSC on 30 July 2001. The 35mm still images and the 16mm film provided limited data due to the poor lighting condition.

SRB separation from the External Tank appeared nominal.

ET separation from the Orbiter was normal. The red-colored purge seal that normally fits around the EO-3 ball fitting had come loose and floated aft, but still secured by its tether.

The EO-3 (LO2 side) separation bolt protrusion was noted. Protrusion appeared to be less than EO-3 bolt protrusion observed on STS-106 film.

No damage was detected on the LO2 ET/ORB umbilical disconnect, sealing surfaces, or closeout TPS. Typical ablation and divoting was noted on the vertical portion of the umbilical cable tray.

No anomalies were detected in the LO2 tank acreage. The BSM burn scars were typical.

Normal amounts of TPS erosion and topcoat charring occurred on the forward ogive near the nose cone, but the presence of divots in this area could not be confirmed. The composite nose cone was in good condition.

ET LH2 tank and intertank acreage appeared nominal. Evaluation of the thrust panel TPS was difficult due to lighting condition and image resolution.

A shallow circular TPS divot, approximately two inches in diameter, was observed near the fwd end of the +Y thrust strut.

The ablation/erosion of LO2 feedline flange closeouts was typical.

5.3 LANDING FILM AND VIDEO SUMMARY

A total of 15 films and videos, which included eight 35mm large format films and nine videos, were reviewed.

The landing gear extended properly. Drag chute deployment appeared normal. No anomalies were detected from touchdown through rollout. No unusual tile damage was visible in the films.

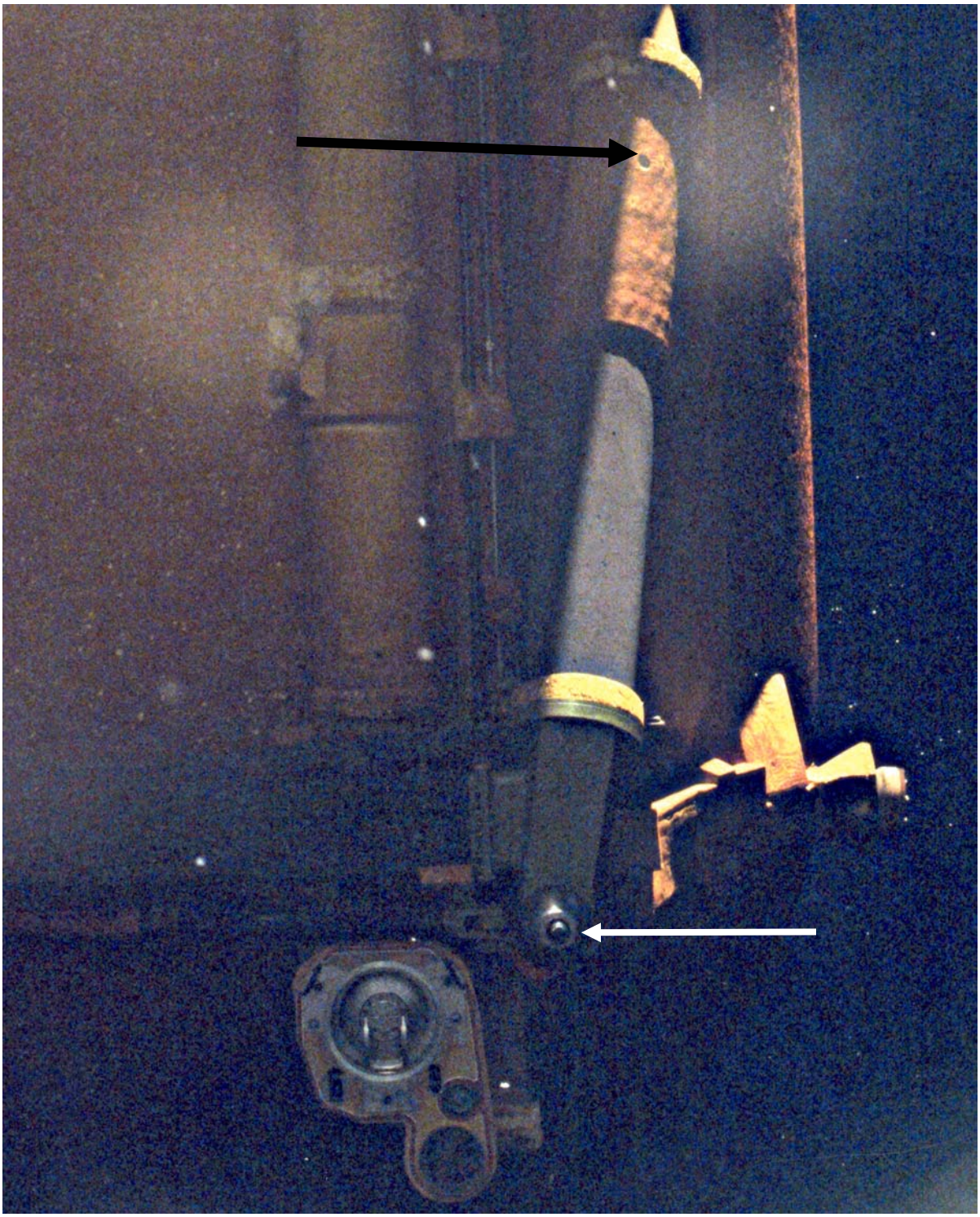


Photo 7: External Tank post separation

A shallow, 2-inch divot noted on the +Y thrust strut. The EO-3 separation bolt is protruding slightly.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-108 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 16 July 2001. Generally, both boosters were in excellent condition.

The LH SRB +Z RSS antenna had the aft phenolic plate and most of the ablator missing. There was no evidence of ascent heating.

The TPS on both frustums exhibited no debonds/unbonds. There was minor localized blistering of the Hypalon paint.

All eight BSM aero heat shield covers had fully opened and locked, but two RH and one LH cover attach rings had been bent at the hinge by parachute riser entanglement

The forward skirts exhibited no debonds or missing TPS. Except for the one previously mentioned, RSS antennae covers/phenolic base plates were intact, though one layer of the RH SRB +Z antenna phenolic base plate had delaminated.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were in good condition with no unbonds observed.

Separation of the aft ET/SRB struts appeared normal.

Aft skirt external surface TPS was in good condition. Typical blistering of Hypalon paint had occurred on the BTA insulation close-outs and GEI cork runs.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally except on HDP No. 5 which was fully obstructed by the frangible nut halves. This condition most likely happened at water impact.

Photo 8: Frustum Post Flight Condition

The frustums exhibited no debonds/unbonds or missing TPS.
All eight BSM aero heat shield covers had locked, but two RH and one LH cover attach rings were bent due to parachute riser entanglement.

Photo 9: SRB Post Flight Condition

Both SRB's were found in good condition regarding debris assessment

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 11:39 p.m. local/eastern time landing on 24 July 2001, a post landing inspection of OV-104 Atlantis was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 126 hits of which 26 had a major dimension of 1-inch or larger. This total does not include the numerous hits on the base heat shields attributed to SSME vibration/acoustics and exhaust plume recirculation.

The following table lists the STS-104 Orbiter damage hits by area:

	HITS > 1-inch	TOTAL HITS
Lower Surface	24	108
Upper Surface	0	0
Window Area	0	14
Right Side	0	0
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	2	4
TOTALS	26	126

The orbiter lower surface sustained 108 total hits, of which 24 had a major dimension of 1-inch or larger. Approximately 39 damage sites (with eight larger than 1-inch in length) were located in the area from the nose gear to the main landing gear wheel wells. More damage occurred on the right-hand side of the vehicle than on the left-hand, with a typical pattern, some of these hits may be attributed to impacts from ice in the LO2 feedline bellows. ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites. Analysis of ET separation film may help determine the cause of these hits.

The majority of the lower surface hits were around the LH2 umbilical area (42 hits). Most of these damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft. The ET TPS venting modifications continue to have a reducing effect on the quantity and size of the damage sites.

The largest lower surface tile damage site, located inboard of the LH2 umbilical, measured 4-1/2-inches long by 3/4-inches wide by 0.250-inches deep. A combination of umbilical ice and/or umbilical purge barrier material could have been the cause of this damage site.

The landing gear tires were reported to be in good condition. There was no ply under cutting on the main landing gear tires.

ET/Orbiter separation devices EO-1, EO-2, and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilicals. The EO-2 and EO-3 fitting retainer springs appeared to be in nominal configuration, though five of the "salad bowl" clips were missing from EO-3. The EO-2/3 pyro debris shutters were fully closed. A small piece of umbilical closeout foam (pyro can closeout) was adhered to the umbilical plate near the LO2 disconnect. No debris was found beneath the umbilicals.

Typical amount of tile damage occurred on the base heat shield. All SSME Dome Heat Shield closeout blankets were in good condition though some small material was torn/frayed. Engines 1 and 2 had blanket damage at the 6 and 9 o'clock positions respectively.

No unusual tile damage occurred on the leading edges of the OMS pods and vertical stabilizer. There were four tile damage sites on the leading edge of the LH OMS Pod, with two having a major dimension greater than one inch.

Damage sites on the window perimeter tiles appeared to be less than usual in quantity and size. Hazing and streaking of forward-facing Orbiter windows appears to be normal.

The post-landing walkdown of Runway 15 was performed immediately after landing. All components, except the mortar cover, of the drag chute were recovered and appeared to have functioned normally.

Two pieces of AMES gap filler, 5" long by 1" wide, were found on the runway under the nose landing gear doors. Tile gap fillers have been found on previous missions and are not considered an anomaly.

