Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-112

Armando Oliu

Technical Memorandum – 2005-212560 **June 2005**

DEBRIS/ICE/TPS ASSESSMENT and INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-112

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October 7, 2002

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FOREWORD

The Debris Team has developed and implemented measures to control damage from debris in the Shuttle operational environment and to make the control measures a part of routine launch flows. These measures include engineering surveillance during vehicle processing and closeout operations, facility and flight hardware inspections before and after launch, and photographic analysis of mission events.

Photographic analyses of mission imagery from launch, on-orbit, and landing provide significant data in verifying proper operation of systems and evaluating anomalies. In addition to the Kennedy Space Center Photo/Video Analysis, reports from Johnson Space Center and Marshall Space Flight Center are also included in this document to provide an integrated assessment of the mission.

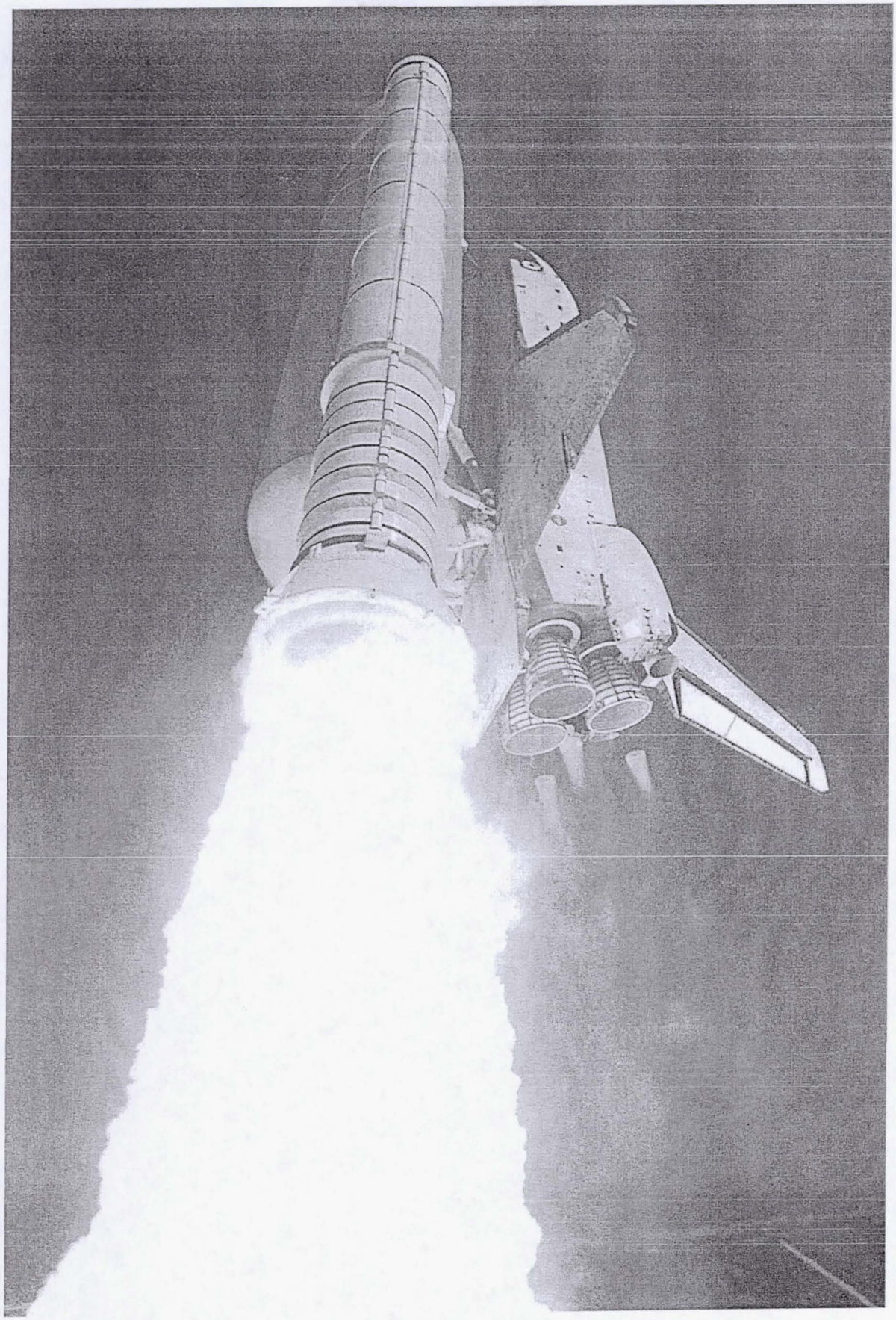


Photo 1: Launch of Shuttle Mission STS-112

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-112 consisted of OV-104 Atlantis (26th flight), ET-115 and BI-115 SRB's on MLP-3 and Pad 39B. Atlantis was launched at 3:46 pm EDT on 7 October 2002. Landing was at 11:44 a.m. local/eastern time on 18 October 2002.

Post landing inspection of Orbiter tiles showed a total of 107 hits, of which 25 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 81 total hits, of which 22 had a major dimension of 1-inch or larger, both numbers are well within family. The majority of the hits were in the area from the nose landing gear to the main landing gear wheel wells. This area sustained 46 hits with 15 greater than 1-inch.

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 1000 hrs. on 4 October 2002. 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. Brewer	USA - SFOC	ET Mechanical Systems
B. Atkinson	Boeing	Systems Integration
T. Wilson	Boeing	Systems Integration
S. Otto	LMMSS	ET Processing
J. Ramirez	LMMSS	ET Processing
M. Eastwood	Thiokol-LSS	SRM Processing

3.0 LAUNCH

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The pre-launch inspection of the MLP-3, Pad B FSS and RSS was conducted on 06 October 2002 from 1500 to 1700 hrs EDT.

Two facility items were documented in Appendix K of S0007VL4. They were:

- Loose transformer box cover on North side of 235 Foot Level of FSS.
- Debris in gutter around MLP zero level.

Both items were in work at the conclusion of walkdown. Overall the Launch Pad was in excellent condition.

No vehicle items were noted.

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 0930 – 1115 hrs on 7 October 2002 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.

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 with no liquid indications observed. Ice/frost had formed on from the 4 to 7 o'clock position on SSME #2 heat shield-to-nozzle interface. SSME's #1 and #3 were free of ice/frost.

3.2.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed. SRB case temperatures measured by the STI radiometers were between 67 to 75 degrees F. All measured temperatures were above the minimum requirement.

3.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run and compared to infrared scanner point measurements. The program predicted temperatures ranging from the upper 50's to upper 60's 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 – 0945hrs	SURFICE Predictions	IR Surface Readings
78 Degrees F.	LO2 ogive 68 Degrees F	LO2 Tank 65-70 Degrees F
83% RH	LO2 barrel 62 Degrees F	
8 knots	LH2 upper 59 Degrees F	LH2 Tank 65-70 Degrees F
332 degrees	LH2 lower 67 Degrees F	

The Final Inspection Team observed moderate condensation on the LO2 tank acreage. No frost was noted on the LO2 tank acreage. There were no TPS anomalies.

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

The LH2 tank had light to moderate condensate on the TPS. No ice/frost was noted on the LH2 tank acreage. Surface temperatures ranged from 65 to70 degrees Fahrenheit. A small frost spot (approximately 3 inch long) was observed at the +Y thrust strut knuckle to longeron interface (aft side). This condition is acceptable per NSTS-0803. There were no acreage TPS anomalies.

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

A 7 inch long and 1/4 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 less than typical. Likewise, very light amounts of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Small 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 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. Most of the frost formation on the acreage TPS had dissipated by T-0. At T-9 minutes 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-112 was launched at 3:46 pm EDT on 7 October 2002.

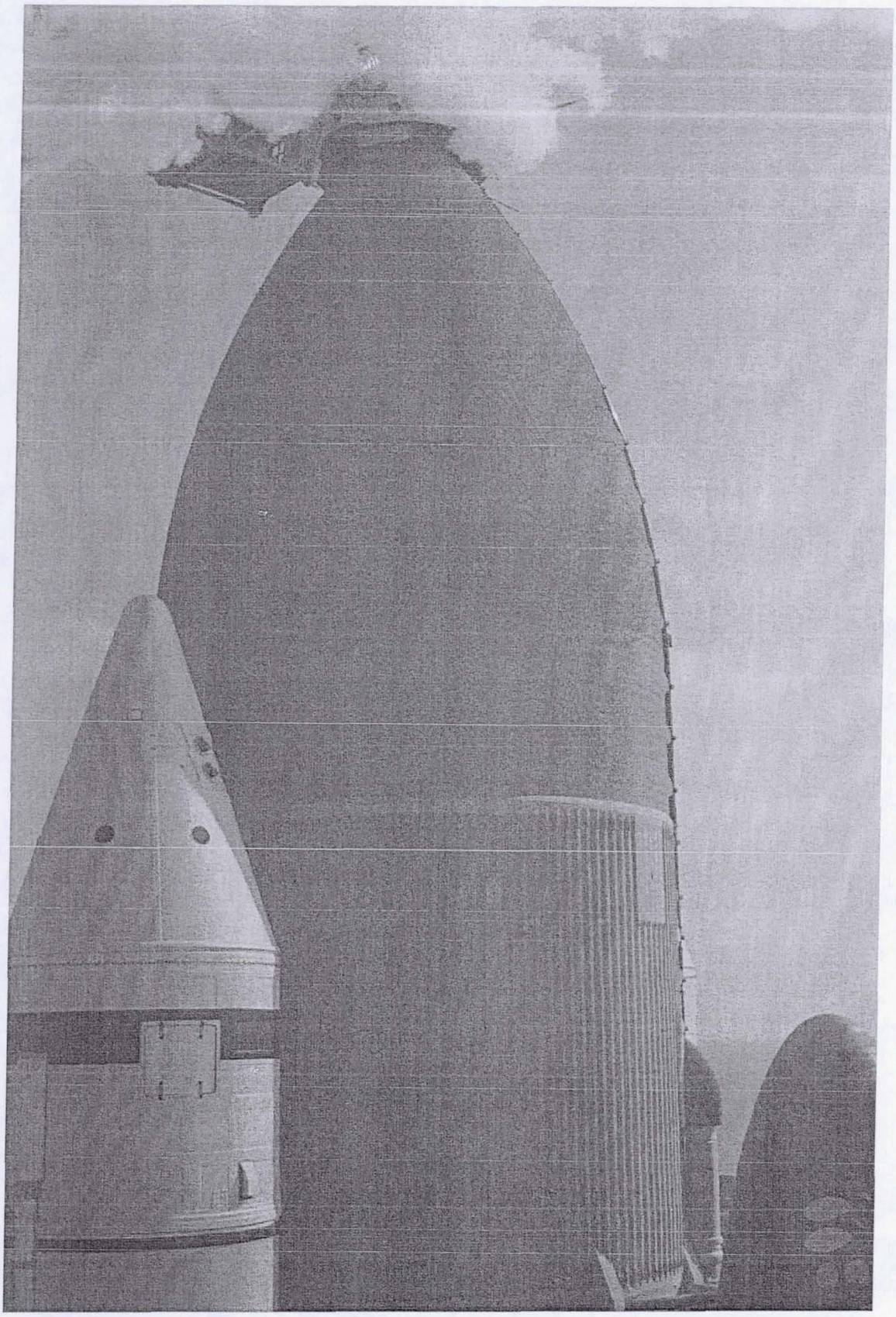


Photo 2: LO2 tank acreage.

Moderate condensate was present on the LO2 tank acreage. Surface temperature ranged from 65 to 70 degrees Fahrenheit. There were no acreage TPS anomalies.

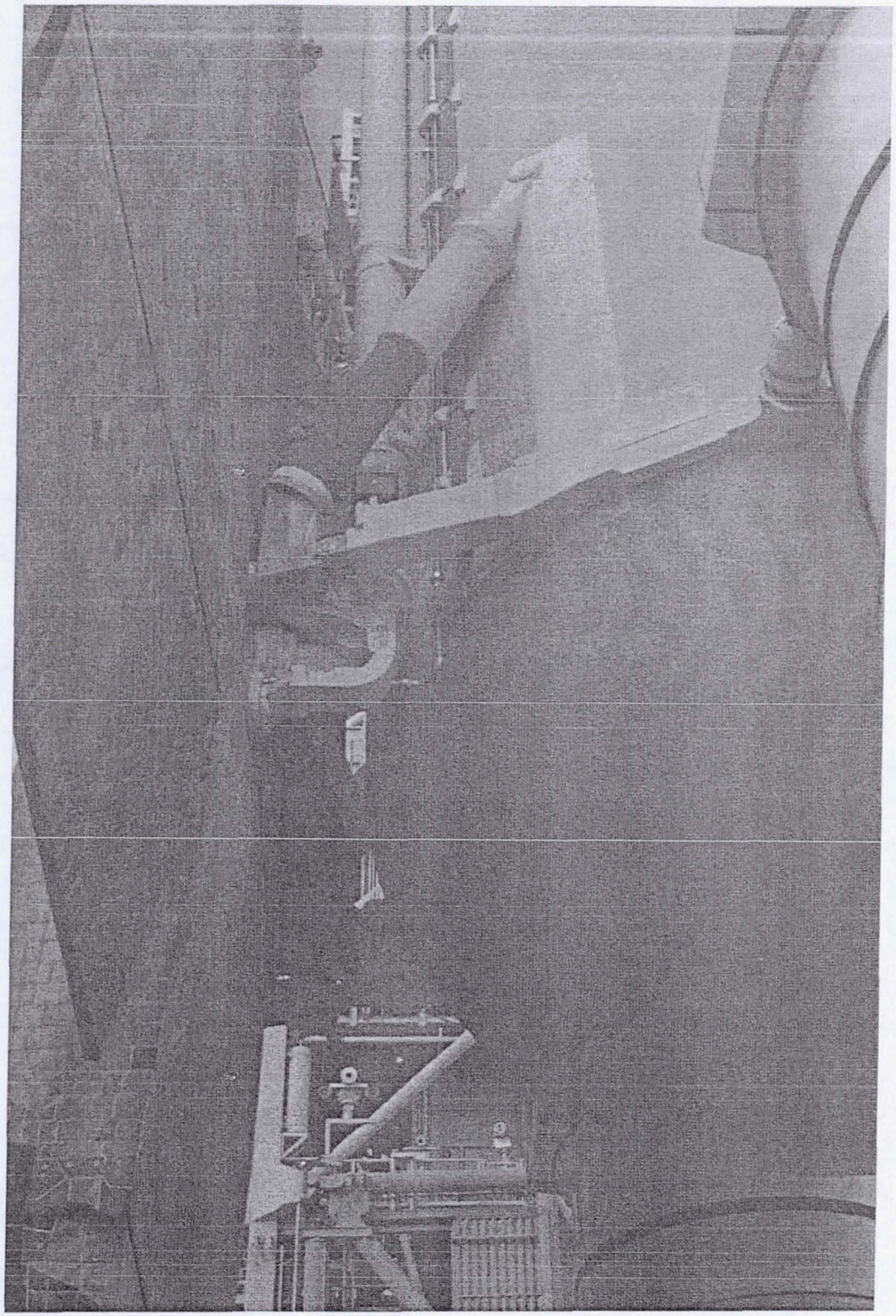


Photo 3: LH2 tank acreage.

Light to moderate condensate was present on the LH2 tank acreage. Surface temperature ranged 65 to 70 degrees Fahrenheit. There were no acreage TPS anomalies.

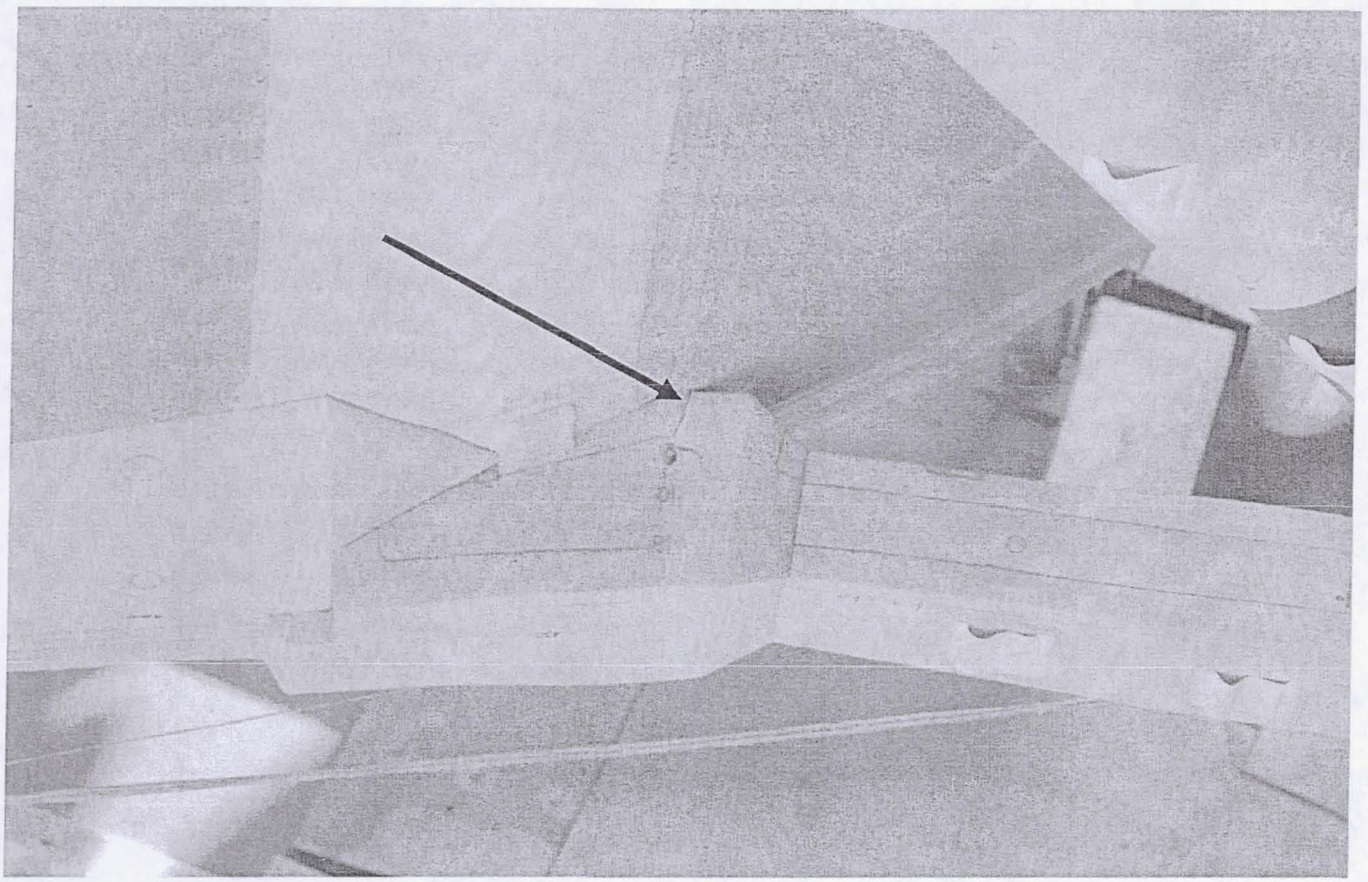


Photo 4: Crack in –Y Vertical Strut TPS

An 7 inch long and 1/4 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.

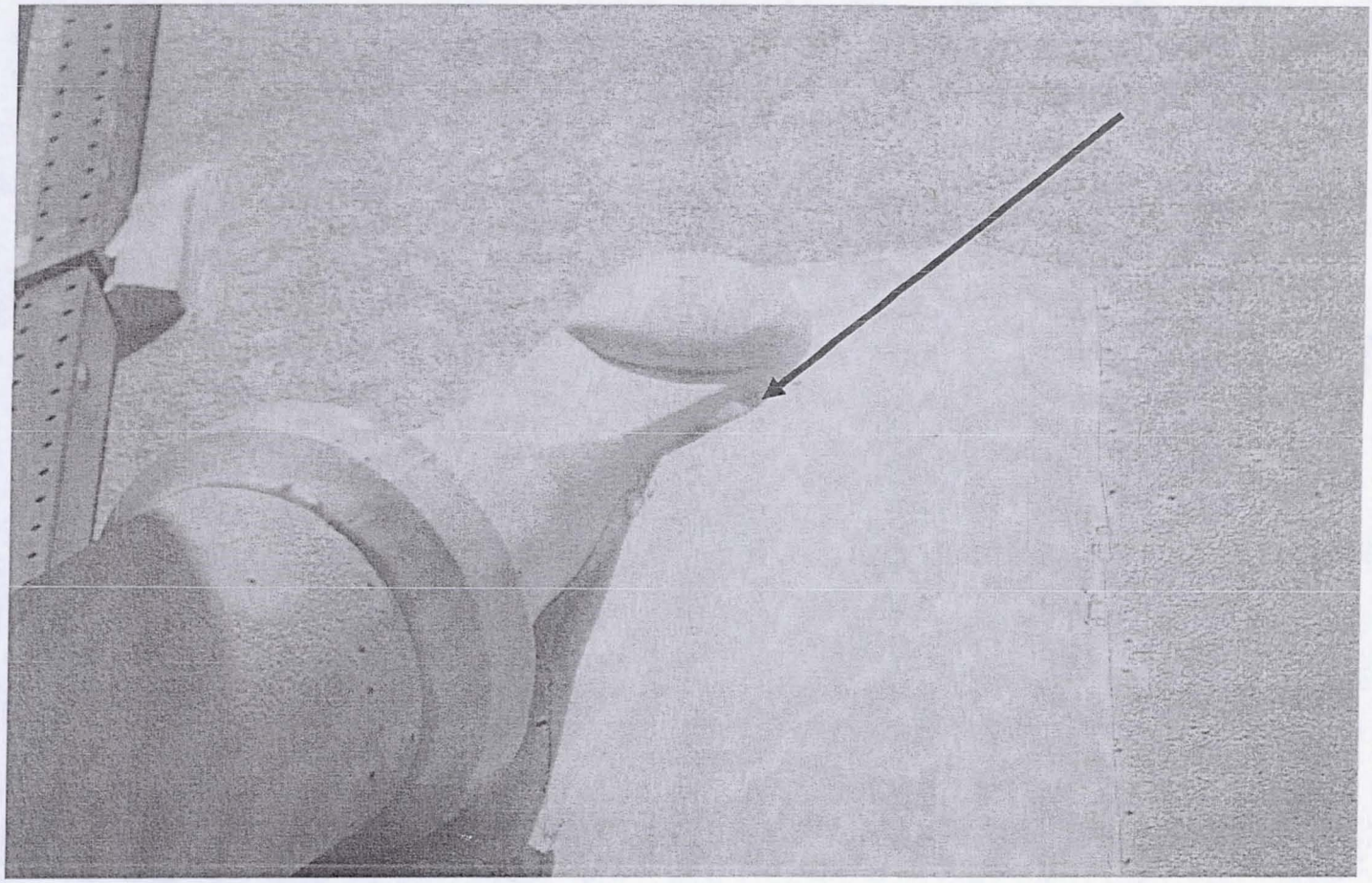


Photo 5: Frost in knuckle of thrust strut to longeron interface.
This is a light frost formation and acceptable per NSTS-08303.

4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP-3, Pad B FSS, north flame trench, and Pad B apron was conducted on 07 October 2002 from Launch + 2 to 4.25 hours (1745 to 2200 EST).

No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach and reported as 0.15g. Inspection was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for both the north and south posts. Epon shim on HDP 1 is cracked with some delamination, no evidence of missing material. North holddown post blast covers and T-0 umbilical exhibited nominal exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact and erect, protective tape layering was partially eroded and exhibited frayed braiding on the RH side.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged with both bonnets observed to have closed properly. The MLP deck was generally in good shape.

The GH2 vent line latched on the fifth tooth on the latching mechanism. The vent line was located in a 'centered' position in the latching mechanism. The GUCP 7-inch quick disconnect probe was accessible for inspection and appeared to be undamaged with sealing surface in good shape. The deceleration cable was in nominal configuration, and the vent line blanket was sooted.

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, ducts and structure appeared to be in nominal condition. The GOX vent seals were inspected and found to be in good shape with no indication of ET paint residue present. Mastic was chipped/missing from two locations on the upper surface of the GOX vent hood.

Debris findings included:

- FSS 115' an "Evacuation Route" sign was found laying on the OWP (Orbiter Weather Protection) structure, it was determined that the sign was from the 135' level.
- FSS 95' "Evacuation Route" was loose and wrapped around banister.
- South Flame trench Apron, SRB Plug material was found.
- North Flame trench Deflector, Significant erosion from left and right boosters; fence is damaged with debris at base.
- Bolts were found loose in the attach points for the Sound Suppression Pipes (SW corner).

Overall damage to the pad appeared to be normal.

5.0 FILM REVIEW

The most significant event observed in the film review was as follows: at 19:46:24.610 UTC (approx. T+33 seconds) a particle was observed traveling along side the ET LH2 tank and impacts the forward face of LH SRB IEA generating a shower of particles aft of IEA. No impact with the orbiter was observed. (E-212, E-220, E-222)

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 69 films and videos, which included 16mm films, 35mm films, and Operational Television Video (OTV) camera videos, were reviewed starting on launch day.

A stud hang-up occurred on HDP #3. The stud was held fully extended until the aft skirt foot was clear. Then the stud twanged briefly before falling into the holddown post. (E-10)

Free burning hydrogen blown past vertical stabilizer. (E-52, E-63, E-77)

GUCP separation and retraction appeared normal (E-33).

Ice particles from the GH2 disconnect fell at T-0. (E-33, E-34)

Umbilical purge barrier baggie material fell during ascent. (E-52, E-207, E-222)

SRB separation appeared normal. (E-207, E-212, E-222)

Particles of SRB aft-skirt instafoam fell along side the SRB plume during ascent. (E-212, E-220, E-223)

OMS-assist firing was visible shortly after SRB separation. (E-207)

Localized flow condensation at various points on the vehicle appeared very pronounced during ascent. (E-212, E-222)

SSME Mach diamond formation sequence was 3-2-1. (E-76)

Body flap movement during ascent was typical. (E-207, E-212, E-220)

Ice particles fell from ET/ORB umbilicals after lift-off. No impact to orbiter lower surface was noted. (E-31, E-52, E-63)

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

Forward RCS paper covers were observed falling aft during early ascent. (E-52, E-222)

Numerous pieces of facility debris entered field of view after vehicle cleared tower. (E-31, E-36).

Debris ejected from SRB exhaust hole at T-0. (E-52, E-63)

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 22 October 2002.

ANOMALIES

A large portion of the –Y bipod ramp is missing. The bipod spindle housing is exposed. The missing foam is most likely the item seen (E-222) striking the LH ETA ring during ascent.

Observations:

SRB separation from the External Tank appeared nominal.

ET separation from the Orbiter was normal.

Small "popcorn" divots were observed on the –Y thrust panel aft of the ET/SRB attach point in the non-vented area.

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.

One TPS divot was observed on the intertank-to-LH2 tank flange closeout near the -Y jack-pad closeout. The divot is approximately 3-inches in diameter and has exposed substrate.

Two shallow divots were noted at the intertank-to-LH2 tank flange closeout. One, approximately 6-inches long and 2-inches wide, was located in between the jack-pad closeouts. The other, approximately 2.5-inches long by 1.5-inches wide, was just forward of the +Y jack pad closeout.

One shallow TPS divot was observed on the LH2 tank near the ice/frost ramp at station Xt-1857. The area is shallow and approximately 5-inches long by 3-inches wide.

No anomalies were detected in the LO2 tank acreage. The BSM scars were typical. The Ogive exhibited no foam loss.

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.

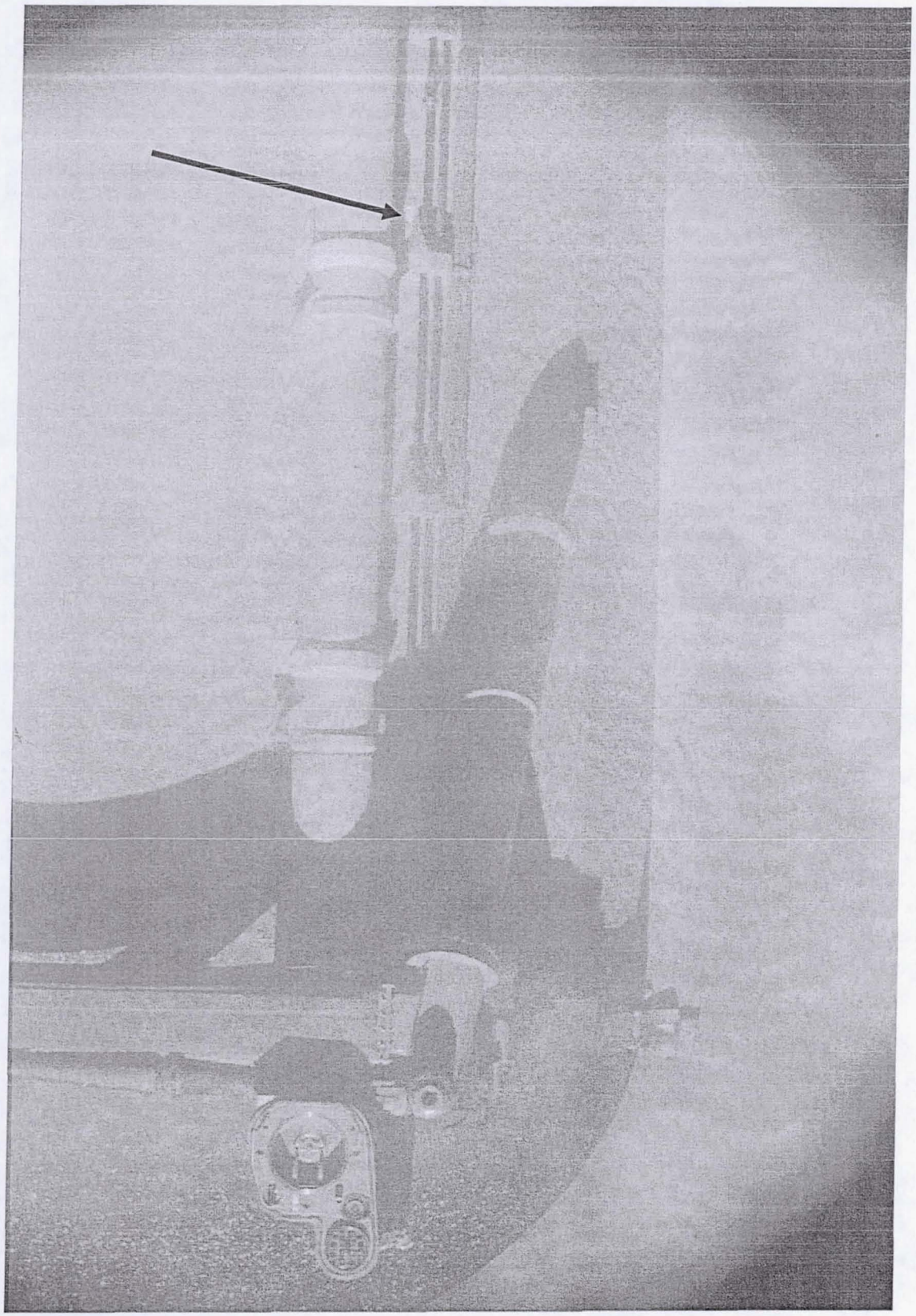


Photo 6: External Tank post separation
One shallow TPS divot was observed on the LH2 tank near the ice/frost ramp at station Xt-1857. The area is shallow and approximately 5-inches long by 3-inches wide.

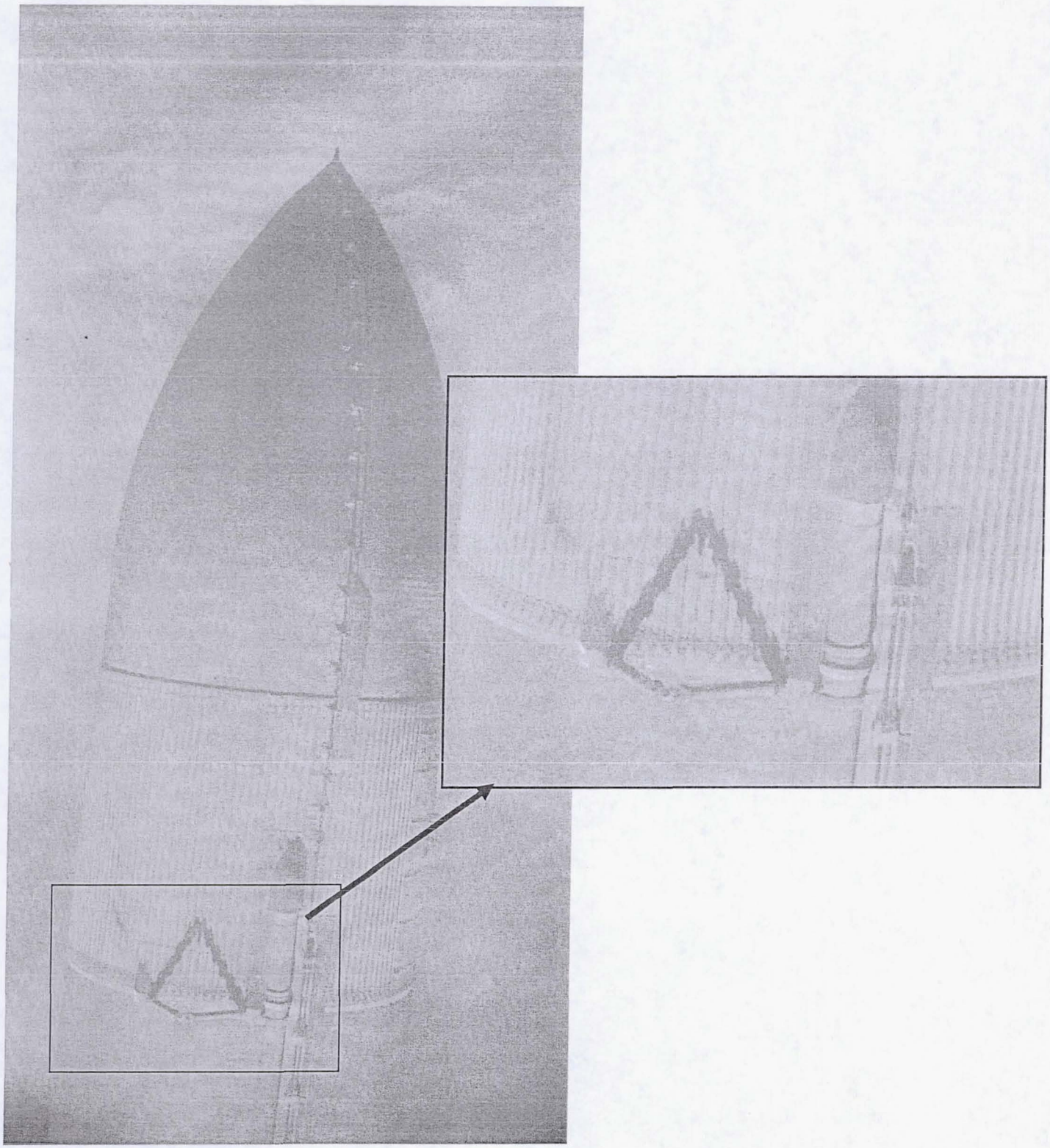


Photo 7: External Tank post separation
View shows portion of –Y bipod ramp missing and three small divots in LH2-to-intertank flange closeout

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-115 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 10 October 2002. Both boosters were in excellent condition.

There was evidence of a debris impact on the ETA ring of the LH SRB near the IEA box. This location coincides with the event seen, and reported, in the high-speed tracking films. The impact site is approximately 4 inches in diameter and 3 inches in depth.

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 one LH cover attach ring had been bent at the hinge by parachute riser entanglement.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact. All primary frustum severance ring pins and retainer clips were intact.

The Field Joint Protection System (FJPS) and the System Tunnel Covers closeouts were generally 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 insulation close-outs and GEI cork runs.

In support of troubleshooting for the System A HDP Fire 1 Command Circuit Failure, all eight of the holddown post Debris Containment Systems (DCS) had already been removed. The report from the investigation team is that the DCS appeared to have functioned normally on all HDP's. All eight of the HDP had one un-fired NSI detonator cartridge.

As expected, broaching occurred in the holddown stud bore of post #3 consistent with stud hang-up seen in the post launch film review. Minor thread marks from the holddown studs could be seen on all of the remaining stud bores.

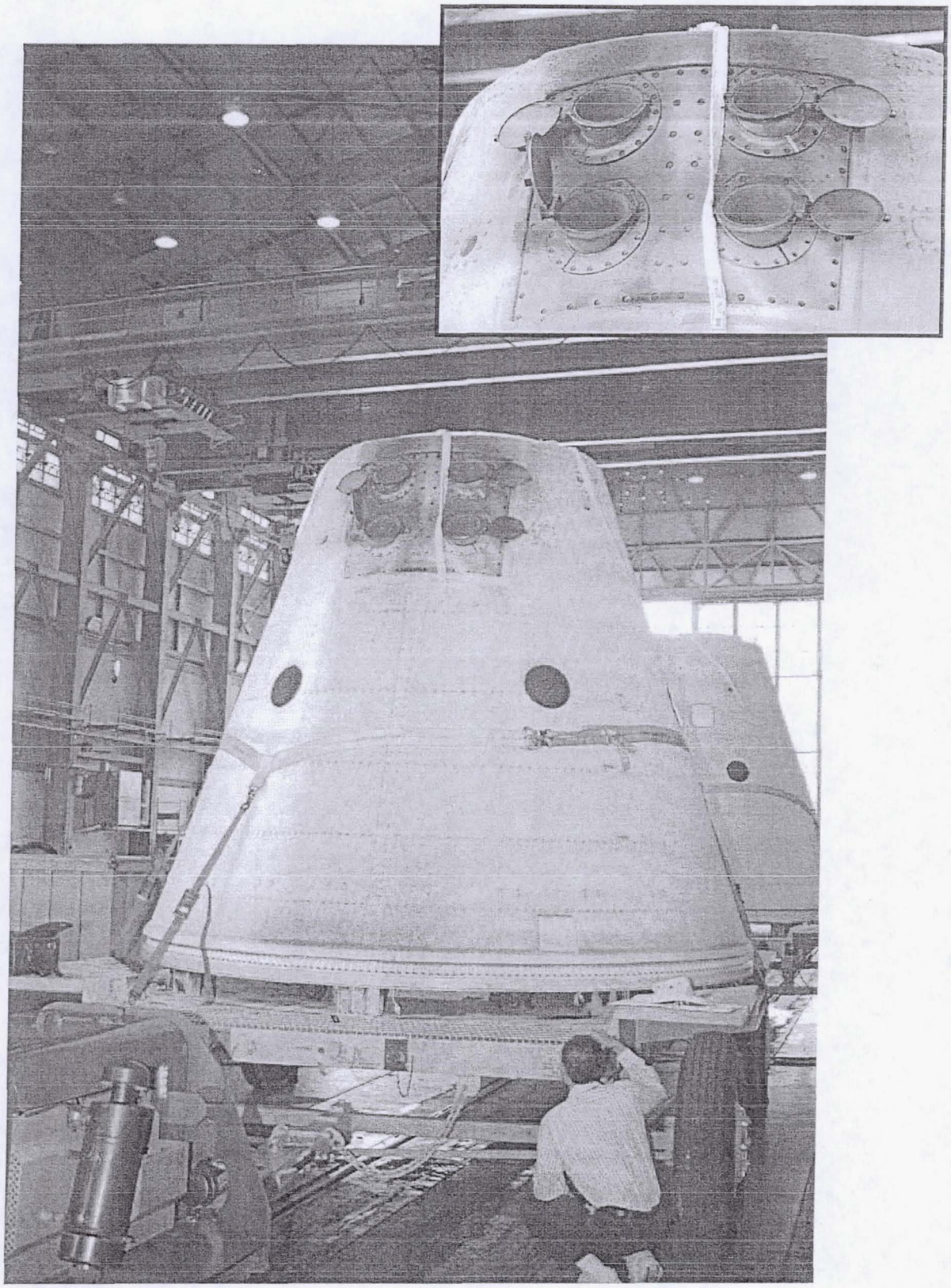


Photo 8: LH Frustum Post Flight Condition

The LH frustum exhibited no debonds/unbonds or missing TPS.
All four BSM aero heat shield covers had fully opened and locked, but one cover attach ring had been bent at the hinge by parachute riser entanglement.

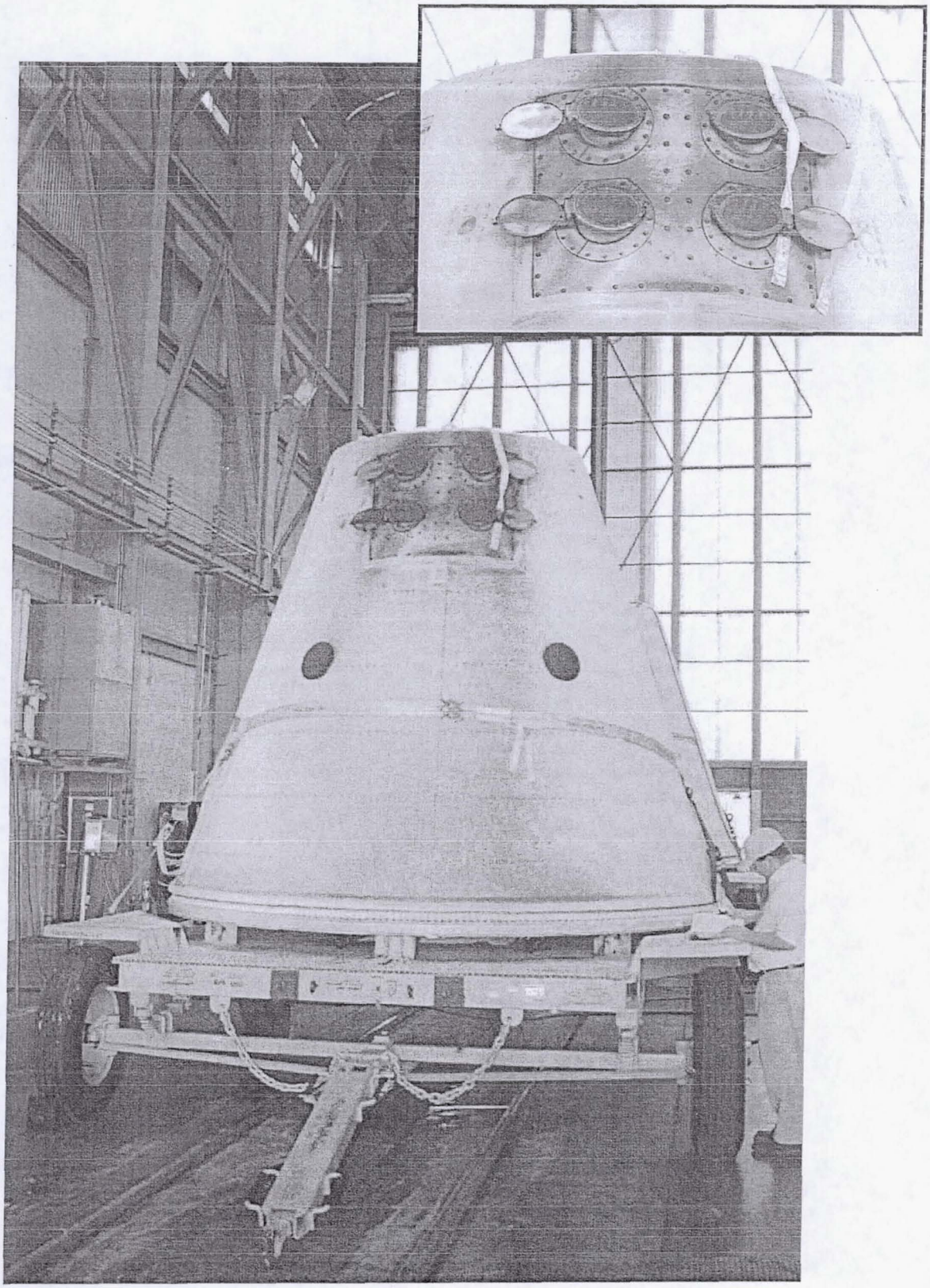


Photo 9: RH Frustum Post Flight Condition

The RH frustum exhibited no debonds/unbonds or missing TPS.
All four BSM aero heat shield covers had fully opened and locked.

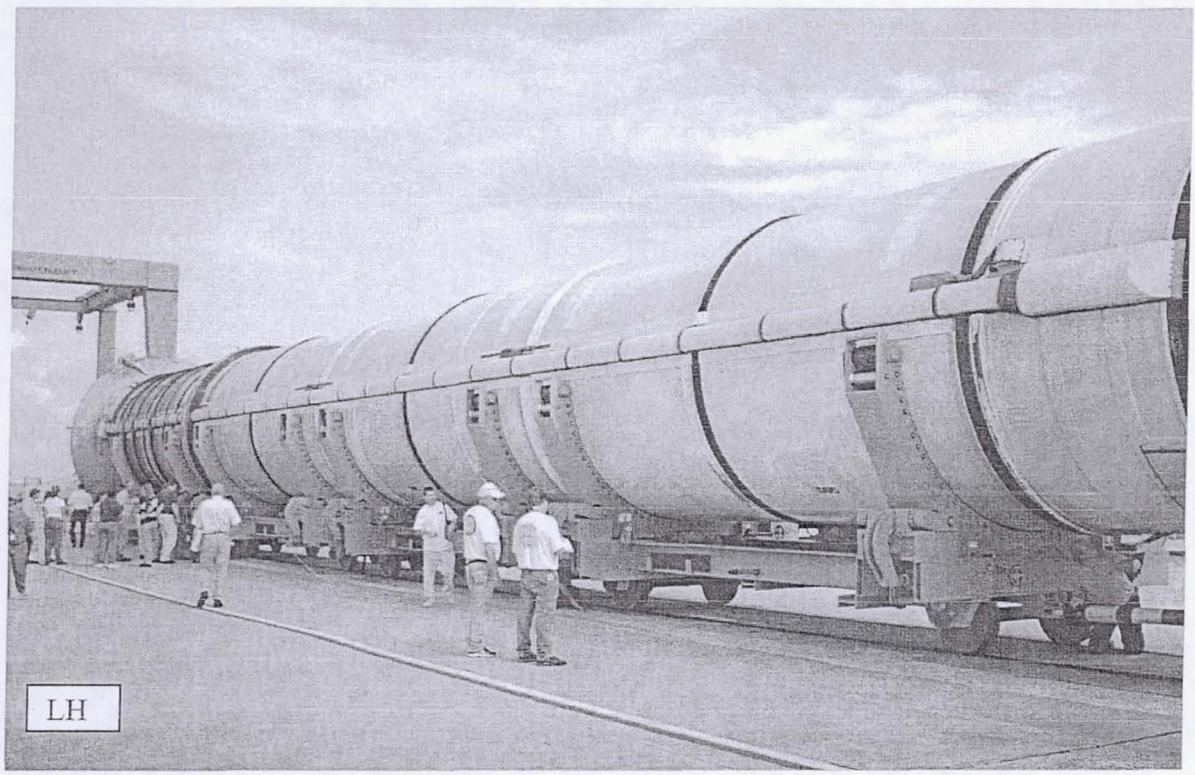


Photo 10: SRB Post Flight Condition

Both SRBs were found in good condition regarding debris assessment

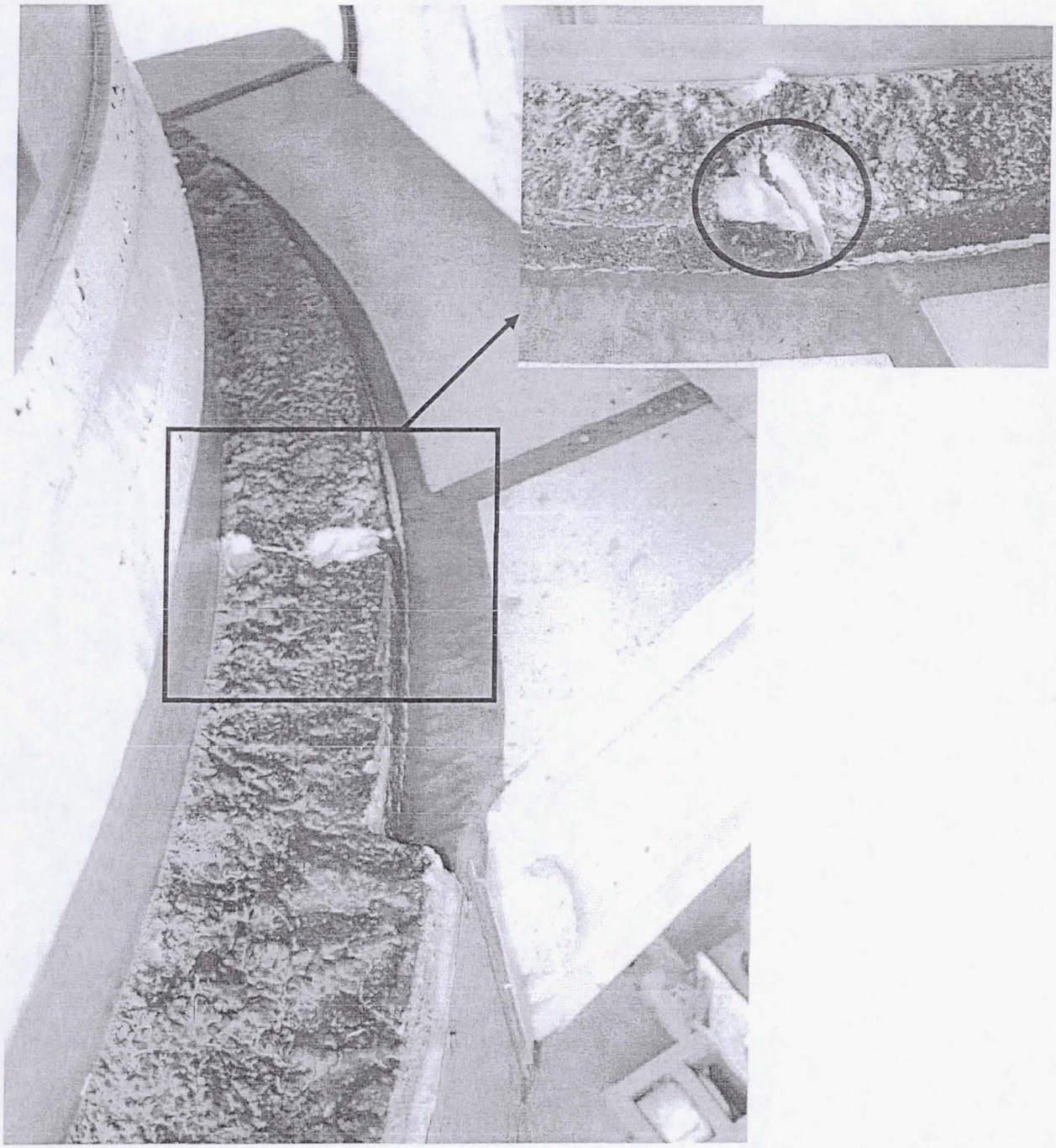


Photo 11: LH SRB Post Flight Condition

Evidence of a debris impact on the ETA ring of the near the IEA box. The impact site is approximately 4 inches in diameter and 3 inches in depth.

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 11:44 am local/eastern time landing on 18 October 2002, a post landing inspection of OV-104 Atlantis was conducted at the Kennedy Space Center on SLF runway 33 and in Orbiter Processing Facility bay 1. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 107 hits of which 25 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-112 Orbiter damage hits by area:

	HITS > 1-inch	TOTAL HITS
Lower Surface	22	81
Upper Surface	0	0
Window Area	3	22
Right Side	0	1
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	0	3
TOTALS	25	107

The Orbiter lower surface sustained 81 total hits, of which 22 had a major dimension of 1-inch or larger, both numbers are well within family. The majority of the hits were in the area from the nose landing gear to the main landing gear wheel wells. This area sustained 46 hits with 15 greater than 1-inch. Most of the hits in this area are shallow, indicative of damage from External Tank foam.

The largest lower surface tile damage site, located just right of centerline in between main landing gear wheel wells, measured 4-1/2 inches long by 1/2-inches wide by 1/4-inches deep. The cause of this damage was most likely ice/frost from the ET LO2 feedline bellows or support brackets.

There was an Ames Gap Filler material protruding from in between two tiles just forward of the RH MLG door.

The landing gear tires were in good condition.

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. The EO-2/3 pyro debris shutters were fully closed. No other 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.

There were a total of 22 hits, with 3 having one dimension greater than 1-inch, on the window perimeter tiles. Hazing and streaking of forward-facing Orbiter windows appears to be lighter than normal.

The post-landing walkdown of Runway 33 was performed immediately after landing. All components of the drag chute were recovered and appeared to have functioned normally.

In summary, the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were within established family. However, the number of hits between the nose landing gear and main landing gear wheel wells is slightly higher than normal.

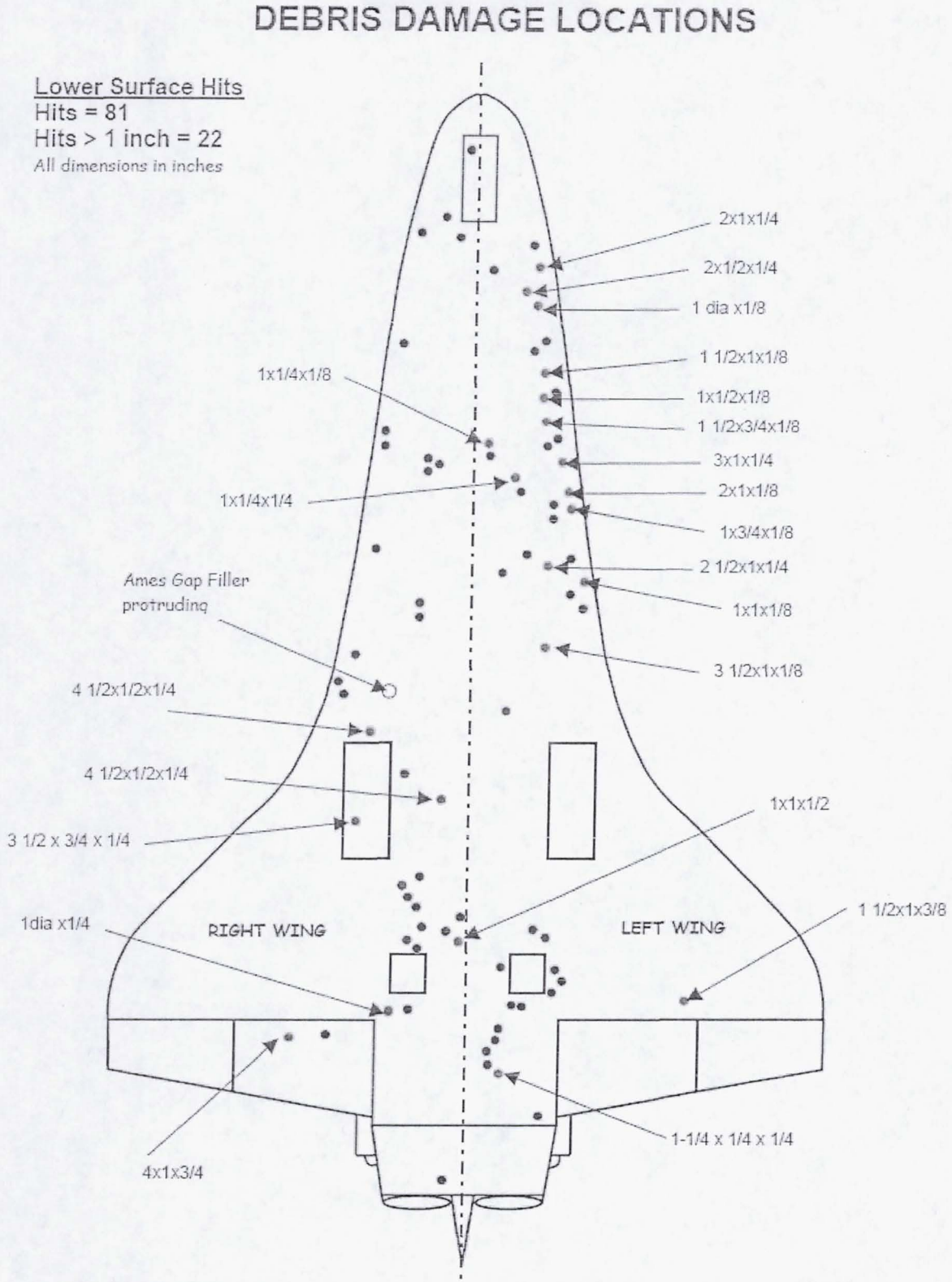


Figure 1: Orbiter Lower Surface Debris Damage Map

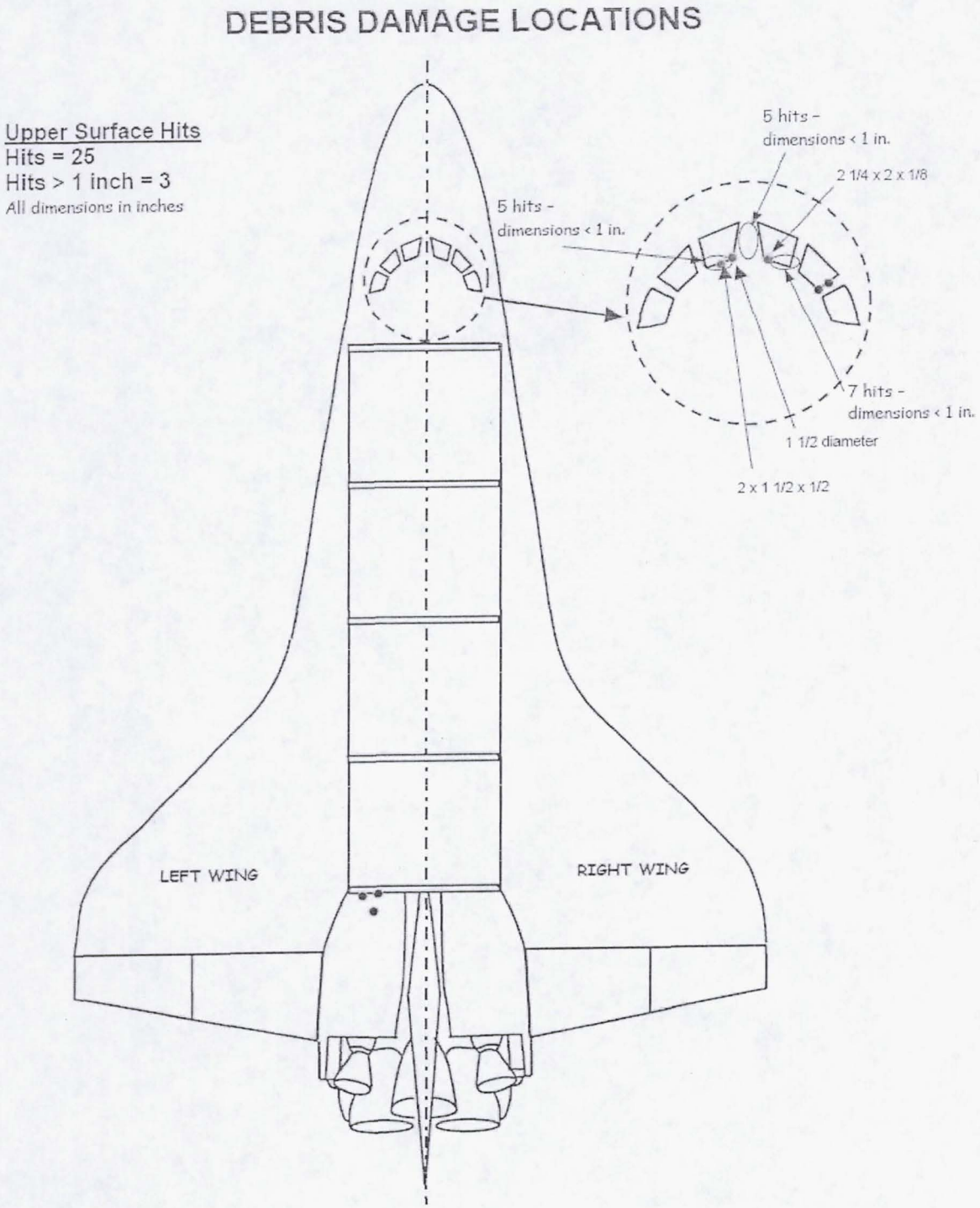


Figure 2: Orbiter Upper Surface Debris Damage Map

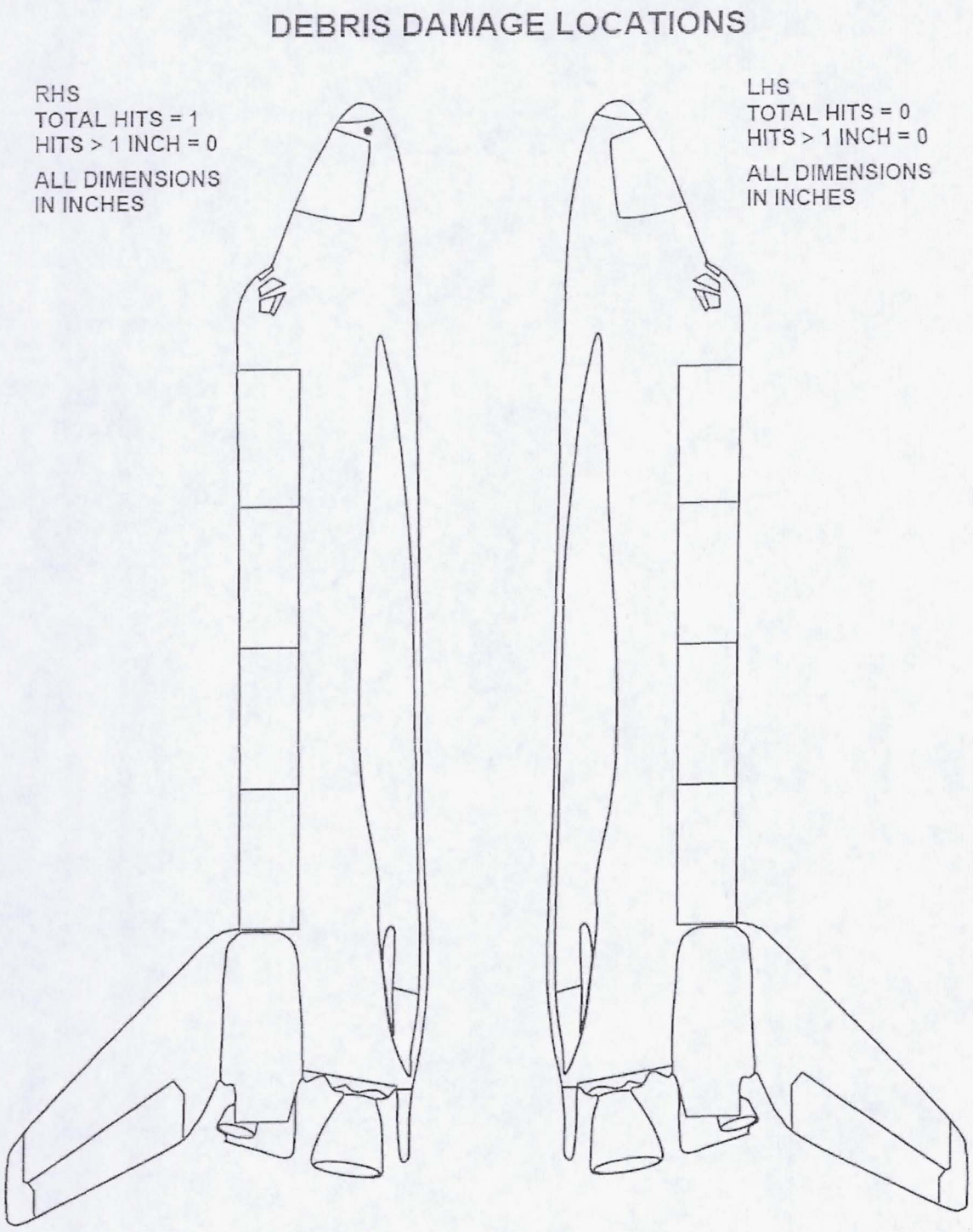
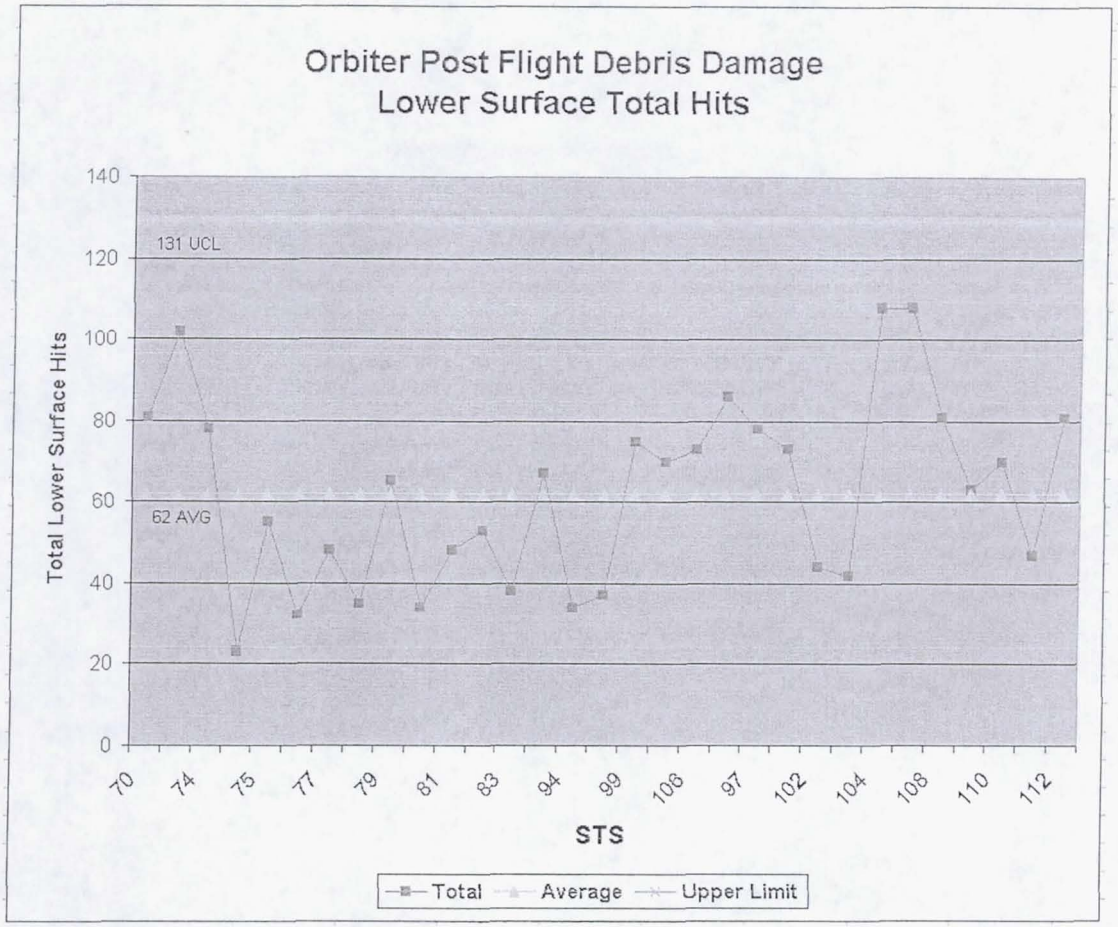


Figure 3: Overall View of Orbiter Sides

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
STS-104	24	108	26	126
STS-105	15	108	25	144
STS-108	17	81	22	95
STS-109	14	63	18	98
STS-110	18	70	22	110
STS-111	21	47	46	76
AVERAGE	12.5	65.3	17.9	103.5
SIGMA	6.0	30.6	8.0	26.6
STS-112	22	81	25	107

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



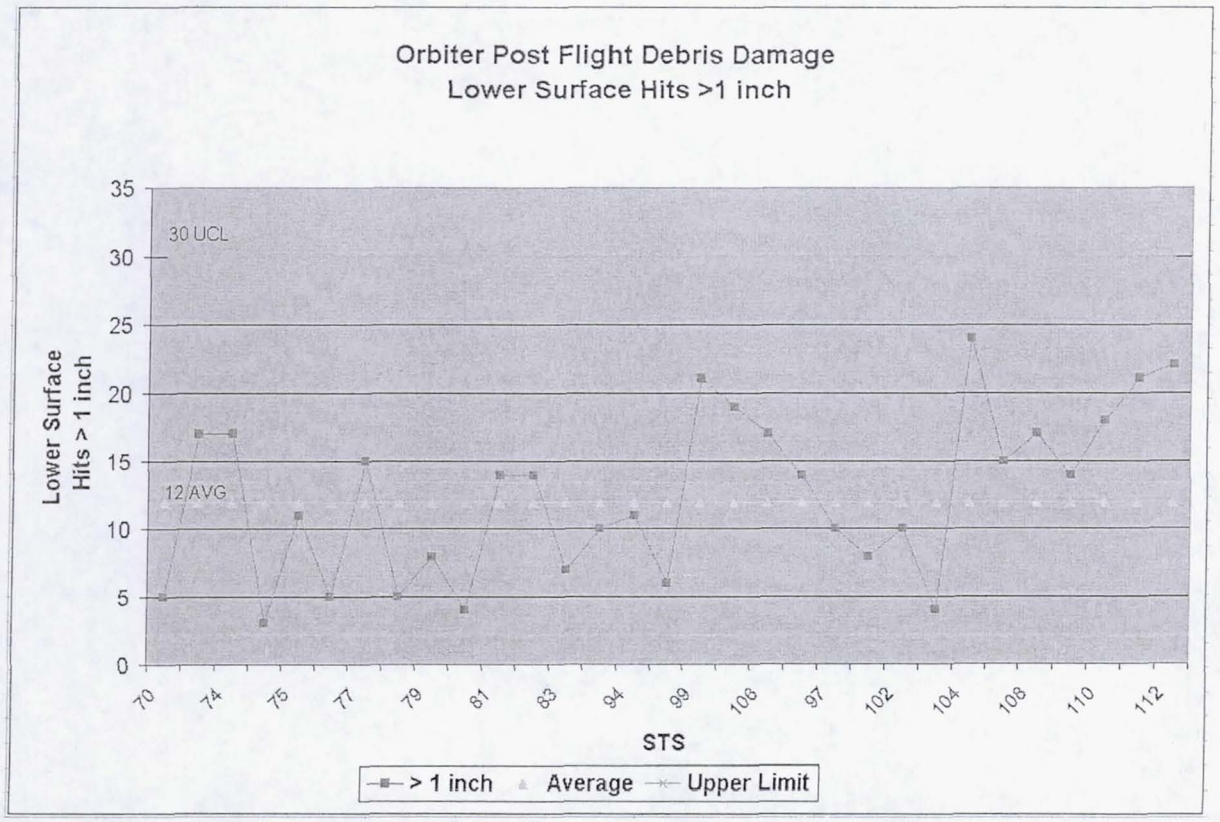
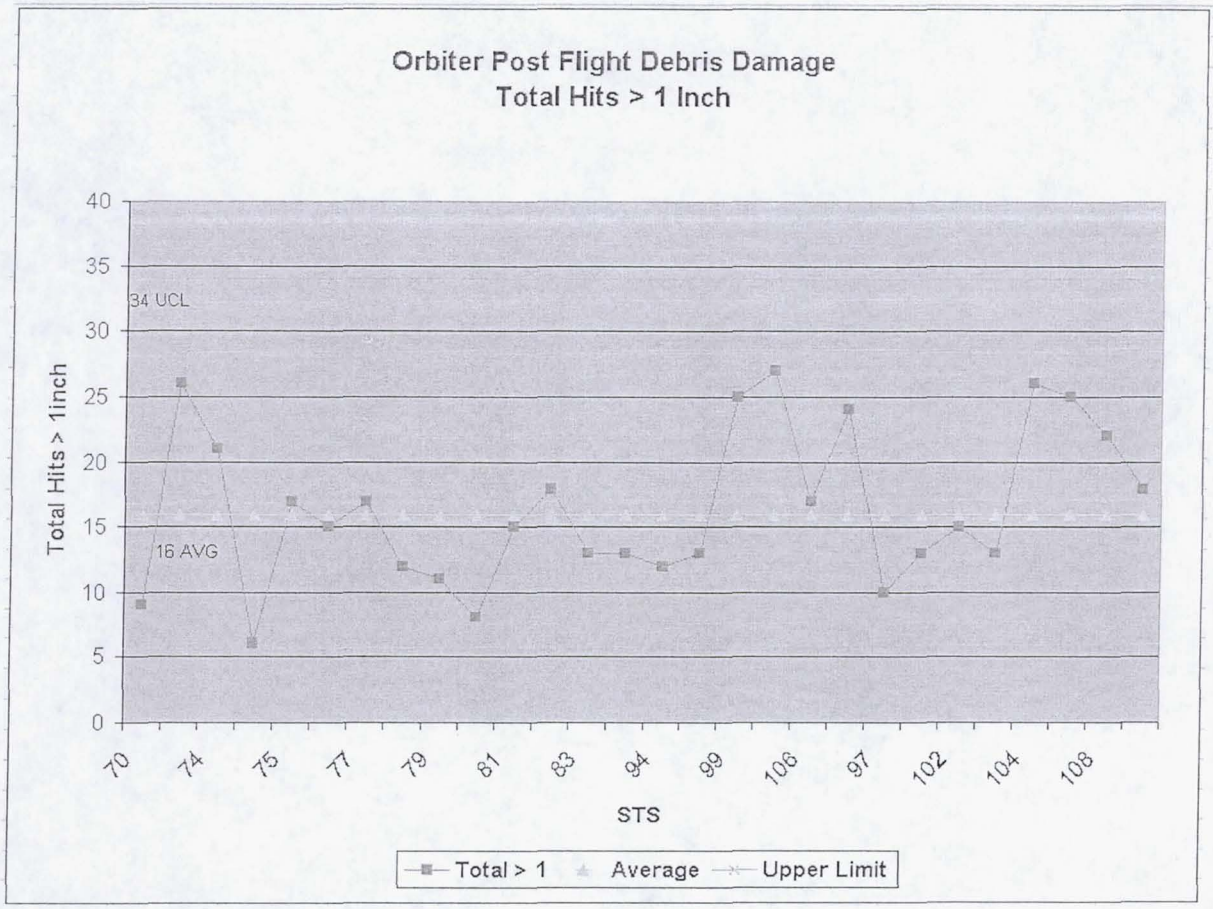


Figure 5: Control Limits for Lower Surface Hits



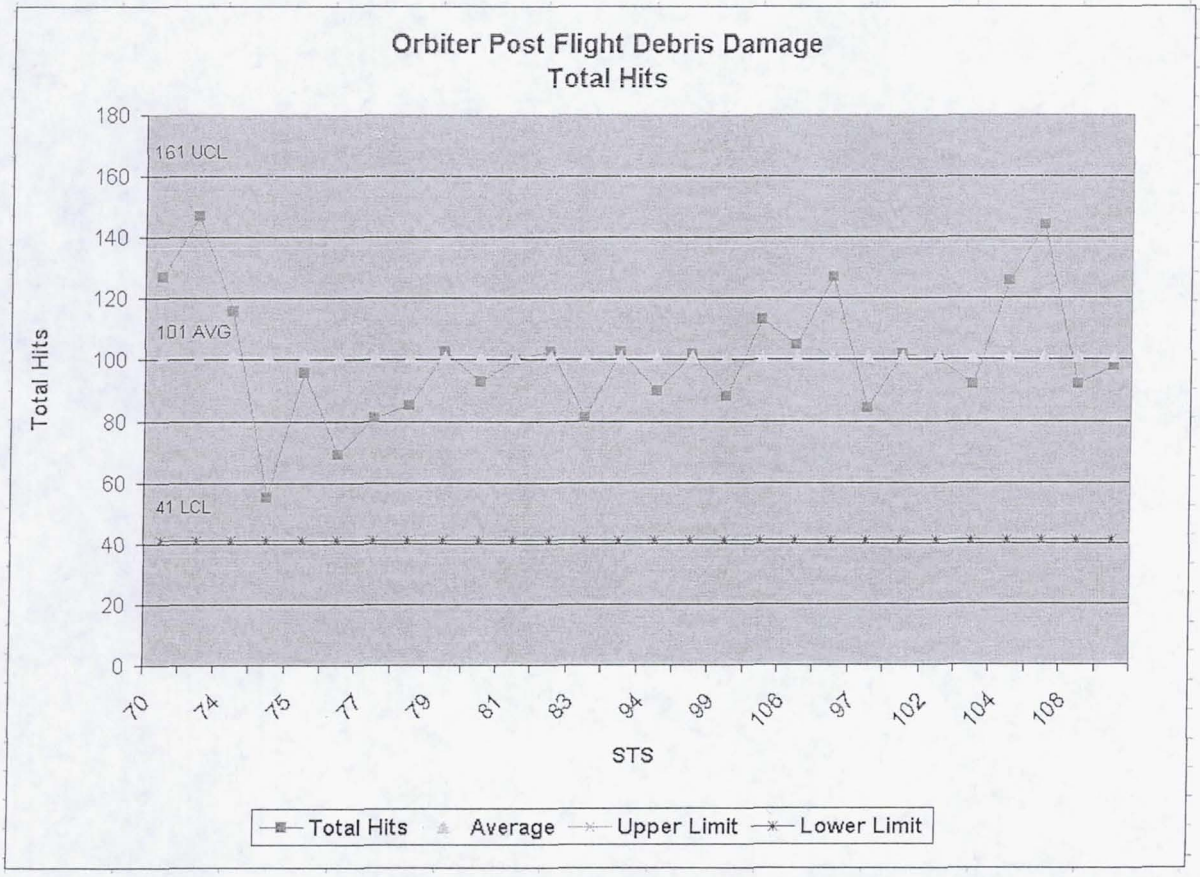


Figure 6: Control Limits for Total Hits

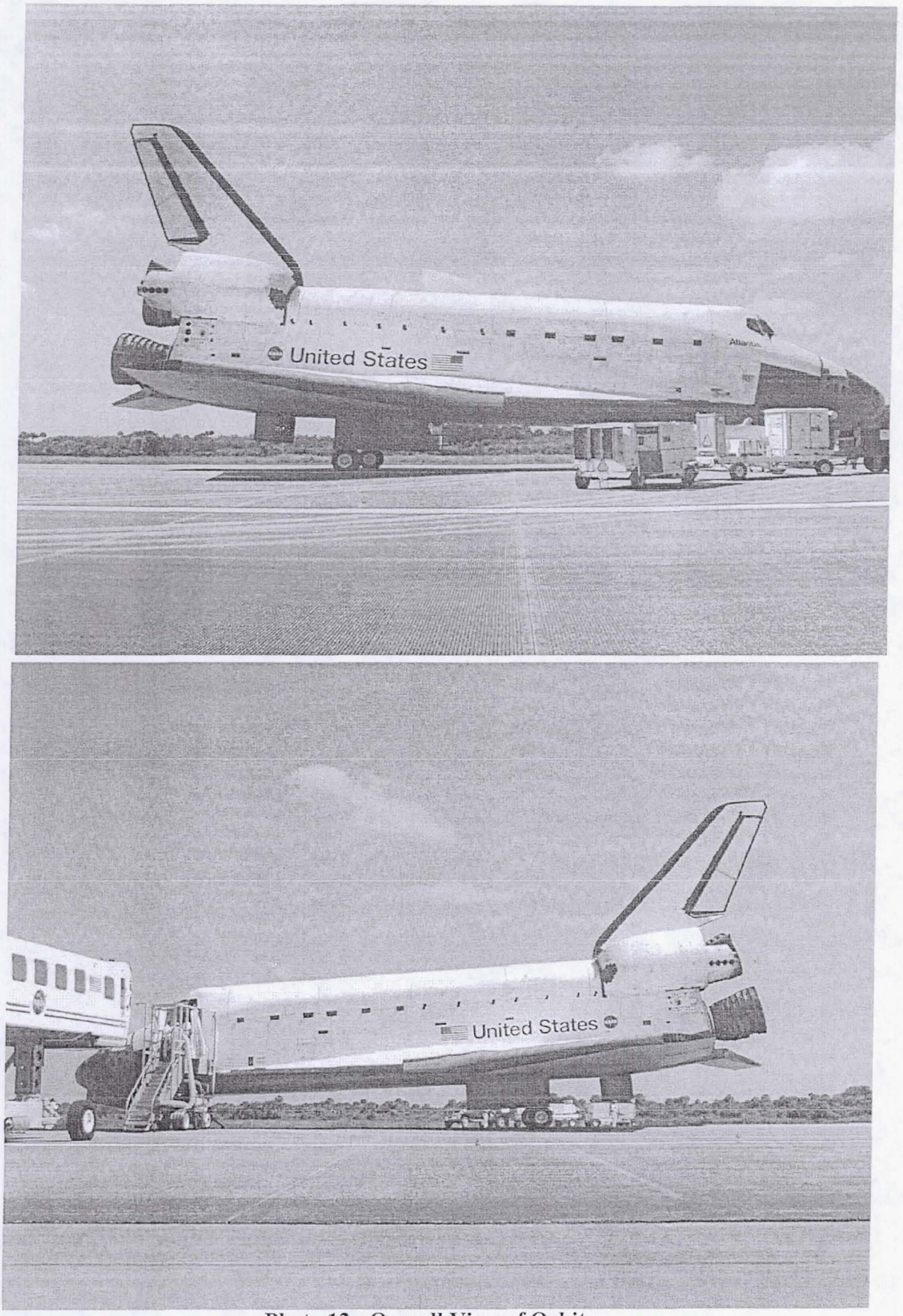


Photo 12: Overall View of Orbiter

The Orbiter TPS sustained a total of 107 hits, of which 25 had a major dimension of 1-inch or larger. Both the total number of Orbiter TPS debris hits and the number of hits 1-inch or larger were within established family.