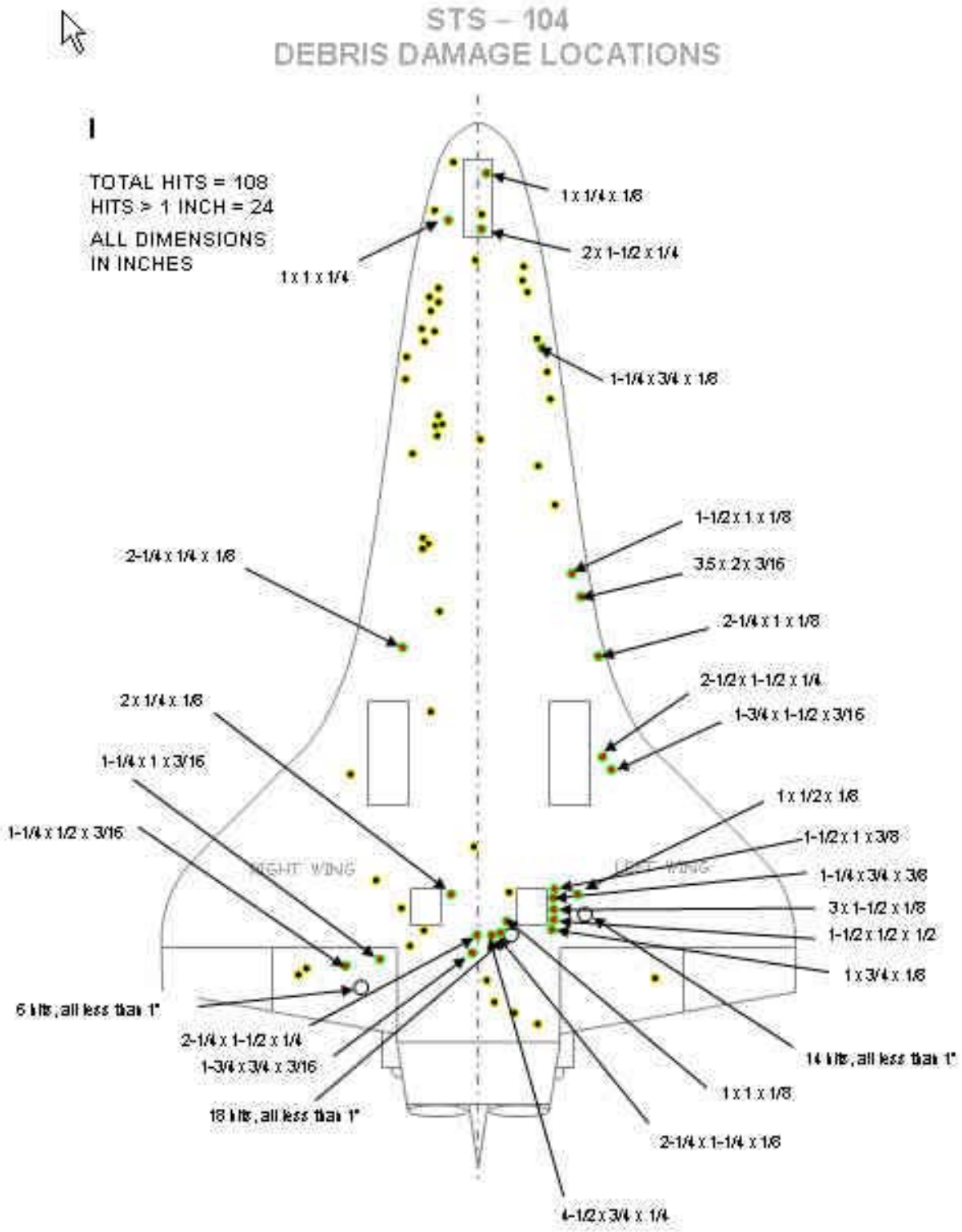


Figure 1: Orbiter Lower Surface Debris Damage Map

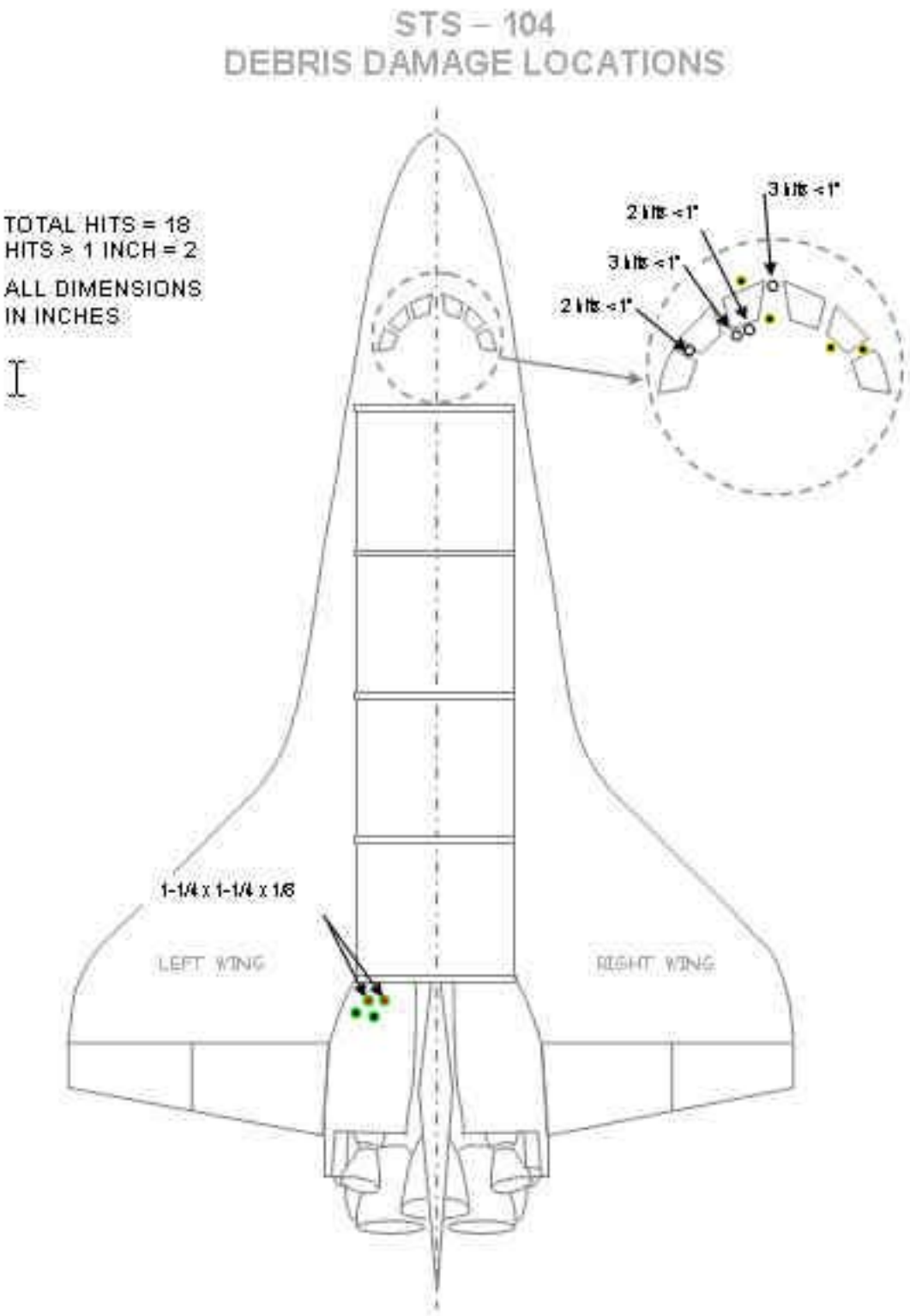


Figure 2: Orbiter Upper Surface Debris Damage Map

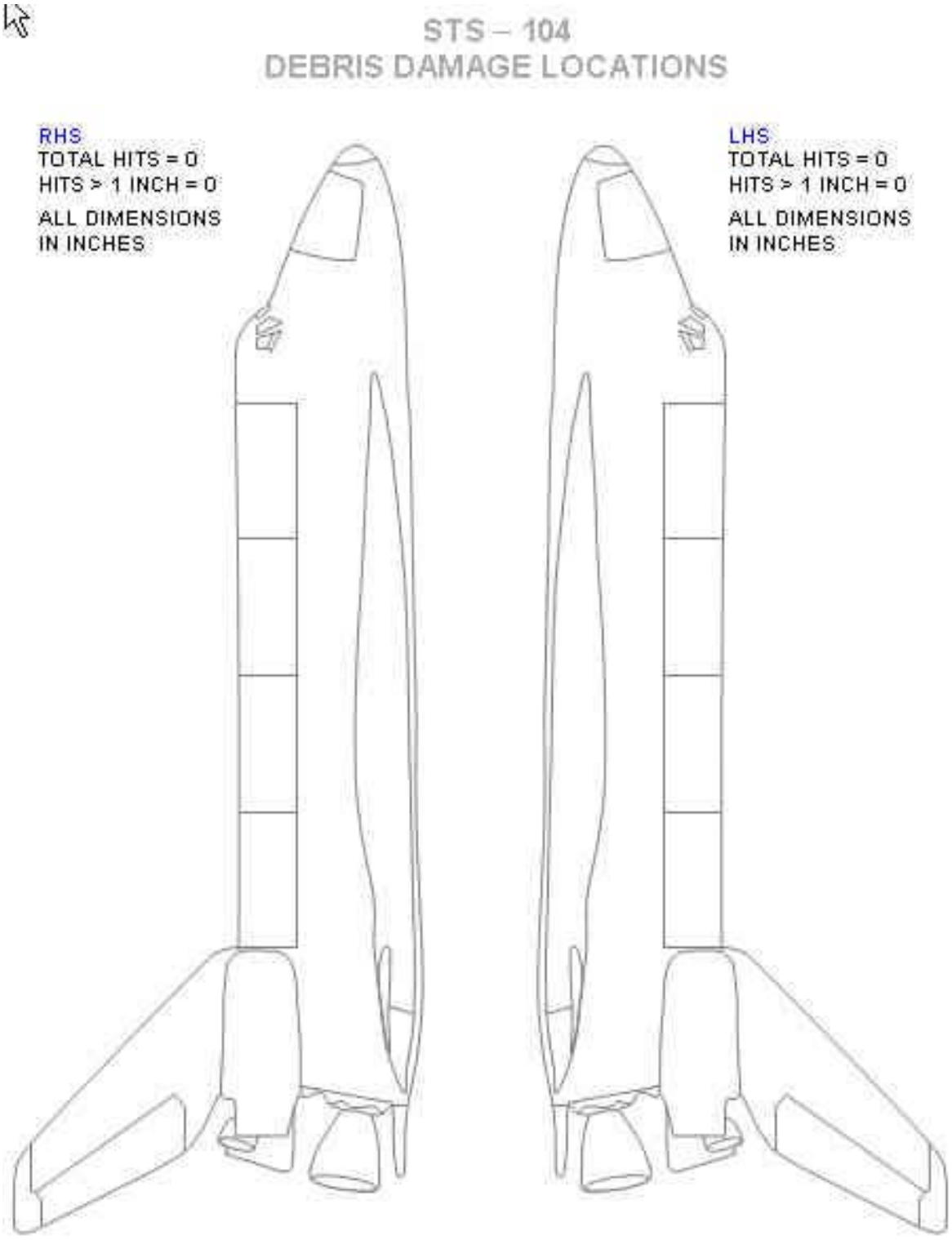
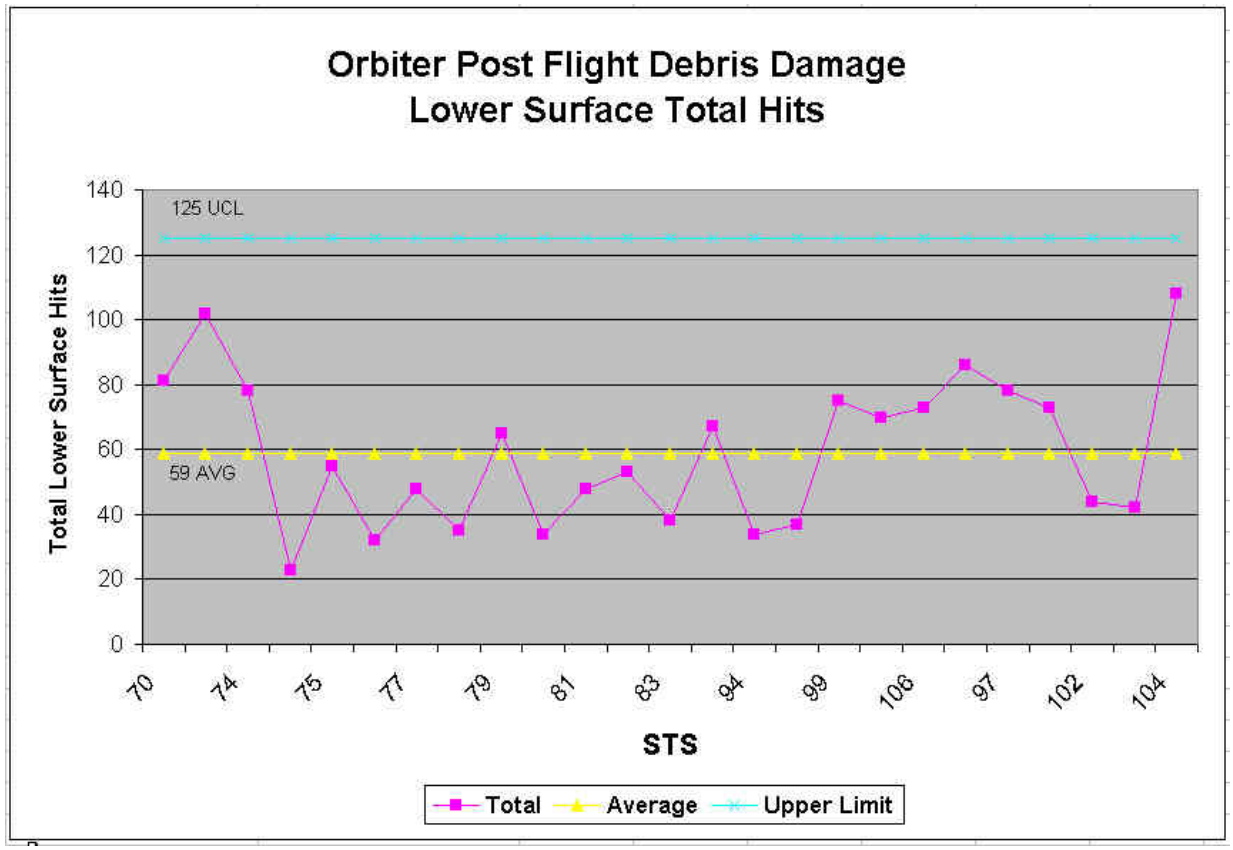


Figure 3: Overall View of Orbiter Sides

STS NUMBER	LOWER SURFACE		ENTIRE SURFACE	
	HITS > 1 INCH	TOTAL HITS	HITS > 1 INCH	TOTAL HITS
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
STS-99	21	75	25	88
STS-101	19	70	27	113
STS-106	17	73	17	105
STS-92	14	86	24	127
STS-97	10	78	10	84
STS-98	8	73	13	102
STS-102	10	44	15	100
STS-100	4	42	13	92
AVERAGE	11.1	61.8	15.9	102.4
SIGMA	5.7	31.3	6.0	27.5
STS-104	24	108	26	126
MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE				
THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS				
SOURCES				

Figure 4: Orbiter Post Flight Debris Damage Summary



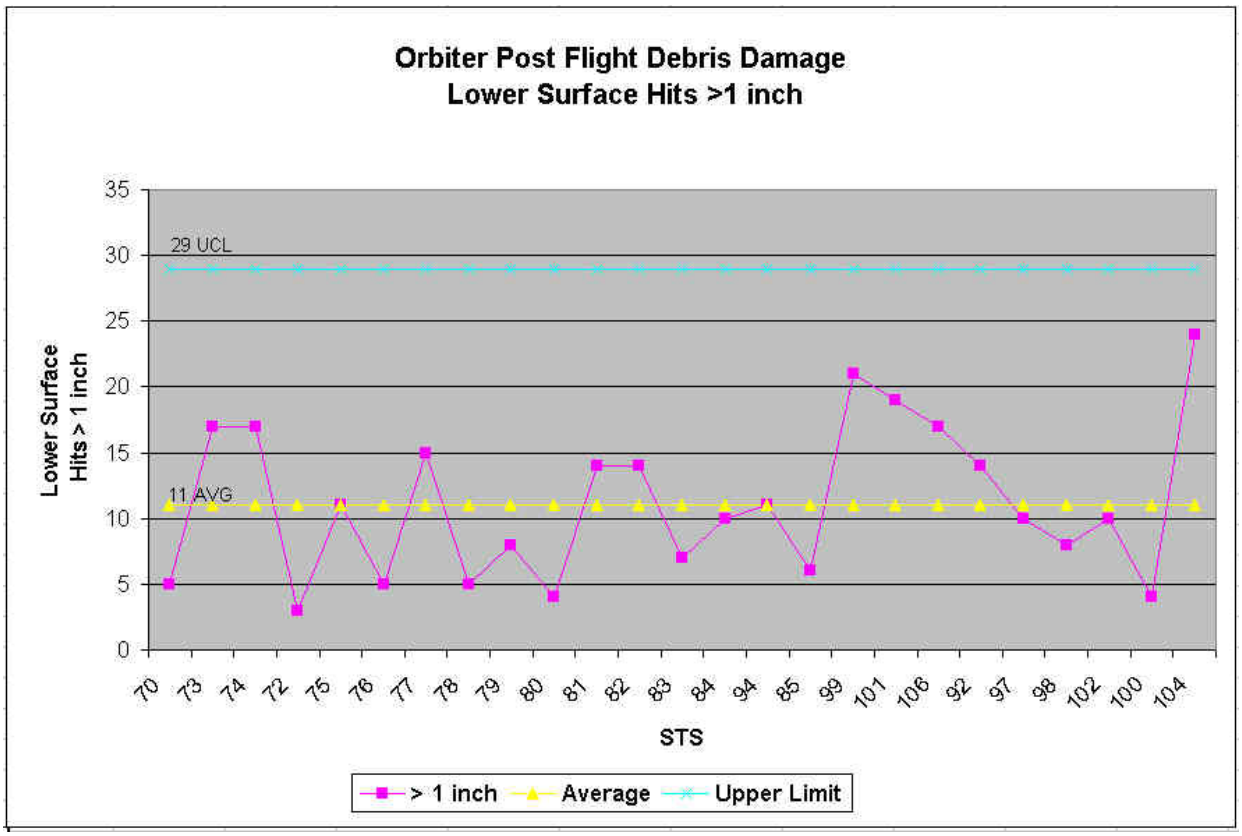
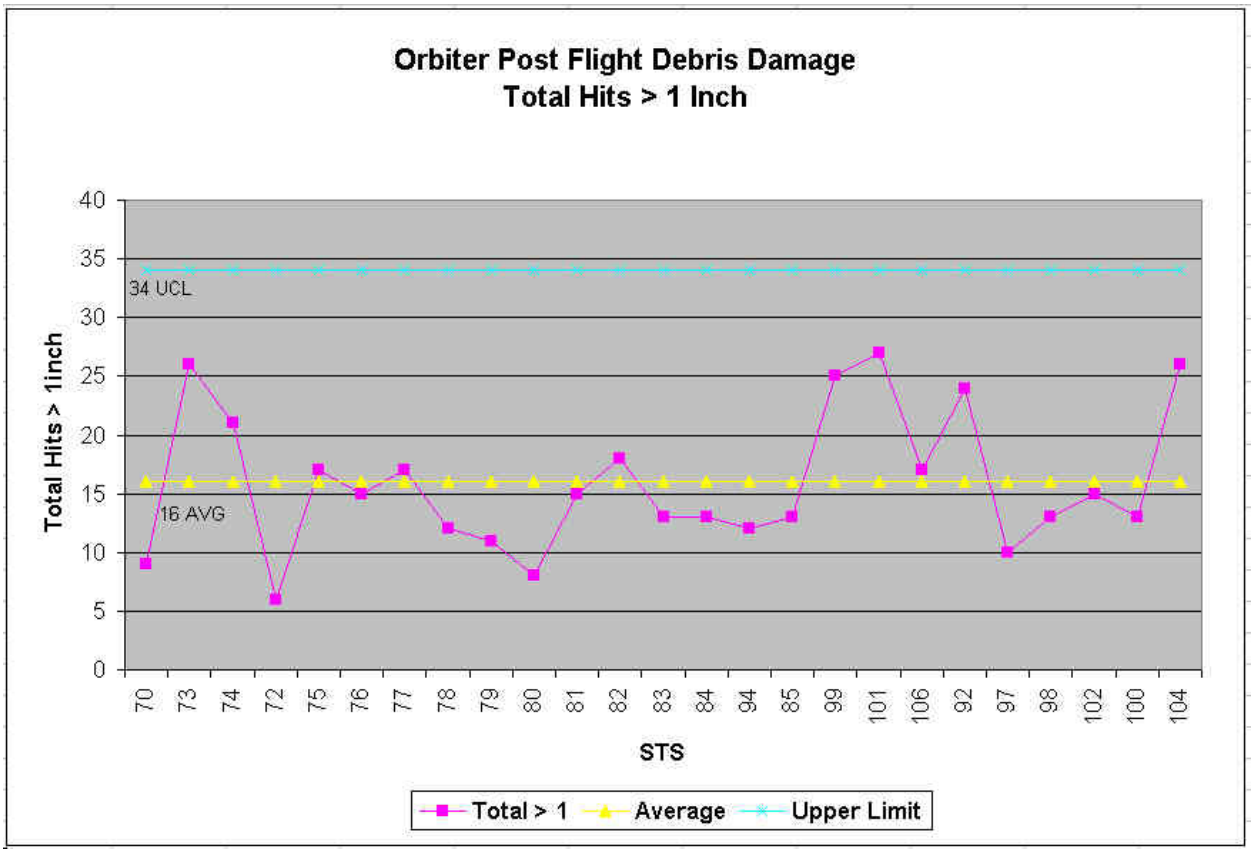


Figure 5: Control Limits for Lower Surface Hits



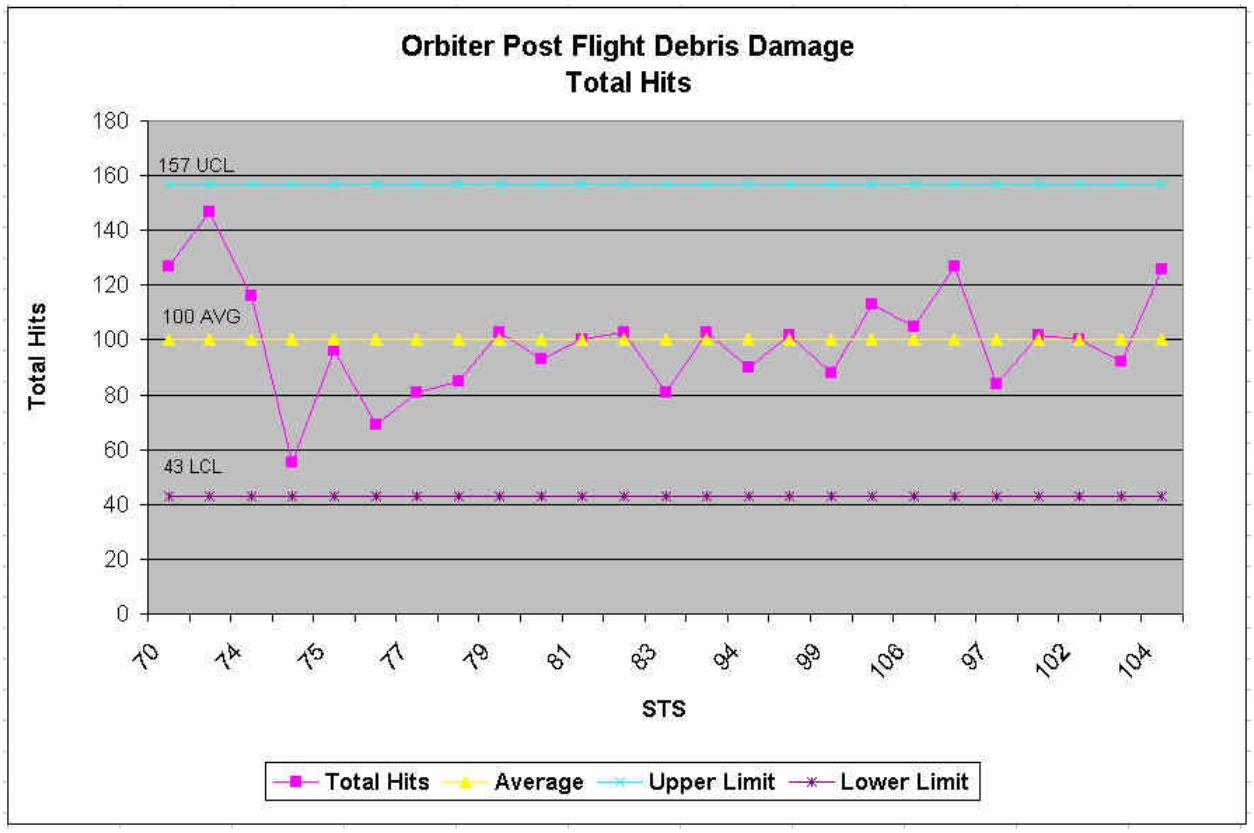


Figure 6: Control Limits for Total Hits

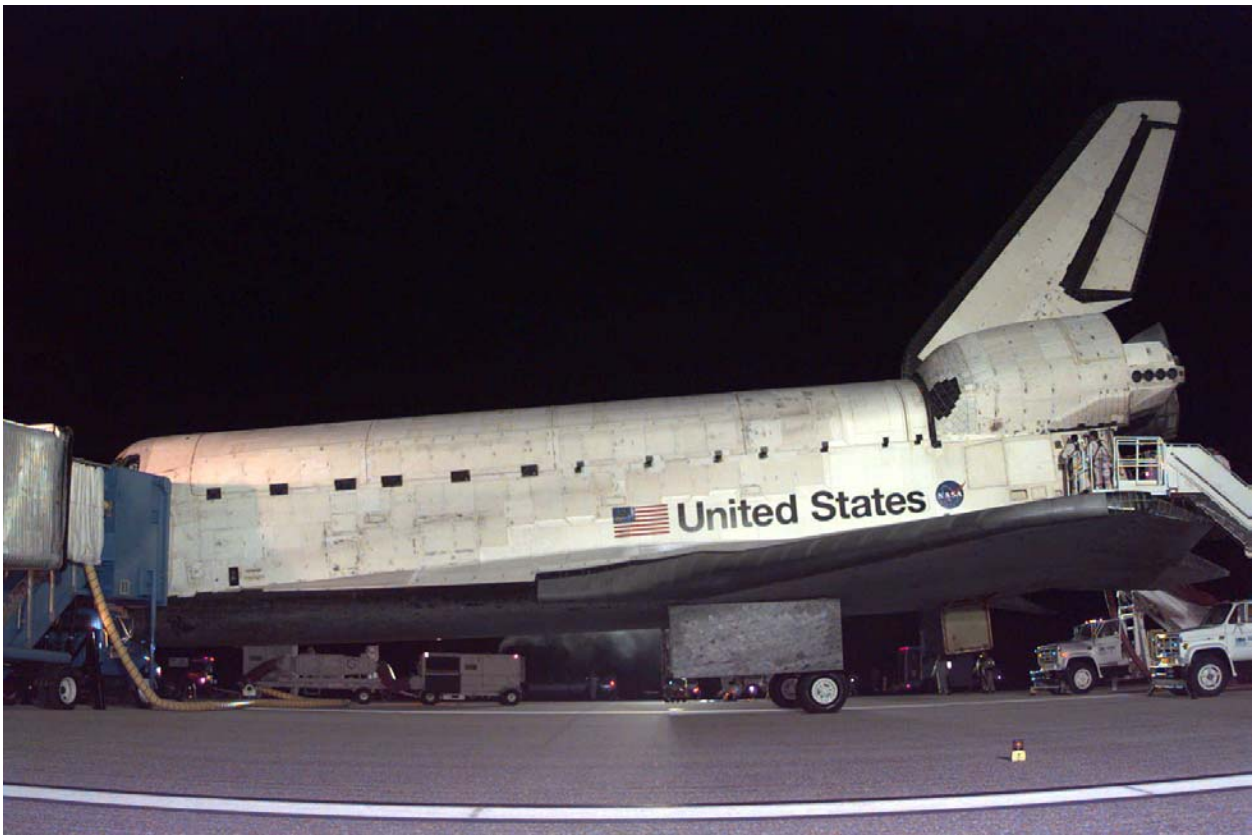


Photo 10: Overall View of Orbiter

The orbiter lower surface sustained 108 total hits. Both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were within established family.