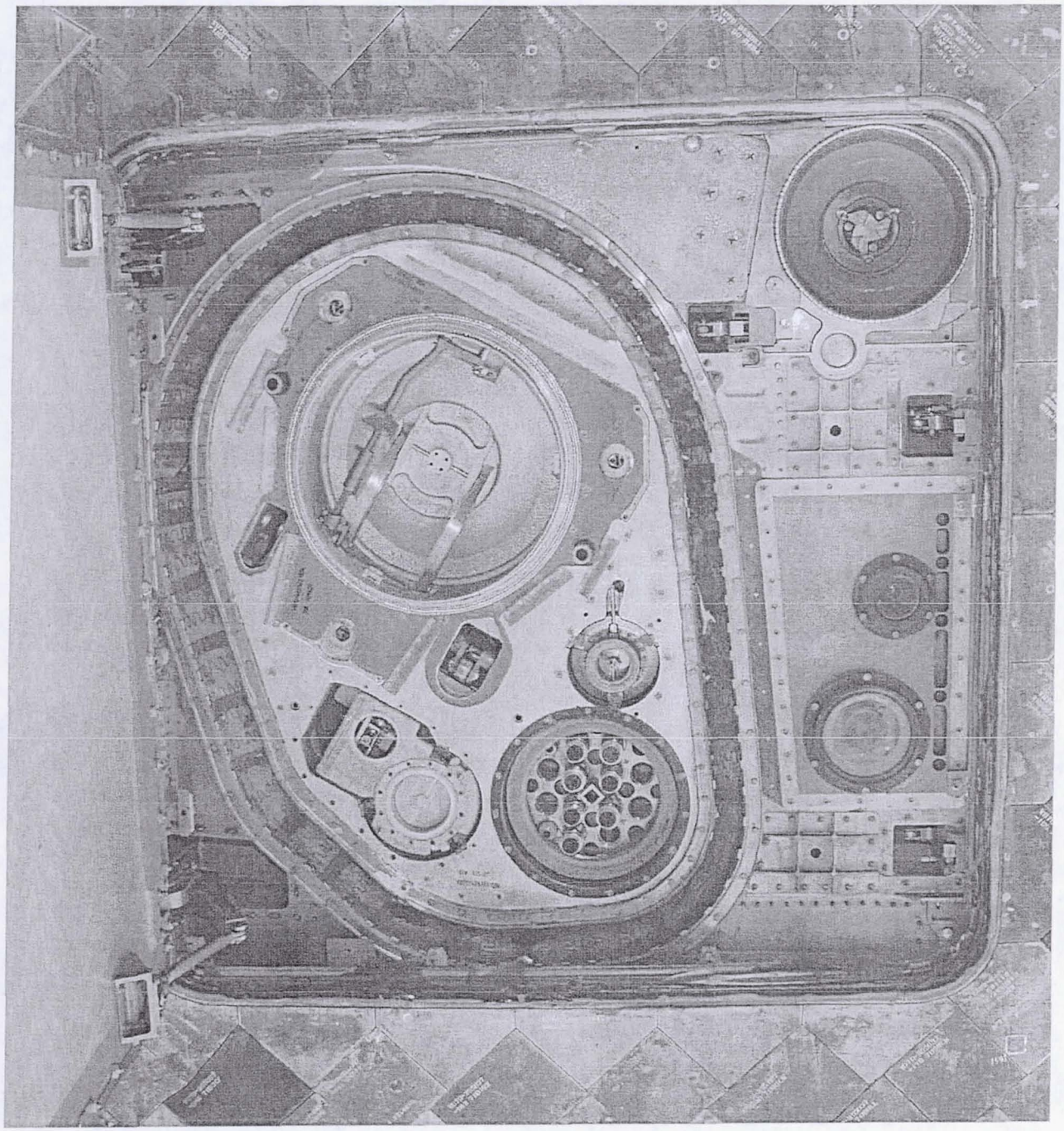


Photo 13: ORB/ET LH2 Umbilical

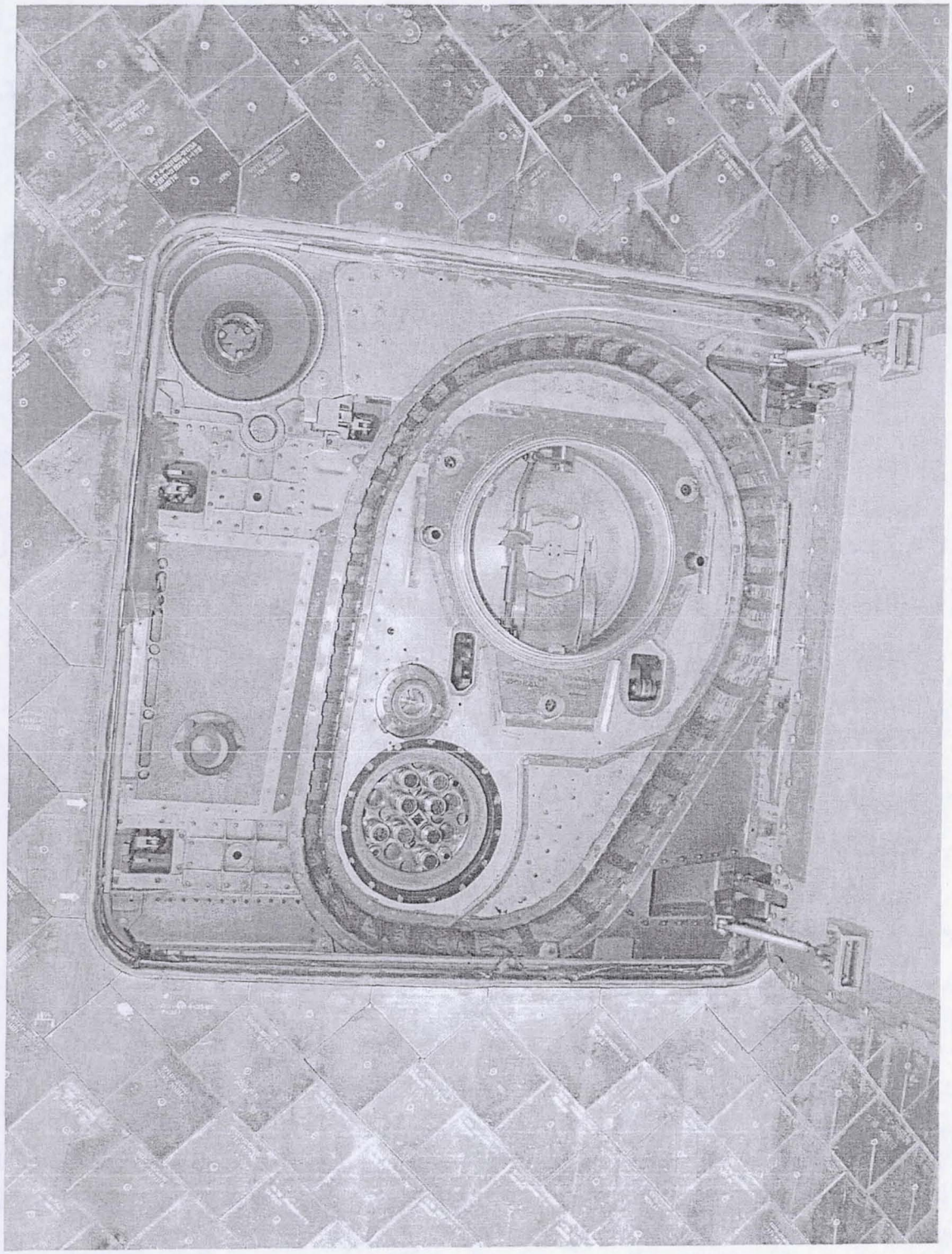


Photo 14: ORB/ET LO2 Umbilical

8.0 DEBRIS SAMPLE LAB REPORTS

Laboratory samples were obtained from the Orbiter vehicle during post landing operations for mission STS-112. These samples consisted of Orbiter window wipes, windows one through eight, isopropyl alcohol solvent wipe and a dry wipe per window. The samples were analyzed by the KSC Materials Science Laboratory for material identification and comparison to known material sources. Results of this analysis provided indications of landing site materials, paint, metal and metal corrosion products, organic materials, and Orbiter Thermal Protection System (TPS) materials. No unusual findings resulted from this analysis and no adverse trends were noted.

9.0 POST-LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, the only post-launch anomaly observed on the STS-112 mission was the event observed in the film review at 19:46:24.610 UTC (approx. T+33 seconds). The particle, which was most likely the large portion of the –Y bipod ramp observed missing on the ET imagery, was observed traveling along side the ET LH2 tank and impacts the forward face of LH SRB IEA generating a shower of particles aft of IEA. No impact with the orbiter was observed. (E-212, E-220, E-222) This event was reported by the Inter-center Photo Working Group chairman to the PRCB.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Table of Contents

Tables and Figures

1 STS-112 (OV-104): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-112 launch of Atlantis (OV-104) from Pad B occurred on October 7, 2002 at 280:19:45:51.026 UTC as seen on the RSRB holddown post M-2 camera E8. SRB separation occurred at approximately 280:19:47:52.674 UTC as seen on camera E207.

On launch day, 24 videos were received and screened. This includes the new External Tank downlink video. Camera KTV-2 was not received. Timing data was not received (or was intermittent) on the ET207, ET212, and ET213 long range tracking camera video views.

Twenty-four launch films were screened and a report was sent to the Shuttle Program distribution on June 8, 2002. This includes film E39 that was provided in support of the STS-108 hydrogen vent umbilical anomaly (SR-1652). Twenty-two additional films were received for contingency support and anomaly resolution.

Two anomaly candidates were seen during the review of the STS-112 launch films that was elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Reports. See section 2.1. (This report consolidates 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). No anomalous events were seen on the on-board films that view the (left) Solid Rocket Booster and the External Tank.

Two 16mm umbilical well cameras and the 35mm umbilical well TPS camera flew on STS-112 (the new 35mm umbilical well camera was used for the second time on STS-112). See section 2.5. Crew handheld still photography of the External Tank was also acquired but was unusable due to the poor lighting conditions. The crew handheld video of the External Tank was not acquired.

Prior to launch, at the request of USA HQ, closeout imagery of a mechanical linkage on the STS-112 Atlantis remote manipulator arm was reviewed for possible misalignment. However, alignment measurements to the accuracy required could not be made due to the lack of resolution on the provided closeout imagery.

1.1.2 On-Orbit

Two unplanned on-orbit Shuttle support tasks were requested by the MER. One was the analysis of an unidentified debris object seen near the Orbiter payload bay prior to docking with the ISS. The second task was a review of downlink video of the "near-miss" of the ISS robotic arm with the Shuttle payload bay door. Pre-planned, real-time analysis support was provided to the ISS

AF-9A Space Station photographic and television external survey. The Space Station image analysis support will be documented in the UF-2 Imagery Overview Report.

Video of debris in the vicinity of the payload bay was taken from payload bay camera A during the day 1 sleep period prior to docking (approximately 6 hours after payload bay door opening). See Figure 1.1.2. The video was recorded at 281/06:04 thru 281/06:06 GMT. The debris object was first seen near the vertical stabilizer and traveled in a +Y/+X direction across the view. The debris was a rectangular-shaped object with a very thin edge when viewed from the side. The debris appeared dark in color in all aspects as it tumbled across the view.

The identification of the debris was not determined. KSC reported that there are many objects of similar appearance in the payload bay including rectangular shaped pieces of TPS of all sizes that are secured with Velcro. Some of the TPS "patches" are as small as 2 x 2 inches that are placed over small objects like bolt heads. The length to width ratio of the debris object was measured to be 1.36 to 1. (The length to width ratio of the drag chute door is 1.25 to 1.) The debris was seen to cross in front of the vertical stabilizer as viewed by the camera. Therefore the debris could not have been further away than the camera is from the vertical stabilizer. The size of the object was estimated assuming the worst case. That is, the object was not close to the camera but was as far aft as the vertical stabilizer (a distance of 718 inches). This was the first assumption. The vertical interval data on the video appeared to be incorrect. Therefore a second assumption was made that the horizontal field-of-view was 74.4 degrees (which is the widest field-of-view and was probably used to show a wide expanse of the earth. Using these two assumptions, the size of the debris object was computed to be 9 +/- 2 inches by 12 +/- 2 inches. This is an upper bound on the size. If the object were closer than the plane of the vertical stabilizer, which in all likelihood it was, the object would be smaller. The size of the drag chute door is 22 x 27 inches. Nothing was reported missing during the post landing inspections that was correlated to this debris object.

At the request of the MER, video was reviewed of the "near miss" of the station RMS arm with the Orbiter payload bay door during the first EVA. The one available view was not adequate to allow a measurement to be made of how close the arm came to the payload bay door. See Figure 1.1.2.

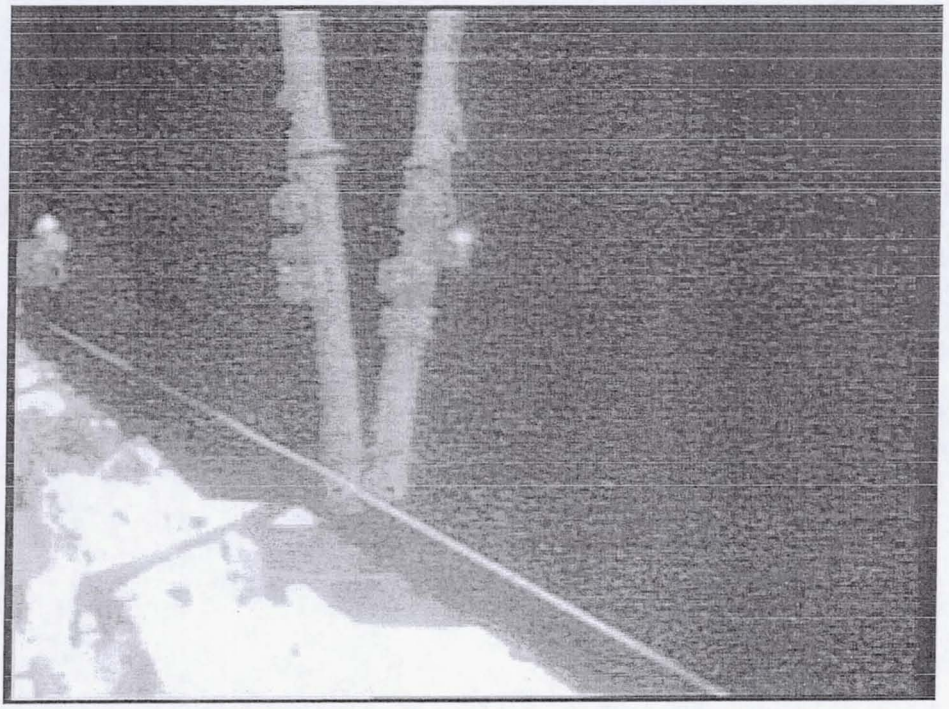


Figure 1.1.2 View of SSRMS in the "near-miss" with the Payload Bay Door

1.1.3 Landing

Endeavour made a day landing on runway 33 at the KSC landing facility on October 18, 2002 (291:15:43:40.160 UTC). Eleven videos and twelve landing films were received.

The approach to landing, touch down, drag chute deploy, and landing roll-out appeared normal on the landing imagery. No damage to the drag chute was detected. The drag chute appeared to deploy straight aft on the landing imagery views.

One anomaly candidate was seen on the post-landing review of the umbilical well film and imagery that was elevated to the KSC, JSC, MSFC Film/Video Analysis Teams Landing +3 Day Intercenter Consolidated Film Review Report. See Section 2.2.

Post landing, a sink rate analysis of the STS-112 main landing gear was performed for the main gear touchdown. See Section 2.6.

2 Summary of Significant Events

2.1 KSC, JSC, MSFC Film/Video Analysis Teams Launch + 4 Day Intercenter Consolidated Film Review Report

Two anomaly candidates were noted during the review of the STS-112 launch films and videos that were elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Team Consolidated Film Review Report.

CFVR-112-01:

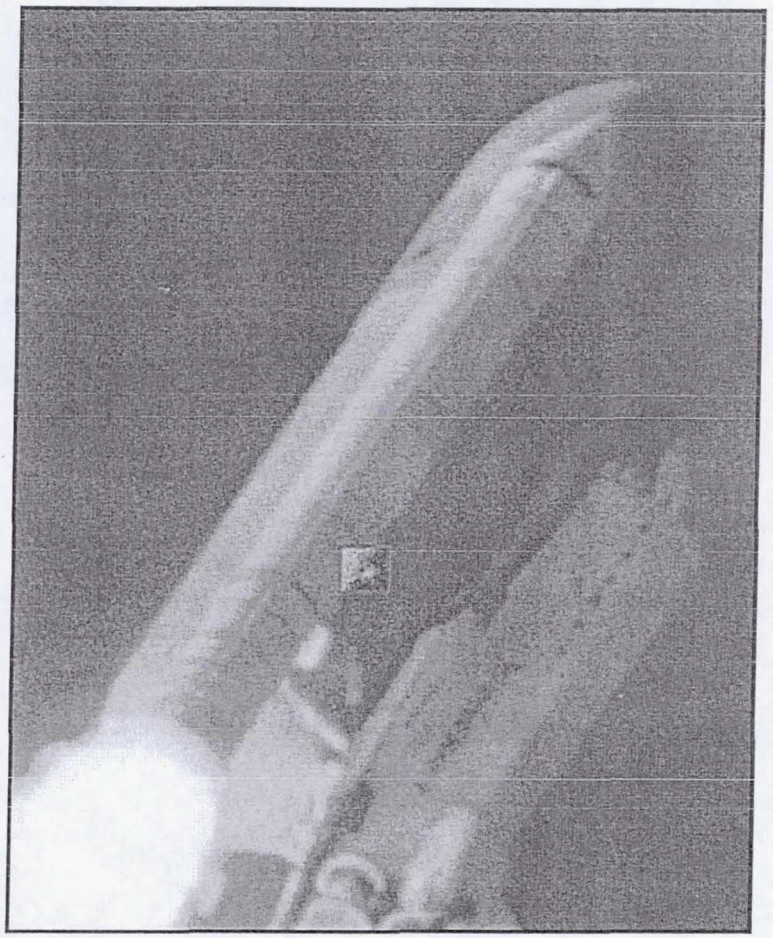


Figure 2.1 (A) Debris Seen Prior to IEA Box Impact (Camera E222)

A single piece of light-colored debris was seen to impact the ETA ring near the IEA box on the LSRB at approximately 33 seconds MET (19:46:24.690 UTC). After impact the debris broke into multiple pieces and fell aft along the LSRB exhaust plume. On Camera E207, a large spray of debris was seen falling aft along the LSRB aft skirt that was probably from this event (19:46:24.727 UTC). The debris was first visible aft of the ET intertank near the ET hydrogen tank TPS (19:46:24.590 UTC), one tenth of a second prior to the debris impact with the ETA ring. The source of this debris may be the missing TPS seen on the ER ramp near the –Y foot of the ET/Orbiter forward bipod attach. See Section 2.4.1. (Cameras E212, E220, E222)

CFVR-112-02:

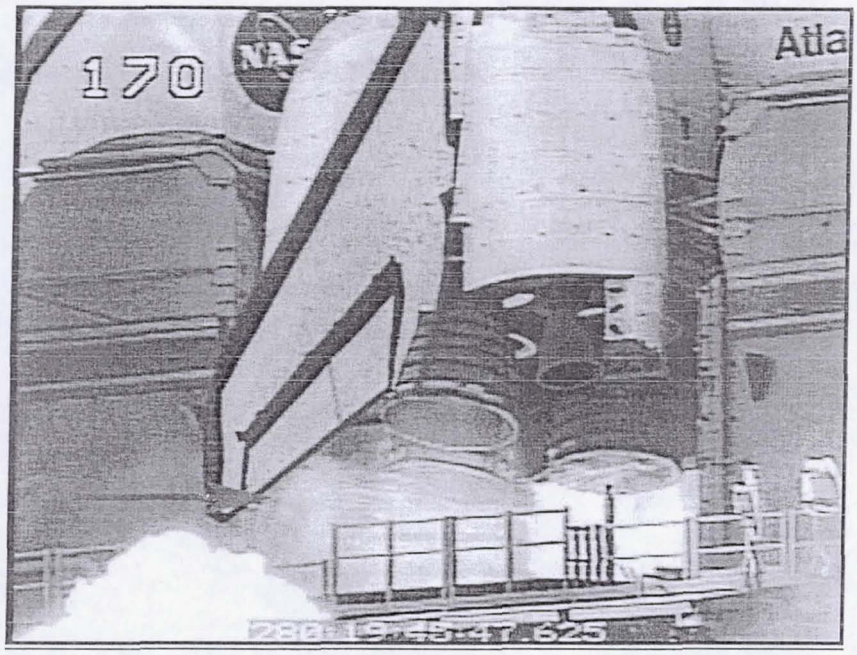


Figure 2.1 (B) Orange Puff Seen Near Vertical Stabilizer During SSME Start-up

During SSME star-up, a large, orange-colored puff was seen near the trailing edge of the vertical stabilizer during SSME ignition (19:45:47.625 UTC) approximately 0.5 seconds prior to the SSME #1 Mach diamond formation. (On STS-111 a similar orange flash was seen at approximately 1.2 seconds prior to the SSME #1 Mach diamond formation.)

2.2 KSC, JSC, MSFC Film/Video Analysis Teams Landing + 3 Day Intercenter Consolidated Film Review Report

One anomaly was reported from the 16mm ET Umbilical Well Camera Films that was elevated to the Landing + 3 Day Intercenter Consolidated Film Review Report.

CFVR-112-03:

On the umbilical well camera films, missing foam material was seen on the -Y Thrust Panel in the +Z direction from the EB Fitting. See Figure 2.1 (C). The missing foam material could be the possible cause of the damage found post-landing on the left side of the Orbiter lower fuselage tiles. Similar patterns of missing foam were seen on STS-99.

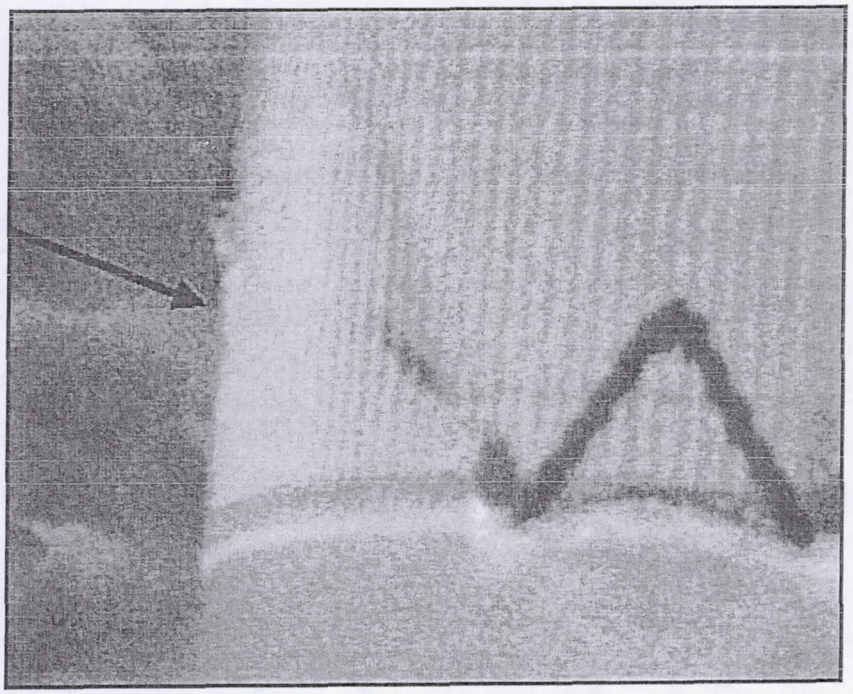


Figure 2.1 (C) Missing Foam Material on –Y Thrust Panel. Image Courtesy of Marshall Space Flight Center (Camera FL102)

2.3 Special Interest Observations

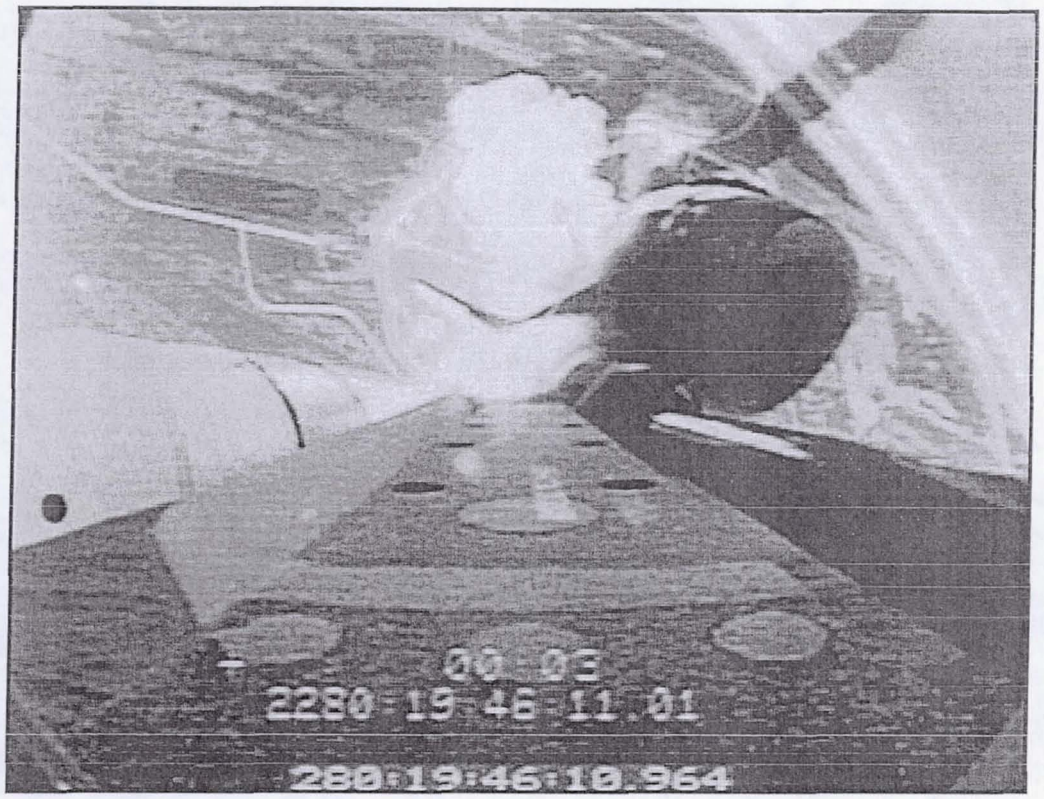


Figure 2.3.1 (A) View from ET Camera During Ascent

2.3.1 Camera Mounted on External Tank (ET)

The following events were seen during launch on the live downlink video from the camera mounted on the forward end of the External Tank. See Figure 2.3.1 (A):

Orange vapor (possibly free burning hydrogen) was seen at the aft end of the Orbiter during SSME start-up.

A single, light-colored piece of debris (frost/ice) was seen near the ET LO2 feedline falling aft toward the Orbiter nose and the forward ET/Orbiter bipod attach and continuing aft along the fuselage tiles approximately three seconds after liftoff (19:45:54.082 UTC).

A second piece of debris was seen falling aft along the ET past the forward bipod at tower clear (19:45:55.417 to 19:45:55.484 UTC). The debris appeared dark at first and then fell into sunlight and appeared light in color. The debris was not seen to contact the vehicle. A third piece of debris, following the same trajectory, was seen falling aft along the ET and past the forward ET/Orbiter bipod at tower clear (19:45:55.500 UTC).

At approximately seventy-two seconds after liftoff, a single light-colored piece of debris was seen above the right wing (19:47:03.218 UTC). This debris appeared to contact the leading edge of the right wing, before deflecting and falling aft (19:47:03.250 UTC). No damage to the wing was noted.

Butcher paper from the (starboard) forward RCS housing cans was seen to detach during the roll maneuver and beyond (19:46:05.826, 19:46:10.964, 19:46:20.859, and 19:46:28.667 UTC). Condensation was seen on the launch vehicle between 19:46:26.664 through 19:46:39.792 UTC.

The ET Camera lens was smudged by exhaust at SRB separation (19:47:52.984 UTC), severely degrading the image quality.

The external tank video replay ran for 2 minutes 43.015 seconds after launch. Of that time approximately 12.2 seconds were either of poor quality or no signal. There were two periods of greater than 3 seconds of signal loss. This amounts to around seven percent of the recording having less than optimal video.

2.3.2 Holddown Post Events

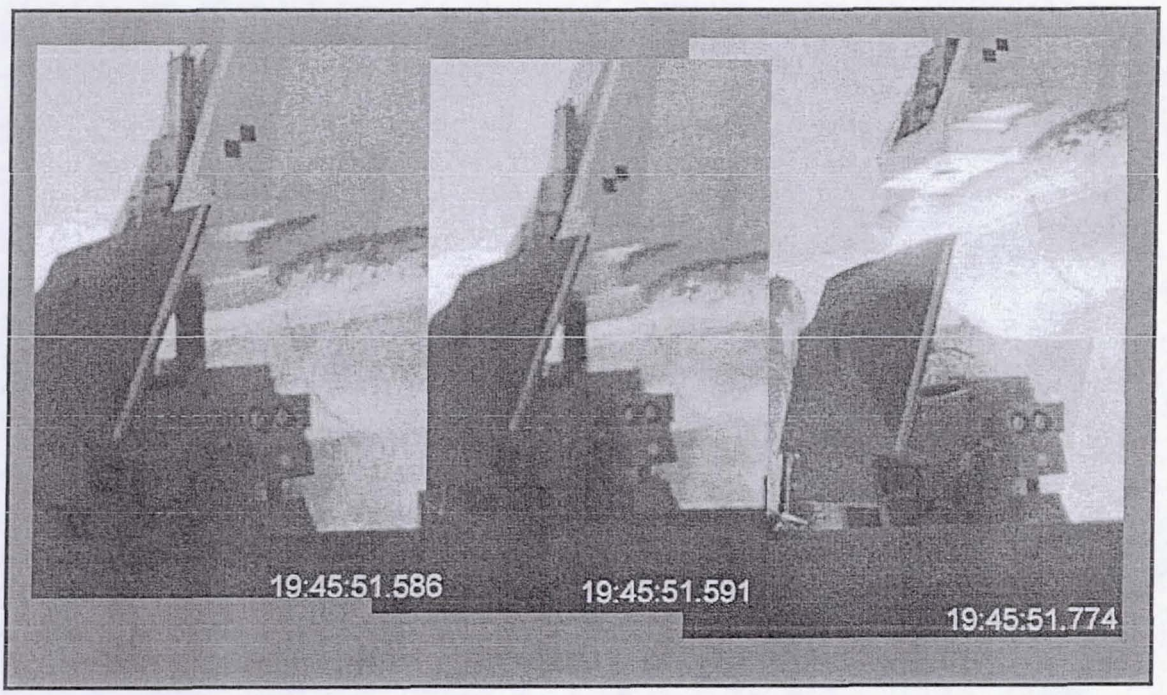


Figure 2.3.2 (A) Image Sequence of Holddown Post M-3 Bolt Hang-up (Camera E10)

The RSRB holddown post M-3 bolt was seen to hang-up during liftoff. The bolt appeared to be fully extended and was estimated to be ten to eleven inches above the plane of the holddown post shoe at the time of release. See Figure 2.3.2 (A). Table 2.3.2 (A) contains a timeline of the holddown post M-3 bolt hang-up events. (Camera E10)

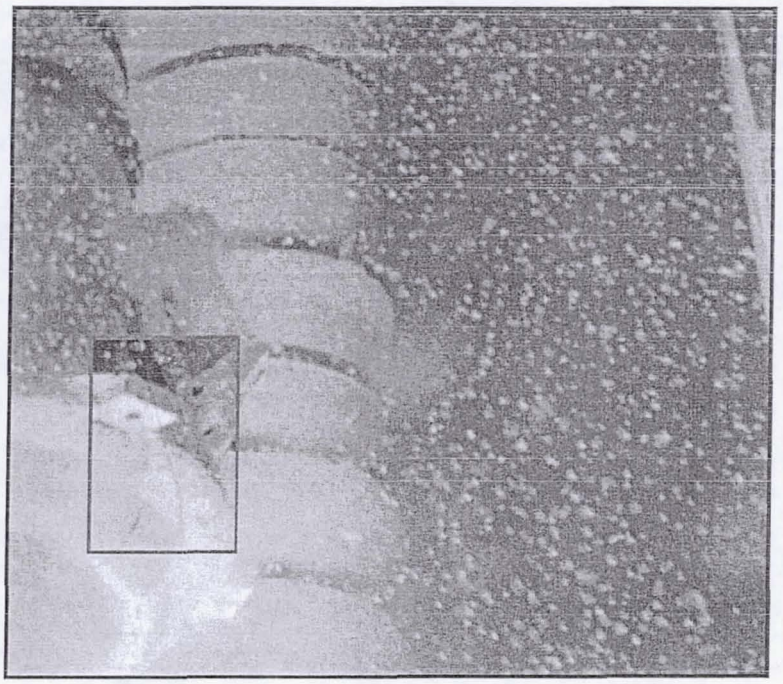


Figure 2.3.2 (B) (Camera E31)

A PIC wire did not release but was seen to remain attached to LSRB aft skirt at the post M-6 DCS during liftoff (19:45:53.0 UTC). See Figure 2.3.2 (B) (Cameras E13, E31, E34)

The SRB holddown posts blast shields on M-3, M-7, and M-8 did not appear to close until after the SRB nozzle exit plane rose past the level of the SRB holddown post shoe(s). (Cameras E10, E11, E14, E15, E16)

Table 2.3.2 (B) contains a comparison of times for similar events seen at each of the STS-112 holddown posts at liftoff.

STS-112 Hold-down Post M-3 Bolt Hang-up Times						
Holddown Post	Camera	PIC Firing (GMT)	Bolt Fully Extended (GMT)	Bolt Release from SRB (GMT)	Bolt Disappears into Holddown Post Shoe (GMT)	Nozzle Even With HD Post Shoe (GMT)
RSRB M-3	E10	NA*	19:45:51.586	19:45:51.591	19:45:51.774	19:45:52.052

NA* Not Available. Obscured by smoke.

Table 2.3.2 (A) Hold-down Post M-3 Bolt Hang-up Times

STS-112 Hold-down Post Event Times						
Holddown Post	Camera	PIC Firing (GMT)	Nozzle Exit Plane Clear (GMT)	Blast Deflection Shield Release (GMT)	Nozzle Even With HD Post Shoe (GMT)	Blast Shield Closed (GMT)
RSRB M-1	E9	19:45:51 .026	19:45:51.656	NA*	19:45:52.052	NA*
RSRB M-2	E8	19:45:51 .026	19:45:51.670	NA*	19:45:52.058	NA*
RSRB M-3	E10, E15	NA*	19:45:51.653	19:45:51.676	19:45:52.052	19:45:52.166
RSRB M-4	E7, E15	NA*	NA*	19:45:51.675	19:45:52.052	19:45:52.166
LSRB M-5	E12	19:45:51 .026	19:45:51.656	NA	19:45:52.062	NA*
LSRB M-6	E13	19:45:51 .029	19:45:51.674	NA	19:45:52.074	NA*
LSRB M-7	E11, E16	NA*	NA*	19:45:51.667	19:45:52.036	19:45:52.158
LSRB M-8	E14, E16	NA*	NA*	19:45:51.675	19:45:52.079	19:45:52.145

NA* Not available. Obscured by smoke.

Table 2.3.2 (B) STS-112 Hold-down Post Event Times

2.4 Other Launch Observations

2.4.1 Debris from SSME Ignition through Liftoff

Typical of previous missions, 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 (19:45:47.910, 19:45:48.242 UTC) and during liftoff (19:45:52.714 UTC). On camera OTV154, ice debris was seen to contact the LO2 umbilical well doorsill during SSME ignition (19:45:47.925 UTC). A single piece of debris may have contacted the +Y/-Z edge of the body flap (mid level) during liftoff (19:45:51.314 UTC). No damage to the launch vehicle was noted. Umbilical ice debris falling aft along the body flap during launch is a typical event. (Cameras OTV109, OTV149, OTV154, OTV163, E1, E17, E18, E20)

A single, light-colored piece of debris was seen between SSME #2 and SSME #3 before falling aft prior to liftoff (19:45:47.476 UTC). (OTV109)

A light-colored piece of debris (probably frost) was seen falling from the Orbiter side of the LSRB / ET aft attach during SSME start-up (19:45:48.3 UTC). (Camera E31)

Multiple pieces of SRB throat plug and/or SRB flame duct debris were seen near the right and left SRBs during liftoff. On camera E63, several pieces of debris (probably SRB throat plug material) were seen near the LSRB at 19:45:52.042 UTC. On camera E5, several pieces of RSRB flame duct debris were seen traveling toward the body flap before falling aft during liftoff (19:45:51.395 UTC). On camera E2, a dark-colored piece of debris was seen between the left and right SRBs that appeared to be traveling from the RSRB flame duct at liftoff (19:45:51.528 UTC). None of the debris was seen to contact the launch vehicle. (Cameras E2, E4, E5, E63)

A fast moving white-colored, linear-shaped streak (possibly debris) was seen coming from beneath the south side of the MLP and traveled away from the launch pad approximately one second prior to liftoff (19:45:50.070 UTC). Also, a dark-colored object was seen on the north side of the view traveling toward the MLP at liftoff (19:45:51.941 UTC). (Camera KTV7B)

A light-colored piece of debris was seen north of the MLP moving toward the SRB exhaust plume at liftoff (19:45:53.230 UTC). (Camera OTV148)

2.4.2 Debris During Ascent

A dark-colored piece of debris was seen falling aft of the ET near the –Y side of the RSRB (forward of the SRB aft skirt) during tower clear. (Camera KTV4B)

A single, dark colored piece of debris was first seen aft of the right inboard elevon and fell aft between the SRBs (19:46:30.406 UTC). (Camera ET207)

A single, fast-moving, dark-colored piece of debris was seen traveling in a +Z direction towards the body flap during ascent. The debris was first seen near the right SRB aft skirt and moved behind the body flap where it was lost from view. The debris did not appear to contact the vehicle. (Camera ET207)

Multiple pieces of debris, too numerous to count (mostly umbilical ice and RCS paper debris), were seen falling aft of the launch vehicle during ascent. On camera E52, multiple pieces of RCS paper debris were seen falling aft over the Orbiter right wing before falling aft into the SSME exhaust plume (19:46:10.527 UTC). Umbilical ice and RCS paper debris during ascent has been seen on previous mission films and videos. (Cameras E52, E54, E207, E212, E222, E223)

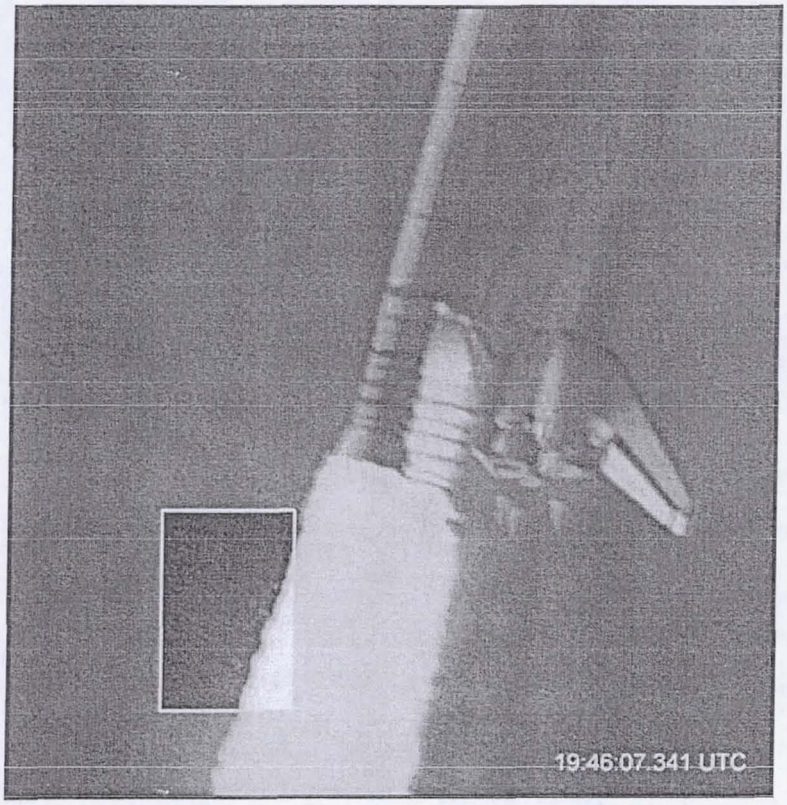


Figure 2.4.2 (A) Spray of Debris Exiting the LSRB Exhaust Plume (Camera E52, E222)

Numerous pieces of debris (in excess of twenty) were seen falling aft from the LSRB exhaust plume near the LSRB aft skirt during early ascent (19:46:07.341 UTC). See Figure 2.4.2 (A). Although debris exiting the SRB exhaust plumes has been typically seen on previous

mission imagery, this event is considered unusual because of the amount (not size) of debris that was visible. (Camera E52, E222)

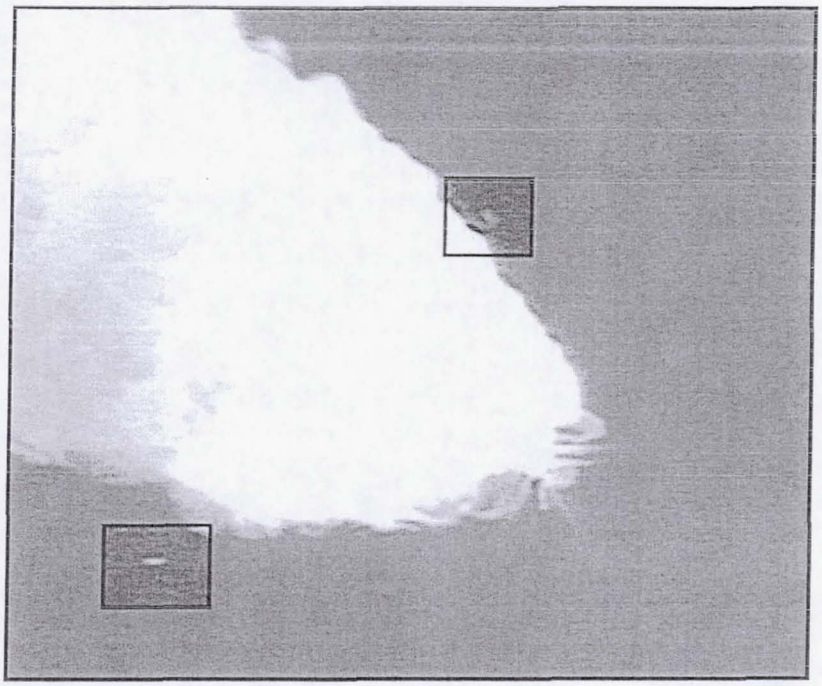


Figure 2.4.2 (B) Debris Exiting the SRB Exhaust Plume During Ascent (Camera KTV4B)

As on previous missions, light-colored debris was seen exiting the SRB exhaust plumes during ascent. The debris exiting the SRB exhaust plumes during late ascent was probably instafoam from the aft end of the SRBs. See Figure 2.4.2 (B). The more dense appearing debris near the time of tail-off, just prior to SRB separation, was probably SRB slag debris. Examples of this debris are provided in Table 2.4.2.

Camera	Event Time (UTC)	Description
E52	19:46:07.353	Debris fell aft along SRB exhaust plume
E52	19:46:20.716	Instafoam debris near LSRB aft skirt
KTV4B	19:47:03.144	Two pieces of debris fell aft along SRB exhaust plume
KTV4B	19:47:04.863	Debris fell aft along SRB exhaust plume
KTV4B	19:47:17.242	Debris fell aft along SRB exhaust plume
KTV4B	19:47:48.589	Debris fell aft along SRB exhaust plume
KTV13	19:47:51.156	Debris fell aft along SRB exhaust plume

Table 2.4.2 Debris Seen Exiting SRB Exhaust Plume

2.4.3 Mobile Launch Platform (MLP) Events

The SSME ignition appeared normal on the launch camera views. During SSME start up, the Mach diamonds formed in the expected 3, 2, 1 sequence. The start times for SSME ignition (from camera OTV170) and the SSME Mach diamond formation times (from camera E19) are provided in Table 2.4.3. (Cameras OTV170, E19, E20, E76)

SSME	SSME Start Time (UTC)	Mach Formation Time (UTC)	~ Delta Time (Seconds)
SSME #3	19:45:46.242	19:45:47.712	1.5
SSME #2	19:45:46.375	19:45:47.965	1.6
SSME #1	19:45:46.492	19:45:48.184	1.7

Table 2.4.3 SSME Mach Diamond Formation Times

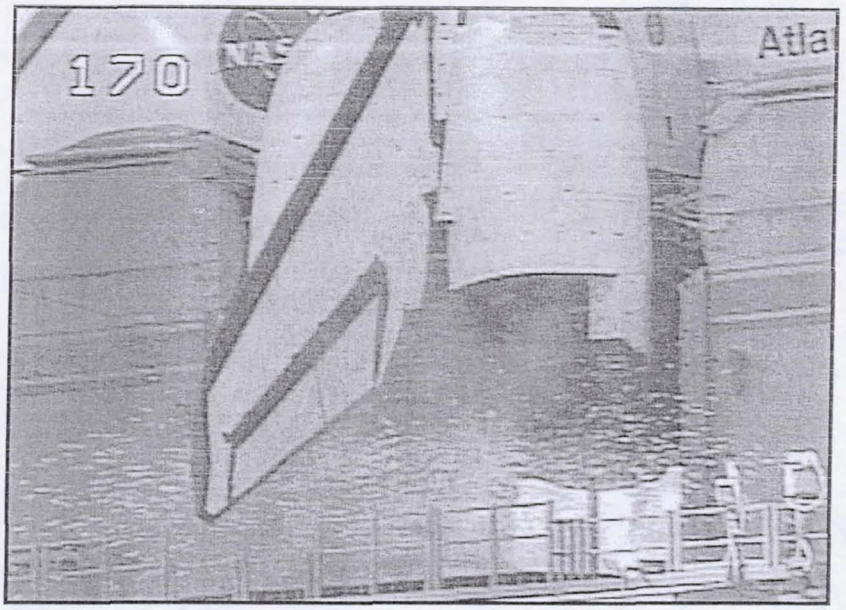


Figure 2.4.3 Orange Vapor Seen Forward of SSME Rims (Camera OTV170)

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, near the drag chute door, forward of the trailing edge of the vertical stabilizer, and near the base heat shield during SSME ignition. See Figure 2.4.3. A large, orange-colored flash was seen near the trailing edge of the vertical stabilizer during SSME ignition (19:45:47.617 UTC) approximately 0.5 seconds prior to the SSME #1 Mach diamond formation. (On STS-111 a similar orange flash was seen at approximately 1.2 seconds prior to the SSME #1 Mach diamond formation.) Orange vapor forward of the SSME rims during SSME ignition has been seen on previous mission films and videos. (Cameras OTV170, KTV4B, ET213, E2, E17, E18, E19, E20, E52, E63, E222)

Frost was visible on the edges of the –Y ET GOX vent louver prior to liftoff. Frost on the ET vent louvers has been seen on previous mission videos. (Camera OTV161)

Faint, light-orange-colored flashes or streaks were seen in the SSME #1 exhaust plume, possibly debris induced, after SSME ignition through liftoff at the times shown below (Cameras E2, E19, E20, E76):

SSME #1 – 19:45:48.492, 19:45:48.617, 19:45:49.507, 19:45:50.432, 19:45:51.322 UTC

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

Small light-colored marks were visible in the camera E19 close-up view of the SSME # 2 engine hot wall. Similar marks were not nearly as apparent on the other two engine hot walls. Nothing unusual was noted on the SSME #2 engine hot wall by the post landing inspection team. (Camera E19)

Typical of previous missions, tile surface material erosion was seen on the tip of the left RCS stinger and in the +Y direction from the left OMS nozzle during SSME ignition. (Camera E20)

No significant movement of the OMS pod tiles during SSME ignition was detected on the STS-112 camera films. (Cameras E17, E18)

The GH2 vent arm retraction from the ET at liftoff appeared normal (19:45:51.029 UTC). Ice and vapors were seen falling aft along the ET during the vent arm retraction. (Camera E33) Ice debris was seen falling aft and contacting the LSRB aft skirt after the GH2 vent arm retraction from the External Tank (19:45:53.385 UTC). No damage to the LSRB aft skirt was noted. (Camera E1)

The GH2 vent arm contact with the deceleration cable was obscured by FSS deluge water. Therefore, the position of the vent arm with respect to the center of the deceleration cable at the time of initial contact could not be evaluated. The GH2 vent arm made initial contact with the FSS latch back mechanism at approximately 19:49:53.070 UTC as seen on the camera E39 view. (Camera E39)

Both of the SRB aft skirt thermal curtains on the north side of the SRBs were seen to indent inward due to the ignition overpressure from the boosters at liftoff. The indentation disappeared by the time the exit plane of the SRB nozzles cleared the level of the SRB holddown posts. (Cameras E15, E16)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 19:45:52.440 UTC (right purge line) and 19:45:52.781 UTC (left purge line). (Cameras E8, E13)

2.4.4 Ascent Events

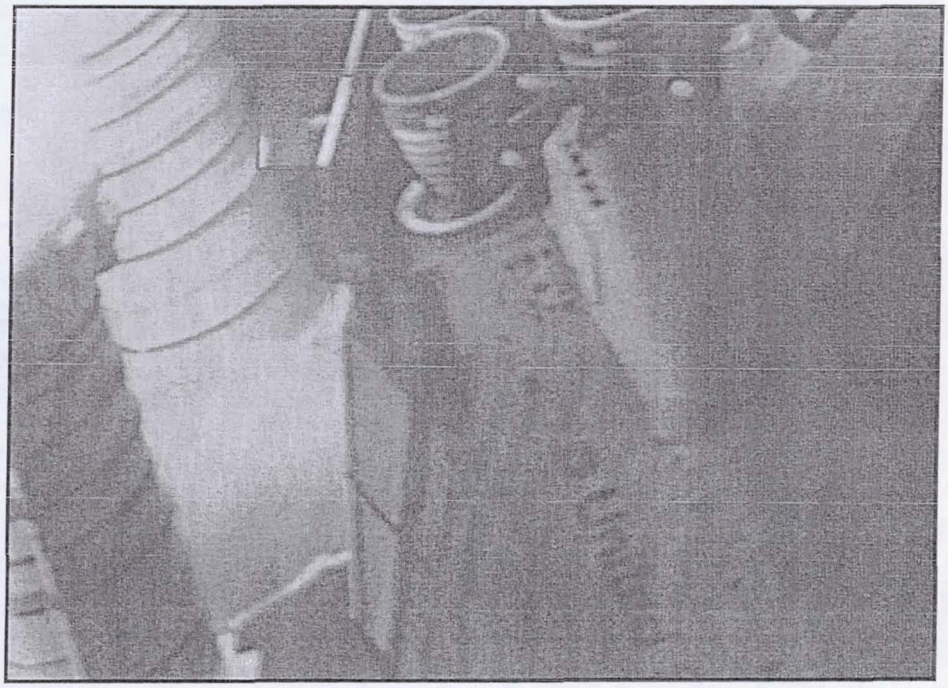


Figure 2.4.4 (A) Umbilical Purge Barrier Material Seen Aft of Body Flap (Camera E207)

Pieces of ET umbilical well purge barrier material were seen along the –Z side of the body flap, aft of the ET aft dome, and between the two SRBs during ascent (19:46:01.686, 19:46:06.686, 19:46:08.025, 19:46:09.6, 19:46:12.086, 19:46:15.183, 19:46:15.561, 19:46:21.364, 19:46:30.717 UTC). See Figure 2.4.4 (A). Umbilical purge barrier material falling from the ET umbilicals has been typically seen on the previous mission tracking camera views. (Cameras ET207, E52, E54, E207, E222)

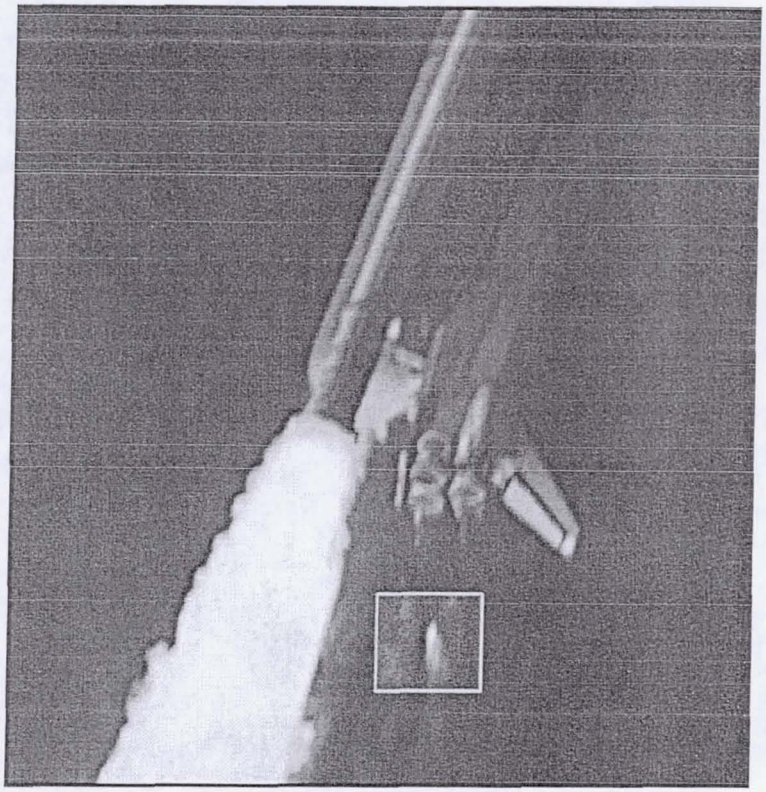


Figure 2.4.4 (B) Flare Seen in SSME Exhaust Plume (Camera E222)

Light-colored flares (possibly debris induced) were seen in the SSME exhaust plumes during ascent on the intermediate and long range tracking camera films and videos. See Figure 2.4.4 (B). (Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris was 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-112 can be seen in Table 2.4.4. Flares in the SSME exhaust plumes have been seen on previous missions films and videos.

Camera	Time (UTC)	Event
E222	19:46:07.101	Flare in SSME exhaust plume
E222	19:46:07.732	Small white-colored flash in SSME plume
E52	19:46:10.022	Flare in SSME exhaust plume
KTV4B	19:46:17.199	Flare in SSME #1 exhaust plume
E222, E223	19:46:17.222	Flare in SSME #1 exhaust plume
KTV4B	19:46:21.324	Flare in SSME exhaust plume
KTV4B, E223	19:46:21.437	Flare in SSME exhaust plume
E222, E223	19:46:21.547	Flare in SSME exhaust plume

Table 2.3.6 Flares Seen in SSME Exhaust Plumes During Ascent

Condensation was observed around the launch vehicle during ascent (19:46:26.2 through

19:46:38.5 UTC). Condensation plumes and condensation streaks off the launch vehicle have been seen on previous mission films and videos. (Cameras KTV4B, ET208, ET212)

Body flap motion typical of that seen on previous missions was seen during ascent (19:46:19.5 through 19:46:56.1 UTC). (Camera E207, E212, ET207)

An orange-colored flash from the early OMS-2 assist burn was seen approximately ten seconds after SRB separation (19:48:03.134 UTC). (Camera KTV13, ET208, E207, E212)

2.5 Onboard Photography of the External Tank (ET-115)

2.5.1 35mm Umbilical Well Camera Film (Roll 384)

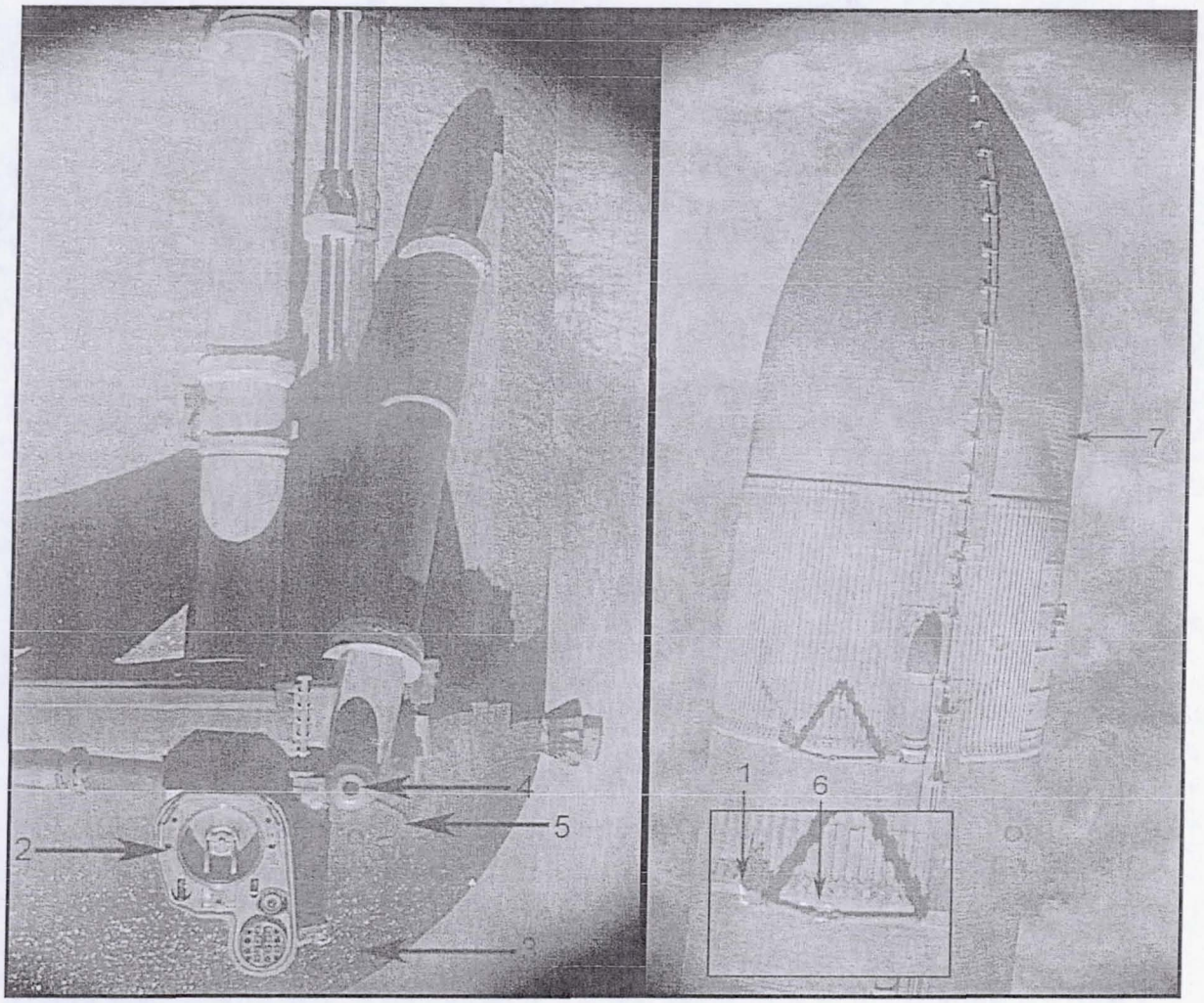


Figure 2.5.1 35mm Images of the ET during Separation (Frames 8 and 30)

A large portion of the ramp adjacent to the –Y foot of the ET / Orbiter forward bipod attach is missing. See Figure 2.5.1, annotation 1. The damaged area measured approximately 6 x 12 inches. Substrate material is visible. This is considered to be a possible source for the debris that was seen striking the LSRB ETA ring on the launch camera films.

A large (approximately 3 by 4.5 inch) divot was seen near the second from the most aft LO2 feedline flange (approximately station XT 1854) between the +Y side of the LO2 feedline and the ramp over the LO2 and LH2 pressurization lines. Some depth to the divot is visible but the substrate was not exposed.

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 2.5.1, annotation 2.

Typical of previous missions, extensive small "popcorn" divots are visible on the images of the ET aft dome. See Figure 2.5.1, annotation 3.

The separation bolt between the ET and the aft end of the Orbiter (EO-3 fitting near the liquid oxygen umbilical) was retracted. See Figure 2.5.1, annotation 4.

Typical ablation and divoting of the TPS on the vertical section of the +Y electric cable tray adjacent to the LO2 umbilical was detected.

Typical of previous missions, charred (as well as missing) TPS was visible on the RSRB aft attach.

The red-colored purge seal on the EO-3 ball joint fitting was seen to be partially detached. Partially detached purge seals on this fitting as been seen on previous mission films. See Figure 2.5.1, annotation 5.

Typical of previous missions, small "popcorn" divots were seen on the aft LH2 tank TPS forward of the cross beam.

White material, probably frozen hydrogen, was seen on the ET aft dome TPS at the –Y end of the +Y diagonal strut just aft of the cross beam. Similar appearing white substance(s) has been seen at this location on previous mission films.

Minor TPS abrasion on the LO2 feedline brackets was visible. As typically seen, a white-colored line (probably frost) was seen on the aft edge of the aft LO2 feedline bellows.

Approximately twelve small areas of TPS erosion (or divots) were visible on the TPS on the forward flange of the +Y ET thrust strut. Overall, the +Y ET thrust strut appeared to be in good condition. However, the image of the most forward portion of the +Y thrust strut was partially obscured by shadow.

Minor surface material erosion, approximately four inches in length, was seen on the outboard press line at approximate station XT 1675.

A small, circular shaped, white-colored divot was seen at the mid-level of the LH2 tank TPS in the -Y direction from the LO2 feedline.

Overall, the LH2 tank-to-intertank close-out flange appeared to be in good condition. However, two small, light-colored TPS divots were seen in the direction of the -Y leg of the forward bipod on the LH2 tank-to-intertank close-out flange. See Figure 2.5.1, annotation 6. One of the divots partially covered the –Y bipod jack pad close-out. The divots appeared shallow and no exposed substrate material was noted. The +Y bipod jack pad close-out appeared to be in good condition.

Several small "popcorn" divots were noted on the intertank stringer heads and in the valleys between the stringer heads just forward of the ET / Orbiter attach bipod. This event has been typically seen on previous mission films.

Approximately three white-colored marks were seen on the –Y thrust panel stringer heads aft of the LSRB / ET forward attach. The view angle is very oblique and difficult to interpret. The size and / or extent of the marks could not be determined.

The visible portion of the +Y ET thrust panel appeared to be in good condition. However, there were scattered small (less than one inch in size) white marks noted on the +Y thrust panel stringer heads forward of the RSRB / ET forward attach.

The typical SRB burn scars and ascent aero heating marks were noted. See Figure 2.5.1, annotation 7.

The LO2 tank TPS and the nose of the ET appeared to be in good condition.

Notes: On STS-112, the new Nikon F5 35mm umbilical camera with the 50mm lens and Kodak color negative film was flown. Coverage included the aft end of the ET and forward along the +Z side of the ET to the tip of the ET.

Thirty-six frames were acquired with the 35mm umbilical camera. The images are excellent quality with very little shadow. The focus and exposure are good.

2.5.2 16mm Umbilical Well Camera Films with the 5mm and 10mm Lenses (FL101 and FL102)

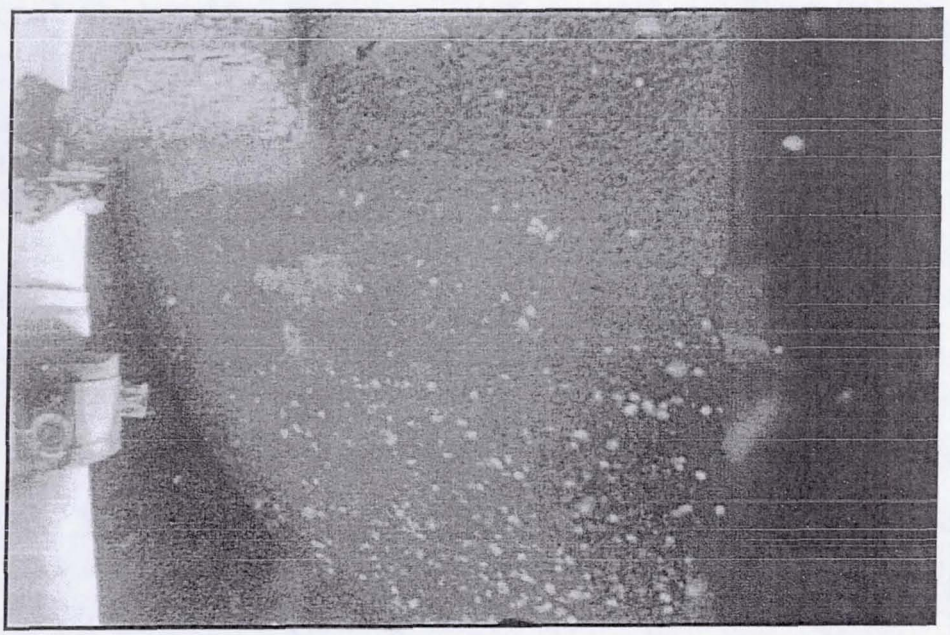


Figure 2.5.2 (A) 16mm Umbilical Well Camera SRB Separation Image

SRB Separation:

The LSRB separation appeared normal on the 16mm umbilical well camera films (recorded through the 5mm and 10 mm lenses).

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.

An unidentified dark-colored mark was visible on the ET aft dome / LH2 tank close-out flange near the LSRB aft attach. This mark could not be found on the pre-launch close-out inspection photography.

No anomalies were seen on the left and right SRB nose caps during SRB separation.

Figure 2.5.2 (B) 16mm Umbilical Well Camera ET Separation Image

ET Separation:

The ET separation from the Orbiter appeared normal (although the view was dark because of the shadow of the Orbiter from the late afternoon Sun).

A large piece of frozen hydrogen was seen contacting the forward surface of the LH2 electric cable tray prior to ET separation. No damage to the cable tray was noted.

Typical vapor and multiple light-colored pieces of debris were seen after the umbilical separation. No anomalies were noted on the face of the LH2 umbilical after ET separation. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect. See Figure 2.5.2 (B), annotation 1. Frozen hydrogen was visible on the aft dome TPS aft of the ET cross beam near the 1 o'clock position of the LH2 umbilical. See Figure 2.5.2 (B), annotation 2.

The separation bolt between the ET and the aft end of the Orbiter (EO-2 fitting near the liquid hydrogen umbilical) appeared to be retracted. See Figure 2.5.2 (B), annotation 3. The red-colored purge seal on the EO-2 ball joint fitting was in place. Small divots / TPS erosion were seen on the forward flange of the –Y thrust strut. See Figure 2.5.2 (B), annotation 4. The TPS covering the length of the –Y thrust strut appeared to be in good condition.

The LH2 tank TPS appeared to be in good condition on the 16mm camera views. No unusual conditions were noted on the ET intertank or nose of the ET.

Typical of many previous missions, the ET had a slight tilt in the +Y direction after separation.

A visual comparison of the relative ET / Orbiter orientation after ET separation for STS-112 and the twelve previous missions (when imagery was acquired) using the 35mm umbilical well TPS camera mounted in the LO2 umbilical was made. The only significant relative angle of the ET and Orbiter noted was on STS-110 when the new IO-29 alpha-beta management (SCR 92353D) was initially implemented. The STS-112 view appears as expected based on our previous mission history with this camera.

Notes: The focus and exposure was good on both of the 16mm umbilical films. Timing data was present on both of the umbilical well camera films.

2.5.3 35mm Crew Handheld Film (Roll 301)

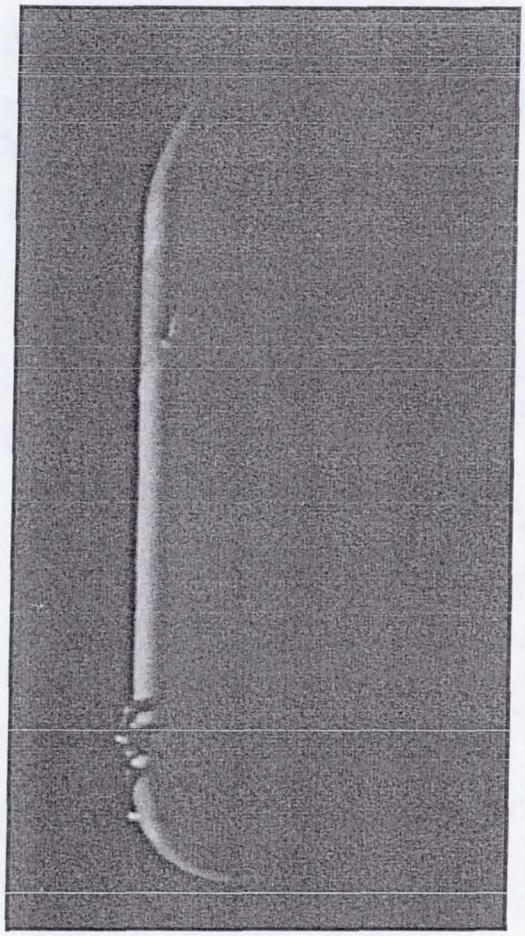


Figure 2.5.3 Handheld Image of the External Tank (Frame 6)

No anomalous or unusual observations were noted on the handheld film views. The ET was almost 100% back-lighted by the late afternoon Sun. Therefore, analysis of the film was not possible because of the extensive shadows on the ET. See Figure 2.5.3.

The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld photography. The first picture was taken at 16.1 minutes MET using the handheld Nikon F5 camera with a 400 mm lens. The distance of the ET was calculated to be approximately 2 km's from the Orbiter on the first image acquired of the tank. A total of thirteen pictures of the ET were obtained. Timing data is present on the film.

2.5.4 Crew Handheld Video

Handheld video of the External Tank was not acquired on STS-112.

2.6 Landing Timing Events

The time codes from videos were used to identify specific events during the screening process. The STS-112 KSC landing event times are provided in Table 2.6.

Event	Time (UTC)	Camera
Left Main Gear Door Opening	291:15:43:16.761	ET207
Right Main Gear Door Opening	291:15:43:16.992	ET207
Left Main Gear Tire Touchdown	291:15:43:40.160	EL17 IR
Right Main Gear Tire Touchdown	291:15:43:40.179	EL17 IR
Nose Gear Touchdown	291:15:43:48.167	EL17 IR
Drag Chute Initiation	291:15:43:50.570	EL17 IR
Pilot Chute at Full Inflation	291:15:43:51.539	KTV 33L
Bag Release	291:15:43:52.542	KTV 15L
Drag Chute Inflation in Reefed Configuration	291:15:43:53.992	SLF North
Drag Chute Initiation in Disreefed Configuration	291:15:43:57.277	SLF North
Drag Chute Release	291:15:44:18.132	SLF North
Wheel Stop	291:15:44:32.433	KTV 15L

Table 2.6 Landing Event Times

2.7 Landing Sink Rate Analysis

Image data from the centerline camera at the approach end of runway 33 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 (100 frames of data during the last second prior to touch down with respect to each landing gear). 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.

The main gear sink rate for STS-112 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.7. A plot describing the sink rate for the main gear can be seen in Figure 2.7. Trend lines for the main gear were determined considering the height of the Orbiter above ground with respect to time. Sink rate equals the slope of each regression line.

Time Prior to Touchdown	Main Gear Midpoint Sink Rate	Estimated Error (1σ)
1.00 Sec.	1.0 ft/sec	+/- 0.1 ft/sec
0.50 Sec.	1.3 ft/sec	+/- 0.2 ft/sec
0.25 Sec.	1.4 ft/sec	+/- 0.3 ft/sec

Table 2.7 Main Gear Midpoint Landing Sink Rate

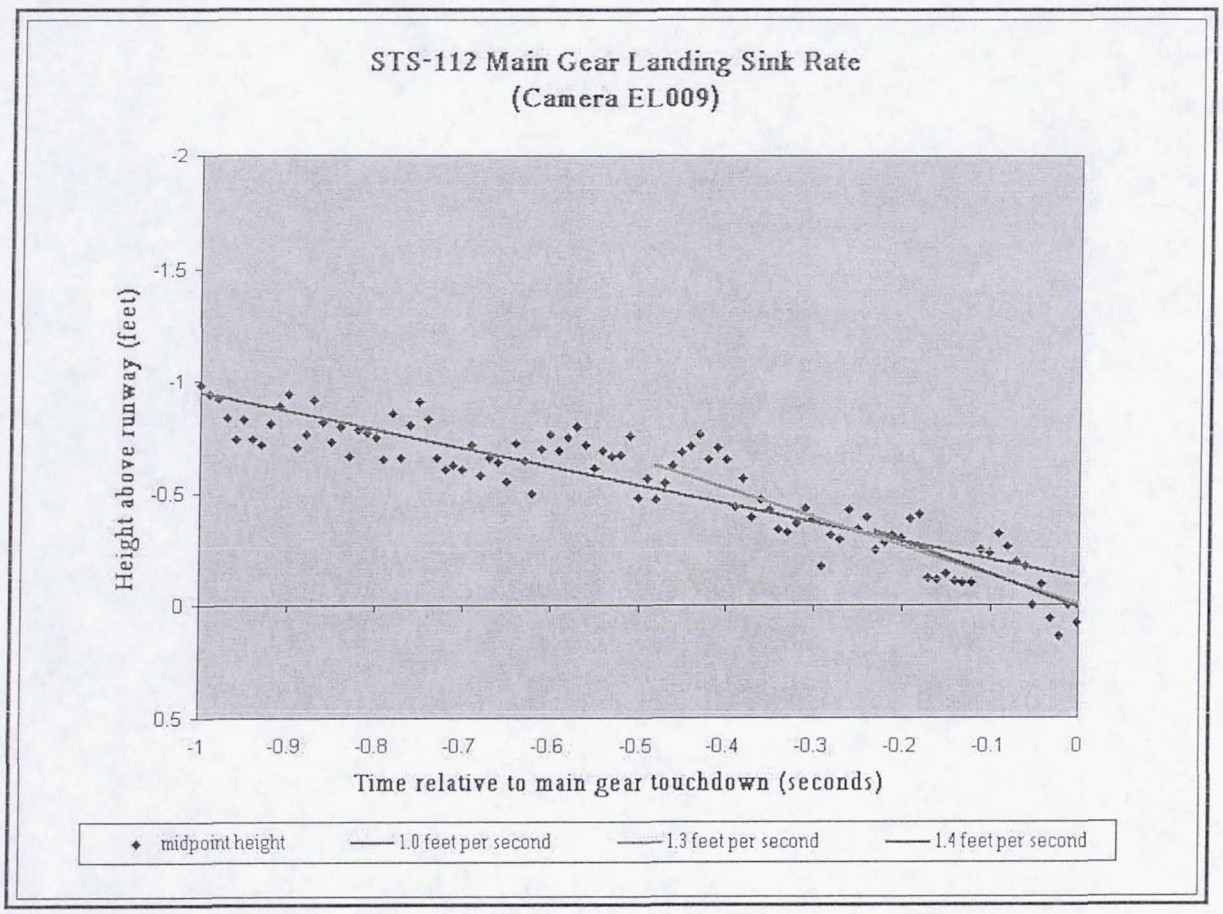


Figure 2.7 Main Gear Midpoint Landing Sink Rate

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-112 vehicle was reported to be 202,709 lbs.