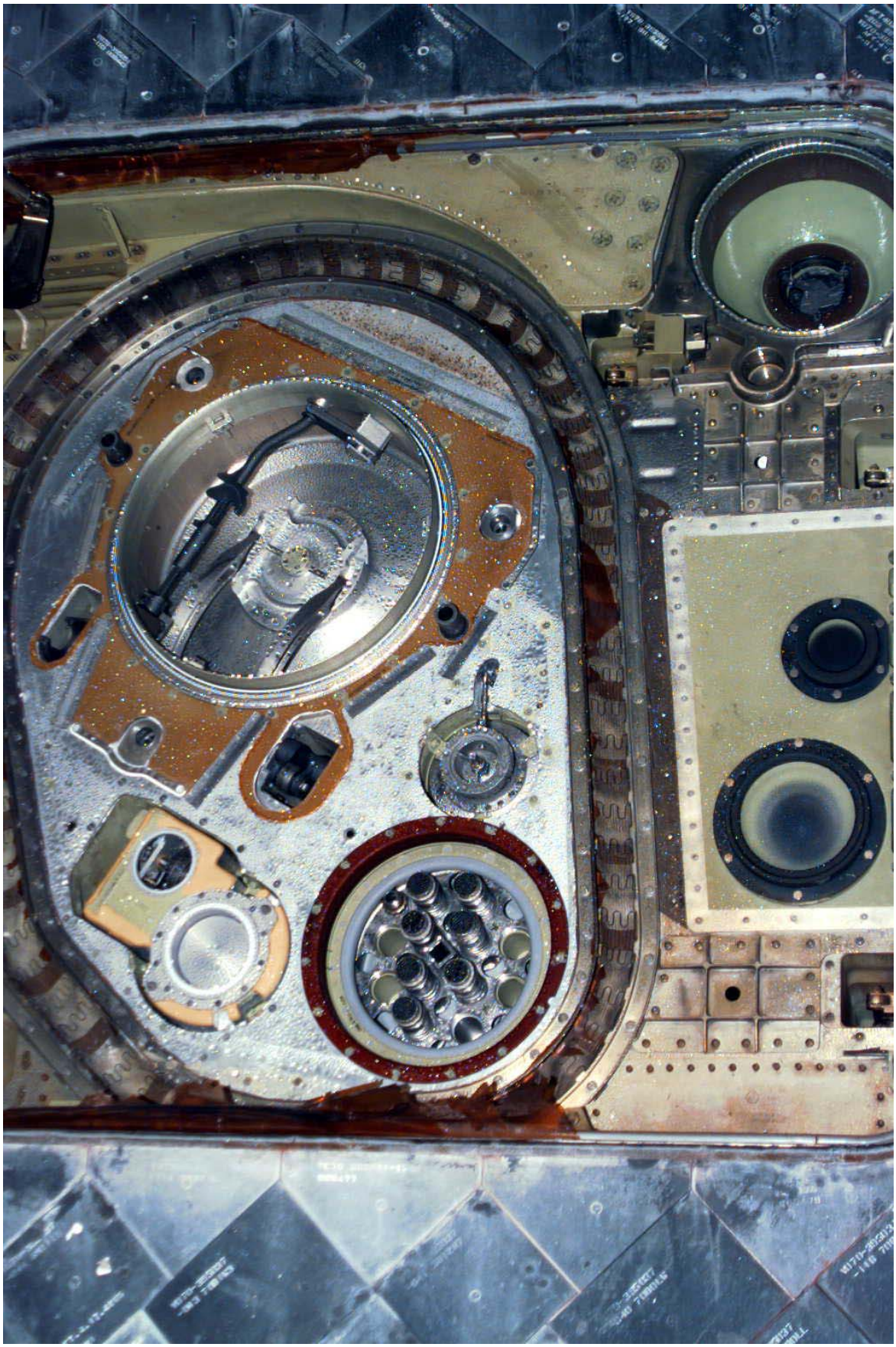


Photo 11: ORB/ET LH2 Umbilical

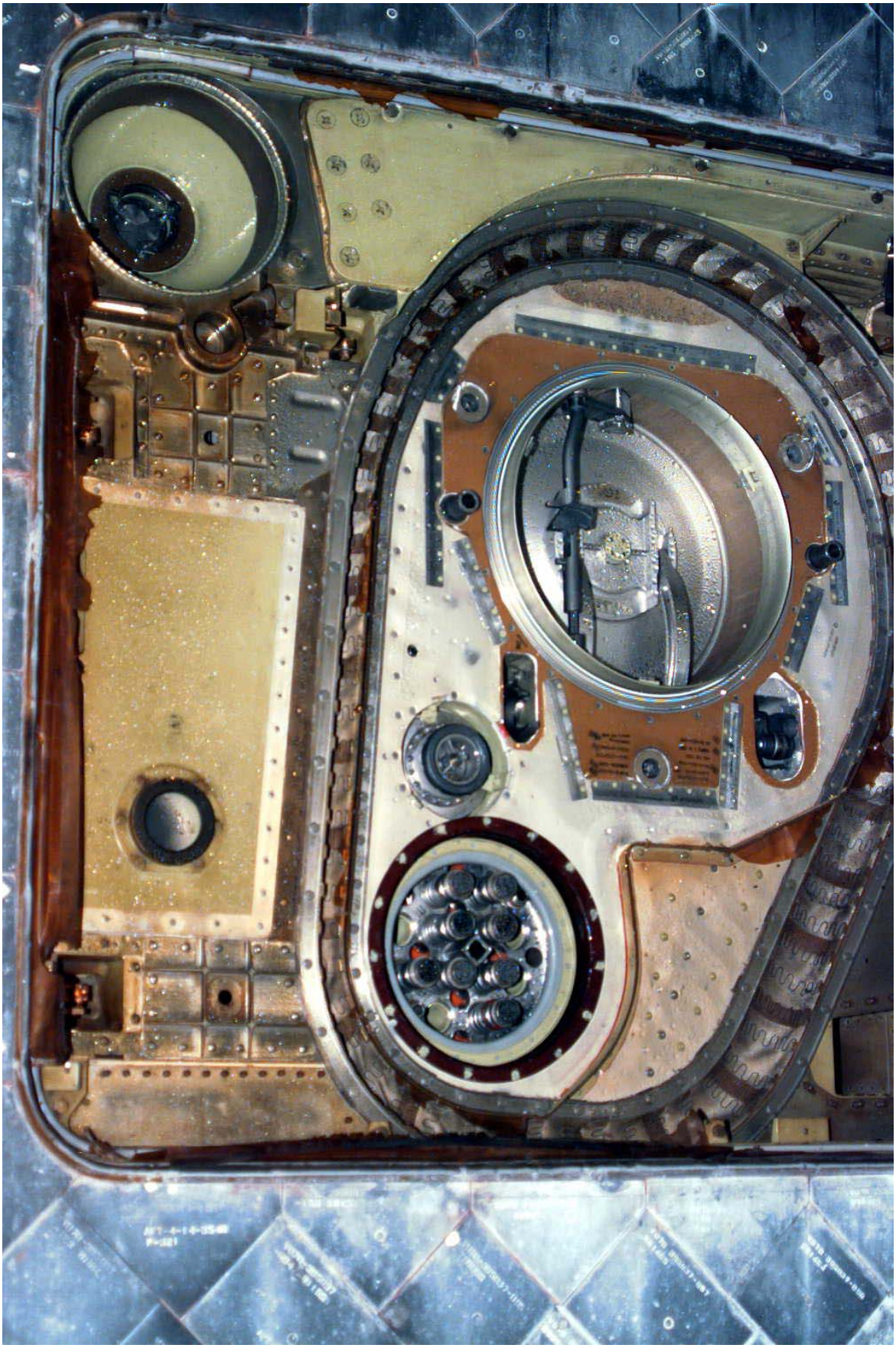


Photo 12: ORB/ET LO2 Umbilical

8.0 DEBRIS SAMPLE LAB REPORTS

Window wipe samples from Orbiter windows 1 thru 8 were submitted to the KSC Microchemical Analysis Branch (MAB) for material/chemical identification analysis and comparison to known STS materials. The results of this analysis are summarized below.

Window sample inorganic results provided indication of Orbiter Thermal Protection System (TPS), metallics and metallic corrosion paints, natural landing site, and window polish residue materials.

Window sample organic results provided indication of silicone from RTV and particles containing materials consistent with those found in the Orbiter Reaction Control System (RCS) thruster cover paper (butcher paper) ink.

Post-landing sample results provided no new information or trend data for debris source analysis.

9.0 POST-LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, no post-launch anomalies were observed on the STS-104 mission.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Table of Contents

Tables and Figures

1. STS-104 (OV-104): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-104 launch of Atlantis (OV-104) from Pad 39B occurred on July 12, 2001 at 193:09:03:59.000 UTC as seen on camera E8. SRB separation occurred at approximately 09:06:00.586 UTC as seen on camera KTV4B.

On launch day, 21 videos were received and screened. The long range tracking videos KTV13 and ET213 were not received. (ET208 is no longer provided).

Twenty launch films were screened and a report was sent to the Shuttle Program distribution on July 15, 2001. Twenty-one additional films were received for contingency support and anomaly resolution. Films E205 and E208 were not received.

No anomalous events were seen during the review of the STS-104 launch films and videos that were elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report. Likewise, no anomalous events were seen during the review of the STS-104 landing films and the on-board films of the External Tank that were elevated to the Landing + 3 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report (These reports consolidate the multi-center post flight photo reviews into a single list of observations for engineering review. This integrates the photo review process into the IFA / PRACA process to ensure that the identified observations are assessed and dispositioned prior to the next flight per established problem reporting criteria).

One 16mm umbilical well camera flew on STS-104. The 35mm umbilical well TPS camera film and the crew handheld still photography and video of the External Tank were acquired. See Section 2.3.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested.

Pre-planned, real-time analysis support was provided to the ISS AF-7A Space Station photographic and television external survey. The Space Station image analysis support will be documented in the AF-7A Imagery Overview Report.

1.1.3 Landing

Atlantis made a night landing on runway 15 at the KSC Shuttle Landing Facility on July 24, 2001 (206:03:38:54.650 UTC). Nine videos and eight landing films were received.

The landing touchdown appeared normal. The drag chute deploy sequence appeared normal on the landing imagery. Using available video including NASA-Select, no anomalous events were seen during the Orbiter approach, landing, and landing rollout.

Post landing, a sink rate analysis of the STS-104 main landing gear was performed for the main gear touchdown. See Section 2.5.

According to the pre-mission agreement, the STS-104 landing films were not screened due to budgetary constraints.

2. Summary of Significant Events

2.1 KSC, JSC, MSFC Film / Video Analysis Teams Consolidated Film Review Reports

No anomalous events were noted during the screening of the STS-104 launch and landing films. No anomalies were reported in the Launch +4 day or the Landing +3 day KSC, JSC, MSFC Film / Video Analysis Teams Consolidated Film Review Reports.

2.2 Other Launch Observations

2.2.1 Debris from SSME Ignition through Liftoff

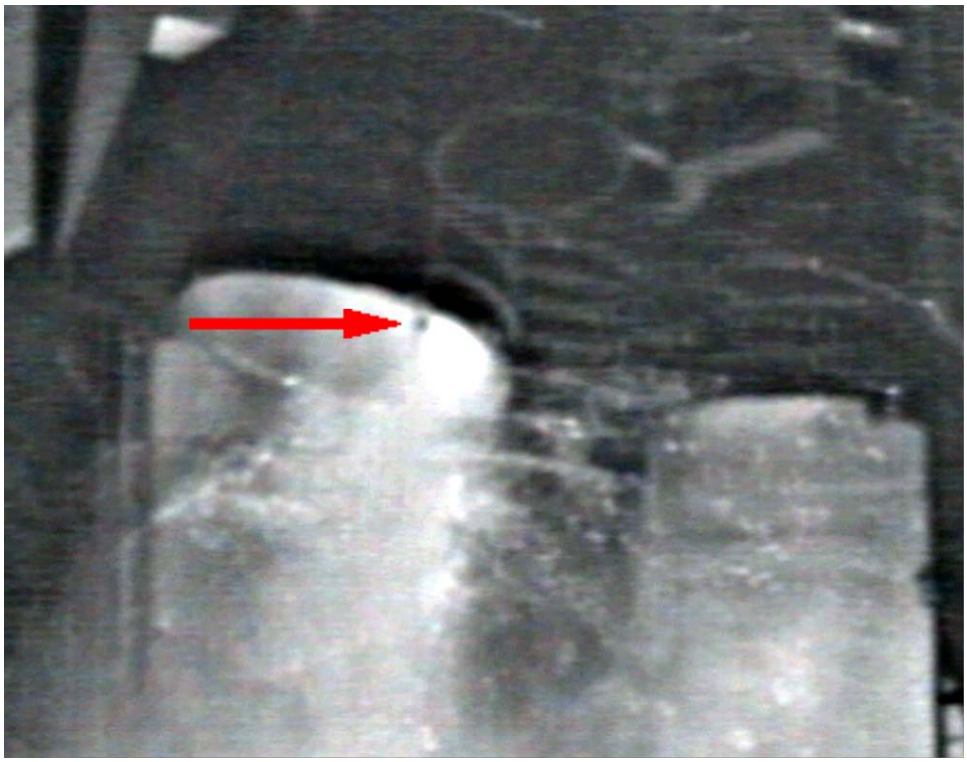


Figure 2.2.1 (A) Ice/frost on SSME #1 Purge Drain Vent (Camera OTV151)

A large ball of ice / frost on a purge drain line vent on the rim of SSME #1 was seen to break loose and fall aft during SSME ignition (09:03:54.131 UTC). (Cameras OTV151, E19, E76)

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the –Z side of the body flap during SSME ignition through liftoff. A small piece of umbilical ice debris was seen to contact the Orbiter fuselage tiles forward of the body flap hinge (09:03:54.226 UTC). Another piece of umbilical ice debris contacted the Orbiter tiles just aft of the LO2 umbilical (09:03:54.794 UTC). No damage to the launch vehicle was detected. Umbilical ice debris contacting the Orbiter tiles has been seen on previous missions. (Cameras OTV109, OTV154, OTV163, OTV171, E1, E4, E17, E18, E20, E31, E34, E54, E63)

A small piece of light-colored ice / frost debris was seen falling from the aft surface of the ET +Y vertical strut closeout during SSME ignition (09:03:54.660 UTC). (Camera OTV154)

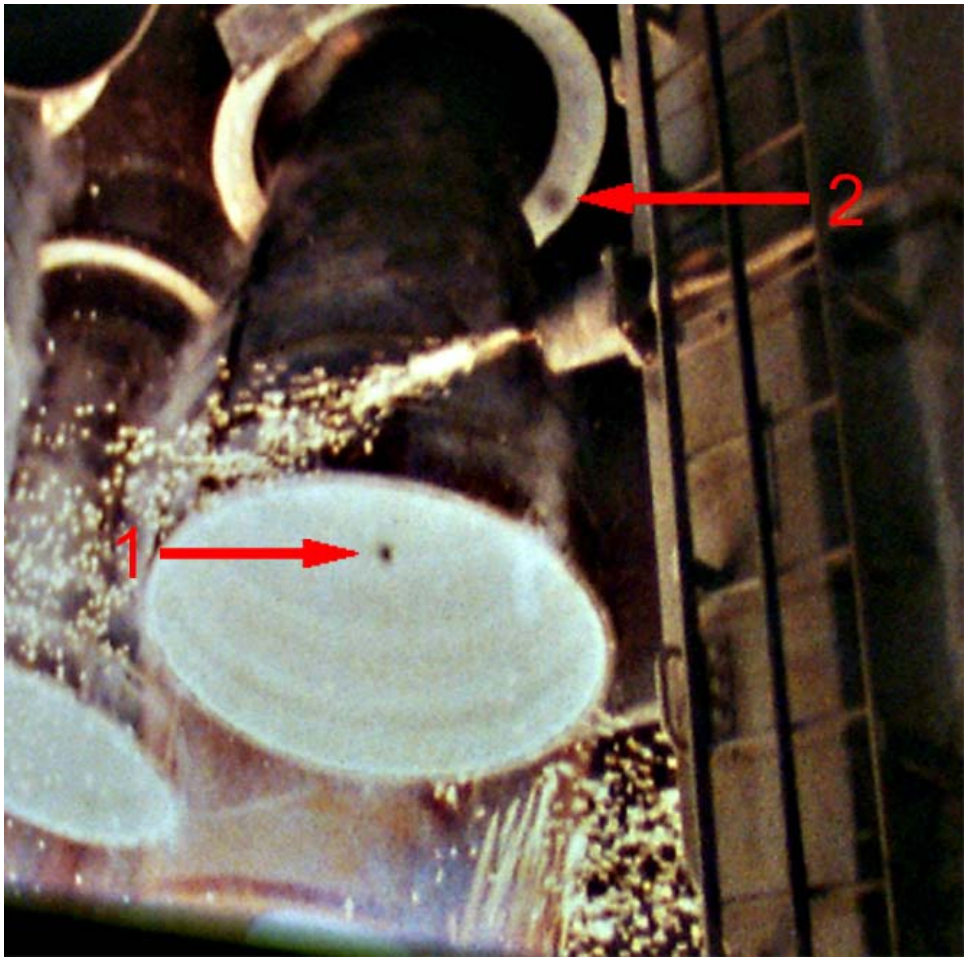


Figure 2.2.1(B) Debris near SSME#3 (Camera E19)

An unidentified, small, dark-colored piece of debris was seen near the right OMS nozzle falling diagonally aft and passing along the +Z side of SSME # 3 prior to liftoff. See Figure 2.2.1(B), annotation 1. The shadow of the debris appeared to be visible on the base heat shield (09:03:56.198 UTC). See Figure 2.2.1(B), annotation 2. (Camera E19)

Several small pieces of unidentified debris (possibly ice or RCS paper) were seen near the base of SSME #1 moving outboard toward the base of the right OMS nozzle prior to liftoff (09:03:55.799 UTC). (Camera E76)

Multiple pieces of light-colored debris (probably SRB instafoam) were seen near the RSRB aft skirt moving in a northerly direction after SRB ignition (09:03:59.479 UTC). None of the debris were seen to contact the launch vehicle. (Cameras OTV109, OTV170, KTV7B, E1, E2, E4, E52)

A light-colored piece of debris, probably a piece of aft skirt instafoam, was seen above the right TSM during liftoff (09:04:00.934 UTC). A similar appearing piece of debris was seen at the same location on STS-100 (film E76) during liftoff. (Camera E63)

2.2.2 Debris During Ascent

As observed on previous missions, multiple pieces of debris (umbilical ice and RCS paper) were seen near the SSME exhaust plume and falling aft of the launch vehicle during ascent. Also during ascent, several pieces of light-colored debris (probably umbilical ice) were seen along the -Z side of the body flap. Examples are (Cameras E52, E207, E212, E223, E224):

E52 - 09:04:11.250 UTC: debris (probable forward RCS paper) was seen near the left wing falling aft.