2.8 Other

2.8.1 Normal Events

Normal events observed included:

- elevon motion prior to liftoff
- ice / frost on SSME purge drain-line vents
- RCS paper debris from SSME ignition through liftoff
- ET twang
- ice and vapor from the LO2 and LH2 TSM T-0 umbilicals 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
- multiple pieces of debris in the exhaust cloud (including water baffle material) after liftoff
- ET aft dome outgassing and charring of the ET aft dome during ascent
- roll maneuver
- expansion waves
- linear optical effects
- recirculation
- SRB plume brightening
- SRB slag debris before, during and after SRB separation

2.8.2 Normal Pad Events

Normal pad events observed included:

- hydrogen burn igniter operation
- FSS and MLP deluge water activation
- sound suppression system water operation
- TSM T-0 umbilicals disconnect and retraction
- LH2 and LO2 TSM door closure
- GH2 vent arm retraction

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-112

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

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November 18, 2002
Marshall Space Flight Center,
Huntsville, AL 35812

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STS-112

Engineering Photographic Analysis

George C. Marshall Space Flight Center

Launch Information

Launch of the 111th Space Shuttle mission STS-112, the twenty sixth flight of the Orbiter Atlantis (OV-104), occurred October 7, 2002 at 2:45 PM CST from launch complex 39-B Kennedy Space Center (KSC), Florida. Launch time was reported as 2002:280:19:45:51.018 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

T-Zero Times

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

Table 1. T-0 Times

Holddown Post	Camera	Time (UTC)
M-2	E008	280:19:45:51.026
M-1	E009	280:19:45:51.026
M-3	E010	280:19:45.51.028
M-5	E012	280:19:45:51.026
M-6	E013	280:19:45:51.027

SRB Separation Time

SRB separation time is the time recorded from the first frame prior to observation of the BSM combustion products from long-range high-speed cameras. The most accurate assessment of the SRB separation time is made from the high-speed long-range tracking film cameras, with film camera E207 often the most reliable. Video timing is assessed to a tenth of a second. The following is a list of cameras, SRB separation times, and error margins where the BSM combustion products could be easily detected.

Table 2. SRB Separation Times

Camera	Time (UTC)	± Error (ms)
E205	280:19:47:52.687	10
E207	280:19:47:52.674	16
E223	280:19:47:52.675	10
ET207	280:19:47:52.7	100
ET208	280:19:47:52.7	100

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.

70 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-112 is enumerated in the following table.

Table 3. Photographic Coverage

	16mm	35mm	Video
MLP	E001 E002 E003 E004 E006 E007 E008 E009 E010 E011 E012 E013 E014 E015 E016 E017 E018 E019 E020		OTV149 OTV150 OTV151 OTV154
FSS	E031 E033 E034 E036 E039 E040		OTV109 OTV161 OTV163
Perimeter		E052 E054 E057 E059 E060 E062 E063	OTV141 OTV148 OTV160 OTV170 OTV171
Tracking		E204 E205 E207 E208 E212 E213 E220 E222 E223 E224	ET204 ET207 ET208 ET212 ET213 TV004B TV005 TV007B TV011 TV013 TV021B
Onboard	FL101 FL102	HH035MM UMB035MM	ETCAM
Other			
Totals	27	19	24

The new ET Camera, ETCAM, provided excellent pictures up to SRB separation. After SRB separation motor firing, the Camera viewport was fogged limiting engineering use of imagery.

The images from cameras E208, E213, ET208, ET204, TV013, and TV21B were not sharp due to either atmospheric haze or soft focus. Images from cameras OTV141 and OTV160 were overexposed and camera OTV141 had images with very high contrast. Images from the astronaut

handheld 35mm still camera, HH035MM, were too dark and the ET too far away for engineering photographic evaluation.

Cameras TV021B, E213, and E220 lose track of the vehicle. Camera E057 doesn't follow vehicle from launch pad as planned and Camera E204 doesn't track the vehicle during the early portion of the ascent. Camera OTV160 was not in the correct orientation. On camera E312 the image size was small and not centered in field of view during portions of the ascent. Film Camera E224 had a short run.

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/sts112/sts112.html

Information available on the MSFC Engineering Photographic Analysis website includes:

- Photographic Acquisition Disposition Document (PADD)
- Individual camera status and assessments
- Movies and annotated images of notable observations
- External Tank 35mm still camera imagery
- Photographic Analysis Mission Summary Report (PDF format)

Out-Of-Family Observations

Debris Impacts Left SRB

Debris impacted an area near the Left SRB IEA Box during ascent at approximately 280:19:46:24.6 UTC. At impact, the original debris item(s) shattered into numerous pieces. Special investigations were made for the debris trajectory and velocity prior to impact.

UMB035MM: TPS Divots under Bipod and Bipod Ramp

A large divot is noted on the -Y (left) bipod ramp. A divot of this type has been seen and imaged previously on mission STS-50. This divot appears to be a likely source for the out-of-family observation in which debris impacted the left SRB IEA Box.

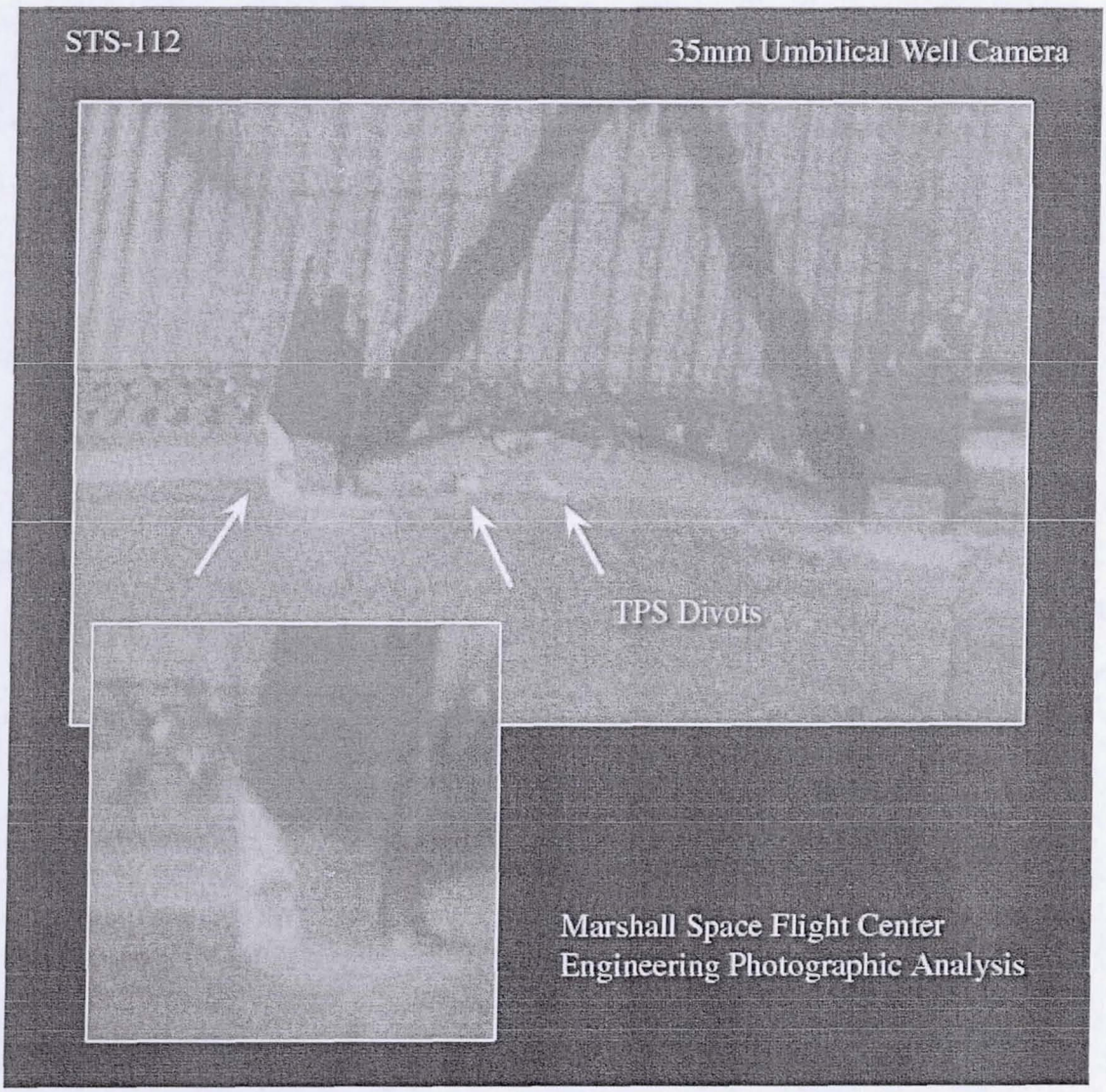


Figure 1. UMB035MM: TPS Divots under Bipod and Bipod Ramp

UMB035MM: Bipod Ramp Divot on STS-50

Illustration of an External Tank TPS divot reported on STS-50 that is similar to the divot noted on STS-112.

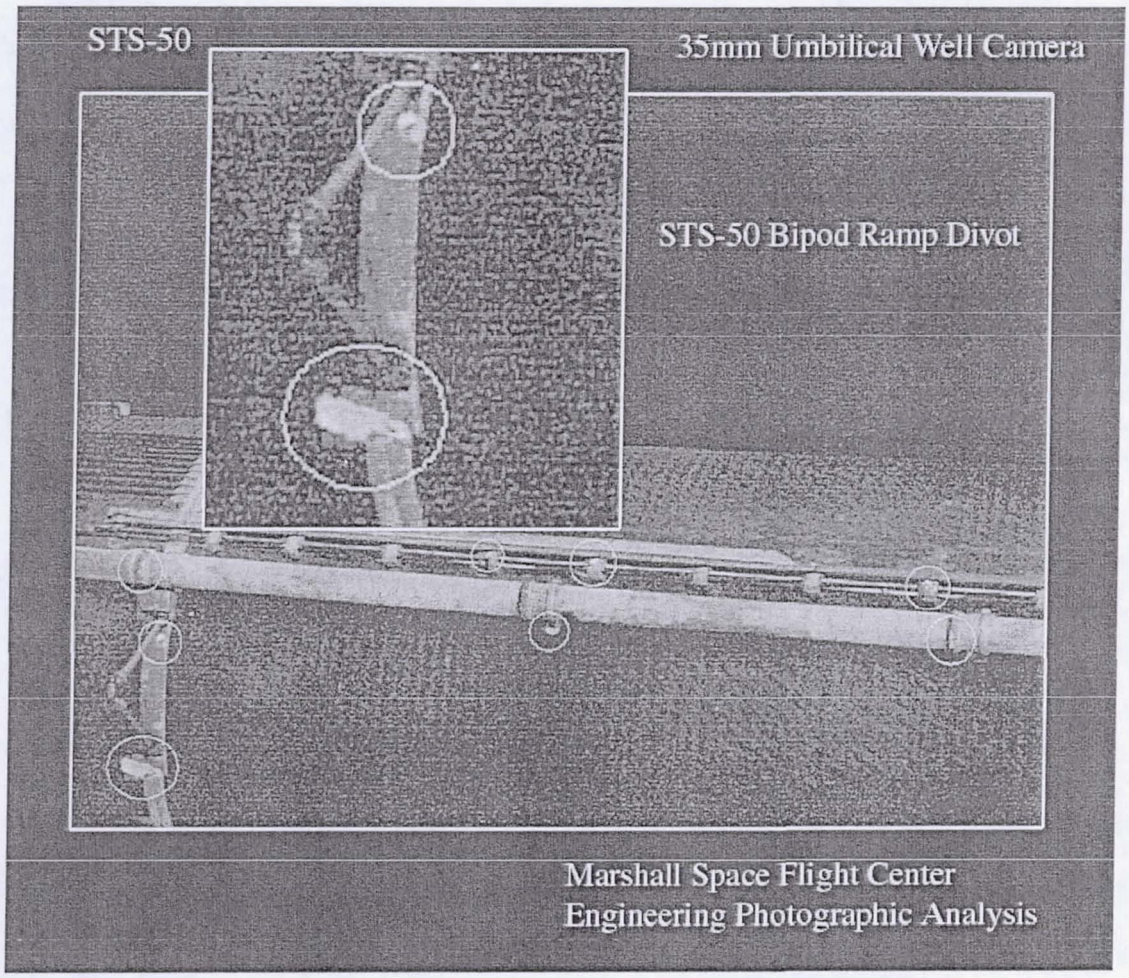


Figure 2. UMB035MM: Bipod Ramp Divot on STS-50

FL101: View of Left SRB IEA Box after SRB Separation

The Left SRB was imaged by the onboard Umbilical Well Camera FL101. In the time period after separation and before the booster drops from view, there were no clear marks on the Left SRB IEA Box area which indicated the debris impact area. From post-launch inspection of the SRB, after retrieval, an area for the impact was determined and is circled in the image.

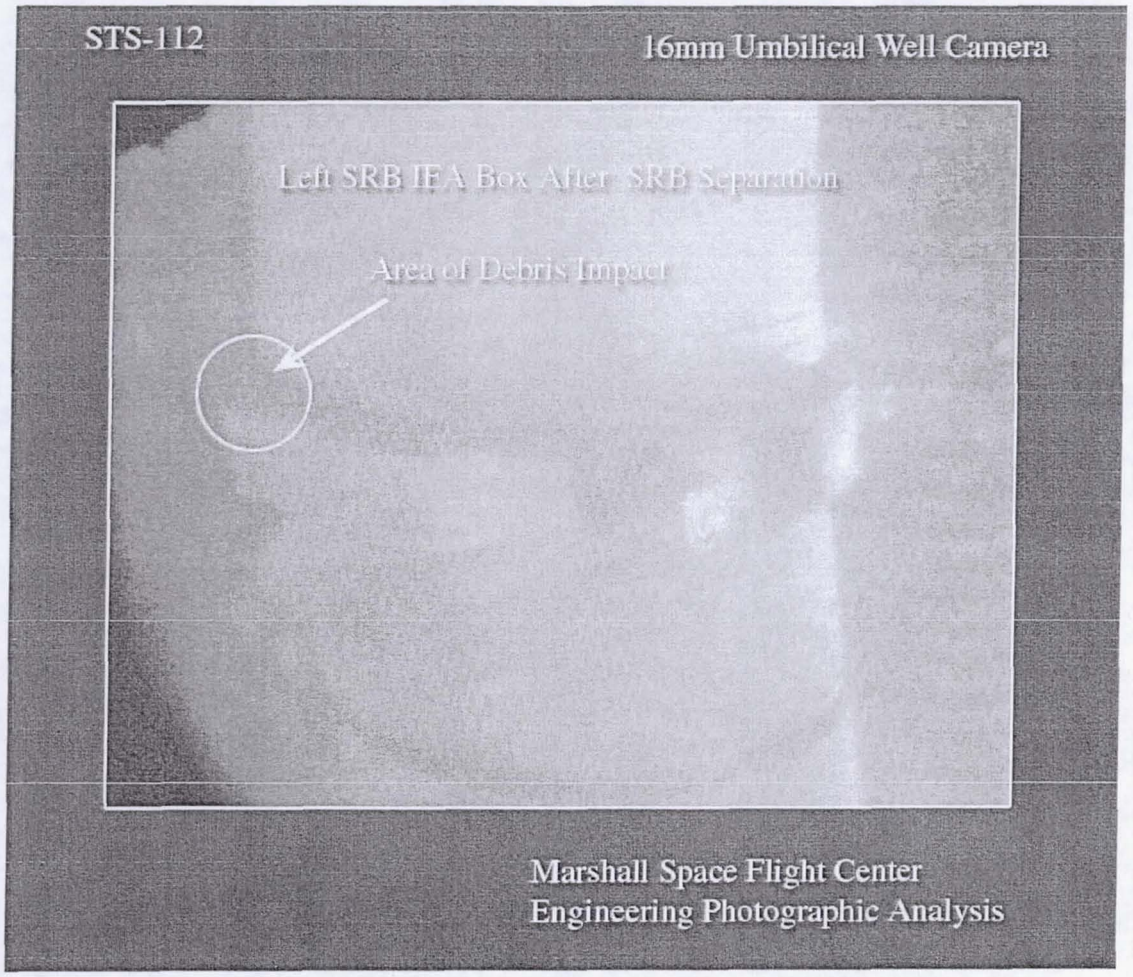


Figure 3. FL101: View of Left SRB IEA Box after SRB Separation

E220: Left SRB IEA Box Debris Impact Sequence

Numerous pieces of debris material are observed after impact with area near the left SRB IEA Box. Inserts illustrate the area prior to and during debris impact with the left SRB.

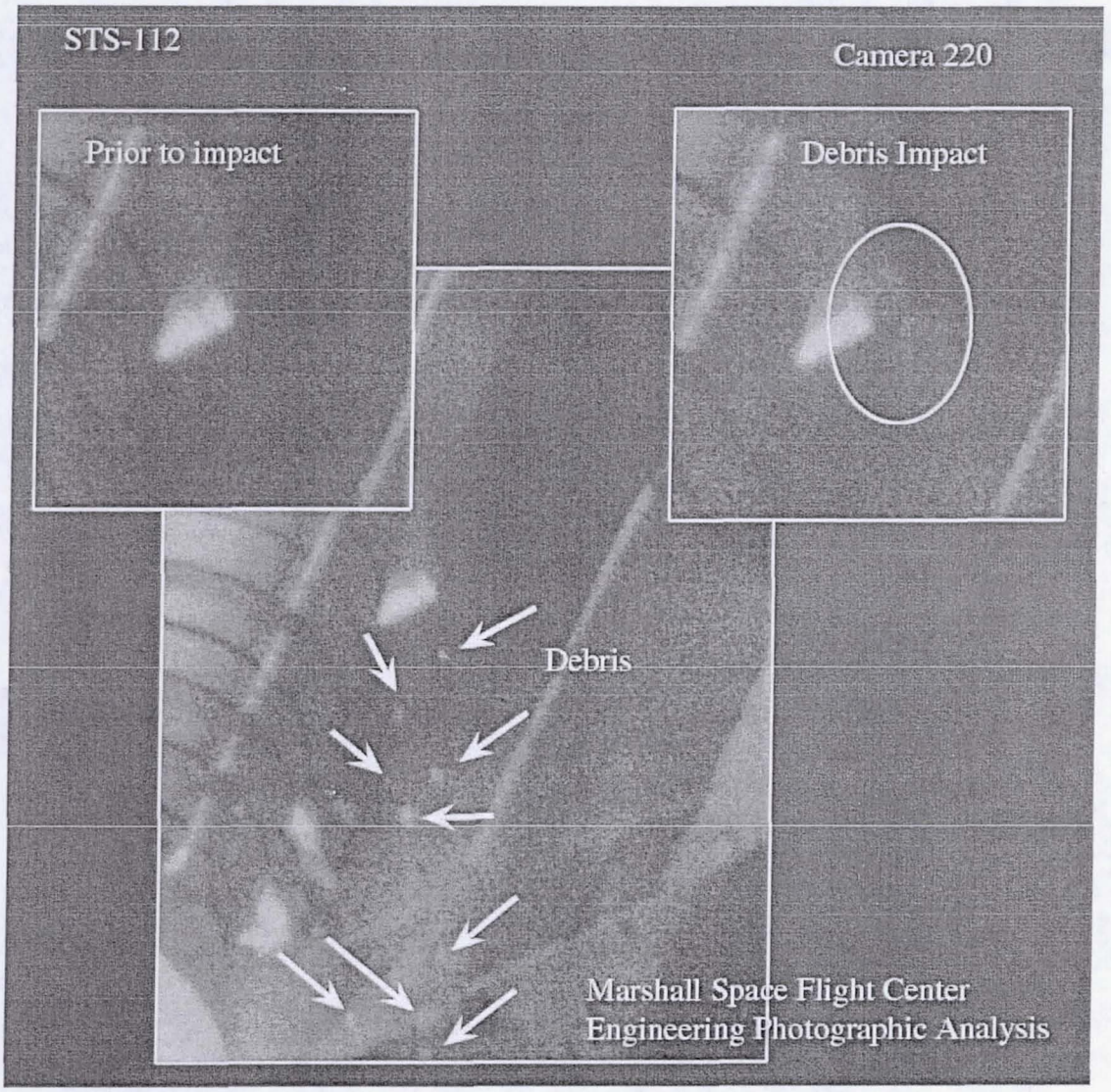


Figure 4. E220: Left SRB IEA Box Debris Impact Sequence

E222: Image Sequence of Debris Prior to Impact with IEA Box

Close-up images that clearly show the debris falling aft toward the Left SRB and finally impacting the IEA Box area. The arrows in the enhanced circular areas of each frame indicate the location of the debris.

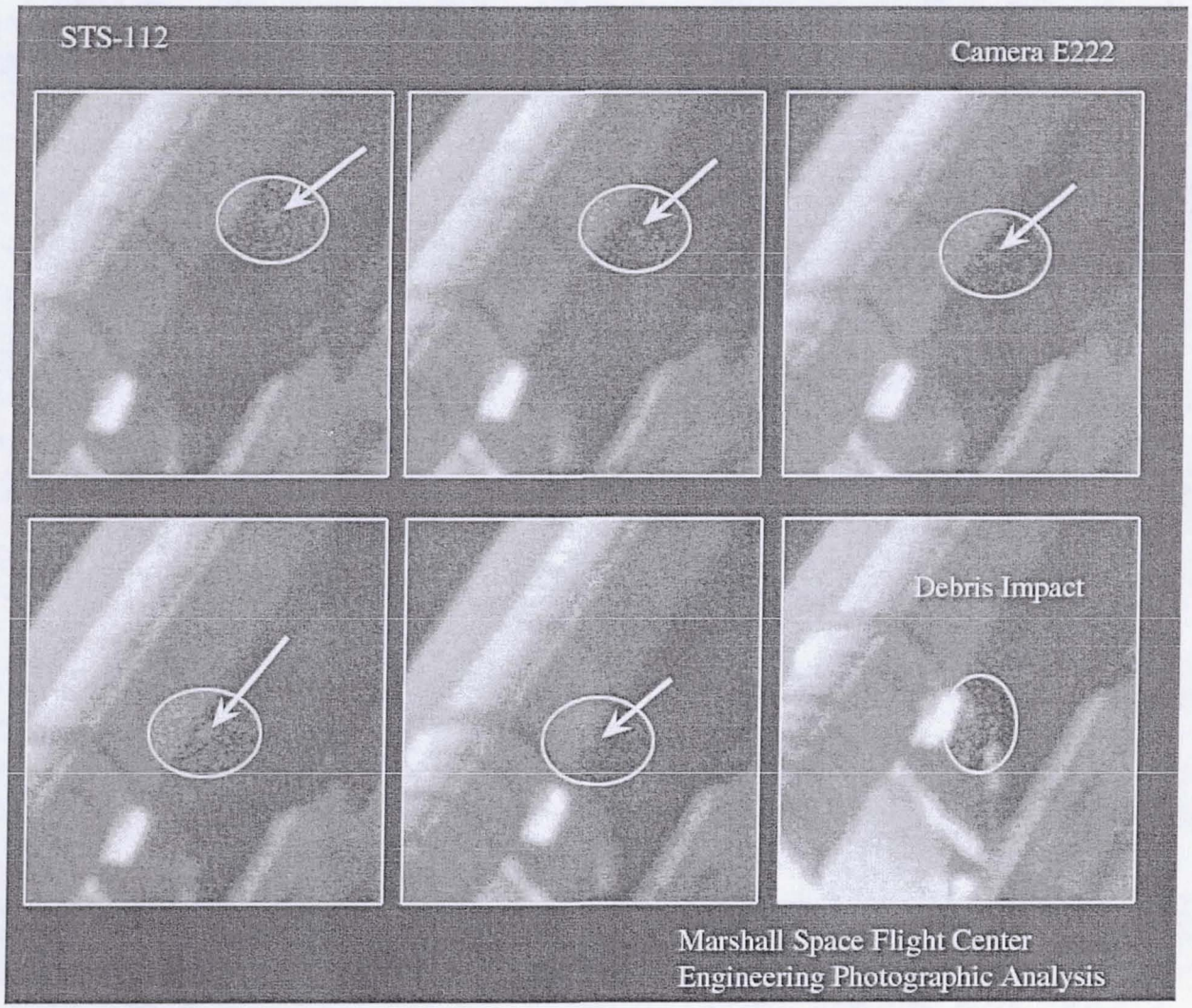


Figure 5. E222: Image Sequence of Debris Prior to Impact with IEA Box

E207: Debris Scatter from Left SRB IEA Box Impact

Although the Left SRB IEA Box was not imaged by film camera E207 at the time of impact, a spray of debris material was noted falling aft.

Figure 6. E207: Debris Scatter from Left SRB IEA Box Impact

Holddown Post M-3 Stud Hang-up

A stud hang-up was observed with the Holddown Post M-3 Bolt.

E010: Holddown Post M-3 Stud Hang-up

The RSRB Holddown Post M-3 Bolt was seen to hang up during liftoff. Stud hang-ups have occurred on previous missions. This event was imaged at 280:19:45:51.611 UTC.

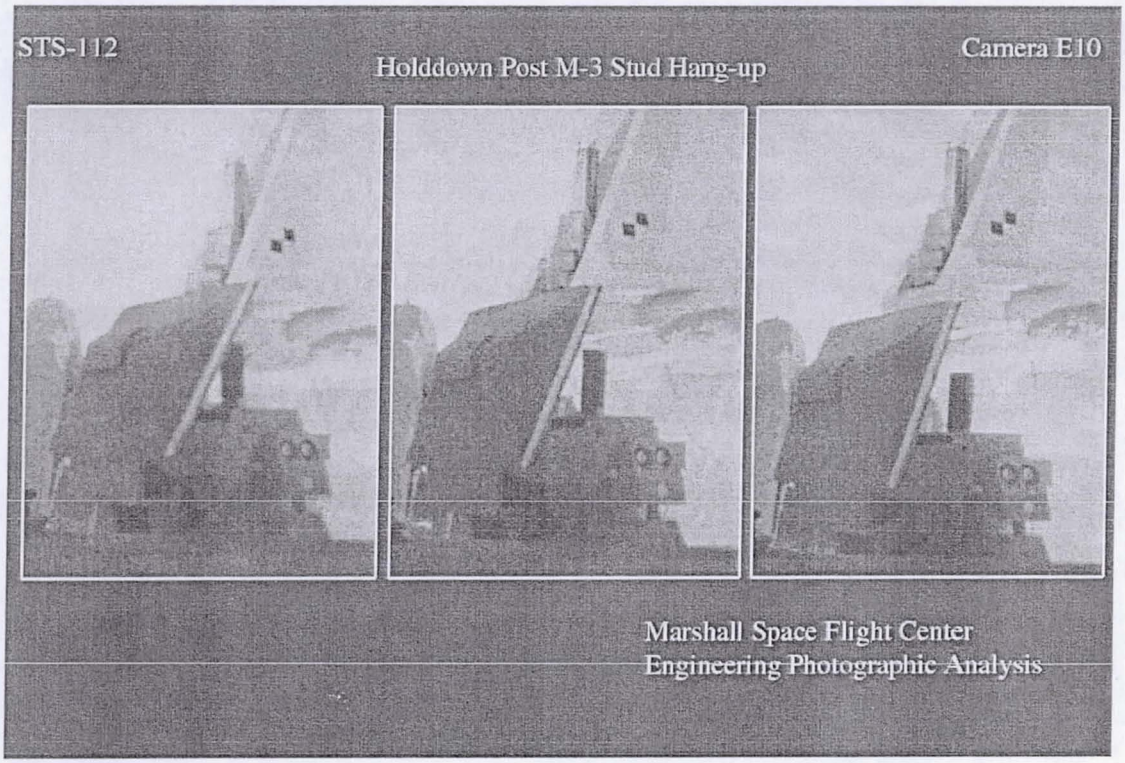


Figure 7. E010: Holddown Post M-3 Stud Hang-up

Observations

ETCAM: Debris Seen Over Right Wing Falling Aft

Debris was noted falling aft during ascent. The debris appears over the right Orbiter wing, but it is uncertain as to whether the debris is near the Orbiter wing.

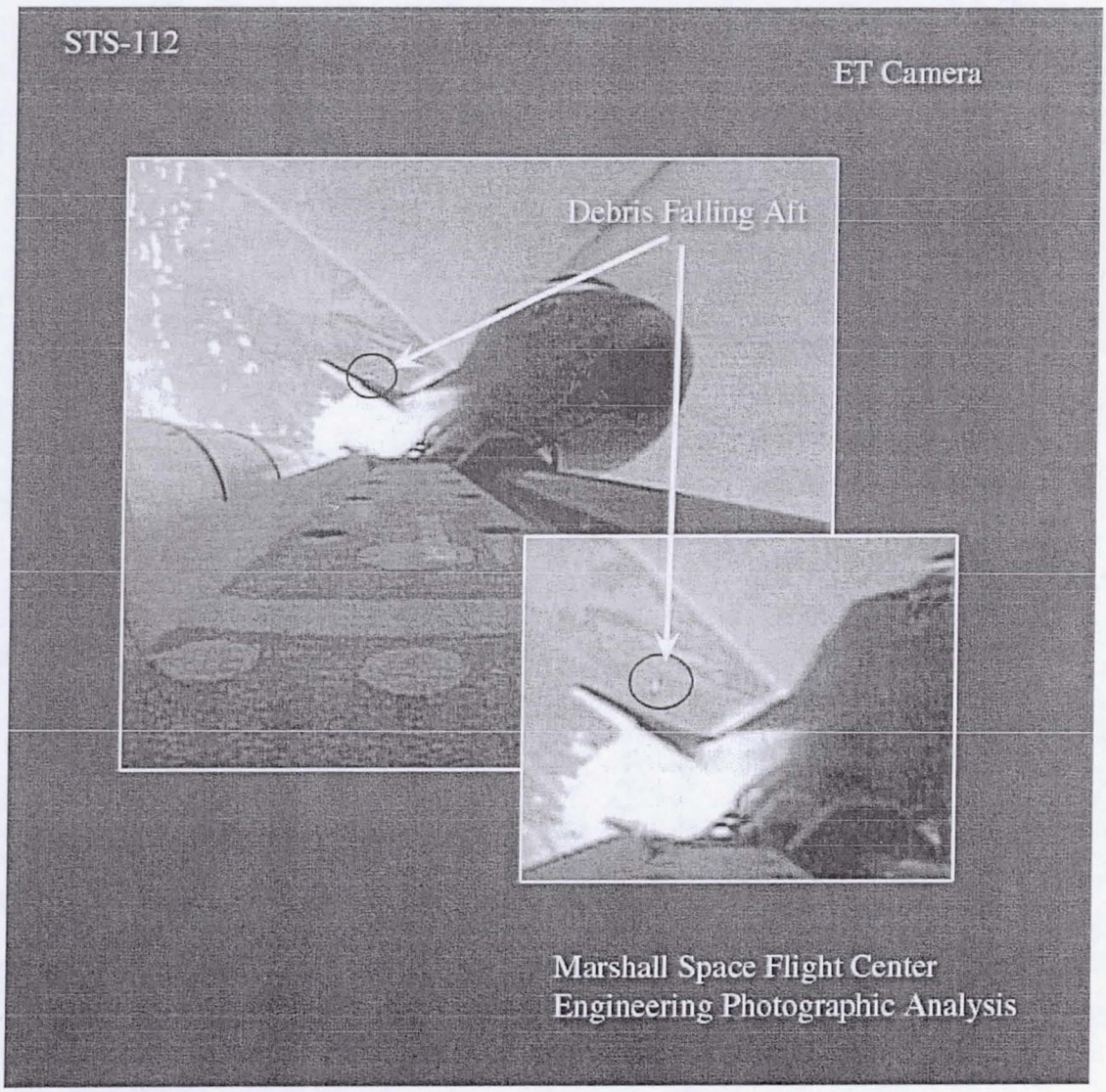


Figure 8. ETCAM: Debris Seen Over Right Wing Falling Aft

ETCAM: Debris Falling Aft from Forward of Camera

Several debris items were noted just after liftoff. These debris items were falling aft from forward of the camera.

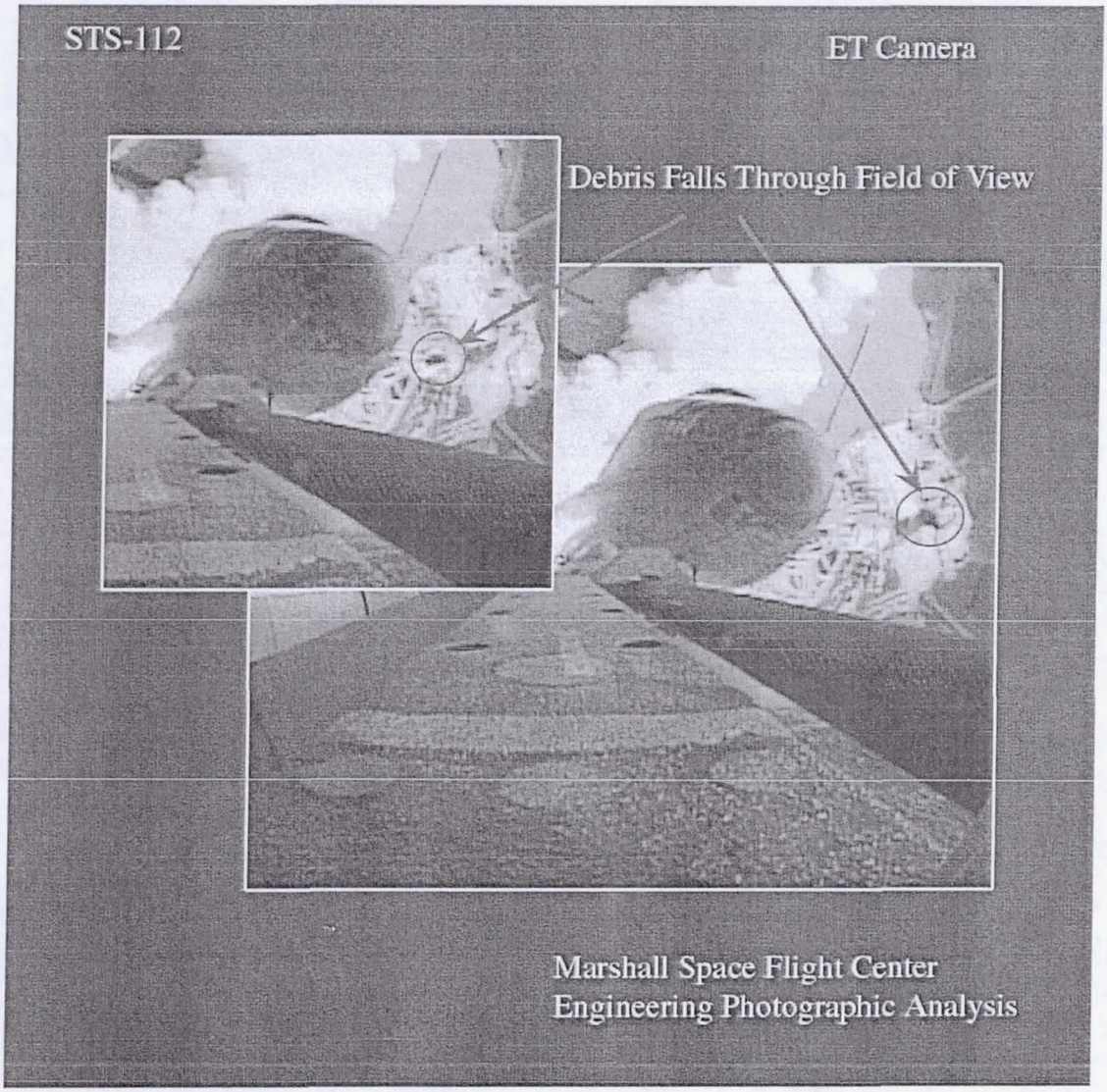


Figure 9. ETCAM: Debris Falling Aft from Forward of Camera

ETCAM: Debris Falling Aft

Debris was observed falling aft of the vehicle during ascent.

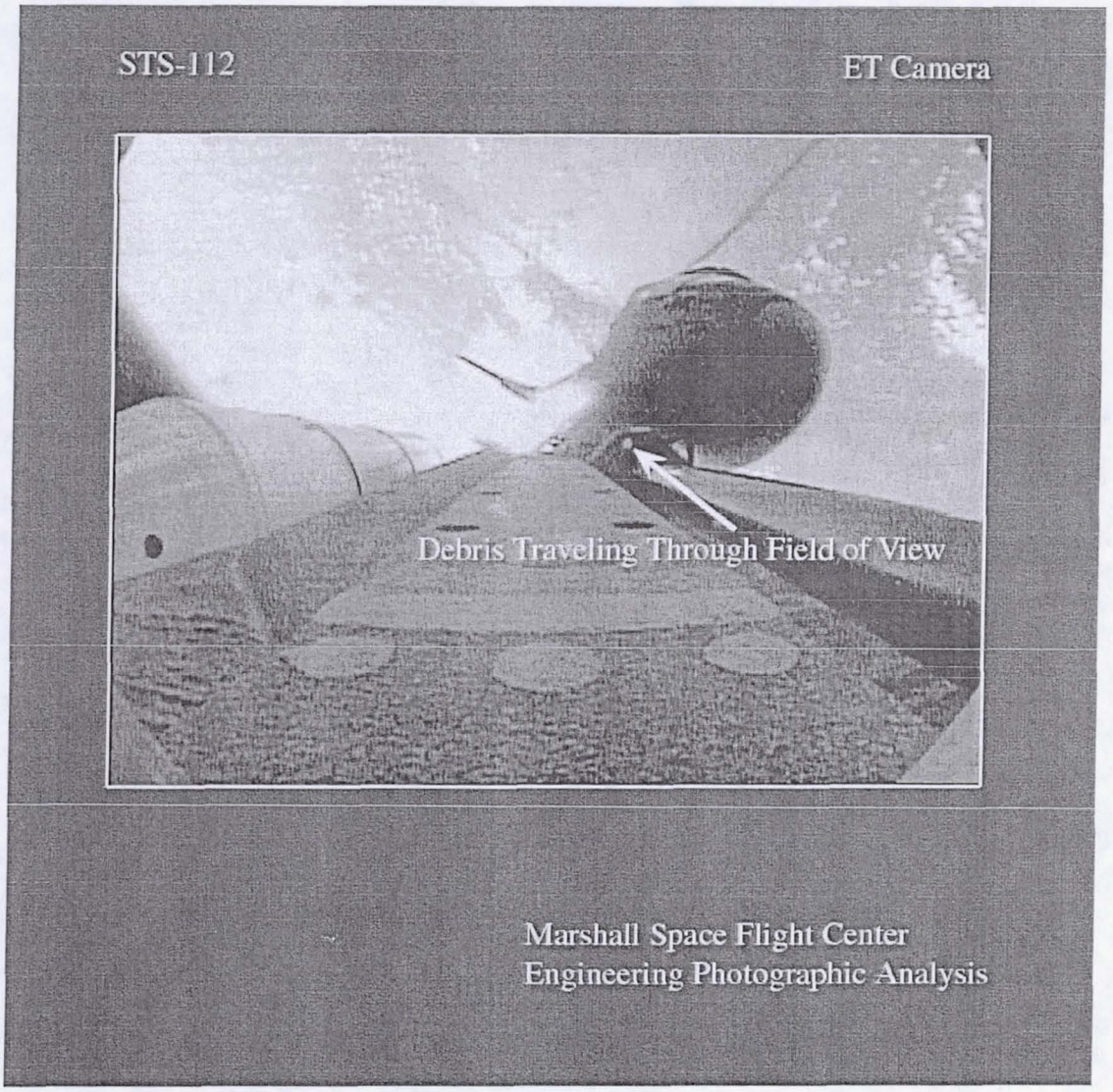


Figure 10. ETCAM: Debris Falling Aft

ET207: Flow Recirculation

Glow from hot recirculating combustion gases near the aft dome, "Flow Recirculation", was observed on this mission. This is a typical and expected observation.