E224 - 09:04:19.699 UTC: a single piece of debris was seen falling aft of the Orbiter right wing.

E207 - frame 973: probable RCS paper debris was seen aft of SSME #1.

E212 - frame 690: forward RCS paper debris was seen near the trailing edge of the vertical stabilizer.

E223 - frame 1873: forward RCS paper debris was seen near the trailing edge of the vertical stabilizer.

E223 - frame 3567: Multiple pieces of forward RCS paper were seen aft of the vertical stabilizer.

A single piece of debris (umbilical ice) was seen falling aft between the body flap and the LSRB during ascent (09:04:49.296 UTC). (Camera ET207)

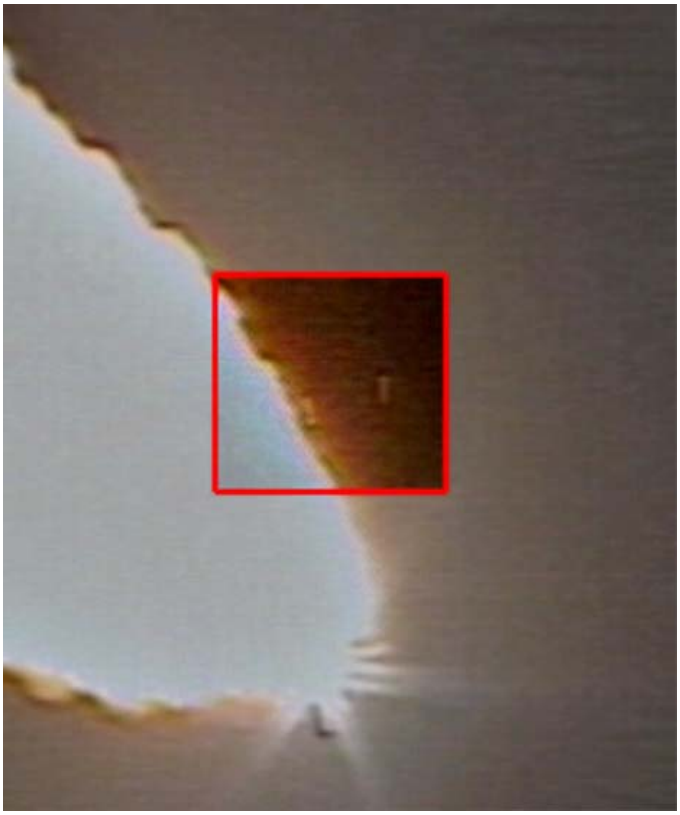


Figure 2.2.2(A) Debris Seen Exiting the SRB Exhaust Plume (Camera KTV4B)

As on previous missions, debris was seen exiting the SRB exhaust plumes. The debris exiting the SRB exhaust plumes during the majority of the ascent was probably instafoam from the aft end of the SRB's. The more dense appearing debris near the time of tail-off, just prior to SRB separation, was probably SRB slag debris (Cameras KTV4B, ET204, E52, E207, E223, E224). Examples are:

09:04:10.807 UTC
09:04:36.737 UTC
09:05:07.743 UTC (two pieces)
09:05:10.303 UTC
09:05:11.304 UTC
09:05:15.875 UTC
09:05:51.711 UTC
09:05:57.280 UTC (five pieces)
09:05:59.015 UTC (six or more pieces)
E207 - frames 6355, 6911, 7370, 7451
E223 - frame 7253

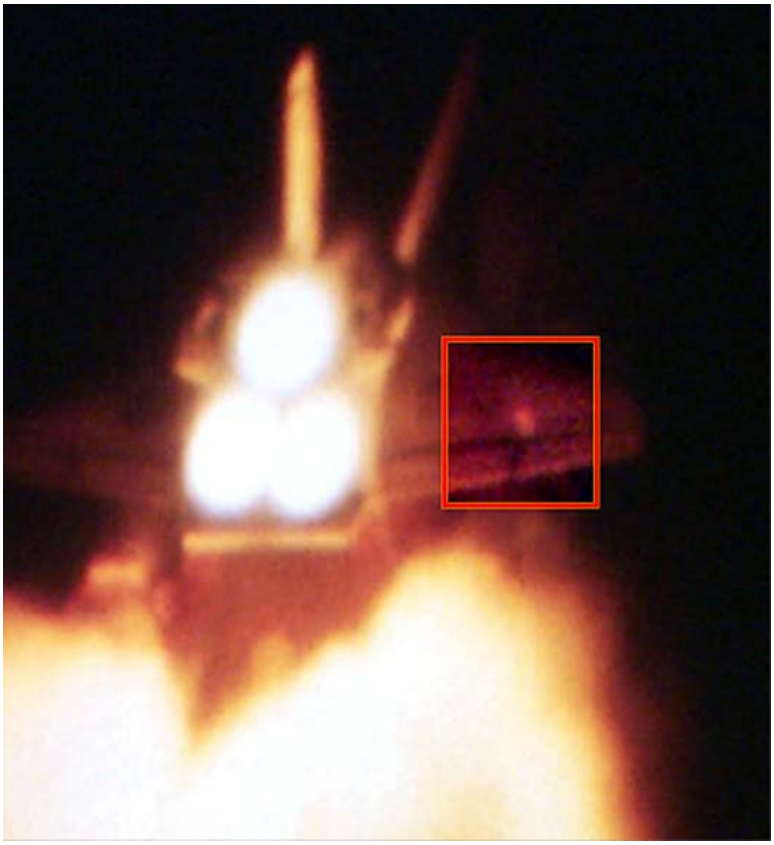


Figure 2.2.2(B) Debris Seen Above Right Wing. (Camera E207)

Several pieces of debris were seen over the port and starboard wings and falling aft of the Orbiter between 2 to 5 seconds prior to SRB separation (Camera E207):

Frame 7135 - Two pieces of debris seen near the inboard leading edge of the left wing.

Frame 7306 - Single piece of debris seen above the right wing.

Frame 7315 - Single piece of debris seen above the left wing.

Frame 7319 - Single piece of debris seen aft of the left wing, outboard of the LSRB.

Frame 7370 - Single piece of debris moving laterally from the apparent direction of the left OMS pod across the +Z side of the left wing.

This event appears similar to debris seen on STS-98 at the same time period. Similar to STS-98, there are no white streaks or other indications of disintegrating tile material on the STS-104 camera E207 views. The STS-104 post landing inspection reports did not indicate a definitive source for this debris. A possible source could have been forward RCS paper debris.

2.2.3 Mobile Launch Platform (MLP) Events

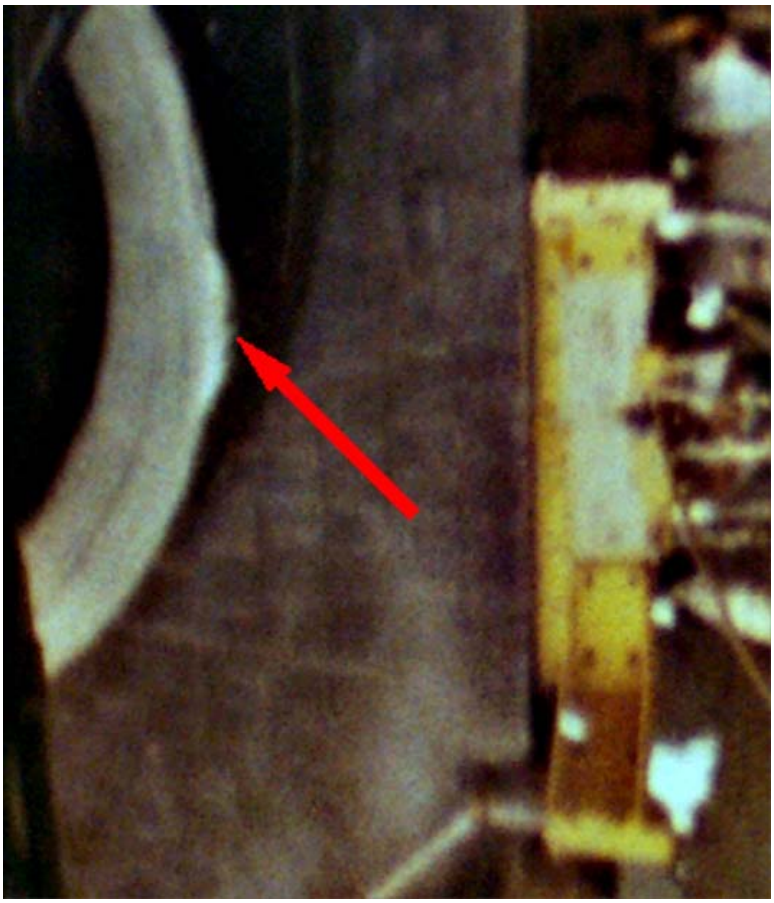


Figure 2.2.3(A) Frayed Thermal Blanket on SSME #2 (Camera E18)

The outboard edge of the SSME #2 dome mounted heat shield (DMHS) thermal blanket was seen to fray during SSME ignition (09:03:55.550 UTC). No significant change to the damage of this thermal blanket was seen on the imagery acquired during the post-landing inspections compared to the pre-liftoff views. (Camera E18)

The SSME ignition appeared normal. However, during SSME start-up, the SSME Mach diamonds did not form in the expected sequence (3, 2, 1). The start-up of the SSME #2 engine was slightly later than SSME #1 (SSME #2 started after SSME #1). This observation is based on the initiation of the orange-colored exhaust flames during engine start-up and the times of the formation of the Mach diamonds. The times for the Mach diamond formation given in Table 2.2.3 are from film E19. (Cameras OTV151, E19, E20, E76)

SSME	TIME (UTC)
SSME #3	09:03:55.681
SSME #1	09:03:55.945
SSME #2	09:03:55.982

Table 2.2.3 SSME Mach Diamond Formation Times

The 3, 1, 2 SSME start-up sequence has been seen on previous mission launches. (The SSME #2 engine on STS-104 was reported to be the first launch using the new Block II engine. KSC explained that the new turbo pumps have more mass than the previous configuration and they take a little longer to spin-up. Consequently, it will not be unusual to see a Block II engine take a bit longer to start up and form the Mach diamond. In the future, when a Block II cluster of three engines is flown, then it can be expected to see the typical 3-2-1 Mach diamond formation order again.)

Figure 2.2.3(B) Orange Vapor Seen During Ignition (Camera OTV163)

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims during SSME ignition. Orange vapor was also seen along the –Z side of the body flap, near the trailing edge of the vertical stabilizer, and moving from beneath SSME #3 toward the LO2 TSM during SSME ignition. Orange vapor forward of the aft end of the Orbiter has been seen on previous mission films and videos. (Cameras OTV163, OTV171, E2, E4, E15, E17, E18, E19, E20, E35, E52, E76)

Slight movement of the base heat shield (flexing) was visible during SSME ignition. Similar motion has been seen on previous mission films and videos. (Cameras E17, E18, E76)

Unlike STS-100, no movement of the OMS pod tiles during SSME ignition was detected on the STS-104 camera films. (Cameras E17, E18)

Light-orange-colored streaks were seen in the SSME exhaust plumes, possibly debris induced, after SSME ignition and prior to liftoff (Cameras E4, E20, E76). Examples are:

SSME #2 - 09:03:55.978 UTC
SSME #3 - 09:03:56.188 UTC
SSME #1 - 09:03:56.762 UTC
SSME #1 - 09:03:56.894 UTC
SSME #1 - 09:03:56.910 UTC
SSME #1 - 09:03:57.675 UTC
SSME #1 - 09:03:58.220 UTC
SSME #1 - 09:03:58.394 UTC

Streaks in the SSME exhaust plume prior to liftoff have been seen on previous mission films.

Typical of previous missions, a small area of possible tile surface material erosion was seen on the upper (+Z) surface of the body flap. On camera E18, a small piece of unidentified dark-colored debris (possibly a piece of tile surface coating material) was seen near the trailing edge of the body flap and falling aft prior to liftoff (09:03:55.845 UTC). Also, two small areas of tile surface coating material erosion were seen on the base heat shield between SSME #2 and the left RCS stinger (09:04:00.0 UTC). (Cameras E18, E19)

SRB ignition was at 09:03:59.000 UTC based on the observation of the PIC firing at RSRB holddown post M-2. (Camera E8)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 09:04:00.904 UTC (right purge line) and 09:04:00.996 UTC (left purge line). (Cameras E8, E13)

During SRB ignition, a cloud of vapors (condensation) on the north side of the launch pad obscured a large portion of the launch vehicle (from 09:03:59.607 to 09:03:59.898 UTC).
(Cameras E1, E4)

2.2.4 Ascent Events

Partially detached RCS paper on the right RCS stinger was seen flapping during ascent. This event has been seen on previous mission tracking camera views. (Camera E207)

Figure 2.2.4 (A) Flare seen in SSME Exhaust Plume. (Camera E223)

Multiple light-orange-colored flares (possibly debris induced) were noted in the SSME exhaust plume during ascent on the intermediate and long range tracking camera films. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris is RCS paper. (On STS-26 and STS-101, debris that resulted in very large orange-colored flares was determined to have been tile material.) Examples of flares seen on STS-104 are (Cameras ET207, E207, E223):

ET207 - 09:04:50.531 UTC
E207 - frames 2044, 2278: two flares seen in SSME #2 / 3 exhaust plume.
E207- frame 2295: flare seen in SSME # 2 /3 exhaust plume.
E207- frame 3658: flare seen in SSME exhaust plume.
E223 - frames 3551, 3658, 3842, 5023: flares seen in the SSME exhaust plume.

Flares in the SSME exhaust plumes have been seen on previous missions films and videos.

Body flap motion typical of that seen on previous missions was seen during ascent (09:04:34 – 09:05:03.5 UTC). However, there was a short interval (camera E207, frames 3055 to 3105) where there appeared to be an increase in the torsional motion of the STS-104 body flap. This increased torsional motion was compared visually to the motion seen on STS-97 and STS-98 and it was determined that further analytical photographic analysis was not warranted. (Camera ET207, E207)

2.3 Onboard Photography of the External Tank (ET-109A)

2.3.1 16mm Umbilical Well Camera Films

One 16 mm umbilical well high speed motion picture film (roll FL101) from the camera with the wide angle (5 mm) lens imaging the SRB separation was acquired. The view of the ET separation was unusable due to poor lighting. Timing data was not present on the FL101 umbilical well camera film. (The second 16 mm umbilical well camera with the 10 mm lens (roll FL102) was not flown on STS-104.)

The LSRB separation appeared normal on the 16 mm umbilical well camera film. Numerous light-colored pieces of debris (insulation) and dark debris (charred insulation) were seen throughout the SRB separation film sequence. Typical ablation and charring of the ET/Orbiter LH2 umbilical electric cable tray and the aft surface of the -Y upper strut fairing were seen prior to SRB separation. Numerous irregularly shaped pieces of debris (charred insulation) were noted near the base of the LSRB electric cable tray prior to SRB separation. (A larger than typical piece of probable charred insulation debris was seen coming from behind the base of the electric cable tray on frame 98). Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. The amount of ablation of the TPS on the aft dome was typical of previous flights. The SRB nose caps were not visible after SRB separation because of the poor lighting.

The ET separation sequence was dark and unusable due to darkness and, later in the sequence, due to the back lighting of the ET by the morning Sun. The view of the EO-2 fitting near the LH2 umbilical was too dark to determine the position of the EO-2 separation bolt.