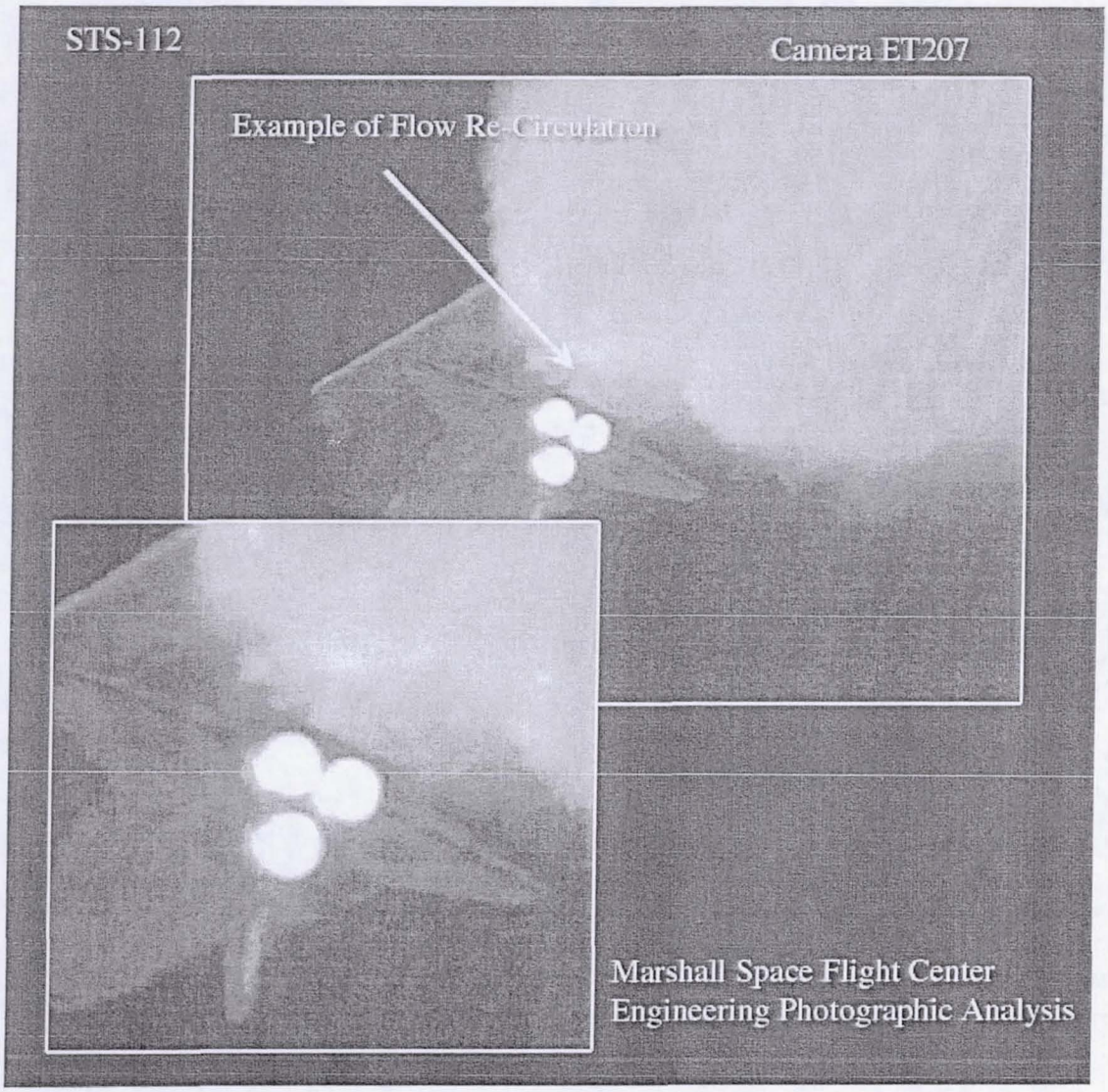


Figure 11. ET207: Flow Recirculation

ET207: Linear Optical Distortion

Several Linear Optical Distortions were observed during this mission. Linear Optical Distortions are a common observation.

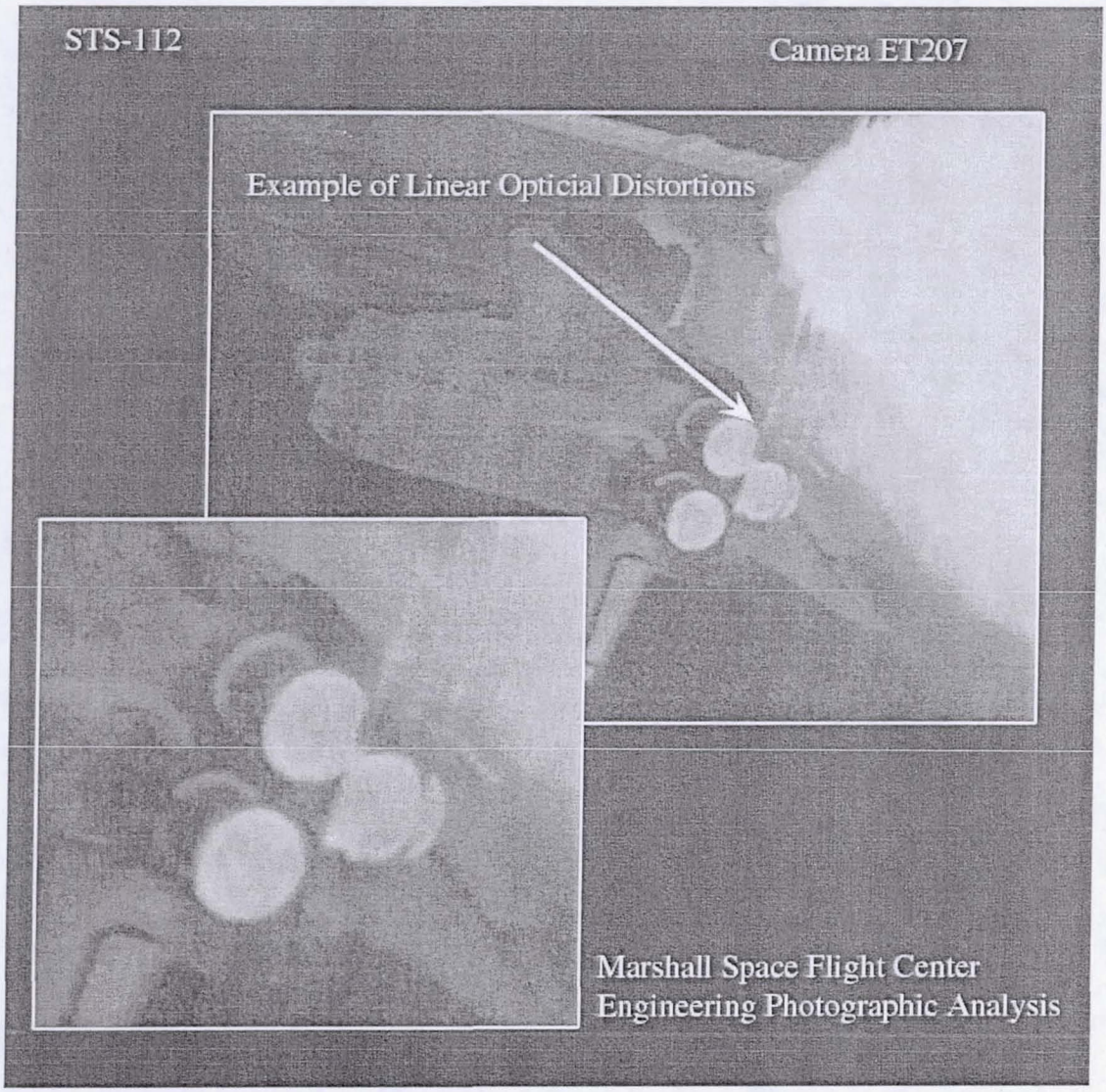


Figure 12. ET207: Linear Optical Distortion

ET207: Slag Ejected from SRB Plumes at SRB Separation

Glowing debris particles, probably SRB slag, was ejected from the SRB plumes at SRB separation. This is a typical observation.

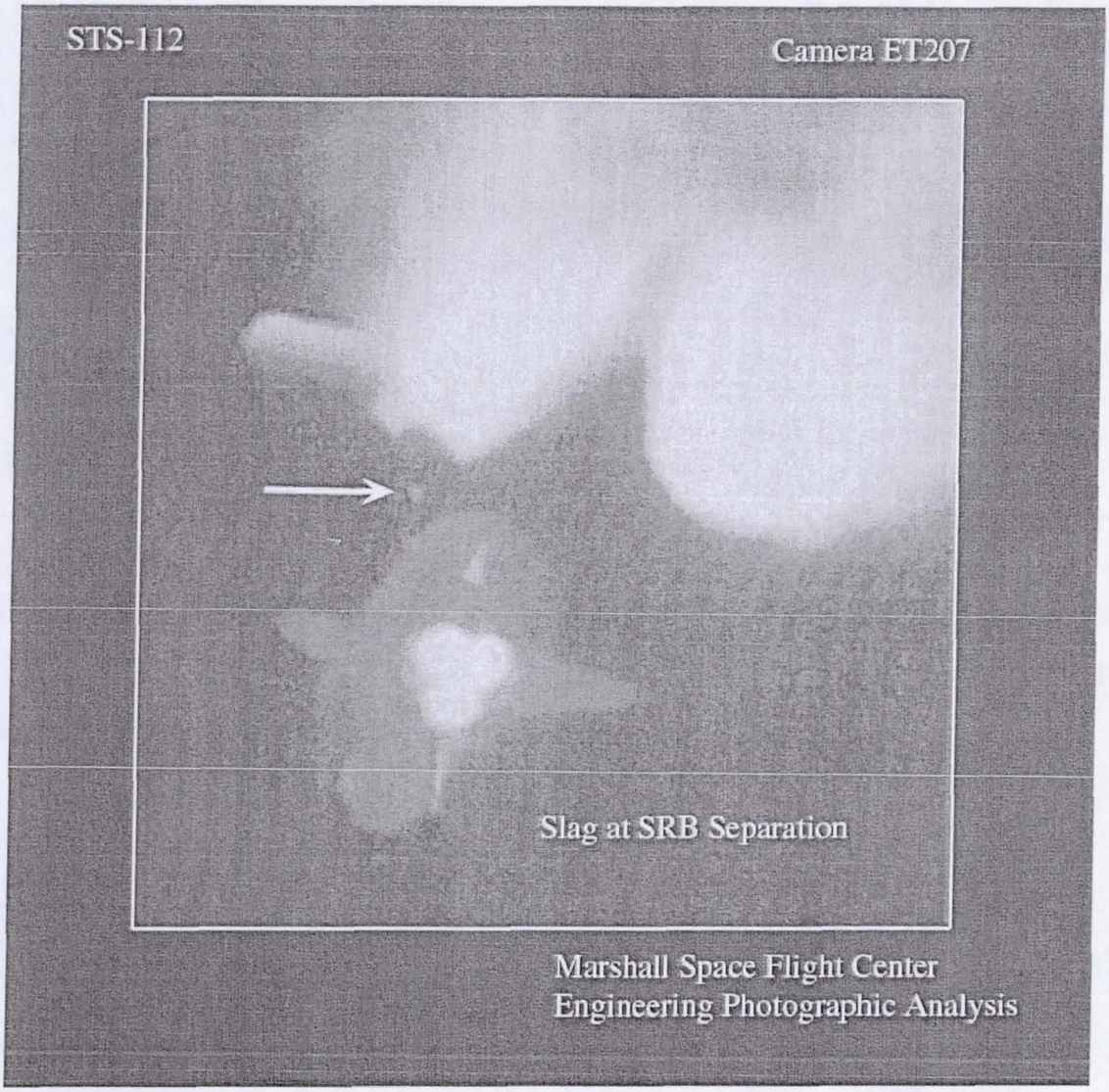


Figure 13. ET207: Slag Ejected from SRB Plumes at SRB Separation

ET207: OMS Burn after SRB Separation

The slightly orange colored streak noted near the SSME exhaust is indicative of the OMS Assist burn. This is a typical observation for this event.

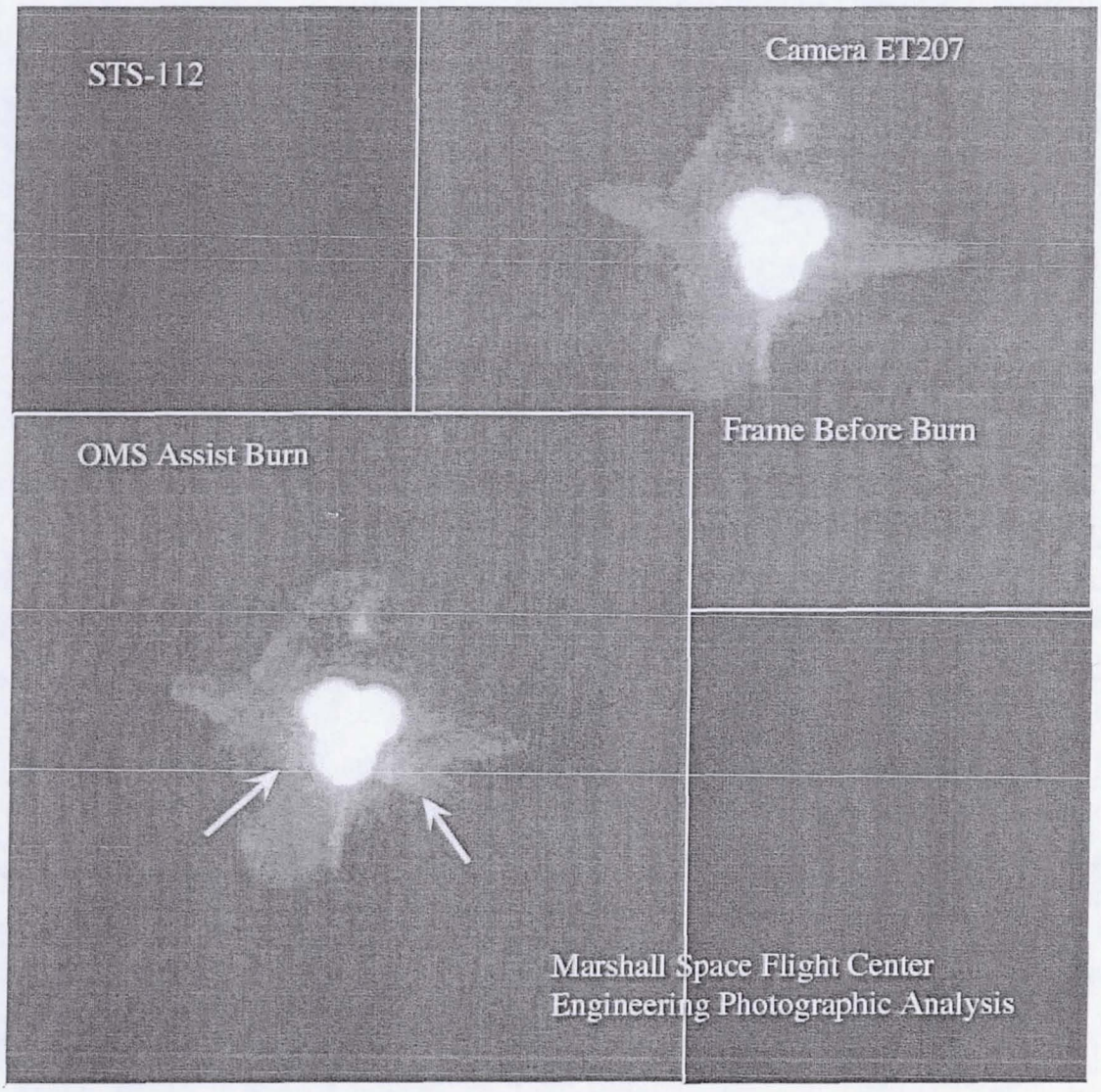


Figure 14. ET207: OMS Burn after SRB Separation

ET212: Debris Ejected from SRB Plumes Prior to SRB Separation

Debris was ejected from the SRB plumes during ascent.

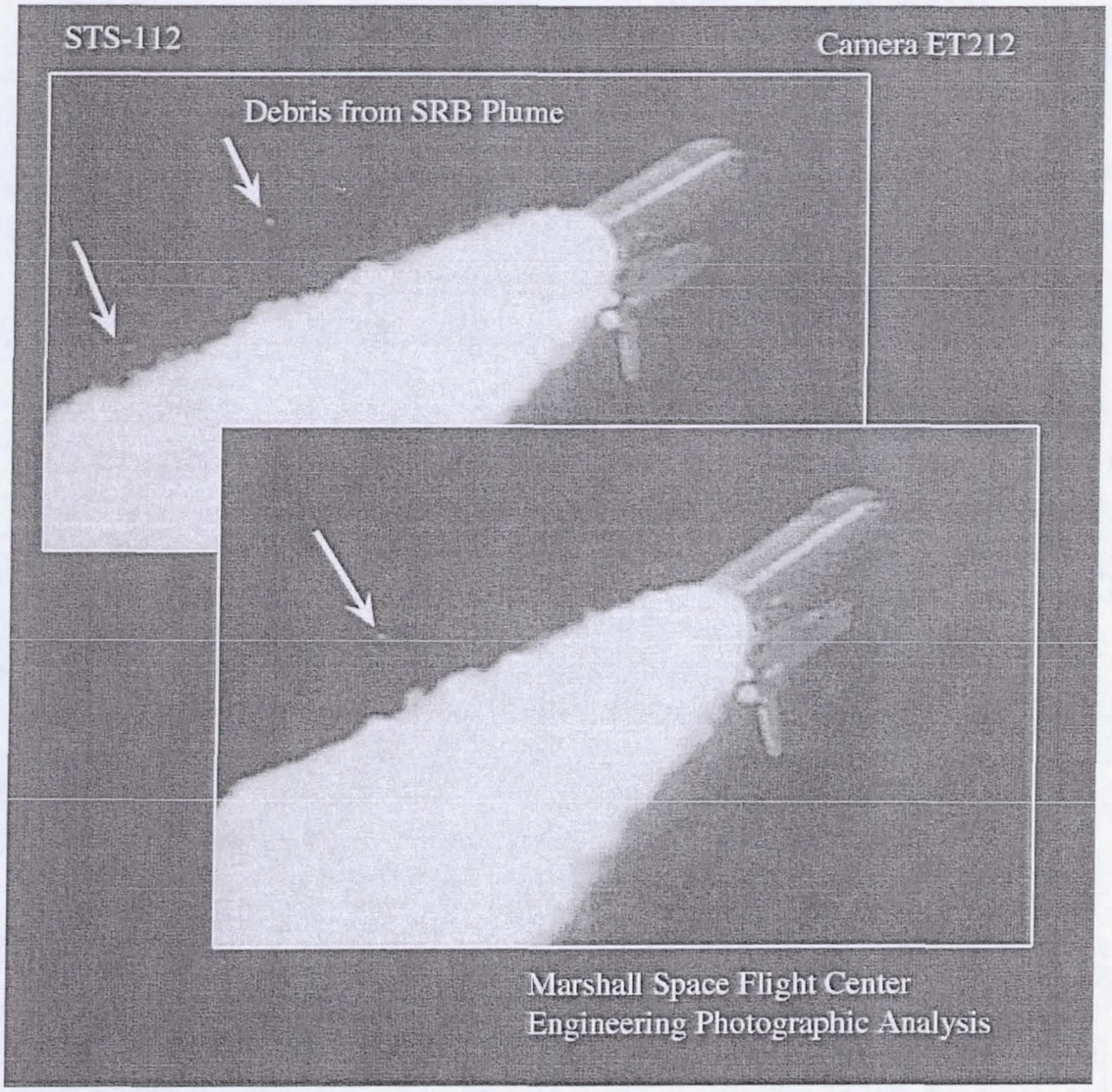


Figure 15. ET212: Debris Ejected from SRB Plumes Prior to SRB Separation

OTV154: Ice/Frost Striking Umbilical Well Door Sill

Ice/frost was observed striking the LO2 Umbilical Well Door Sill. No damage to the vehicle was noted. This is a common observation.

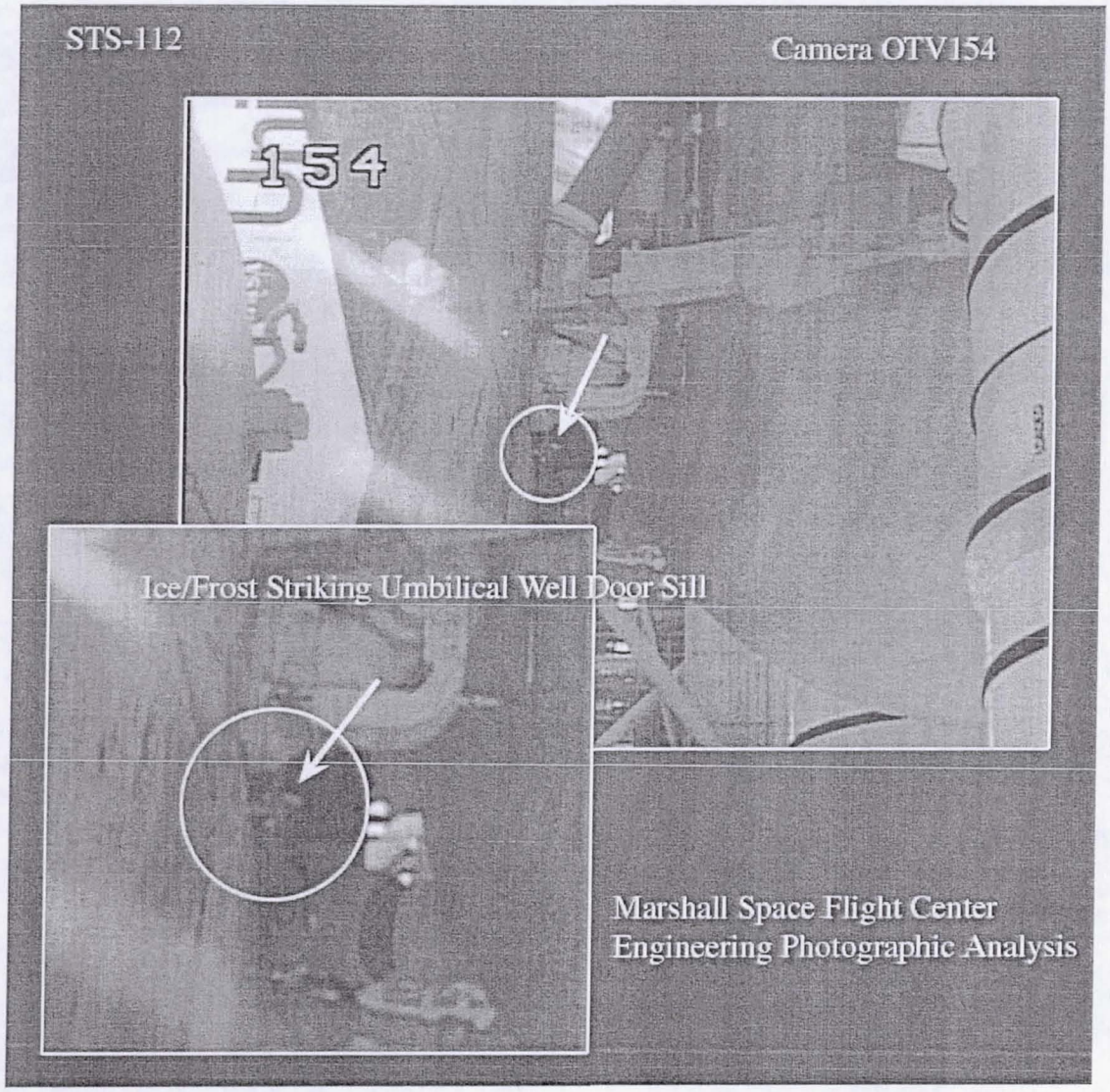


Figure 16. OTV154: Ice/Frost Striking Umbilical Well Door Sill

OTV109: Debris Falling Aft of Vehicle at Liftoff

A fast moving debris particle was imaged as it fell aft of the vehicle. This is a common observation.

Figure 17. OTV109: Debris Falling Aft of Vehicle at Liftoff

OTV170: Free Burning Hydrogen

An orange-colored vapor was noted near vertical stabilizer at SSME ignition. This is a typical observation and is assumed to be an indicator of free burning Hydrogen.

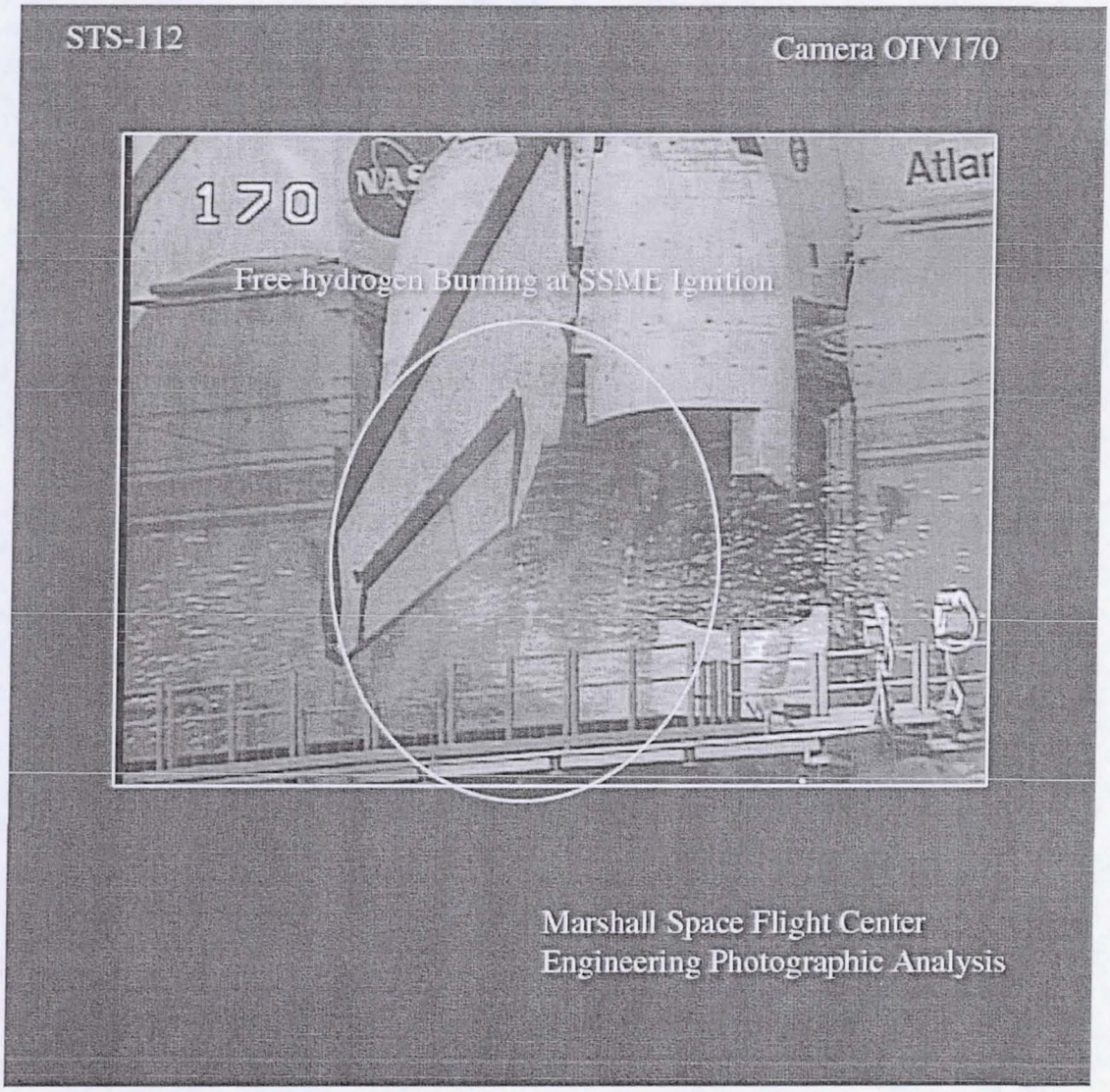


Figure 18. OTV170: Free Burning Hydrogen

E002: Late Occurring SSME Plume Bulge

A bulge in SSME#1 plume was observed, beginning at 280:19:45:47.611 UTC, or approximately 2.9 seconds after SSME#1 start time (280:19:45:44.694 UTC). This is similar to the bulge noted in SSME#1 plume on missions STS-111 and STS-110.

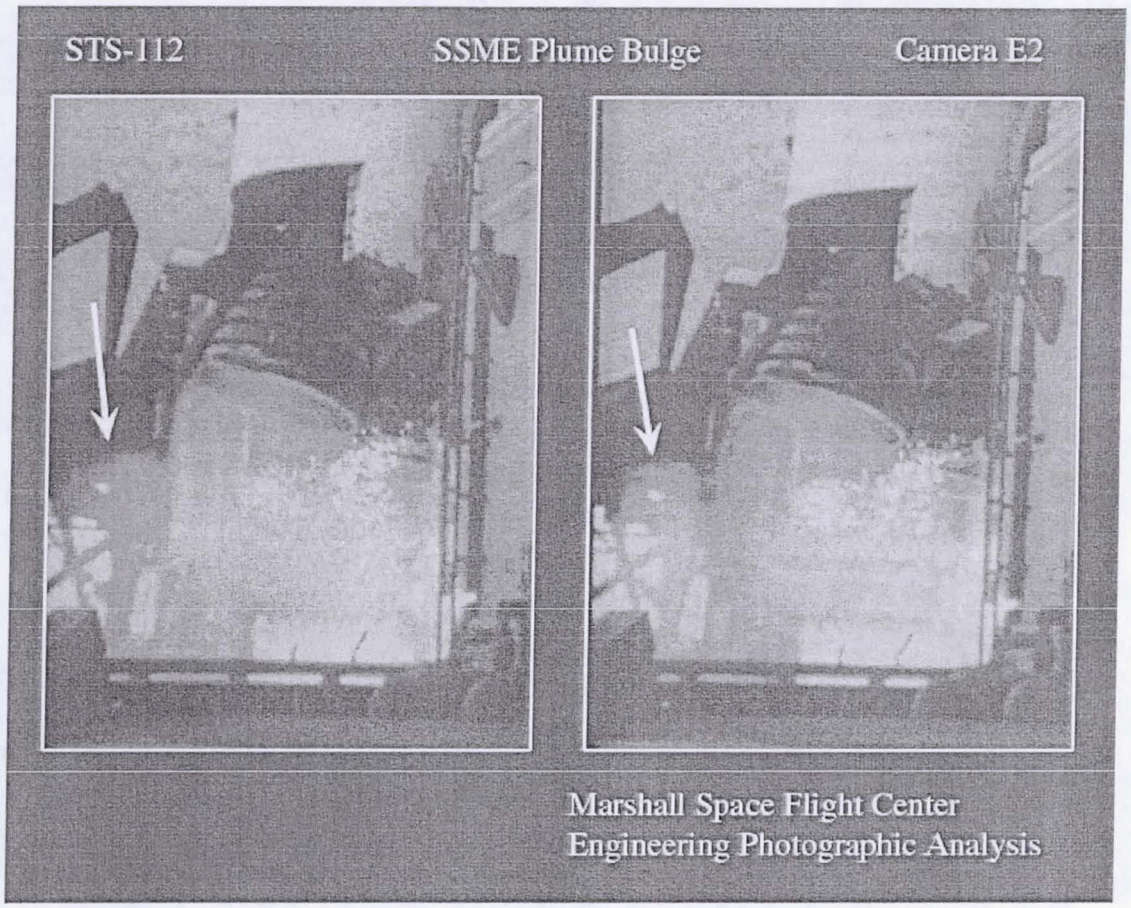


Figure 19. E002: Late Occurring SSME Plume Bulge

OTV170: Late Occurring SSME Plume Bulge

A view of an SSME#1 plume bulge from video camera OTV170. This is the same plume bulge noted and imaged from film camera E002.

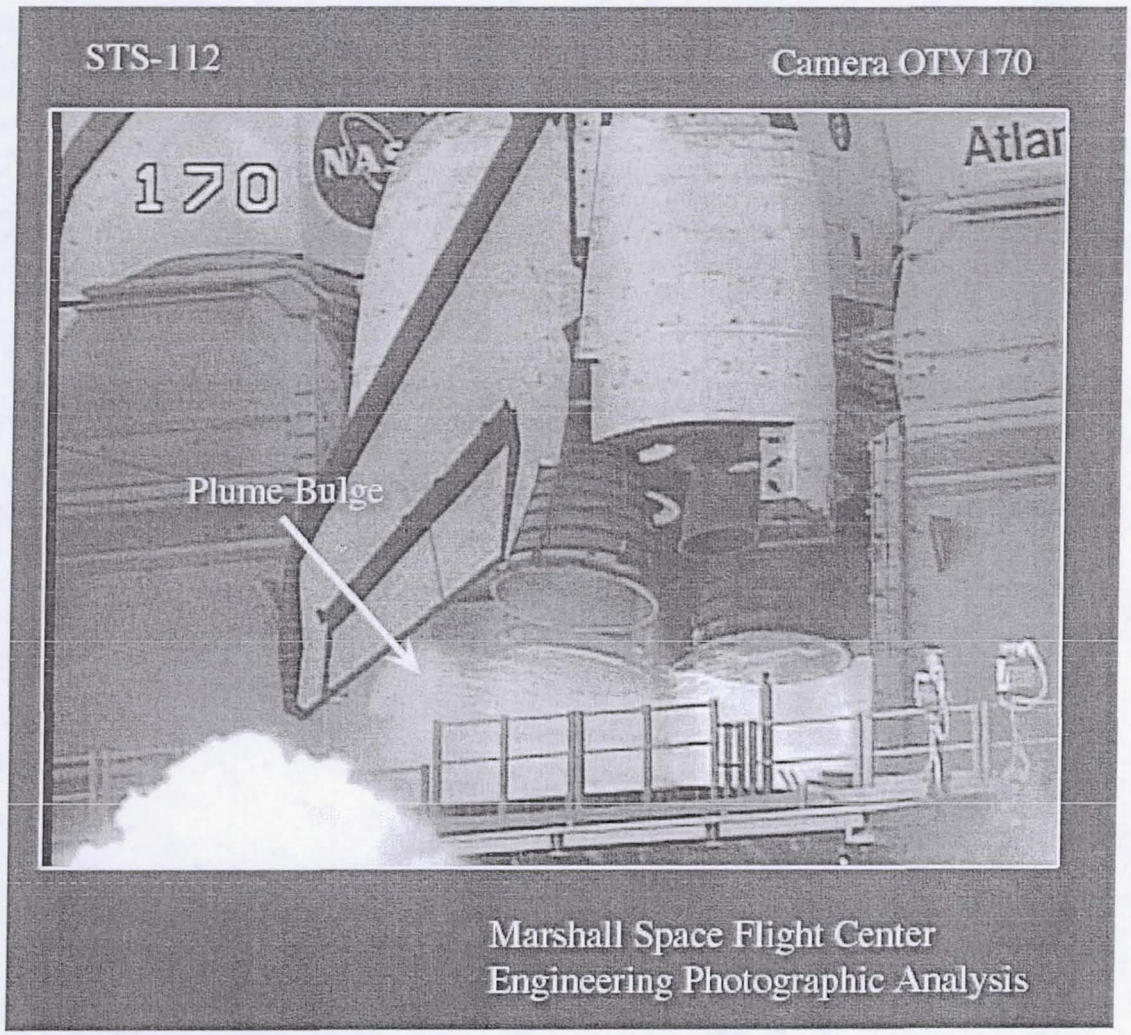


Figure 20. OTV170: Late Occurring SSME Plume Bulge

OTV148: Debris Noted Traveling Towards MLP

Debris was noted traveling towards MLP just after liftoff.

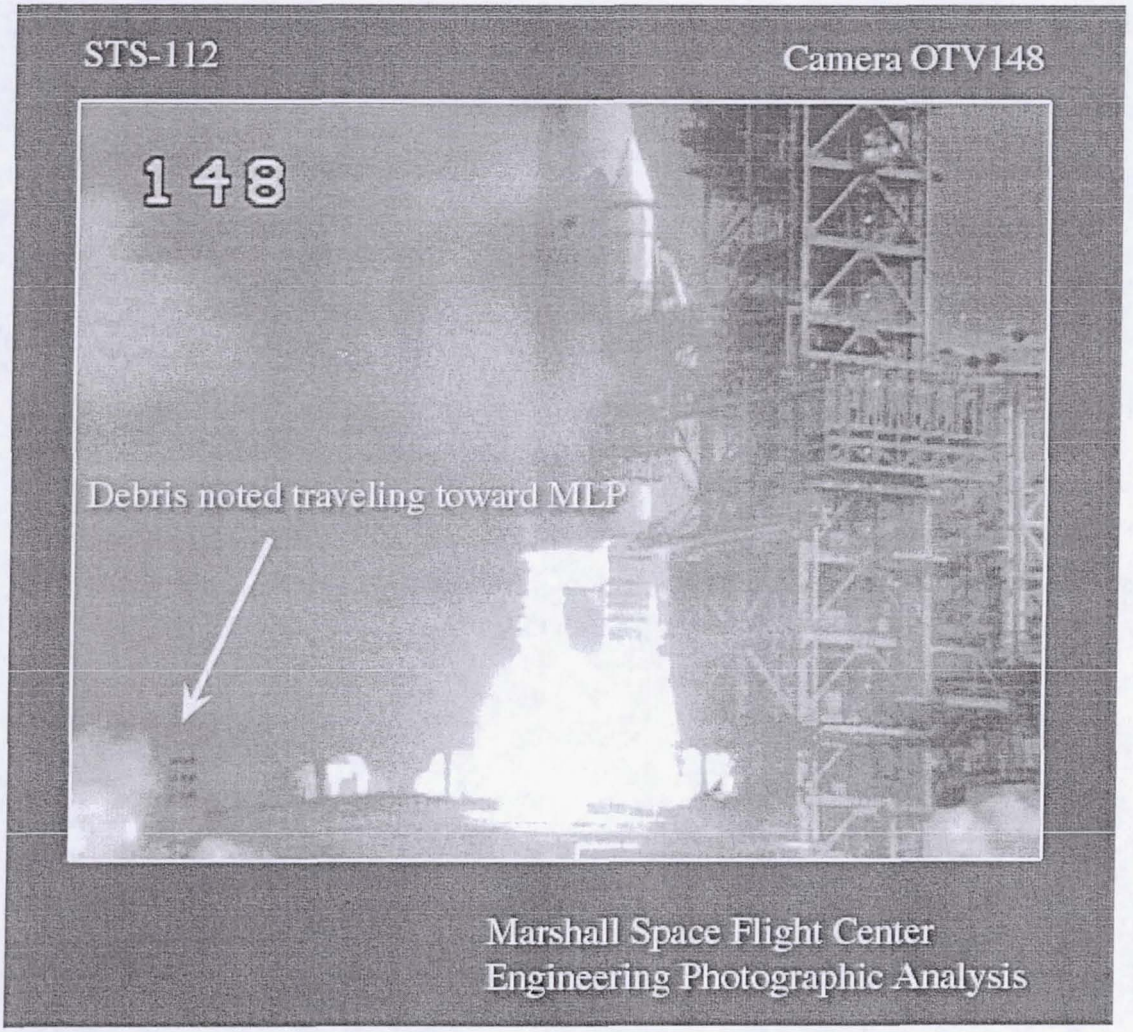


Figure 21. OTV148: Debris Noted Traveling Towards MLP

TV004B: Debris Falling Aft

Typical debris falling aft of the vehicle was imaged. At this time during ascent, Instafoam is the likely source for the debris ejected from the SRB plumes.