2.3.2 35mm Umbilical Well Camera Film

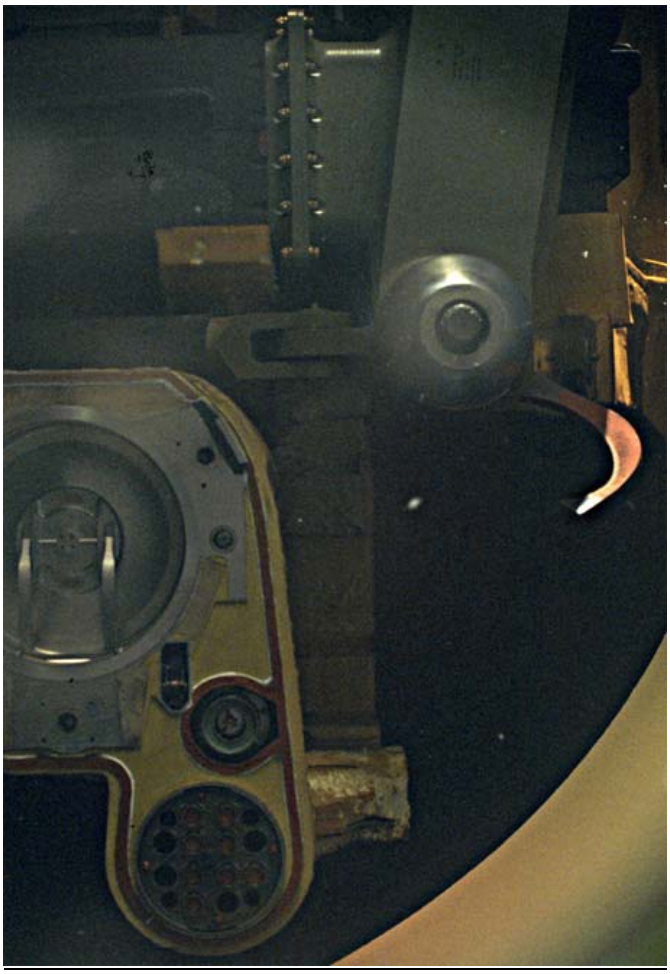


Figure 2.3.2 (A) 35mm Umbilical Well Camera View of ET Bolt (frame 5)

One special interest observation was noted on the 35 mm umbilical well camera film: The separation bolt between the ET and the aft end of the Orbiter (EO-3 fitting near the liquid oxygen umbilical) was observed to be protruding (not fully retracted) and probably free floating. The EO-3 bolt appeared to be similar to the protruded EO-3 bolts seen on STS-106, STS-102, and STS-100. (A Shuttle Program investigation of the STS-106 bolt extension was previously conducted in October, 2000). An animated movie (gif image using multiple views) confirmed that the bolt was free floating and not rigid. (A rigid bolt is a concern since it could interfere with the proper separation of the ET from the Orbiter.) Also, what appeared to be possible damage to the visible end on the EO-3 bolt was noted. However, engineering personnel at JSC explained that when the booster cartridges fire, the frangible nut splits into two pieces that rebound inside the debris container. The end of the separation bolt quite often is impacted at that time. Also as the bolt pulls out of the container, the frangible nut halves scrape along the side of the bolt. Many of the bolts that had been used in qualification tests showed the same type of markings. Therefore, the scrape marks seen on the end of the STS-104 (ET-109A) EO-3 bolt are not anomalous.

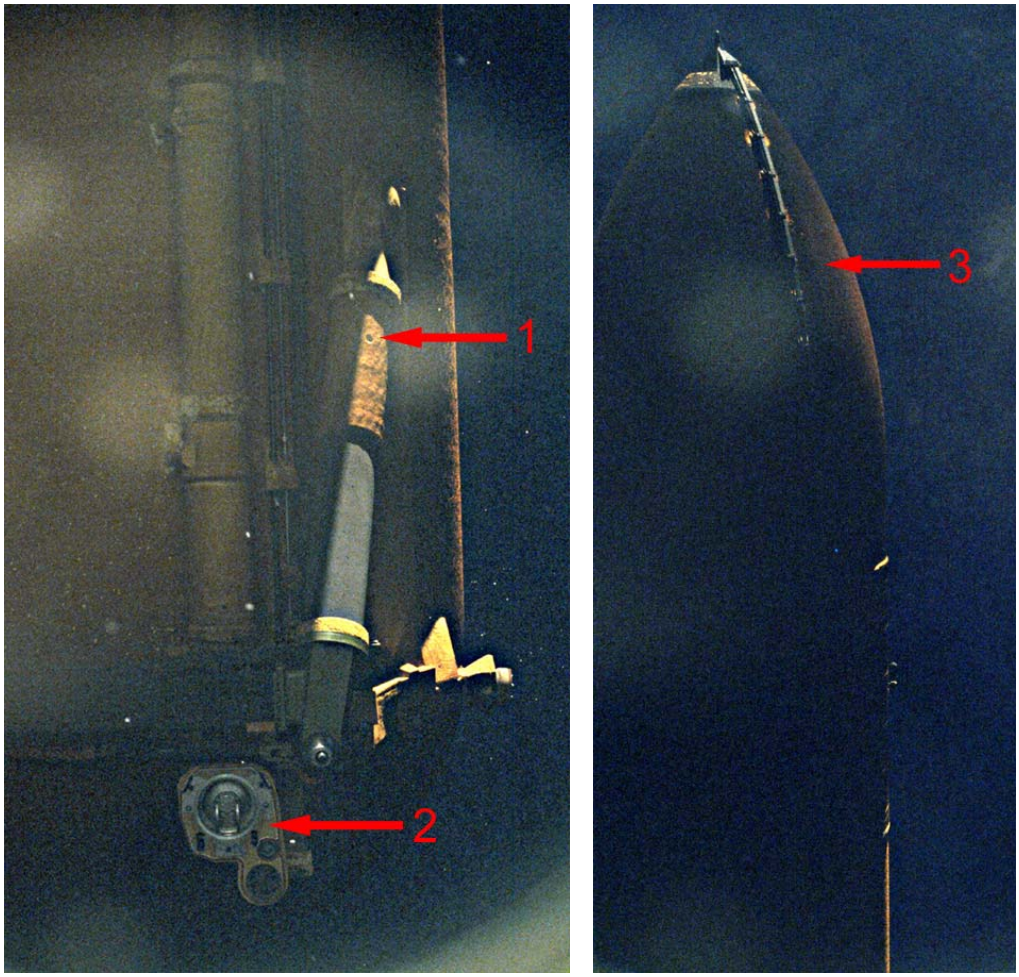


Figure 2.3.2 (B) 35mm Umbilical Well Camera Views of the Aft and Forward ET (frames 15, 53)

A circular-shaped divot with a dark center (possibly due to shadow), approximately two inches in diameter, was visible near the forward end of the +Y thrust strut. See figure 2.3.2 (B), annotation 1. Minor TPS chipping and very small divots (typical of previous missions) were seen on the aft LO2 feedline flanges and on the aft bracket over the press lines. Small, shallow areas of TPS erosion and divoting were visible on the aft flange of the +Y ET/Orbiter thrust strut and on the aft bellows of the LO2 feedline. Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical were detected.

The face of the LO2 umbilical carrier plate appeared to be in excellent condition (no indication of damaged or missing lightning contact strips was detected). See figure 2.3.2 (B), annotation 2.

The red-colored purge seal on the EO-3 ball joint fitting was detached but still in the field-of-view (secured by it's tether).

The +Z/+Y ET thrust panel was almost completely obscured by shadow and could not be analyzed. The –Y ET thrust panel was not in view.

The portion of the LO2 tank / Ojive TPS not obscured by shadow appeared to be in excellent condition. See figure 2.3.2 (B), annotation 3. The visible portion of the nose of the ET appeared free of damage and the nose cap appeared in good condition. The aero friction and aero heating marks seen on the TPS just aft of the nose cone appeared normal and similar to that seen on previous missions.

The +Z/+Y LH2 tank TPS, the forward ET/Orbiter attach bipod, the intertank rib heads forward of the bipod, the LH2 tank TPS, the bipod jack pad closeouts, and the LH2 tank-to-intertank closeout flange were obscured by shadow.

Notes: Sixty 35mm umbilical well camera frames imaging the ET were acquired. However, the images were severely degraded by shadow. The +X translation maneuver was performed on STS-104 to facilitate the imaging of the ET with the umbilical well cameras.

2.3.3 ET Handheld Photography

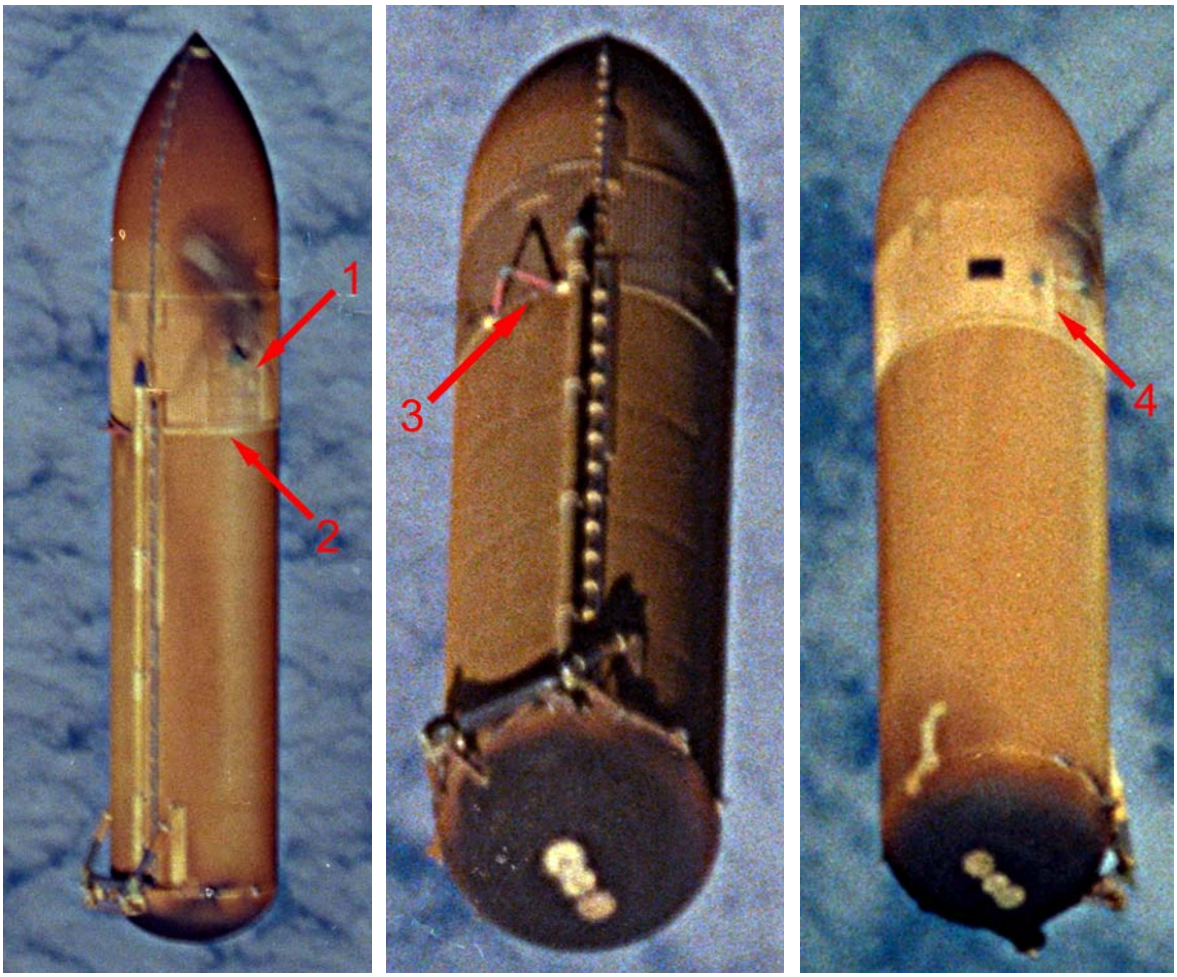


Figure 2.3.3 Crew Handheld Images of the External Tank (frames 3, 18, 29)

Exceptionally good quality crew handheld views of all aspects of the ET were obtained using the handheld 35mm Nikon F5 camera with a 400mm lens (rolls 301 and 302). The ET was fully illuminated with very little shadowing on the handheld views. The distance of the ET was calculated to be approximately 2.3 km on the first photographic frame acquired. The best minimum resolvable object size on the handheld film at 2.3 km was estimated to be approximately six inches. A total of sixty-nine pictures of the ET were obtained. Timing data is present on the film. The first picture was taken at approximately 16 minutes MET. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld video and photography.

Several light-colored marks were seen on the +Y thrust panel TPS aft of the RSRB / ET forward attach. See figure 2.3.3, annotation 1. These light-colored marks may be areas of divots but are more likely to be sanded areas that were present prior to launch. A very faint, light-colored mark that may possibly be a divot was seen on the +Y LH2 tank-to-intertank closeout flange. See figure 2.3.3, annotation 2. A light-colored mark that may possibly be a divot was seen on the

LH2 tank-to-intertank closeout flange between the legs of the ET / Orbiter forward attach bipod. See figure 2.3.3, annotation 3. Light-colored marks on the –Y edge of the –Y thrust panel appeared to be sanded areas that were present prior to launch. See figure 2.3.3, annotation 4. The normal SRB separation burn scars and aero-heating marks were noted on the intertank and nose TPS of the ET. The LO2 tank / Ojive TPS appeared to be in good condition at the level of detail that could be resolved on this film.

2.3.4 ET Handheld Video

More than five minutes of good quality video imaging the External Tank using the new PD-100 camcorder was acquired commencing at approximately 19 minutes MET. Views of the ET aft dome, -Y axis, and the ET nose were acquired. No anomalous or unusual observations were noted on the video views. No venting from the ET intertank gaseous hydrogen vent or the aft ET umbilicals was seen on the STS-104 video.

2.4 Landing Events Timing

The time codes from videos were used to identify specific events during the screening process. The landing event times are provided in Table 2.4.

STS-104 Landing and Drag Chute Event Times from Video:

Event Description	Time (UTC)	Camera
Main gear door opening	Not Observed	NA
Left main gear tire touchdown	206:03:38:54.650	EL18IR
Right main gear tire touchdown	206:03:38:54.784	EL18IR
Drag chute initiation	206:03:38:57.658	EL18IR
Pilot chute at full inflation	~206:03:38:58.415	KTV5L
Bag release	206:03:38:59.195	EL18IR
Drag chute inflation in reefed configuration	206:03:39:00.632	EL18IR
Drag chute inflation in disreefed configuration	206:03:39:03.477	KTV11L
Nose gear tire touchdown	206:03:39:05.448	EL18IR
Drag chute release	206:03:39:38.545	KTV11L
Wheel Stop	~206:03:40:37.289	EL18IR

Note: ~ Denotes that the time shown is approximate.

Table 2.4 Landing Event Times

2.5 Landing Sink Rate Analysis

Image data from the centerline camera at the approach end of runway 15 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touch down for each of the landing gear was considered. Data points defining the main gear struts were collected on every frame (50 frames of data during the last second prior to touch down with respect to each landing gear; the speed of Camera E7 was calculated to be 49.0 frames per second). An assumption was made that the line of sight of the camera was perpendicular to the Orbiter's y-axis. The distance between the main gear struts (272 inches) was used as a scaling factor. The main gear midpoint height above the runway was calculated by the change in vertical difference between the main gear struts and the reference point on the runway. A trendline for the main gear midpoint (between the main gears) was

determined considering the height of the Orbiter above ground with respect to time. Sink rate equals the slope of this regression line.

The main gear sink rate for STS-104 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.5.

Time Prior to Touchdown	Main Gear Midpoint Sink Rate	Estimated Error (1σ)
1.00 Sec.	4.3 ft/sec	± 0.1 ft/sec
0.50 Sec.	4.3 ft/sec	± 0.1 ft/sec
0.25 Sec.	4.6 ft/sec	± 0.2 ft/sec

Table 2.5 Main Gear Midpoint Landing Sink Rate

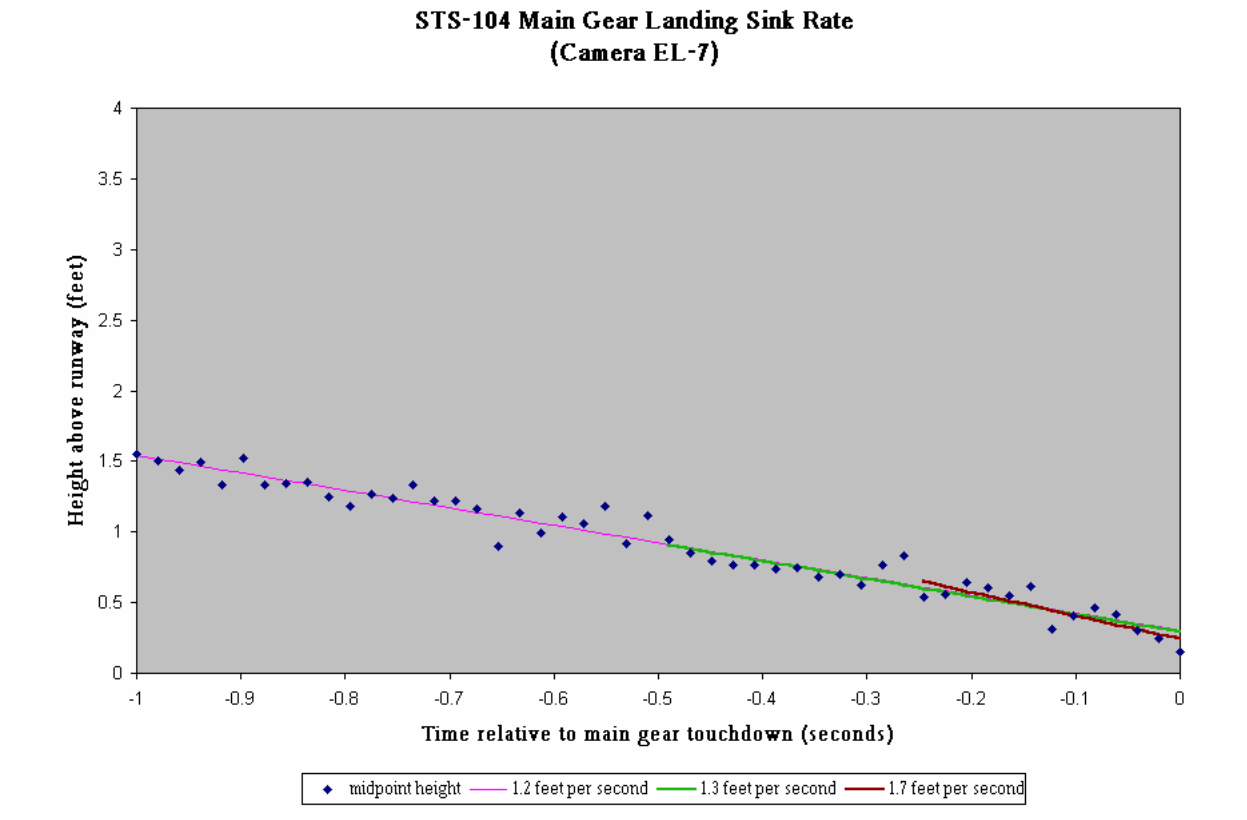


Figure 2.5 Main Gear Midpoint Landing Sink Rate

The maximum allowable main gear sink rate values are 9.6 feet / second for a 212,000 lb. vehicle and 6.0 feet/second for a 240,000 lb. vehicle. The landing weight of the STS-104 vehicle was reported to be 210,021 lbs.