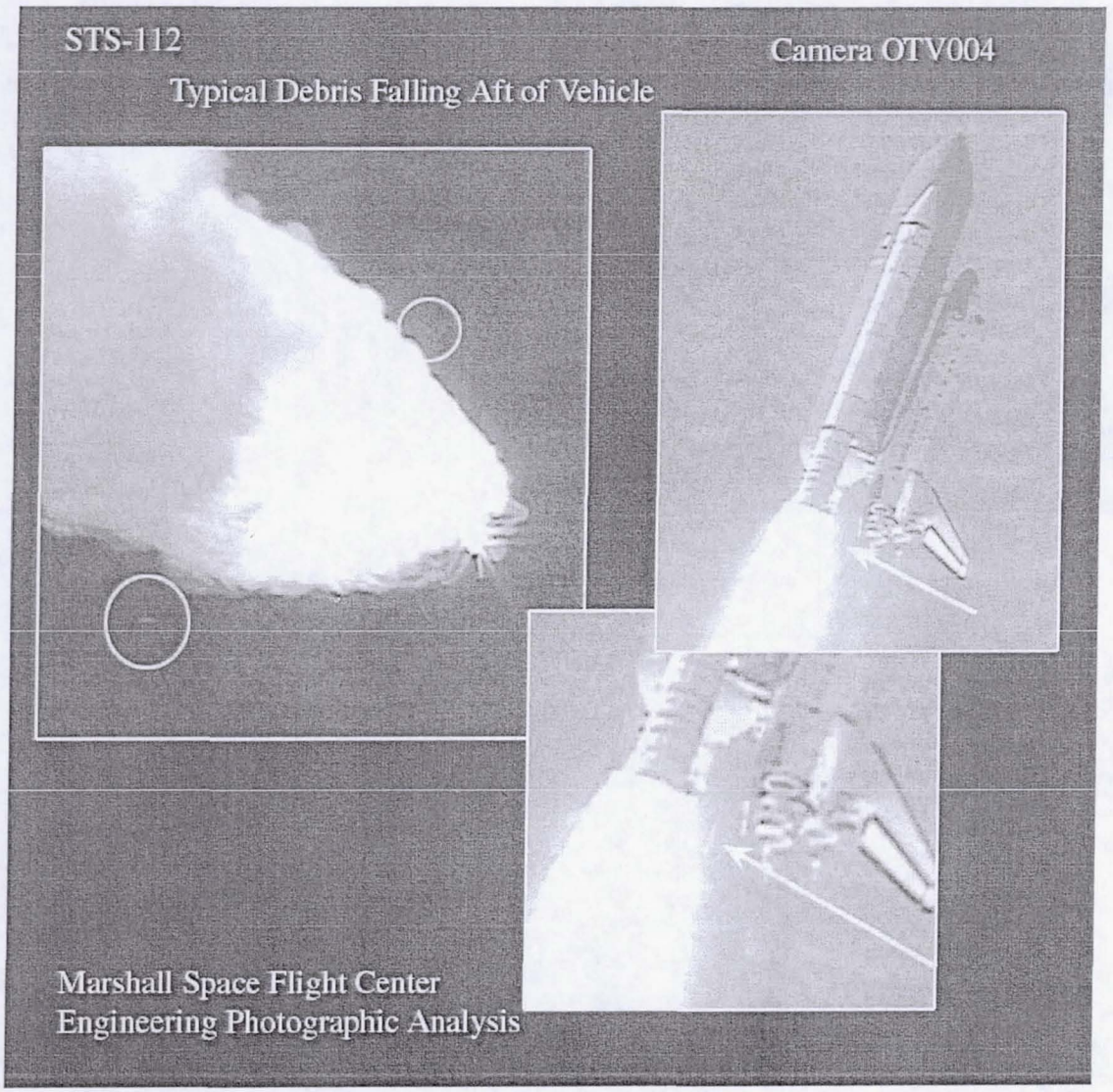


Figure 22. TV004B: Debris Falling Aft

E222: Purge Barrier Material Debris Falling Aft

Umbilical Well Purge Barrier material is a frequent source of debris.

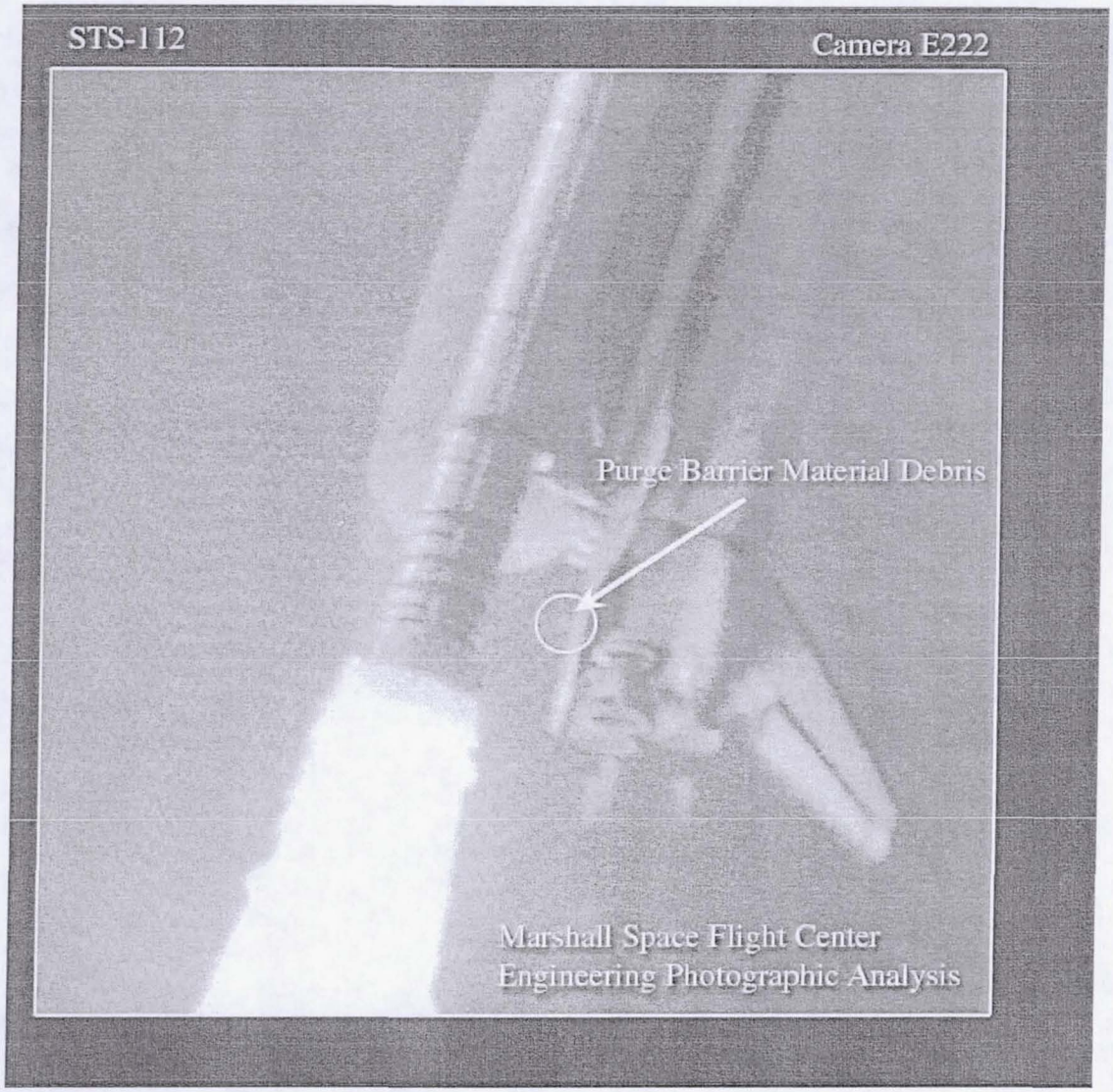


Figure 23. E222: Purge Barrier Material Debris Falling Aft

E207: OMS Burn after SRB Separation

The slightly orange colored streak noted near the SSME exhaust is indicative of the OMS Assist burn. This OMS Assist burn was imaged at 280:19:48:03.213 UTC, approximately 10 seconds after SRB separation. Due to the clarity of the viewing conditions, the OMS burn was seen to persist for some time, note the arrows pointing to the small glow emanating from the OMS motors.

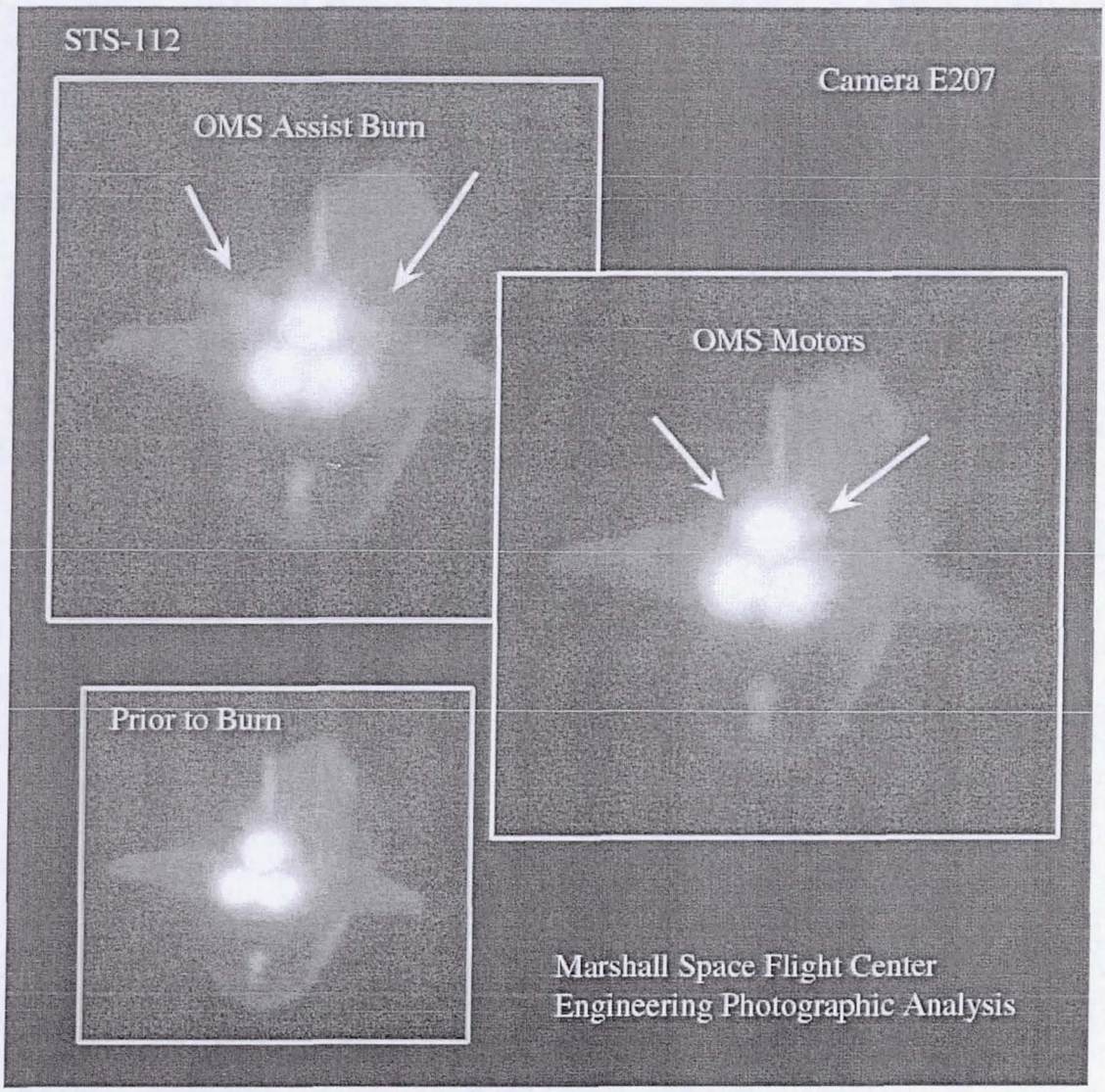


Figure 24. E207: OMS Burn after SRB Separation

E212: Debris Ejected from SRB Plumes

Debris was ejected from the SRB plumes during ascent. Also imaged at this time were Linear Optical Distortions.

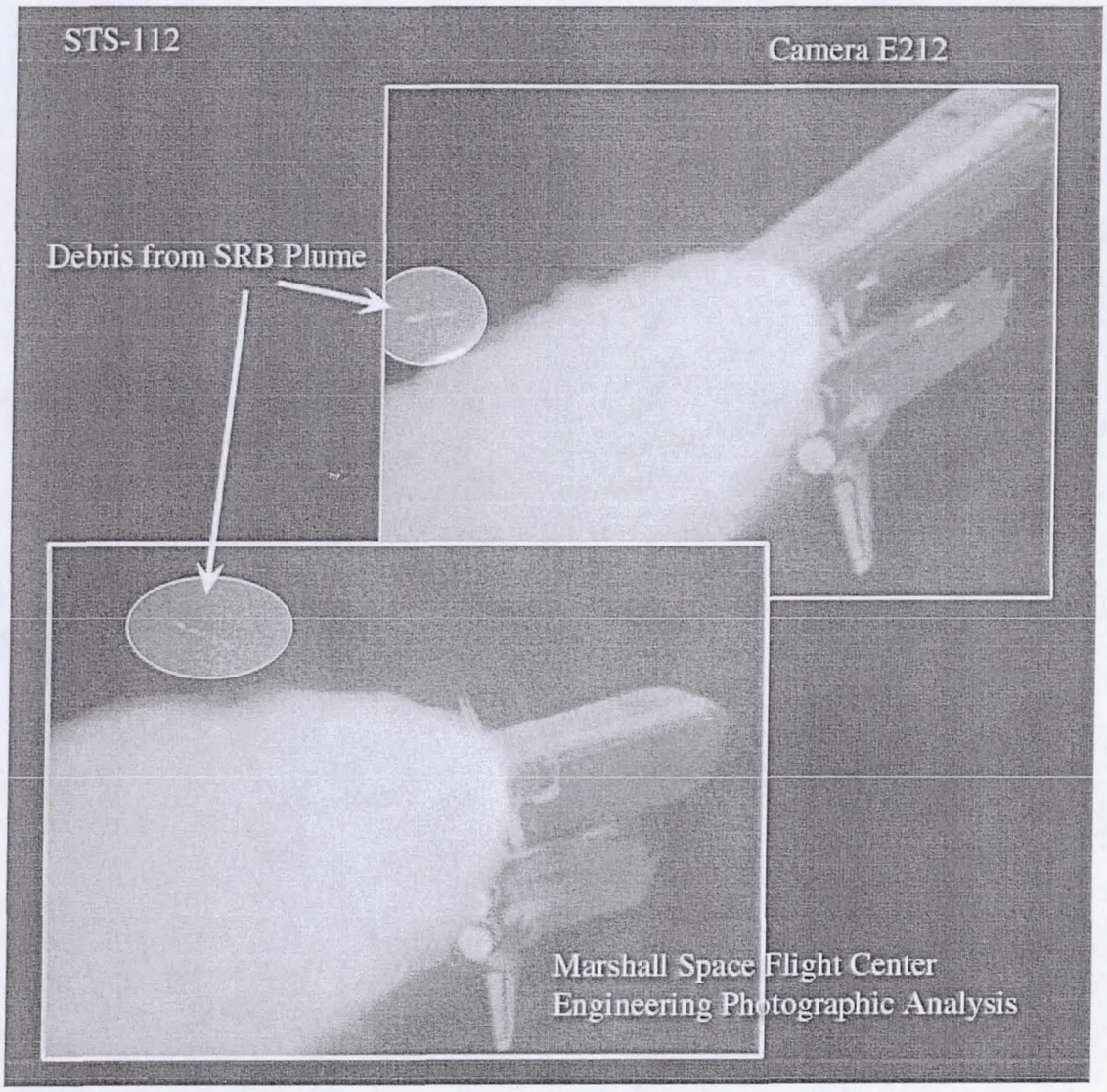


Figure 25. E212: Debris Ejected from SRB Plumes

E013: Pyrotechnic Cable Stays Attached to Vehicle

The left-hand Pyrotechnic Cable for Holddown Post M-6 was noted to remain attached during liftoff. The attached cable was imaged at 280:19:45:51.889 UTC.

It was learned that during STS-112 launch, the "A Circuit" on the Left SRB failed to initiate firing. This failure would aid in preventing the explosive from severing the left (A side) Pyrotechnic Cable and as a result, the cable would likely remain attached until snapped by separation of the HDP from the booster. It was also noted that the left (A side) cable on other HDP's was stretched further than the cable on the right before being snapped.

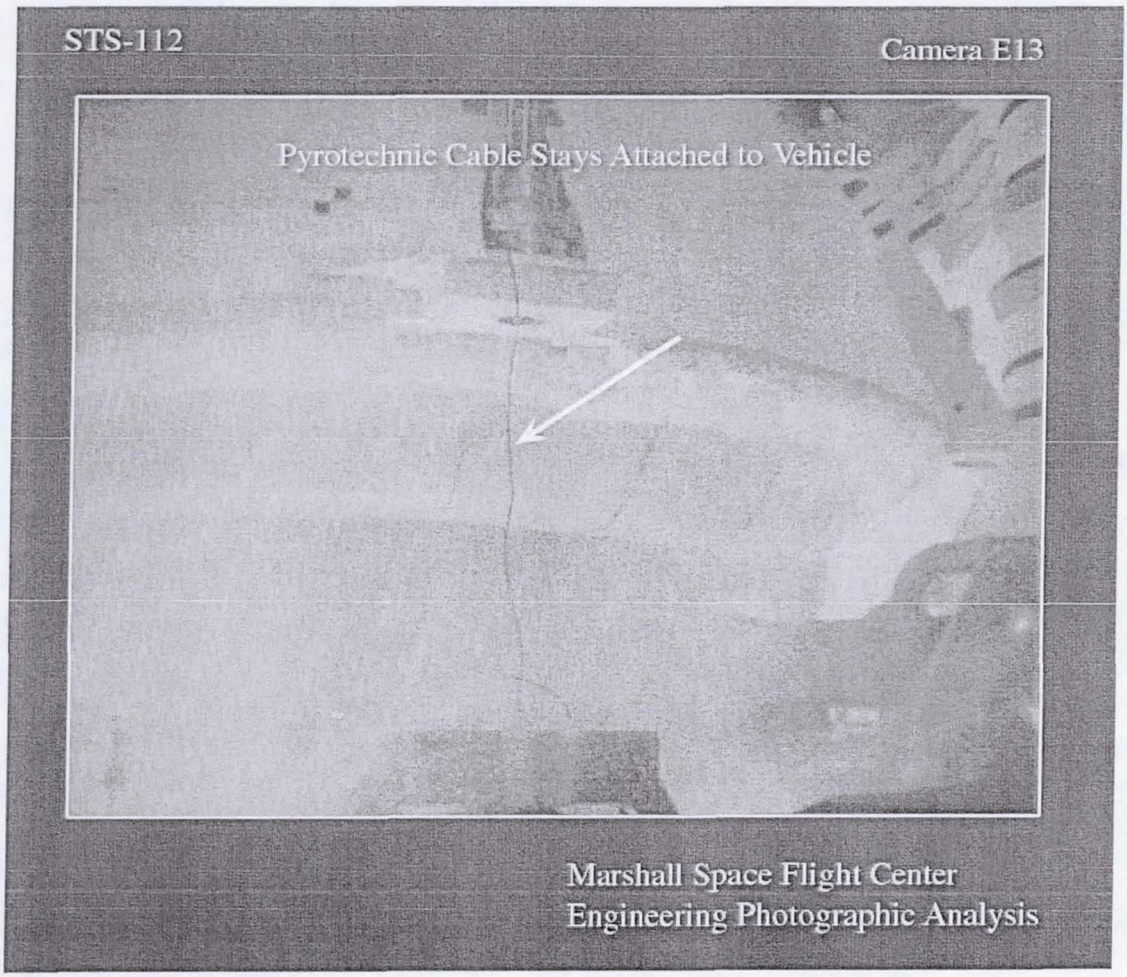


Figure 26. E013: Pyrotechnic Cable Stays Attached to Vehicle

E040: Pyrotechnic Cable Remains Attached to Left SRB

The left-hand Pyrotechnic Cable for Holddown Post M-6 was noted to remain attached to the Left SRB as it clears the FSS.

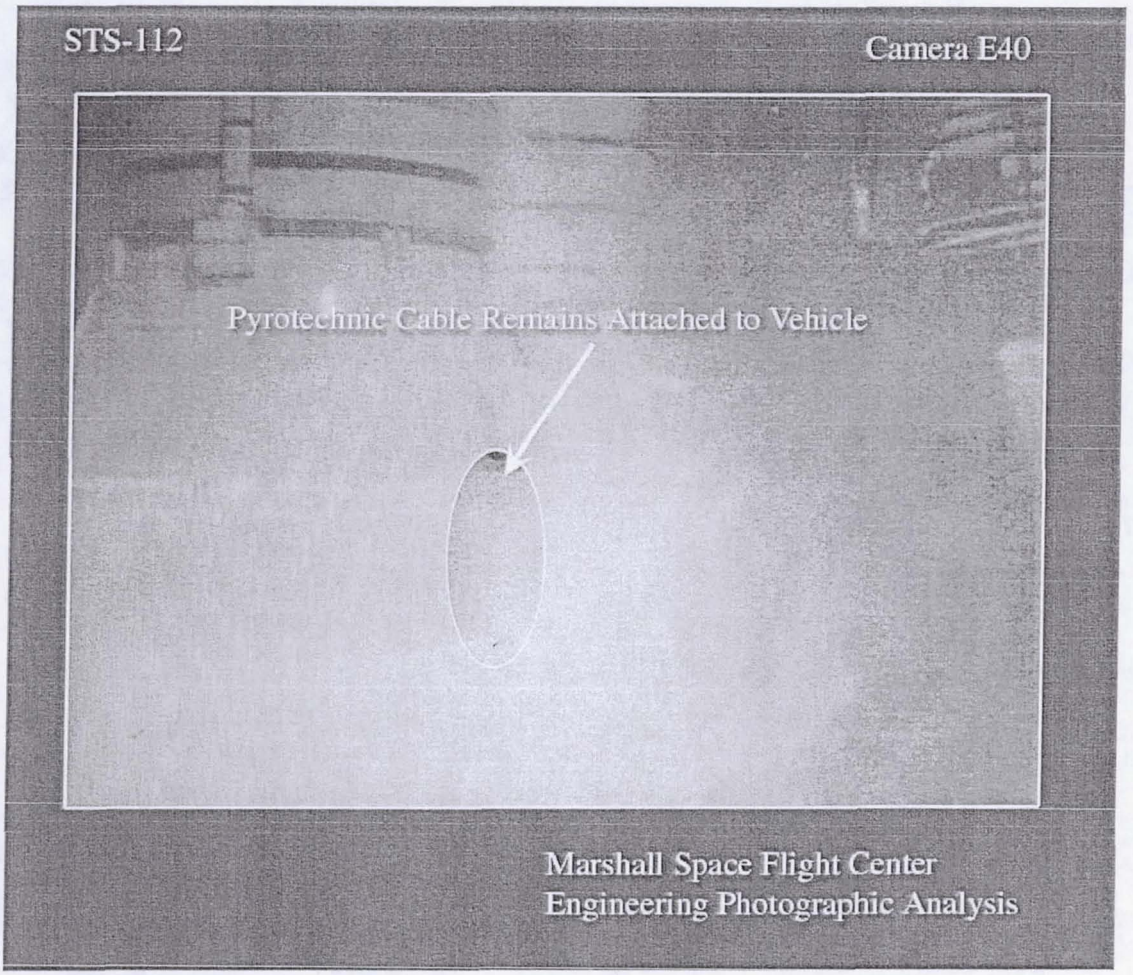


Figure 27. E040: Pyrotechnic Cable Remains Attached to Left SRB

E017: Ice/Frost from LO2 T-0 Umbilical

A notable amount of ice/frost fell from the LO2 T-0 Umbilical. Ice/frost falling from the LO2 T-0 Umbilical is a common event.

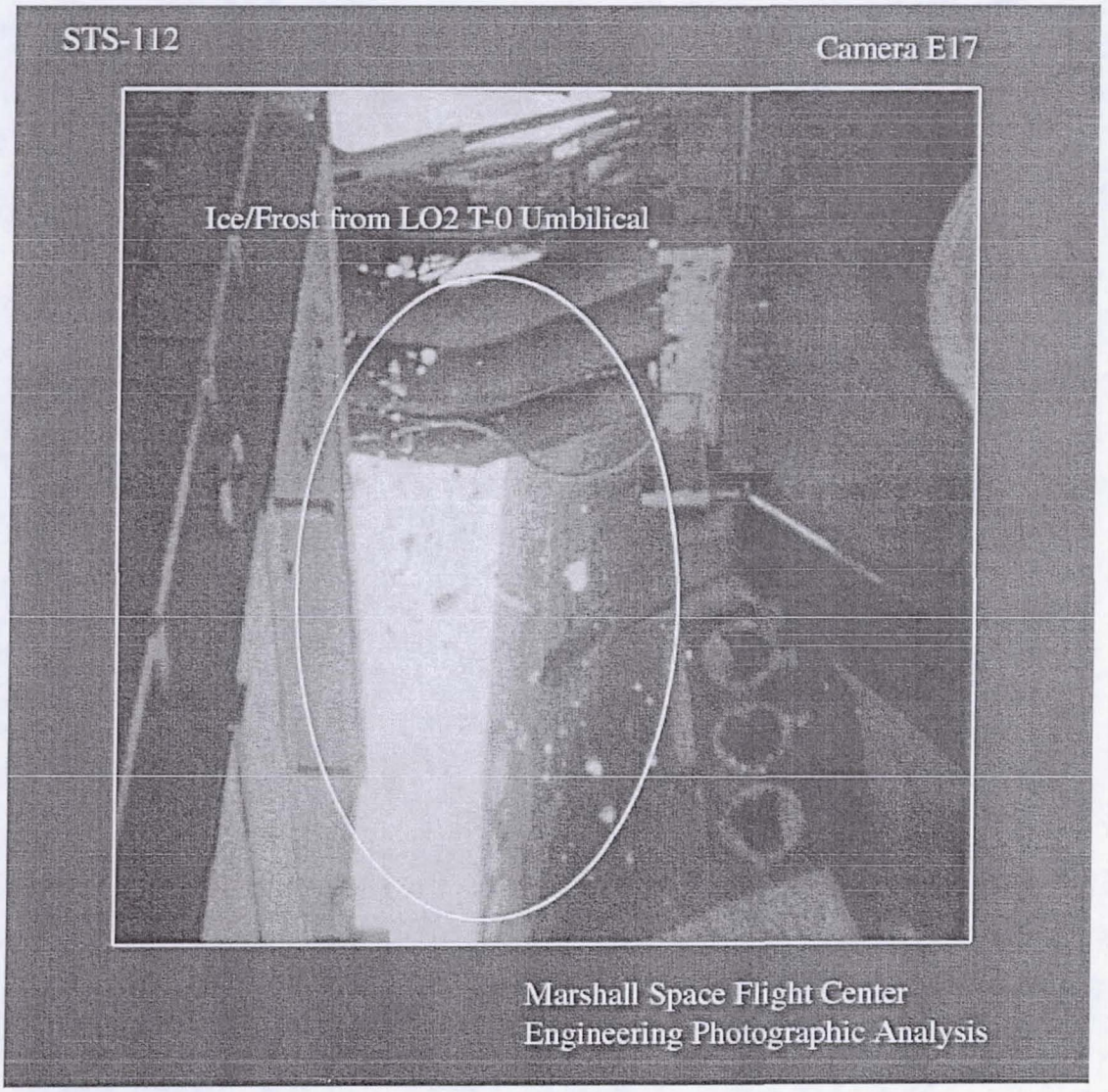


Figure 28. E017: Ice/Frost from LO2 T-0 Umbilical

E016: Thermal Curtain Flexing at Left SRB Ignition

Image of the Thermal Curtain flexing at Left SRB ignition.

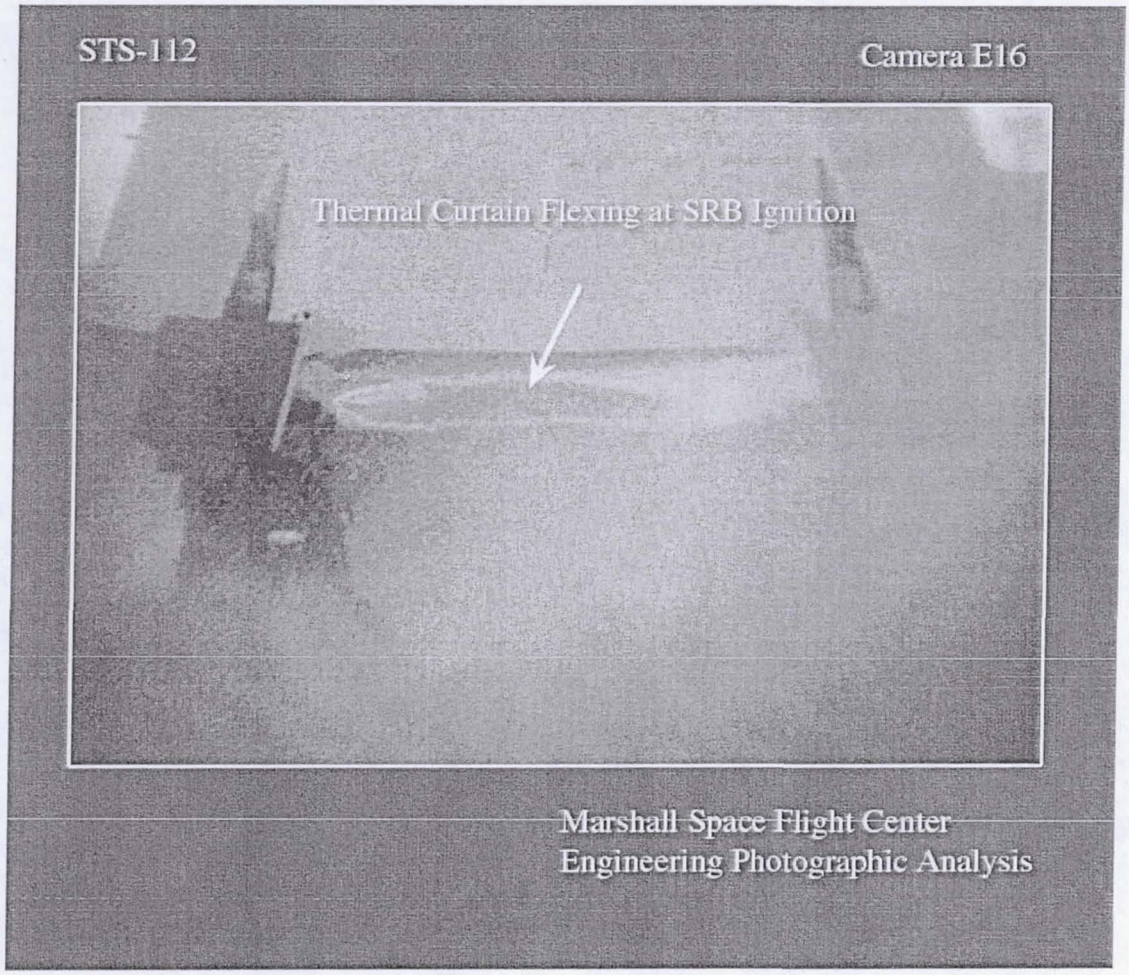


Figure 29. E016: Thermal Curtain Flexing at Left SRB Ignition

E015: Thermal Curtain Flexing at Right SRB Ignition

Image of the Thermal Curtain flexing at Right SRB ignition.

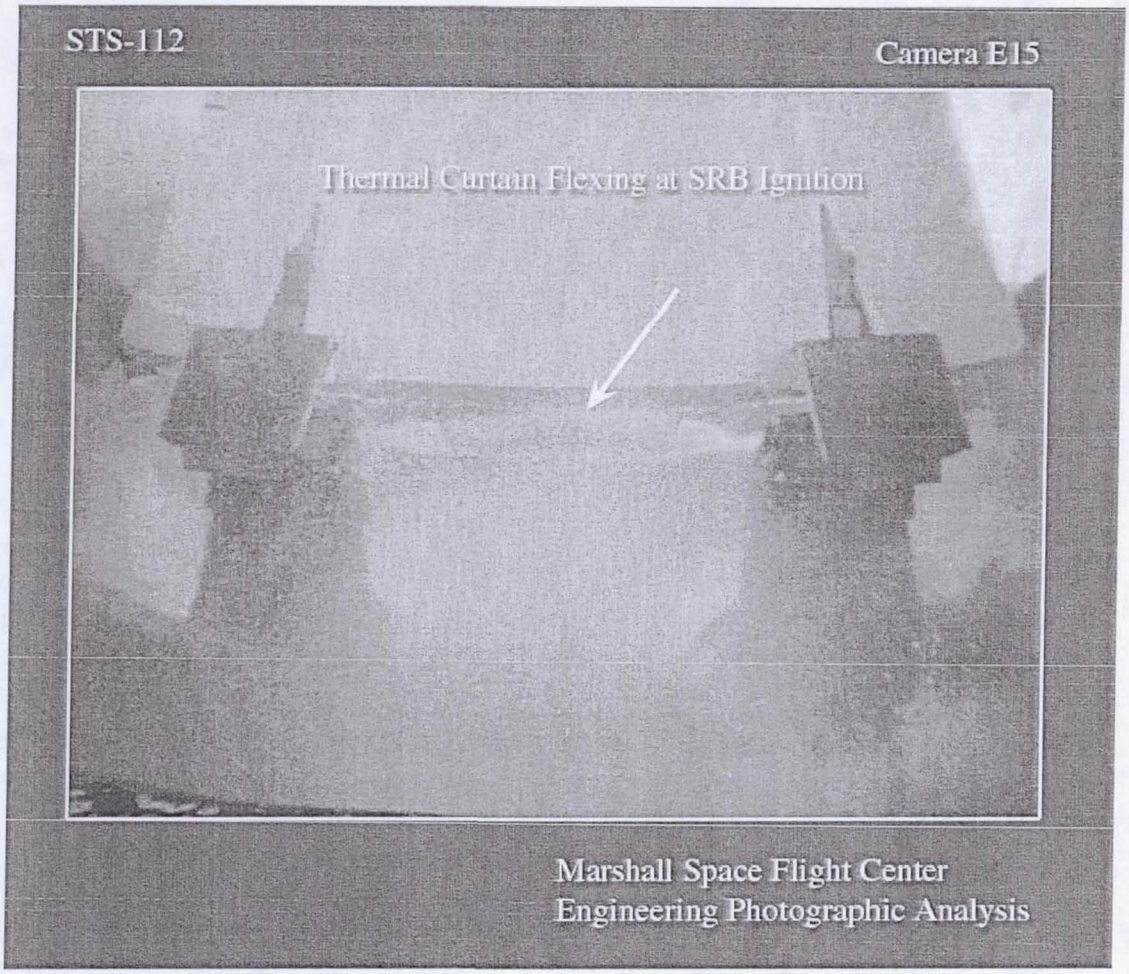


Figure 30. E015: Thermal Curtain Flexing at Right SRB Ignition

E007: Possible Debris from Holddown Post Hole M-4

Debris was noted above HDP M-4 shoe. A possible source of this debris was from the Holddown Post Hole.

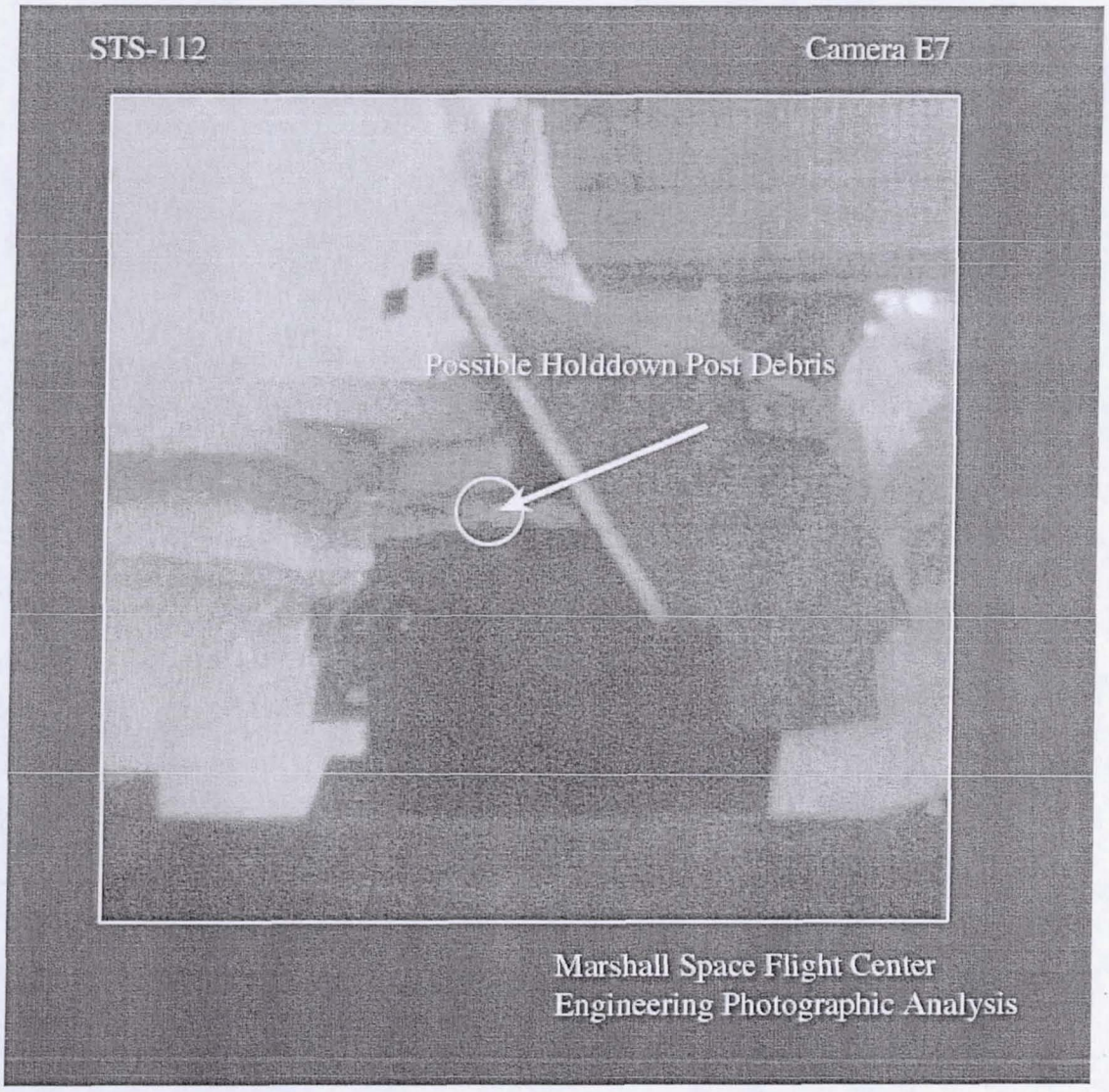


Figure 31. E007: Possible Debris from Holddown Post Hole M4

FL102: View showing -Y Thrust Panel TPS loss

Divots may be observed in the TPS on the -Y Thrust Panel, but the loss appears to be in an unvented region and is considered normal. The large divot on the foot of the bipod, as well as two divots under the bipod, are also visible.