2.6 Other

2.6.1 Normal Events

Normal events observed included:

- elevon and body flap motion prior to liftoff
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilical prior to and / after disconnect
- multiple pieces of ET/Orbiter umbilical ice debris falling along the body flap during liftoff
- vapor off the SRB stiffener rings
- acoustic waves in the exhaust cloud during liftoff
- debris in the exhaust cloud (including water baffle material) after liftoff
- charring of the ET aft dome after liftoff
- ET aft dome outgassing
- roll maneuver
- expansion waves
- condensation around the launch vehicle (with vapor trails off the Orbiter wing tips)
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during, and after SRB separation

2.6.2 Normal Pad Events

Normal pad events observed included:

- hydrogen burn ignitor operation
- FSS and MLP deluge water activation
- sound suppression system water operation

- GH2 vent arm retraction
- TSM T-0 umbilical disconnect and retraction
- LH2 and LO2 TSM door closures

APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

The MSFC Report can be accessed on their Engineering Photographic Analysis website at https://photo4.msfc.nasa.gov/.

Space Shuttle Mission STS-104

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

T. J. Rieckhoff (NASA/MSFC)
M. Covan (USA)
J.M. O'Farrell (USA)
D.H. Osborne (ERC)

August 22, 2001
Marshall Space Flight Center,
Huntsville, AL 35812

Contents

Figures

Engineering Photographic Analysis Report for STS-104

Launch of the one-hundred-fifth Space Shuttle mission, STS-104, the twenty-fourth flight of the Orbiter Atlantis (OV-104), occurred July 12, 2001 at approximately 5:04 AM EDT, from launch complex 39B, Kennedy Space Center (KSC), Florida. Launch time was reported as 01:193:09:03:58.991Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

STS-104 Photographic Analysis Summary:

One significant out-of-family condition was observed on launch film and/or video products covering Space Shuttle Mission STS-104. Debris was observed near the left and right wings of the Orbiter approximately four seconds prior to SRB separation

Other notable or interesting observations from STS-104 were the protruding EO3 Separation Bolt observed after Orbiter/ET separation, a bright spot on SSME#2 hot wall, a frayed blanket on SSME#2 eyelid, and a flash in the green room prior to lift-off.

Photographic Analysis Website:

Further information concerning photographic analysis of this and previous space shuttle missions is available on the MSFC Engineering Photographic Analysis website at URL:

http://photo4.msfc.nasa.gov/STS/sts104/sts104.html

Information available on the MSFC Engineering Photographic Analysis website includes:

- Photographic Acquisition Disposition Document (PADD),
- Individual camera status and assessments,
- Annotated images of notable observations,
- Movies of select events, and
- Photographic Analysis Mission Summary Report (PDF format).

Photographic Coverage:

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle.

Sixty-six engineering photographic products consisting of launch video, ground-based engineering films and onboard film were received and reviewed at MSFC. Camera coverage received at MSFC for STS-104 is illustrated in the following table.

	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	5
Tracking	0	8	10
Onboard	1	3	1
Other	0	0	0
Totals	25	18	23

No video was received from video camera TV13. A slight camera rocking motion noted on Film Camera E36 and some camera vibration was noted on Film Camera 220. Images from film camera E213 were overexposed early in flight and images from OTV 148 were overexposed at liftoff. Focus was soft on Film Camera E222. An LED segment on the "minutes" line of the timing display on film camera E13 was inoperative.

T-Zero Times :

T-Zero times are regularly determined from MLP cameras that view the SRB Holddown posts, without doghouse covers, M-1, M-2, M-5, and M-6. These cameras, listed below with their corresponding Holddown Post, record the explosive bolt combustion products.

Holddown Post	Camera	Time (UTC)
M-1	E9	193:09:03:58.999
M-2	E8	193:09:03:58.998
M-5	E12	193:09:03:58.998
M-6	E13	193:09:03:58.999

SRB Separation Timing:

SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E207, occurred at 193:09:06:00.655 UTC.

Anomalies:

No anomalous events or significant problems were noted on this mission.

Out of Family Observations:

Video Camera ET207: Orbiter Debris near SRB Separation

Debris was observed near the right and left wings of the Orbiter from five to two seconds prior to SRB separation. This debris resembles the debris observed on Mission STS-98 at approximately the same time and location.

This debris did not appear to be slag ejected from the SRB plumes.

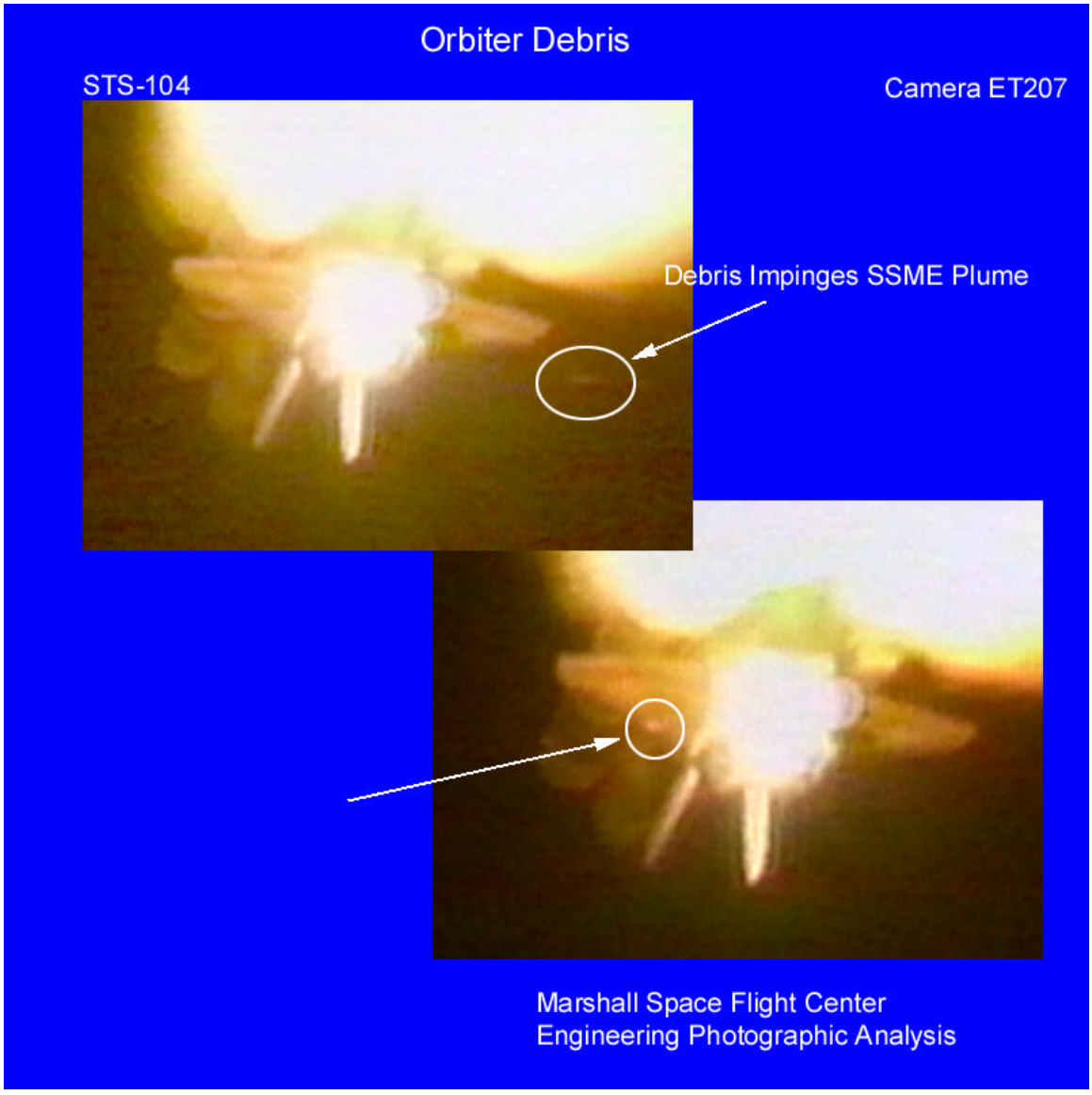


Figure 1. Orbiter Debris Near SRB Separation

Observations:

Video Camera OTV161: Frost on Nose Cap Louvers

Edges of the louvers on the External Tank appear to be coated with frost prior to liftoff.

Figure 2. Frost on ET Nose Cap Louvers

Video Camera OTV163: Free Burning Hydrogen at SSME Ignition

Free burning hydrogen was observed on the –Z side of the body flap under the ET at SSME startup. This type of event is typical.

Figure 3. Free Hydrogen Burning at SSME Ignition

Video Camera TV4B: Condensation Vapors

Condensation vapors were noted around the forward section of the vehicle and trailing from the orbiter wingtips during ascent. This phenomenon is common in high humidity.

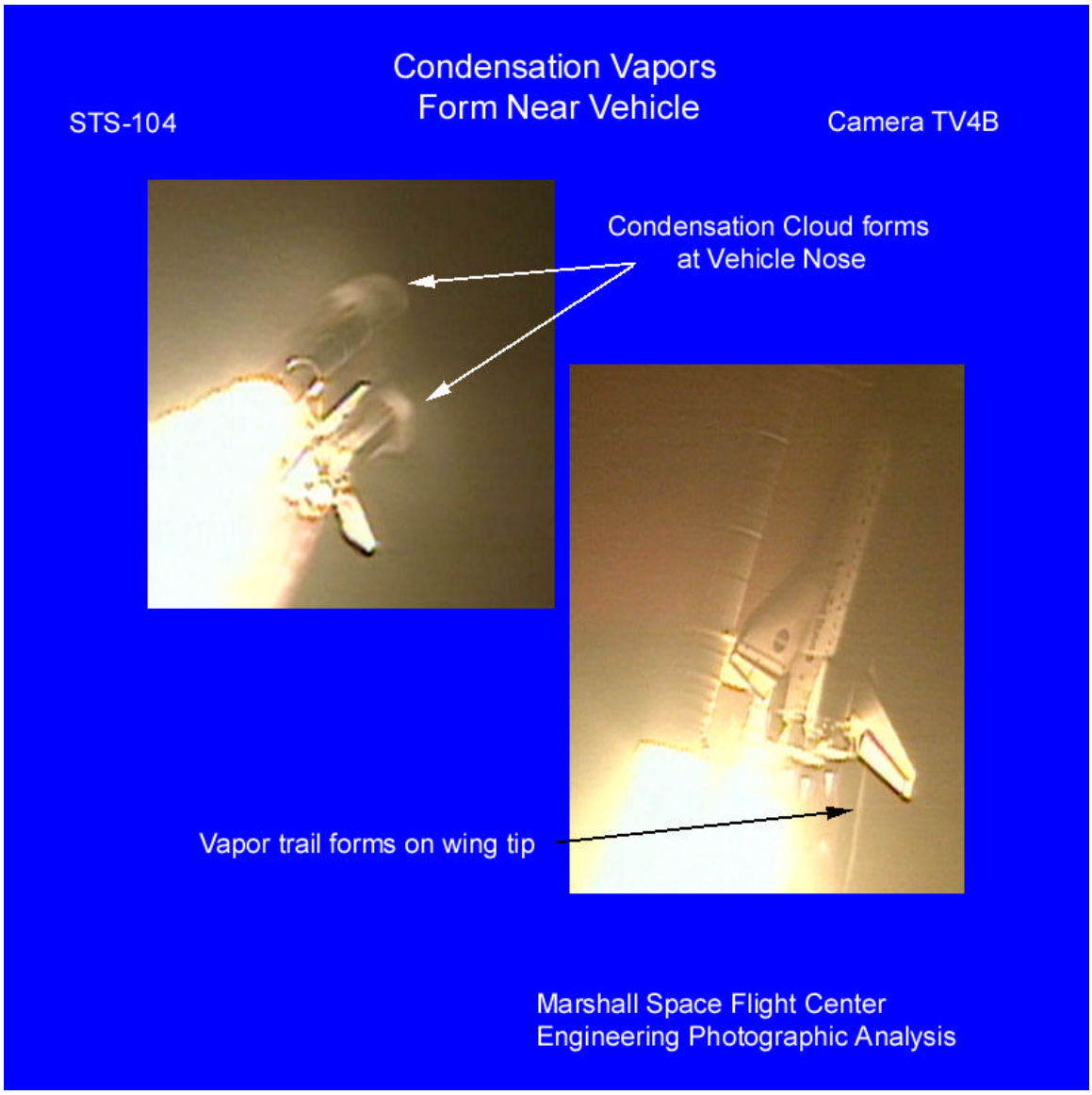


Figure 4. Condensation Vapors

Video Camera ET207: Streak in SSME Plumes

Several debris induced streaks in SSME plumes were observed on this mission. The streak shown in Figure 5 is thought to be a debris-induced streak.

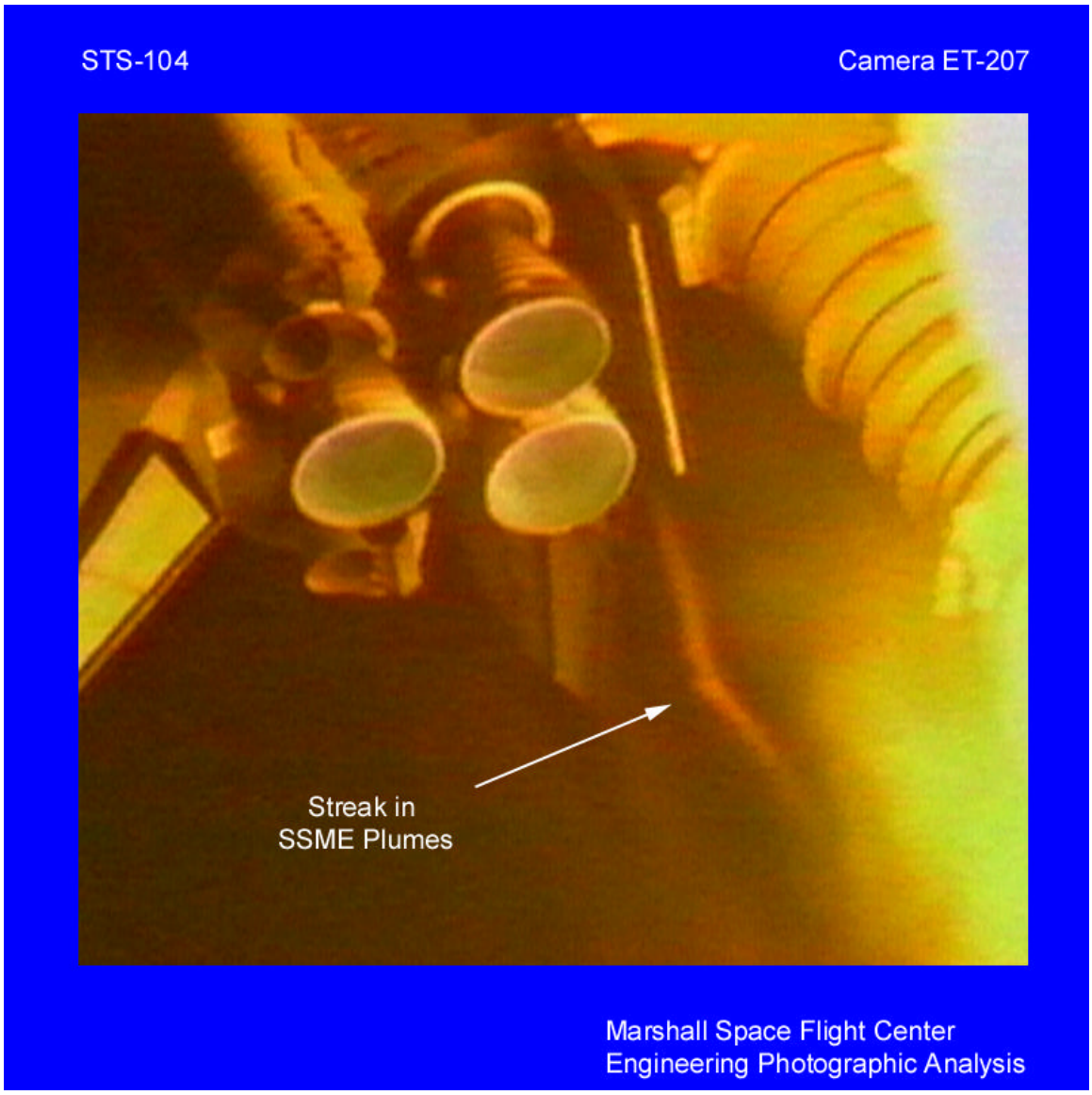


Figure 5. Streak in SSME Plumes

Video Camera TV4B: Debris Ejected from SRB Plumes

Several pieces of debris were ejected from the SRB plumes during ascent. This debris is thought to be Instafoam from the SRB aft skirt thermal protective surface. Due to lighting conditions during night/early morning flights, this type of debris becomes more visible.

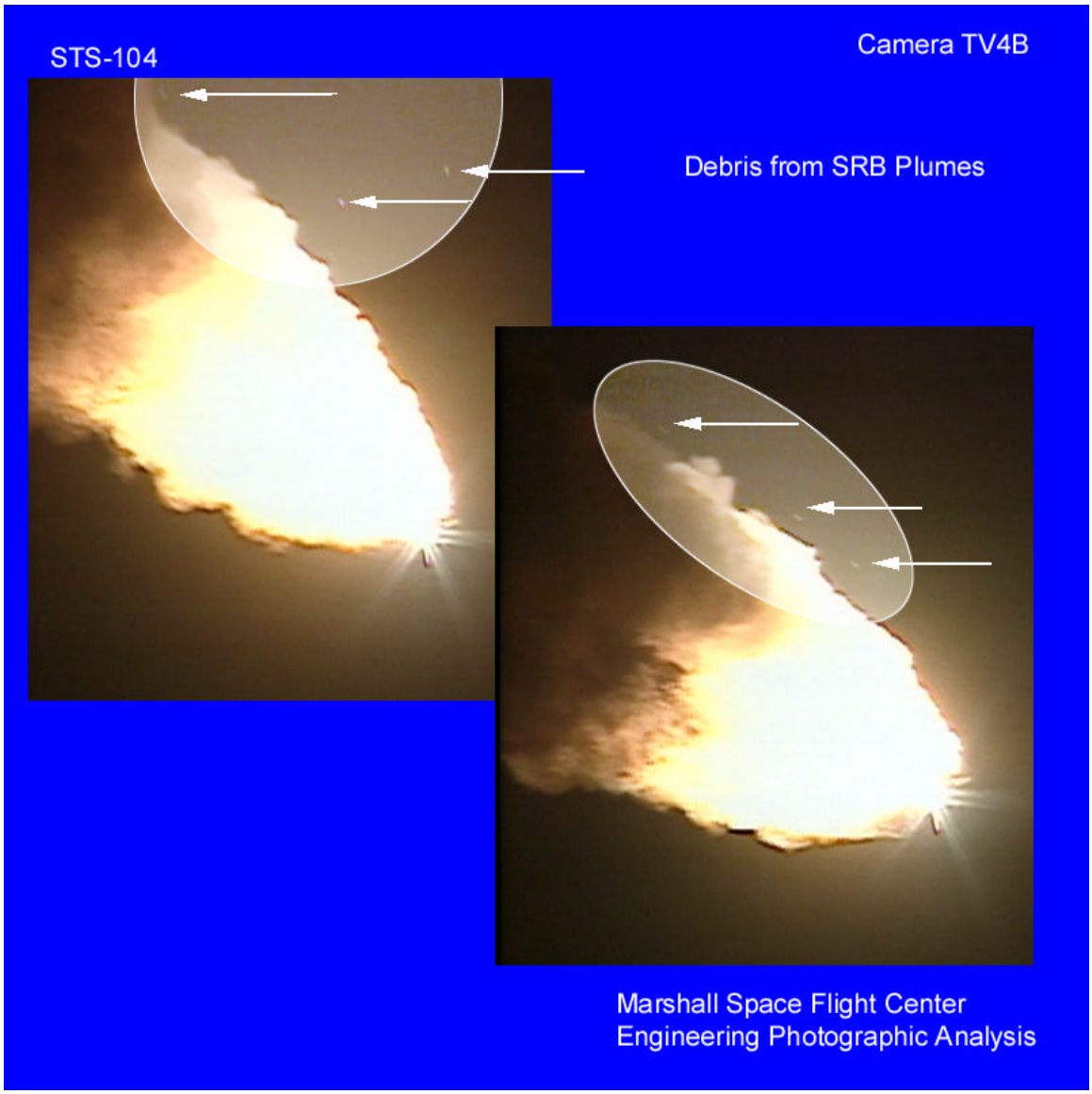


Figure 6. Debris Ejected from SRB Plumes

Film Camera E18: Frayed SSME #2 Eyelid Blanket

A portion of SSME#2 Eyelid Blanket appeared to be frayed during SSME startup.

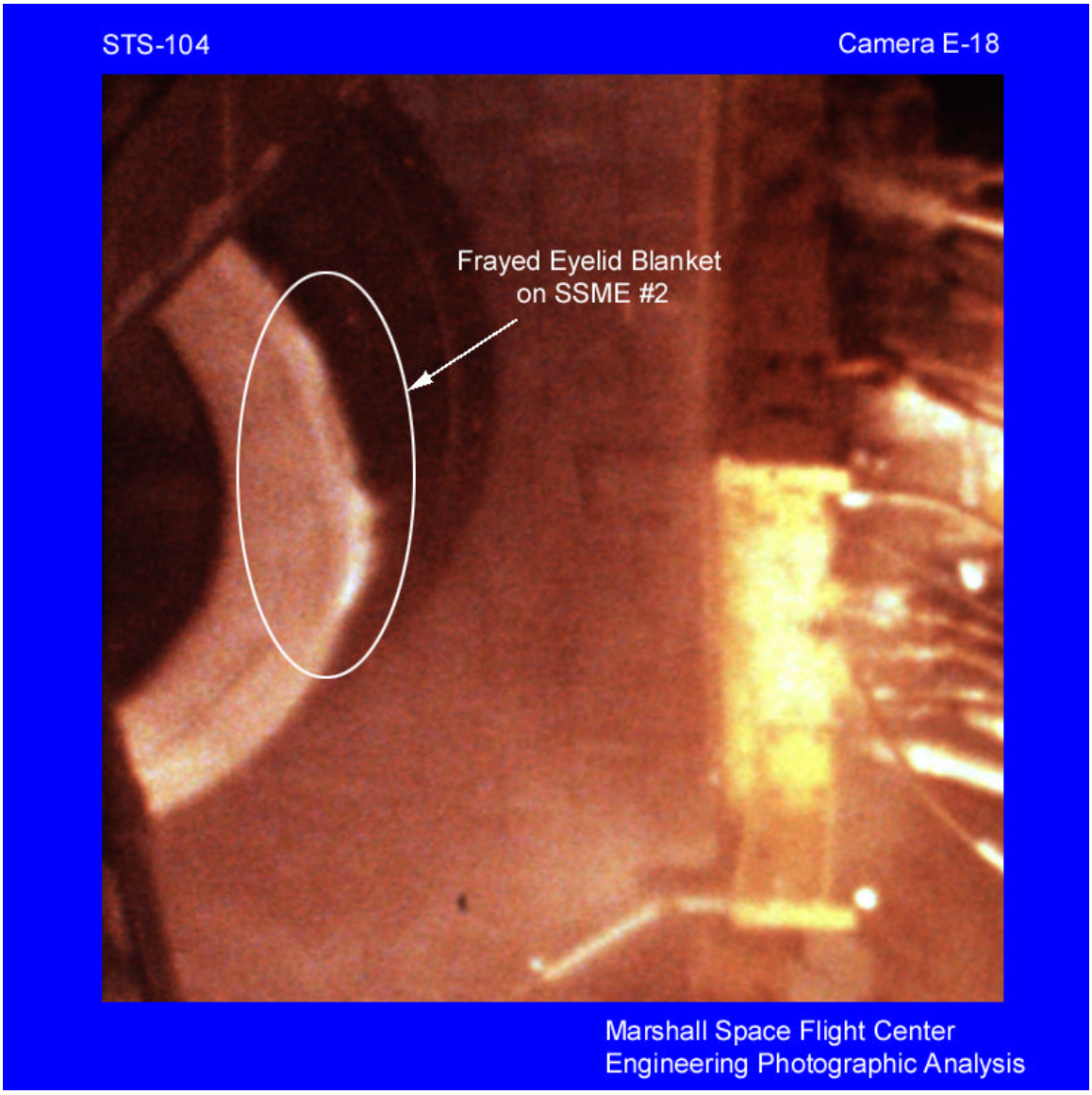


Figure 7. Frayed SSME#2 Eyelid Blanket

Film Camera E62: Green Room Flash

A flash was observed in the Green Room, 193:09:03:51:860 UTC, prior to lift-off. In Figure 8, a normal frame exposure of the Green Room in this time frame is contrasted with the single frame in which the flash was detected.

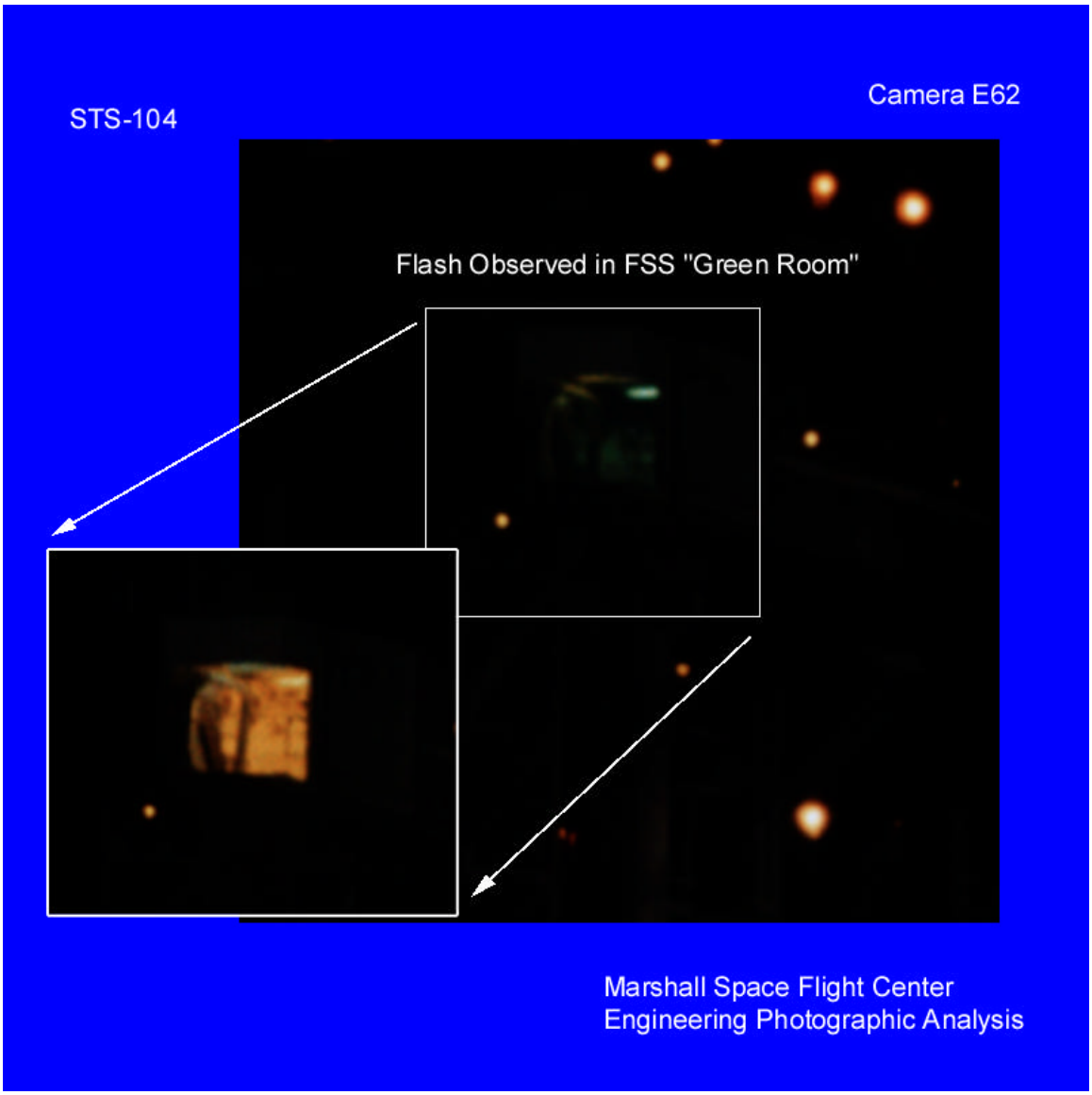


Figure 8. Flash in Green Room

Film Camera E52: Bright Spot on SSME # 2 Nozzle Hot Wall

A light colored, bright area was observed on the hot wall of the SSME#2 nozzle. Bright areas have been observed during SSME testing and have been associated with nozzle repairs.

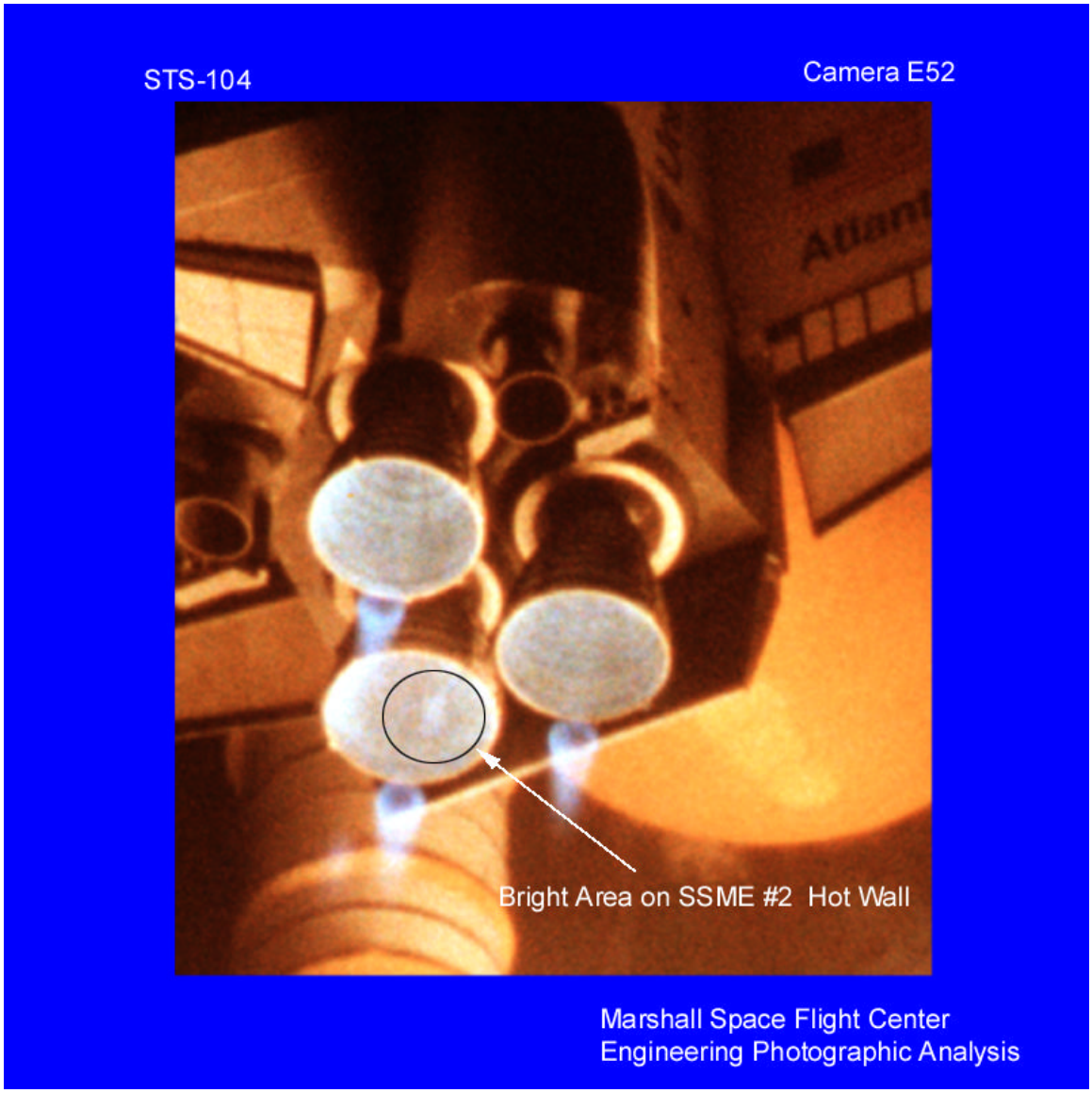


Figure 9. Bright Spot on SSME #2 Nozzle Hot Wall

Umbilical Well 35mm Still Camera: Divot on the Aft ET +Y Thrust Strut

A notable divot was observed on the ET Aft +Y thrust strut. The divot appeared to be approximately two inches in diameter.

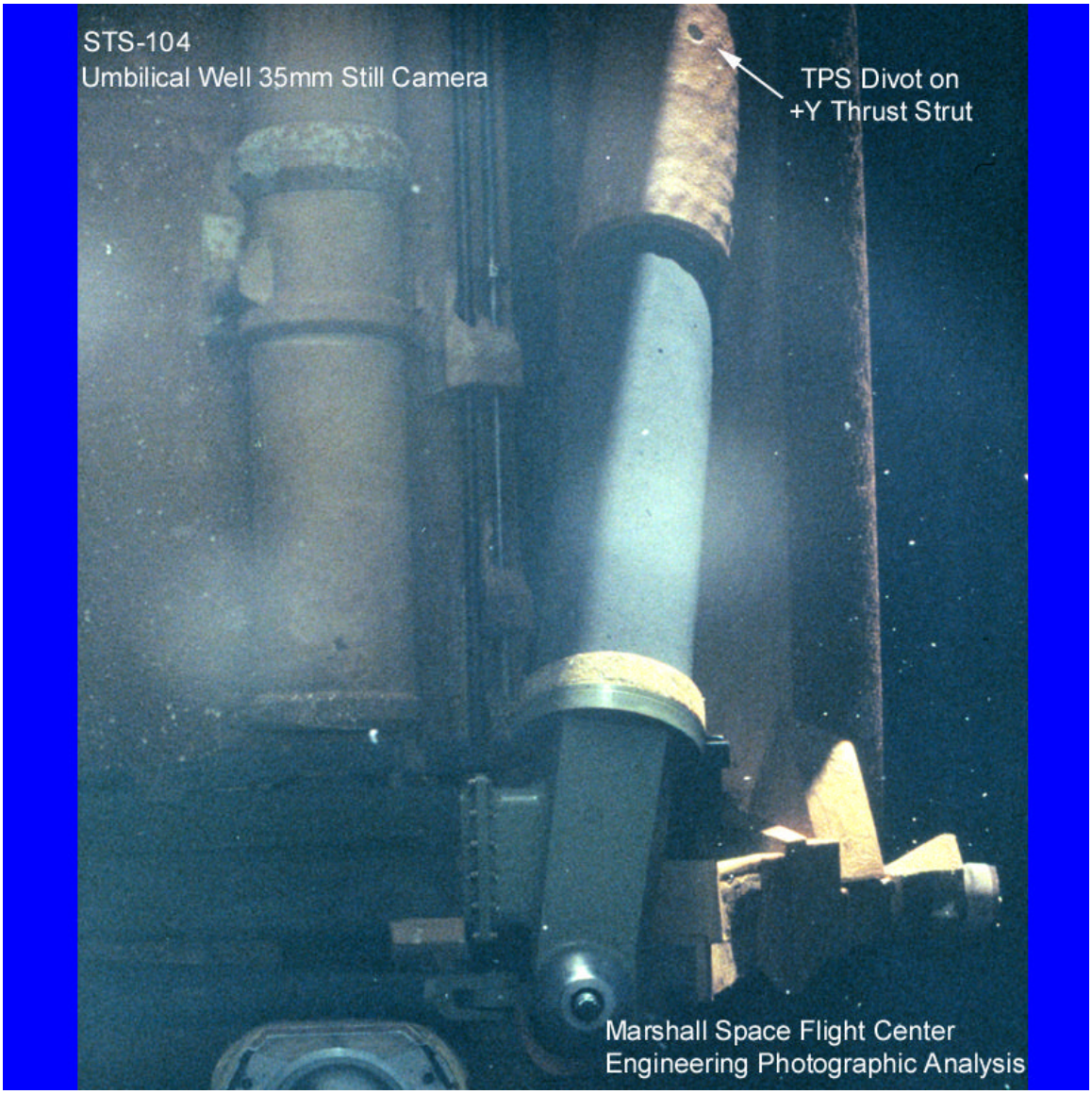


Figure 10. Divot on ET Aft +Y Thrust Strut

Umbilical Well 35mm Still Camera: Protruding EO-3 Separation Bolt

The EO-3 separation Bolt was observed protruding. Further analysis determined that the bolt exhibited motion in the fitting bore and was not rigid. The imagery of the EO-2 Separation bolt from the 16mm Film Camera FL101 was not detailed enough to discern whether that bolt was also protruding.