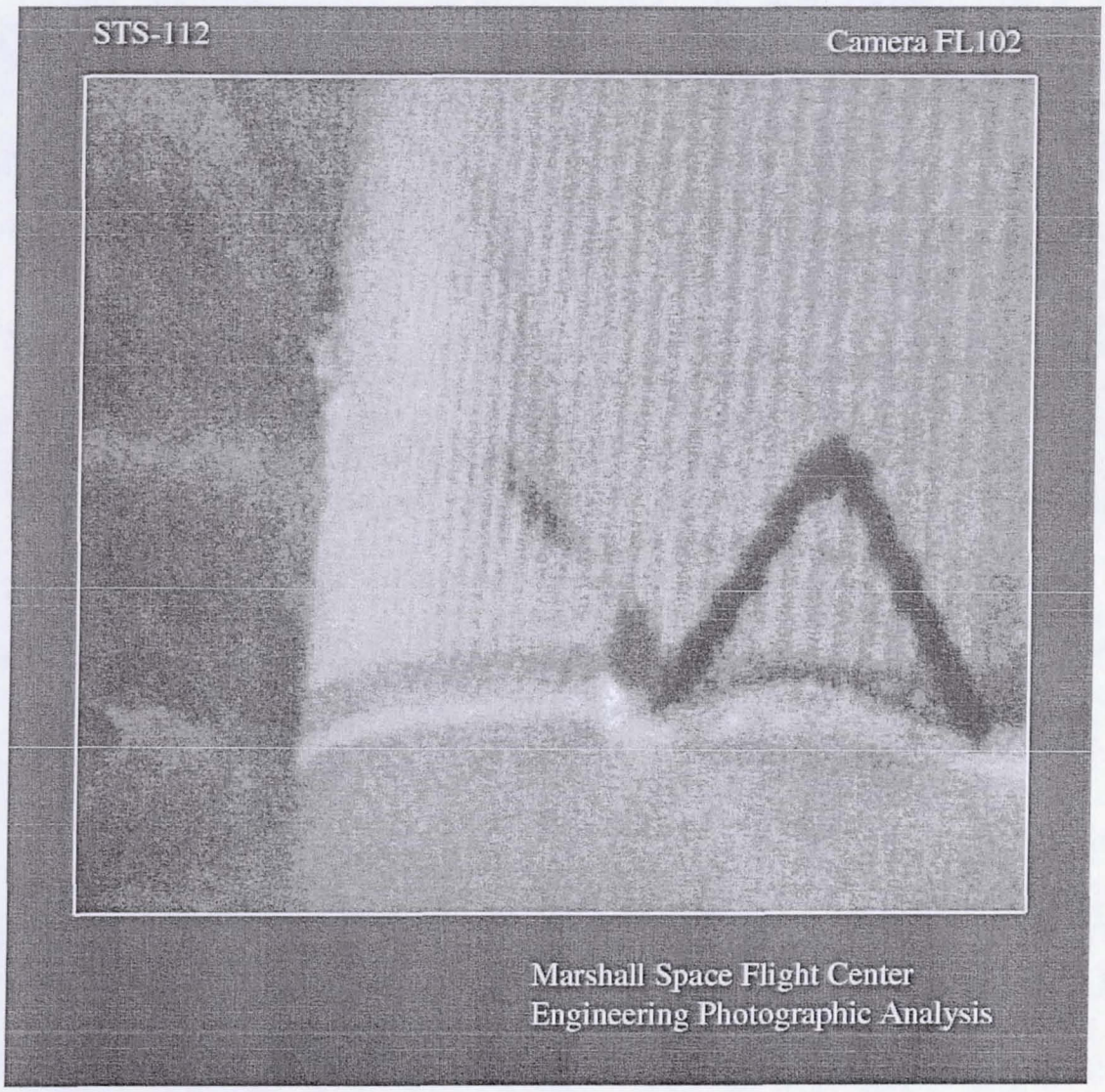


Figure 32. FL102: View showing -Y Thrust Panel TPS loss

Special Investigations

Debris Impact on Left SRB

Debris impacted the Left SRB near the IEA Box. This event occurred at approximately 280:19:46:24.6 UTC. The position of the debris was tracked for several frames prior to impact and a linear curve fit was generated. The results show the possible debris extrapolated trajectory originating from an area near the Bipod. Also a request was made to determine the velocity of the debris particle. The average velocity was determined to be approximately 295 ft/sec.

Linear Debris Trajectory Estimate

The debris impact on the left SRB observed Near IEA Box occurred at approximately 280:19:46:24.6 UTC. A sequence of images tracking debris prior to impact indicate the general direction of travel of the debris. A linear curve fit to the pixel coordinates of the debris at frames where the debris was visible yields the linear debris trajectory estimate shown. This linear extrapolation places the debris in the vicinity of the Bipod foot/ramp during its trajectory.

Figure 33. Linear Debris Trajectory Estimate

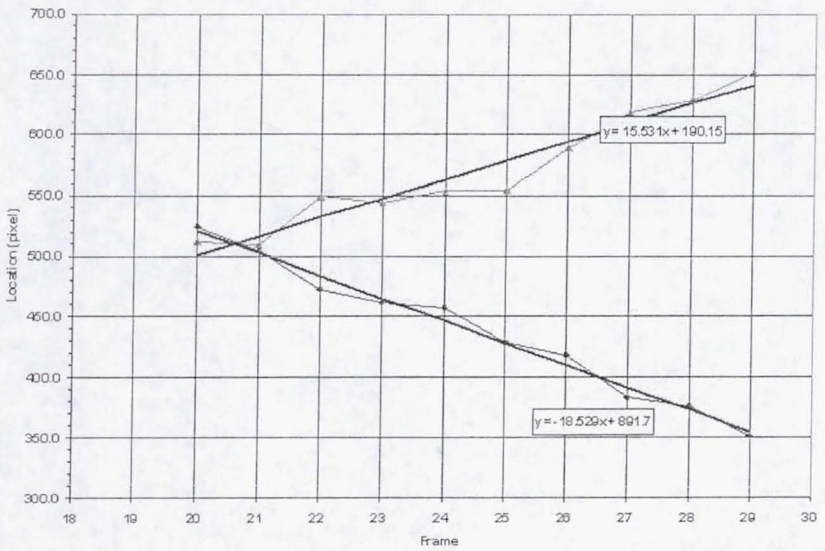
Debris Position Curve Fit

The position of the debris was tracked for several frames prior to impact. The coordinates of the debris were plotted and linear curve fit to points performed. Curves were generated for both x-coordinates and y-coordinates separately.

X-coordinate curve fit x = -18.529*frame + 891.7

Y-coordinate curve fit y = 15.531*frame + 190.15

Frame values prior to "frame 16" place the debris forward of the Bipod.



Frame	X-Coord	Y-Coord
29	354.359	640.549
28	372.888	625.018
27	391.417	609.487
26	409.946	593.956
25	428.475	578.425
24	447.004	562.894
23	465.533	547.363
22	484.062	531.832
21	502.591	516.301
20	521.12	500.77
19	539.649	485.239
18	558.178	469.708
17	576.707	454.177
16	595.236	438.646
15	613.765	423.115
14	632.294	407.584

Figure 34. Debris Position Curve Fit

Debris Velocity Determination

In order to perform a velocity calculation, scaling from the image dimension in pixels to the physical dimensions of the vehicle were necessary.

Diameter of External Tank = 331.0 inches

Diameter of SRB = 146.0 inches

Measured Diameter of the ET = 270 pixels which implies a scale factor of 1.22 inches/pixel. Measured Diameter of the SRB = 113 pixels which implies a scale factor of 1.29 inches/pixel. An average scale factor of 1.26 inches/pixel was used.

The average velocity was calculated by:

a) Determining distance traveled between frames (in pixels)

b) Converting pixel distance to feet (multiplication by Scalefactor/12)

c) Multiplying by the film speed (100 frames per second)

d) Calculating the average of the separate velocity calculations.

Average velocity over frames tracking debris particle is 295 ft/sec

frame	x	y	distance traveled (px)	distance traveled (ft)	speed (ft/sec)
19	534	441	20.51828453	2.154419876	215.4419876
20	519	455	24.18677324	2.539611191	253.9611191
21	498	467	25.8088758	2.709732459	270.9732459
22	483	488	17.4642492	1.833746166	183.3746166
23	466	492	43.8634244	4.605659562	460.5659562
24	436	524	26.90724809	2.82526105	282.526105
25	418	544	34.6554469	3.638821925	363.8821925
26	394	569	29.06888371	3.052232789	305.2232789
27	375	591	31.82766093	3.341904397	334.1904397
28	353	614	27.29468813	2.865942253	286.5942253
29	340	638			
					295.6733167

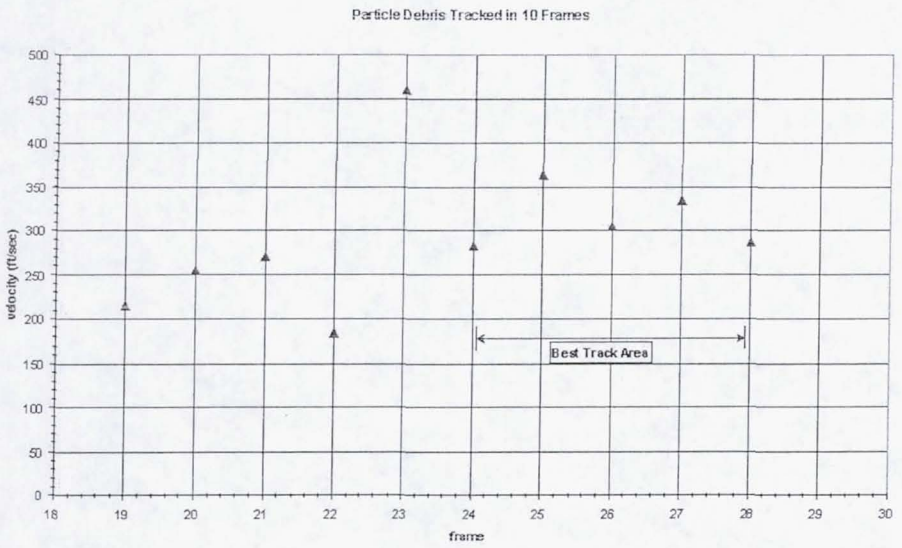


Figure 35. Debris Velocity Determination

Special Review of STS-112 Holddown Post Films

A special review of films which view the Holddown Posts was requested by the chairman of the Intercenter Photographic Working Group, Bob Page KSC/MK-SIO, to support the HDP A Circuit Anomaly investigation. Results are noted for Film Cameras E8, E9, and E10.

E009: Debris and Combustion Products HDP M1

Debris was observed, originating from area near top of tape on right pyrotechnic cable and falling past HDP shoe. The debris was imaged at 280:19:45:46.829 UTC.

Outgassing was observed from the alcove of the debris containment system. This was imaged at 280:19:45:47.391 UTC.

A reflection was observed from the tape on the left pyrotechnic wire. This was imaged at 280:19:45:51.031 UTC. PIC firing combustion products are also visible in the image.

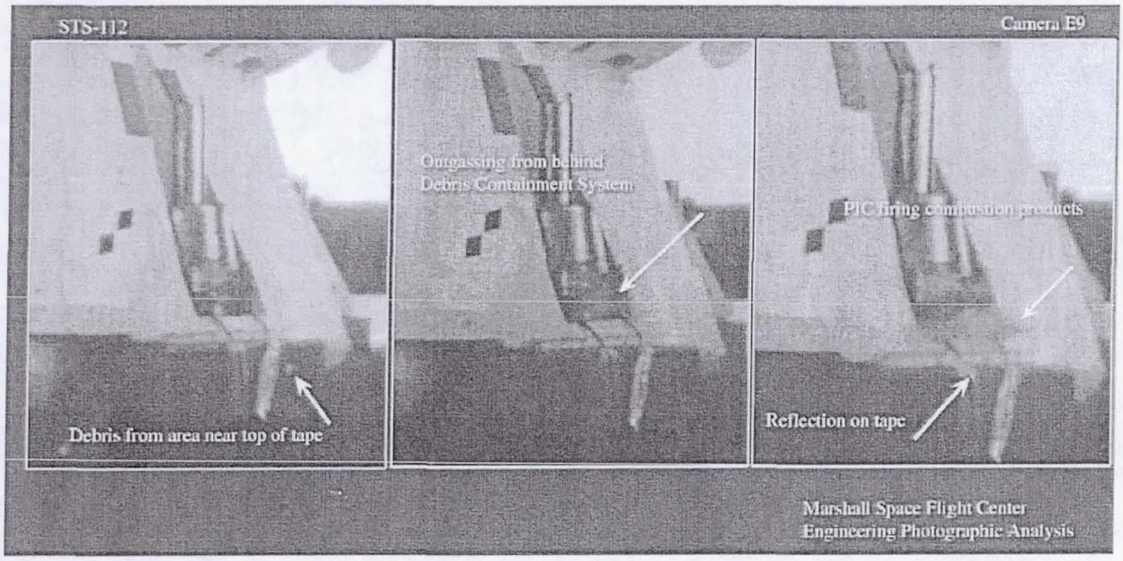


Figure 36. E009: Debris and Combustion Products HDP M1

E008: Debris and Outgassing HDP M2

Debris, originating from under the left pyrotechnic cable at Holddown Post M2, was observed falling from the Debris Containment System. The first image was timed at 280:19:45:46.447 UTC and the second, as the debris fell, was timed at 280:19:45:46.507 UTC.

Outgassing from the right side of the Debris Containment System Alcove, first noted at 280:19:45:47.322 UTC, was also observed. The image illustrating the outgassing was timed at 280:19:45:47.398 UTC.

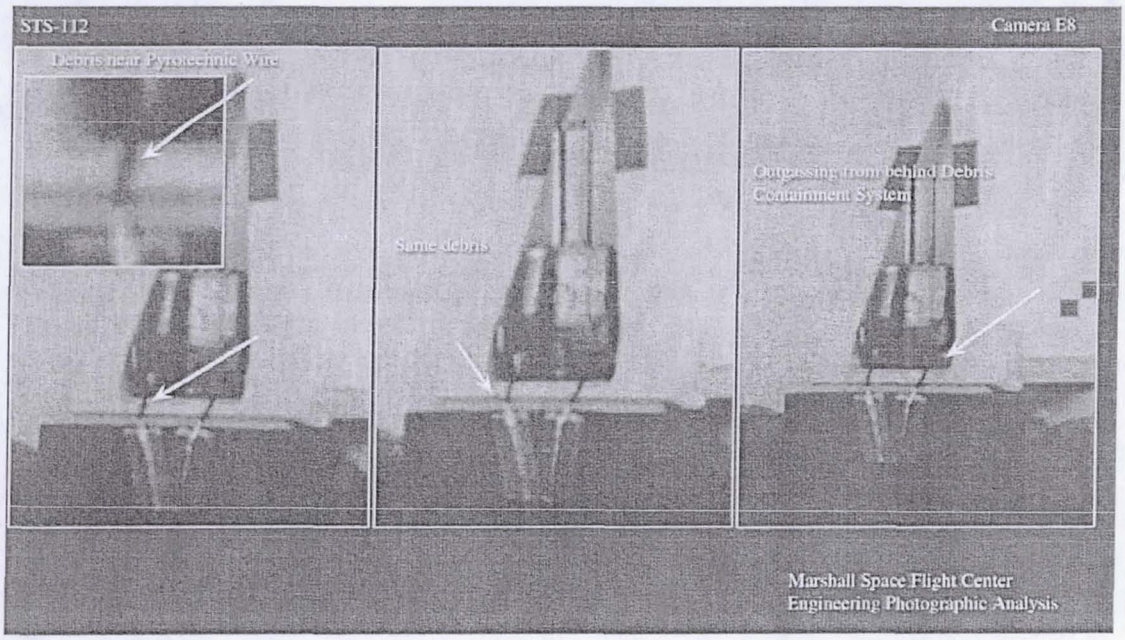


Figure 37. E008: Debris and Outgassing HDP M2

E010: Flash from PIC Firing HDP M3

Usually, the combustion products from PIC firing are obscured by the Holddown Post covers. However, occasionally PIC firing combustion products can be observed. SRB holddown post M3 PIC firing time noted at 280:19:45.51.028 UTC.

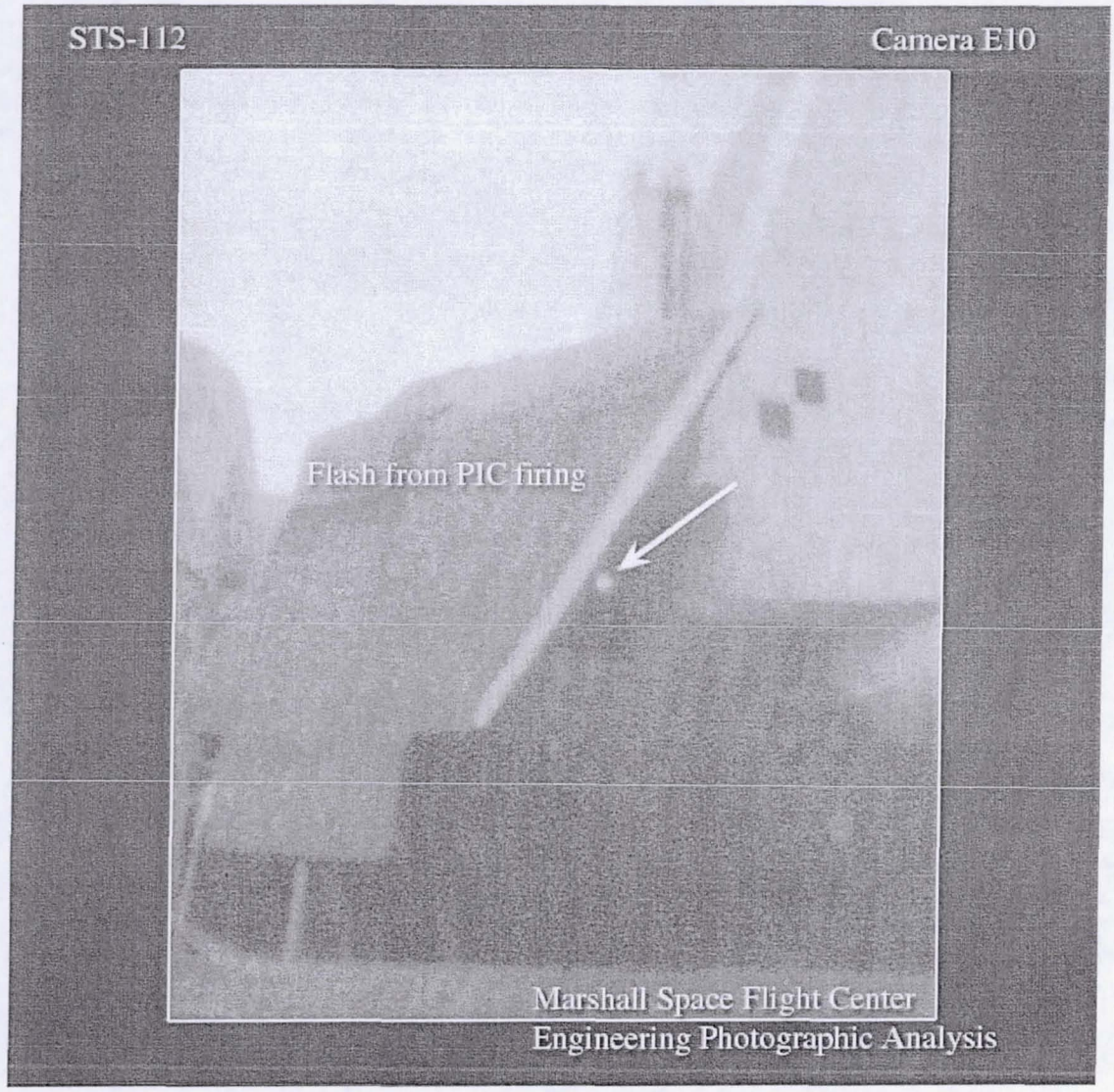


Figure 38. E010: Flash from PIC Firing HDP M3

Review of Archived Film for Flash in SSME#1 Plume Prior to Launch

A review of missions STS-108 and STS-109 was performed to determine if there were similar plume characteristics in recent Block IIA engines.

Additionally, we were asked to perform a similar review of plume boundary fluctuations for missions STS-99, STS-89, STS-85, STS-82, STS-75, STS-69, STS-54, STS-44, and STS-37. Results are shown in the "Plume Bulge Comparison" links below.

E002: STS-108 and STS-109 Plume Review

In reviewing missions STS-108 and STS-109 plume bulges were also observed. These SSME #1 plume bulges were of lesser magnitude and appeared to be further from the nozzle than those noted on STS-111, STS-110, or STS-112. Also noted and imaged on STS-109, at the time of the plume bulge, is an acoustic shock moving away from the plume. The three images in the sequence were timed at 060:11:21:58.479, 060:11:21:58.482, and 060:11:21:58.484 UTC, or approximately 2.8 seconds from STS-109 SSME#1 start time (060:11:21:55.703 UTC).

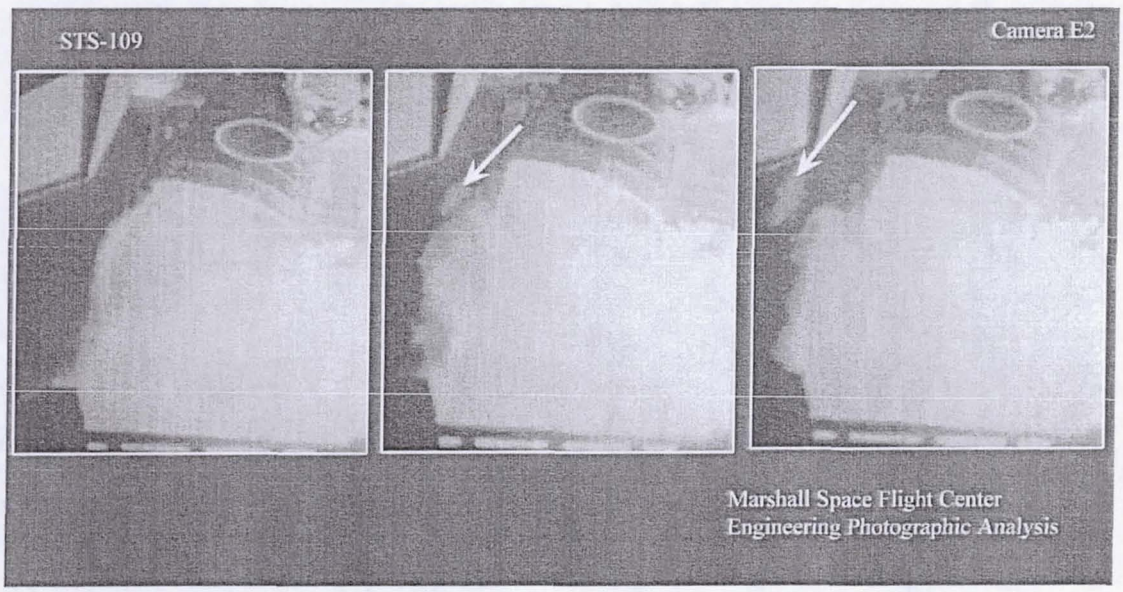


Figure 39. E002: STS-108 and STS-109 Plume Review

E002: Plume Bulge Comparison Imagery

Each film was analyzed during the time between SSME#1 ignition and Mach diamond formation for plume fluctuations similar to the type noted in STS-111. Plume boundary fluctuations were evident in each film. The largest fluctuation observed was placed in the image for comparison.

Information concerning each mission relative to the engine controller and time each plume bulge was noted is found in the Plume Bulge Comparison Information chart.

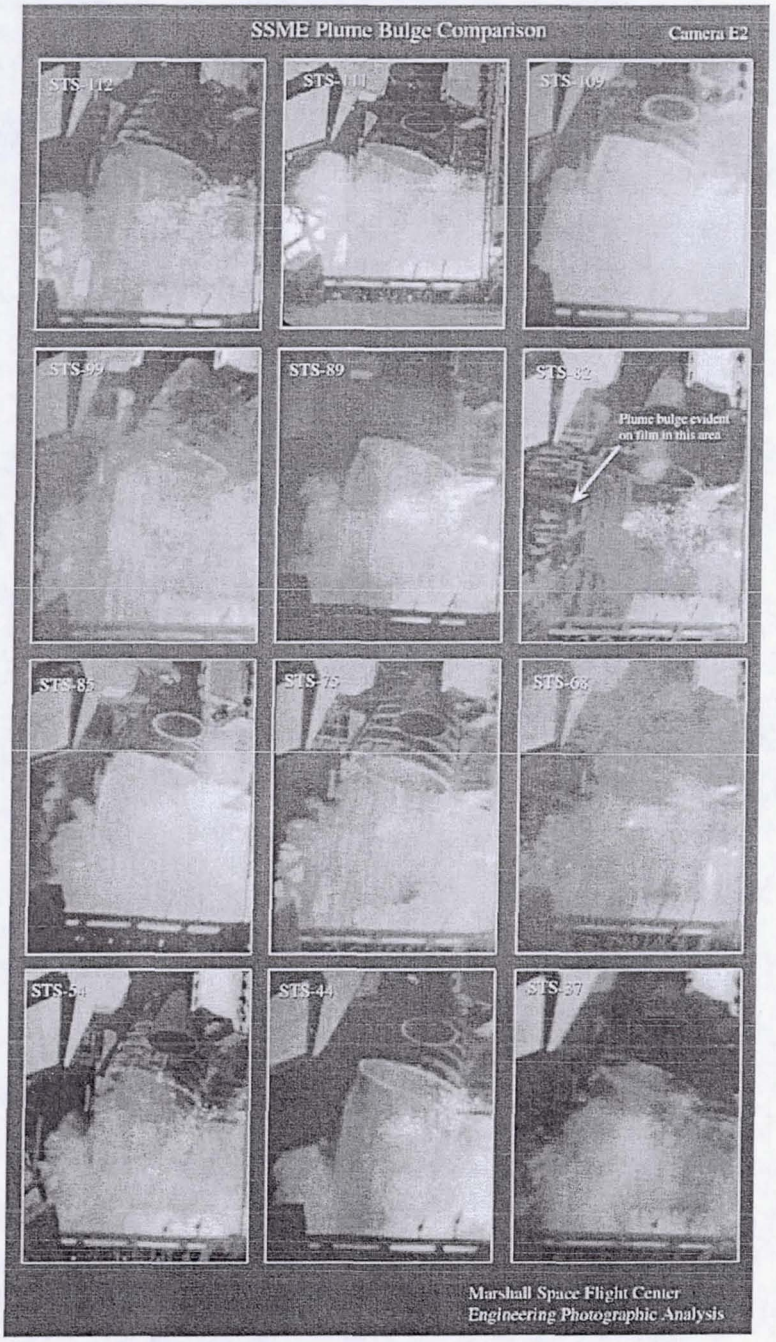


Figure 40. E002: Plume Bulge Comparison Imagery

Plume Bulge Comparison Information

The type of motor, timing for the start of the bulge and SSME#1 ignition is given for each of the missions listed in the following chart. An image of the observed plume bulge at the listed time is shown in the Plume Bulge Comparison Imagery.

STS	Engine	Boundary Fluctuation	SSME#1 Start	Seconds from Engine Start
112	Block II	19:45:47.611	19:45:44.694	2.92
111	Block II	21:22:45.535	21:22:42.692	2.84
109	Block IIa	11:21:58.482	11:21:55.703	2.78
99	Block IIa	17:43:36.710	17:43:33.691	3.02
89	Block IIa	02:48:11.412	02:48:08.708	2.70
85	Block Ia	14:40:56.611	14:40:53.705	2.91
82	Block Ia	08:55:13.622	08:55:10.699	2.92
75	Phase II	20:17:56.488	20:17:53.699	2.79
69	Phase II	15:08:56.667	15:08:53.671	3.00
54	Phase II	13:59:26.458	13:59:23.685	2.77

Table 4. Plume Bulge Comparison Information

STS-112 Holddown Post Cover Closure Rate

At JSC request a movie was made, film camera E16 footage, showing the Left SRB holddown posts M7 and M8 from T-0 until the SRB nozzle exit plane passes the holddown post covers. An observation on the holddown post cover closure rate was listed on the STS-111 Intercenter Consolidated Film/Video Launch+4 Day Report. It had been previously noted on Mission STS-111, that the blast deflection shield for holddown post M3 on MLP-1 appeared to take longer than usual to completely descend to a level position, with the shield not completely closed as the nozzle exit plane rises past the holddown post. The movie is available on the website.

STS-112 Individual Camera Assessments

Camera	Comments
E001	Typical pad debris.
E002	Bulge in SSME#1 plume prior to mach diamond formation, imaged at 280:19:45:47.611, 280:19:45:47.614 and 280:19:45:47.619 UTC.
E003	Bulge in SSME#1 plume prior to mach diamond formation observed. Typical pad debris.
E004	Typical ice/frost from 17-inch disconnects.
E006	Ice/frost impacts LO2 disconnect umbilical well door sill. Purge barrier material noted flapping. Typical ice/frost falling through field of view. Typical wing motion at lift-off.
E007	Foam debris observed. Possible debris emanating from the holddown post bore. White line noted between foot and shoe of HDP becomes obscured at 280:19:45:51.030 UTC by what is assumed to be combustion products. Typical debris observed falling aft of vehicle.
E008	Pyrotechnic wires appear in nominal configuration. Outgassing from alcove of debris containment system, first noted at 280:19:45:47.322 UTC, imaged at 280:19:45:47.398 UTC. Debris emanates from region near/behind left pyrotechnic wire, first noted at 280:19:45:46.447 UTC and imaged at 280:19:45:46.507 UTC. SRB holddown post M-2 PIC firing time noted at 280:19:45:51.026 UTC.
E009	Pyrotechnic wires appear in nominal configuration. Debris observed, originating from area near top of tape on right pyrotechnic wire, falling past HDP shoe, imaged at 280:19:45:46.829 UTC. Outgassing observed from alcove of debris containment system, imaged at 280:19:45:47.391 UTC. Reflection observed from tape on left pyrotechnic wire, imaged at 280:19:45:51.031 UTC. SRB holddown post M-1 PIC firing time noted at 280:19:45:51.026 UTC.
E010	Stud hang-up observed on Holddown Post M-3, imaged at 280:19:45.51.611 UTC. Typical lift-off debris from SRB. SRB holddown post M-3 PIC firing time noted at 280:19:45.51.028 UTC.
E011	Foam debris emanating from SRB blast hole. Typical pad debris.
E012	Pyrotechnic wires appear in nominal configuration. Typical pad debris. Left pyrotechnic wire stretched several feet before detaching from SRB. SRB holddown post M-5 PIC firing time noted at 280:19:45:51.026 UTC.
E013	Pyrotechnic wires appear in a nominal configuration. Pyrotechnic wire observed trailing from Holddown Post M-6 foot, imaged at 280:19:45:51.889 UTC. Typical pad debris. Even distribution of combustion products from holddown post housing observed. Post launch inspection of the HDP determined that only one of the pyrotechnic devices had fired. This suggests that combustion products are not a good indicator of pyrotechnic device performance. Outgassing from alcove of debris containment system observed, first noted at 280:19:45:47.372 UTC. SRB holddown post M-6 PIC firing time noted at 280:19:45:51.027 UTC.
E014	Dark debris noted falling through field of view prior to launch. Left pyrotechnic wire stretches before becoming detached from the SRB.
E015	Flexing of SRB thermal curtain noted. Pad debris noted rising and falling.
E016	Flexing of thermal curtain noted. Typical pad debris.

E017	Ice/frost noted from LO2 T0 umbilical.
E018	Free burning Hydrogen observed. Body flap motion observed. Typical ice/frost from LH2 T-0 umbilical.
E019	Free burning Hydrogen noted. Three-pronged wire-like debris noted after liftoff.
E020	Free burning Hydrogen noted. Typical pad debris. Typical debris observed falling aft of vehicle.
E031	Pyrotechnic cable observed trailing from Holddown Post M6 foot after liftoff. Typical ice/frost from 17-inch disconnects.
E033	Ice/frost noted on GUCA after GUCP separation from ET.
E034	Pyrotechnic wire observed attached to SRB. Typical debris falling aft of vehicle.
E036	Typical debris observed falling aft of vehicle.
E039	No anomalies noted. No events timed.
E040	Pyrotechnic wire at Holddown Post M6 foot still attached to vehicle. Typical debris observed falling aft of vehicle.
E052	Free burning Hydrogen observed. Bulge in SSME#1 plume observed prior to mach diamond formation. Typical debris observed falling aft of vehicle.
E054	No anomalies noted. No events timed.
E057	Camera doesn't follow vehicle from launch pad.
E059	Camera doesn't follow vehicle from pad. Typical debris observed falling aft of vehicle.
E060	GH2 Vent Arm retraction appears normal.
E062	Free burning Hydrogen noted near vertical stabilizer at SSME ignition. Bulge in SSME#1 plume prior to mach diamond formation, noted at 280:19:45:47.606 UTC.
E063	No anomalies noted. No events timed.
E204	Vehicle not tracked during early portion of ascent. Glowing debris particles ejected from SRB plume after separation.
E205	Body flap motion observed. Three dark plume events noted in SRB plumes prior to SRB separation. OMS Motor burn noted after separation. Inconsistent track of vehicle. SRB separation: 280:19:47:52.687 UTC. Glowing debris particles ejected from SRB plume prior to, during and after separation. Flow recirculation noted.
E207	Debris, also noted in film camera E222, observed over left SRB aft end at approximately 280:19:46:24.6 UTC. Instafoam debris noted in right SRB plume, imaged at 280:19:46:31.471 UTC. Debris observed flowing aft under orbiter, imaged at 280:19:46:36.760 UTC. OMS burn after SRB separation, imaged at 280:19:48:03.213 UTC. OMS motor firing still visible at 280:19:48:42.369 UTC. RCS motor firing noted at SRB separation. SRB separation: 280:19:47:52.674 UTC. Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted. Flow recirculation noted.
E208	Film of little engineering use due to soft focus. Glowing debris particles ejected from SRB plume after separation.

E212	Debris ejected from SRB plumes during ascent (two images). RCS motor firing at SRB separation noted. OMS burn after SRB separation noted. Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks in SSME plume. Linear optical distortions noted.
E213	Film of little engineering use due to poor focus. Camera loses track of vehicle during ascent.
E220	Debris impacts the left SRB IEA Box during ascent (imaged). Camera loses track of vehicle during ascent. Typical debris observed falling aft of vehicle.
E222	Debris flowing under orbiter left wing imaged at 280:19:46:09.433 UTC. Numerous pieces of light colored debris ejected from SRB plumes just after roll maneuver. Debris apparently impacts the left SRB IEA Box, imaged at approximately 280:19:46:24 UTC. Purge barrier material debris noted. Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume.
E223	Debris ejected from SRB plumes during ascent. SRB separation: 280:19:47:52.675 UTC. Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume. Linear optical distortions noted. Flow recirculation noted.
E224	Short run.
ET204	Image hazy and not clear. No anomalies noted. No events timed.
ET207	Body flap motion observed. Numerous linear optical distortions. OMS burn after SRB separation noted. SRB separation: 280:19:47:52.7 UTC. Typical debris observed falling aft of vehicle. Flow recirculation noted.
ET208	Image somewhat hazy. SRB separation: 280:19:47:52.7 UTC.
ET212	Debris flare noted in SSME plumes. Condensation collar noted around vehicle. Debris ejected from SRB plumes during ascent. Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted.
ET213	Image size small and not centered in field of view during part of ascent.
ETCAM	Debris from forward of the ET Camera observed falling aft. Small patches of TPS erosion observed on ET surface on +Y side and -Y side of electrical cable tray. Condensation cloud noted around top of orbiter and right SRB. Camera viewport fogged over during SRB Separation Motor firing.
FL101	Twang observed on SRB section of EB9 interface at SRB/ET upper aft stabilization strut at SRB/ET separation. Debris impact area on SRB IEA Box not discernible. Small positive ET/Orbiter yaw angle noted. BSM motor firing noted. Typical observations include popcorning of aft dome, charring of vertical thrust strut, nominal EO2 bolt retraction, EO2 interface fitting purge seal appears in place, EO3 interface fitting purge seal is loose, BSM burn scars visible on ET, aeroheating marks near bipod, and ablated TPS on cable tray. The divot, noted in the 35mm umbilical still camera UMB035mm, at the bipod foot/ramp was visible.
FL102	Twang observed on SRB section of EB9 interface at SRB/ET upper aft stabilization strut at SRB/ET separation. Small positive ET/Orbiter yaw angle noted. Typical popcorning of the aft dome noted. BSM burn scars on the External Tank noted. Divots noted on the Left SRB Thrust Panel. Divots under the bipod and on the bipod foot/ramp noted.
HH035MM	Images were too dark and the ET too far away for engineering photographic evaluation.
OTV109	Typical wing motion noted at liftoff. White streak lines noted traveling in aft direction. Typical ice/frost from 17-inch disconnects.

OTV141	Image is overexposed, has very high contrast and is of little engineering value.
OTV148	Debris noted at lift-off which appears to travel toward the vehicle, however, debris does not come close to vehicle.
OTV149	No anomalies noted. No events timed.
OTV150	No anomalies noted. No events timed.
OTV151	No anomalies noted. No events timed.
OTV154	Typical wing motion at SSME ignition. Ice impacts LO2 umbilical well door sill. No damage noted.
OTV160	Camera view not in correct orientation. Image somewhat overexposed.
OTV161	Water on lens distorts view. Typical debris observed falling aft of vehicle.
OTV163	Typical ice/frost from LH2 disconnect.
OTV170	Free burning Hydrogen observed at SSME ignition. Bulge observed in SSME#1 plume prior to Mach diamond formation. Mach diamond formation in 3-2-1 order. Typical debris observed falling aft of vehicle.
OTV171	No anomalies noted. No events timed.
TV004B	Free burning Hydrogen noted prior to lift-off. Debris induced flares and streaks in the SSME plumes observed. Debris ejected from SRB plumes during ascent.
TV005	No anomalies noted. No events timed.
TV007B	Free burning Hydrogen noted.
TV011	No anomalies noted. No events timed.
TV013	Image somewhat hazy. Glowing debris particles ejected from SRB plume after separation.
TV021B	Image focus soft. Camera loses track of vehicle.
UMB035MM	Popcorning on Aft Dome is nominal. Purge seal is still attached at EO3 Ball Interface Fitting. Erosion of TPS observed just below the Diagonal Strut attach to the EO3 Ball Interface Fitting. Other areas of External Tank TPS loss noted were on Right Thrust Strut, between LO2 Feedline and GO2 Pressurization Line just forward of the Right Thrust Strut, under the ET/Orbiter Forward Attach Bipod, and on the Intertank. Additionally, there was an area of TPS loss on the -Y side of the ET/Orbiter Forward Attach Bipod which could have been the source of the debris which impacted the Left SRB IEA Box area. SRB BSM burn scars were noted. Aeroheating lines/marks noted just forward and to either side of the Bipod.

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

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14. ABSTRACT

A debris/ice/thermal protection system assessment and integrated photographic analysis was conducted for Shuttle mission STS-112. Debris inspections of the flight elements and launch pad were performed before and after launch. Icing conditions on the External Tank were assessed by the use of computer programs and infrared scanned data during cryogenic loading of the vehicle, followed by on-pad visual inspection. High speed photography of the launch was analyzed to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. The report documents the debris/ice/thermal protection system conditions and integrated photographic analysis of Space Shuttle mission STS-112 and the resulting effect of the Space Shuttle Program.

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