A movie viewing the EO-3 separation bolt as the External Tank floats away from the orbiter was made. Each frame is taken five seconds apart. The movie may be viewed at:

http://photo4/STS/sts104/bolt.mov

The protruding EO-3 bolt has also been observed on three recent missions: STS-106, STS-102, and STS100.

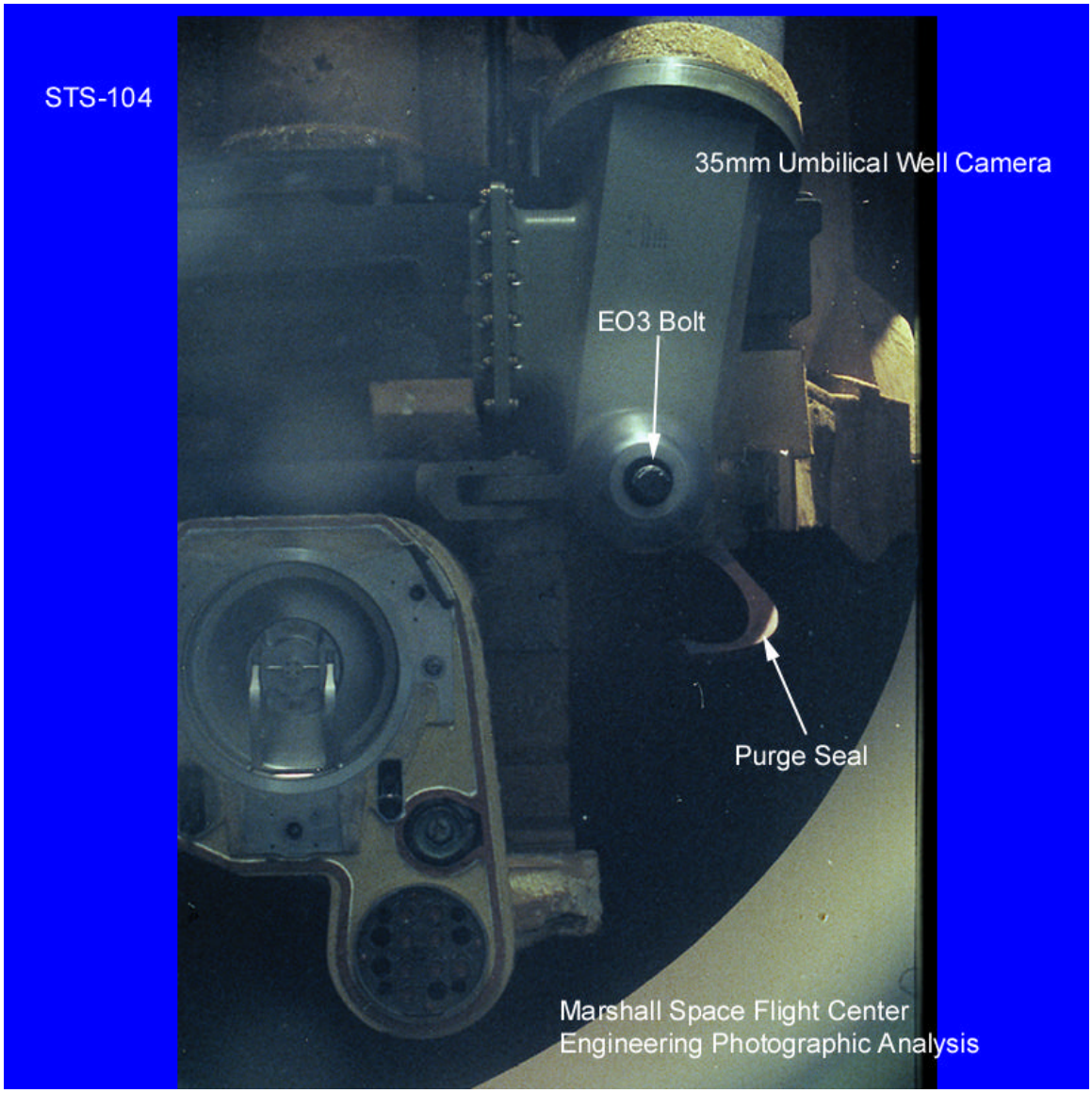


Figure 11. Protruding EO-3 Separation Bolt

Umbilical Well 35mm Still Camera: Close-up of the EO-3 Separation Bolt

A close-up view of the EO-3 separation bolt.

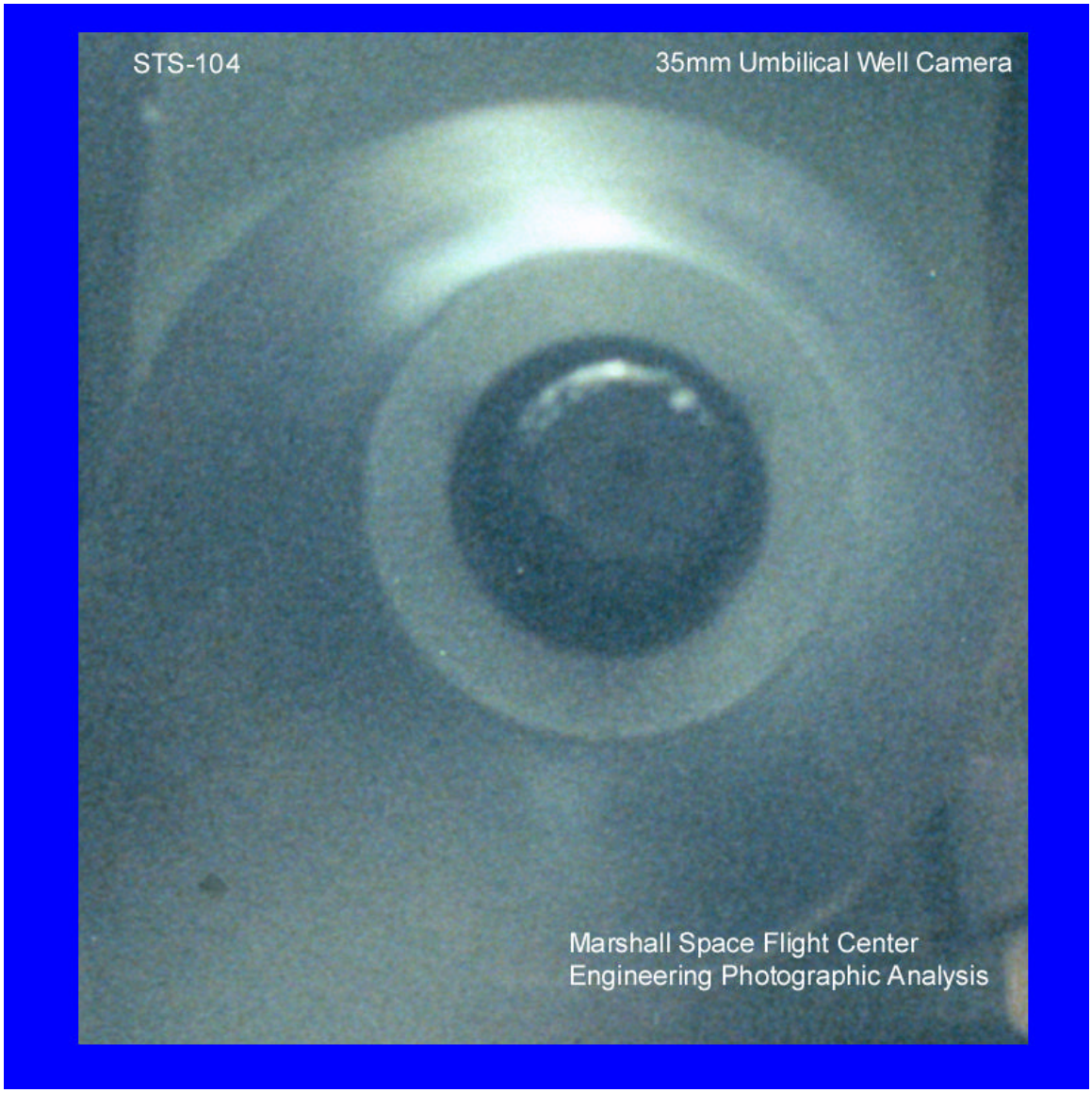


Figure 12. Close-up of the EO-3 Separation Bolt

Individual Camera Assessments:

Assessments for individual cameras are listed below. The assessments for all individual cameras including camera characteristics as noted in the Photographic Acquisition Disposition Document (PADD) for flight STS-104 may also be found on the website.

Video Camera Assessments

TV5	Glowing debris particles ejected from SRB plume prior to separation.
TV13	No video received.
TV4B	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Vapors from Orbiter wingtip noted early in flight. SRB separation: 193:09:06:00.635 UTC. Streak in SSME plume noted.
TV7B	Pad debris noted rising and falling. SRB ignition shock wave noted traveling North of MLP
ET204	Glowing debris particles ejected from SRB plume prior to and after separation.
ET207	Typical debris observed falling aft of vehicle. Linear optical distortions noted. SRB separation: 193:09:06:00.856 UTC. Body flap motion observed. Streak in SSME plumes observed. Flashing near right OMS Stinger Pod appears to be flapping semi-attached RCS paper. Debris observed near the right wing at 193:09:05:55.784 UTC, the left wing at 193:09:05:55.851 UTC, and the left wing again at 193:09:05:55.917 UTC. This debris resembles the debris observed on Mission STS-98.
TV21B	Typical debris observed falling aft of vehicle. SRB ignition shock wave visible.
OTV109	Pad debris noted rising and falling. Typical ice/frost from LH2 disconnect. Typical elevon motion at lift-off.
OTV141	Shock wave traveling North of MLP at SRB ignition noted. Contrail from right wing noted during roll maneuver.
OTV148	Shock wave traveling North of MLP at SRB ignition. Camera becomes overexposed at vehicle lift-off.
OTV149	Typical debris observed falling aft of vehicle. Reflections from metal tags on T-0 umbilical hardware noted.
OTV151	SSME Mach diamond formation in 3-1-2 order.
OTV154	Typical ice/frost from LO2 disconnect. An ice/frost debris particle falls from above the field of view, appears to impact the right wing above the elevon and change trajectory. No damage was noted. Typical ice/frost from the LO2 umbilical impacts the umbilical door well sill. No damage was noted.
OTV160	Shock wave traveling North of MLP noted.
OTV161	Frost noted on ET nose cap louvers. Ice/frost noted falling from LOX Feedline area falling between Orbiter and ET. No impact noted.
OTV163	Pad debris noted rising and falling. Typical ice/frost from LH2 disconnect. Free burning Hydrogen noted beyond the Orbiter body flap towards the ET.
OTV170	Pad debris noted rising and falling. SRB ignition shock wave traveling north of pad.

Astronaut Handheld Video - No unusual observations noted.

Film Camera Assessments

E1	Pad debris noted rising and falling. Vapor partially obscures base of vehicle prior to launch.
E2	Pad debris noted rising and falling. Small streak in SSME #1 plume observed prior to lift-off.
E3	Typical debris observed.
E4	Pad debris noted rising and falling. Typical ice/frost from 17-inch disconnects. Free burning Hydrogen noted under ET side of body flap. Engine streak noted in SSME#3 plume prior to launch at 193:09:03:56.188 UTC.
E6	Typical ice/frost from 17-inch disconnects. Purge barrier material observed protruding from LH2 umbilical well door.
E7	Pad debris noted rising and falling. Tangle of water bag ropes observed after SRB ignition.

E8 SRB Holddown Post M2 PIC Firing time at 193:09:03:58.998 UTC. Typical debris observed.

E9 Free burning hydrogen cloud comes into the field of view. PIC firing 193:09:03:58.999 UTC.

E10 Pad debris noted rising and falling.

E11 Pad debris noted rising and falling.

E12 Pad debris noted rising and falling. SRB Holddown Post M5 PIC firing time at 193:09:03:58.998 UTC.

E13 Pad debris noted rising and falling. SRB Holddown Post M6 PIC firing time at 193:09:03:58.999 UTC.

E14 Pad debris noted rising and falling. Tangle of water bag ropes observed. Large piece aft skirt foam debris observed.

E15 Pad debris noted rising and falling.

E16 Pad debris noted rising and falling.

E17 Typical ice/frost from LO2 T-0 umbilical.

E18 Typical ice/frost from LH2 T-0 umbilical. Frayed SSME #2 eyelid blanket observed.

E19 Mach diamond formation in 3-1-2 order.

E20 SSME#2 eyelid blanket was frayed.

E31 Pad debris noted rising and falling. Typical ice/frost from 17-inch disconnects. Typical wing motion observed.

E33 Normal GUCP retraction.

E34 Typical ice/frost from 17-inch disconnects.

E36 Pad debris noted rising and falling. Typical ice/frost from LH2 disconnect. Slight camera rocking motion noted.

E40 Typical debris observed falling aft of vehicle. Typical ice/frost from 17-inch disconnects.

E52 Typical debris observed falling aft of vehicle. Debris-induced streak in SSME plume. Typical ice/frost from 17-inch disconnects. Contrail noted on right wing during early ascent.

E54 Typical debris observed falling aft of vehicle.

E57 Debris ejected from SRB plumes just after roll maneuver.

E60 Base of vehicle partially obscured by vapors at SSME ignition. Shock wave noted at SRB ignition.

E62 Pad debris noted rising and falling. White flash observed inside green room prior to SSME ignition at 193:09:03:51.860 UTC. Shock wave noted at SRB ignition.

E63 Pad debris noted rising and falling. Typical debris observed falling aft of vehicle.

E204 Glowing debris particles ejected from SRB plume prior to, during and after separation.

E207 Typical debris observed falling aft of vehicle. Linear optical distortions noted. Flow recirculation noted. Streak in SSME plume observed. Body flap motion observed. Vapor trails from wings noted early in flight. Flashing near right OMS Stinger Pod appears to be semi-attached RCS Paper. Numerous pieces of debris noted near orbiter during time period beginning approximately four seconds prior to SRB separation through SRB separation.

E212 Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted.

E213 Condensation collar visible. Image overexposed during early ascent.

E220 Glowing debris particles ejected from SRB plume prior to separation. Excessive camera vibration noted.

E222 Typical debris observed falling aft of vehicle. Debris-induced streak in SSME plume. Condensation collar visible. Focus was soft.

E223 Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Vapors from Orbiter wingtip noted early in flight. Linear optical distortions noted. Flow recirculation noted. Vehicle partially obscured by clouds.

E224 Glowing debris particles ejected from SRB plume prior to separation. Debris-induced streaks in SSME plume. Condensation collar visible.

FL101 - Normal Left SRB separation observed. Images were either too dark or had too much glare to determine the status of the EO-2 separation bolt. TPS condition appears to be nominal.

Astronaut Handheld 35mm Stills - Burns scars on the +Y thrust panel appeared normal. -Y Thrust panel not imaged well but no obvious TPS damage. Image resolution is such that only large scale TPS damage would be observed.

Umbilical Well 35mm Stills - The EO-3 separation bolt was observed to be protruding and appears to be "free floating". The red-colored purge seal was detached but visible. A notable divot was observed in the TPS on the forward end of the +Y thrust strut. Otherwise, nominal TPS popcorning/divoting was observed. Images of forward end of ET were dark and little detail was discernible.

For further information concerning this report contact Tom Rieckhoff/TD53 at 256-544-7677 or Michael O'Farrell at 256-544-2620.

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

NASA - KSC

MK/D. Kross
MK-SIO/R. Page
PH-M2/T. Hawkins
PH-H/J. D. Kelley
PH-H2/Oliu (10)
PH-P4-B/A. Willett
IT-D2-C/C. Brown
SK/J. Key
USK-321/J. Cippolleti
USK-708/A Ekhlassi
721Z-K086 T. Wilson
KICS-700/R. Robinson
MMC-15/D. S. Otto
USK-840/L. Clark

NASA - JSC

Johnson Space Center
Houston, Texas 77058

ES/G. Galbreath
MV/K. Brown
MS3/T. Murphy
SX/E. Christiansen
SX/G. Byrne

NASA - MSFC

Marshall Space Flight Center
Huntsville, AL 35812

EE31/J. L. Lusaka
TD53/T. J. Rieckhoff
MP51/J. Sambamurthi
841-ZA12/J. Hixson

Boeing-Huntington Beach

The Boeing Company
5301 Bolsa Ave.
Huntington Beach, CA 92647

H019-F701 /J. McClymonds
H013-B318/ A. Khodadoust

Lockheed Martin
Facility

LockheedMartin Michoud Assembly

13800 Old Gentilly Road
New Orleans, Louisiana 70129

Dept. 4610/P. A. Kopfinger
MAF Technical Library