Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-109

Armando Oliu

Technical Memorandum – 2005-212557 **March 2005**

DEBRIS/ICE/TPS ASSESSMENT and INTEGRATED PHOTOGRAPHIC ANALYSIS OF SHUTTLE MISSION STS-109

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OF
SHUTTLE MISSION STS-109

March 1, 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.

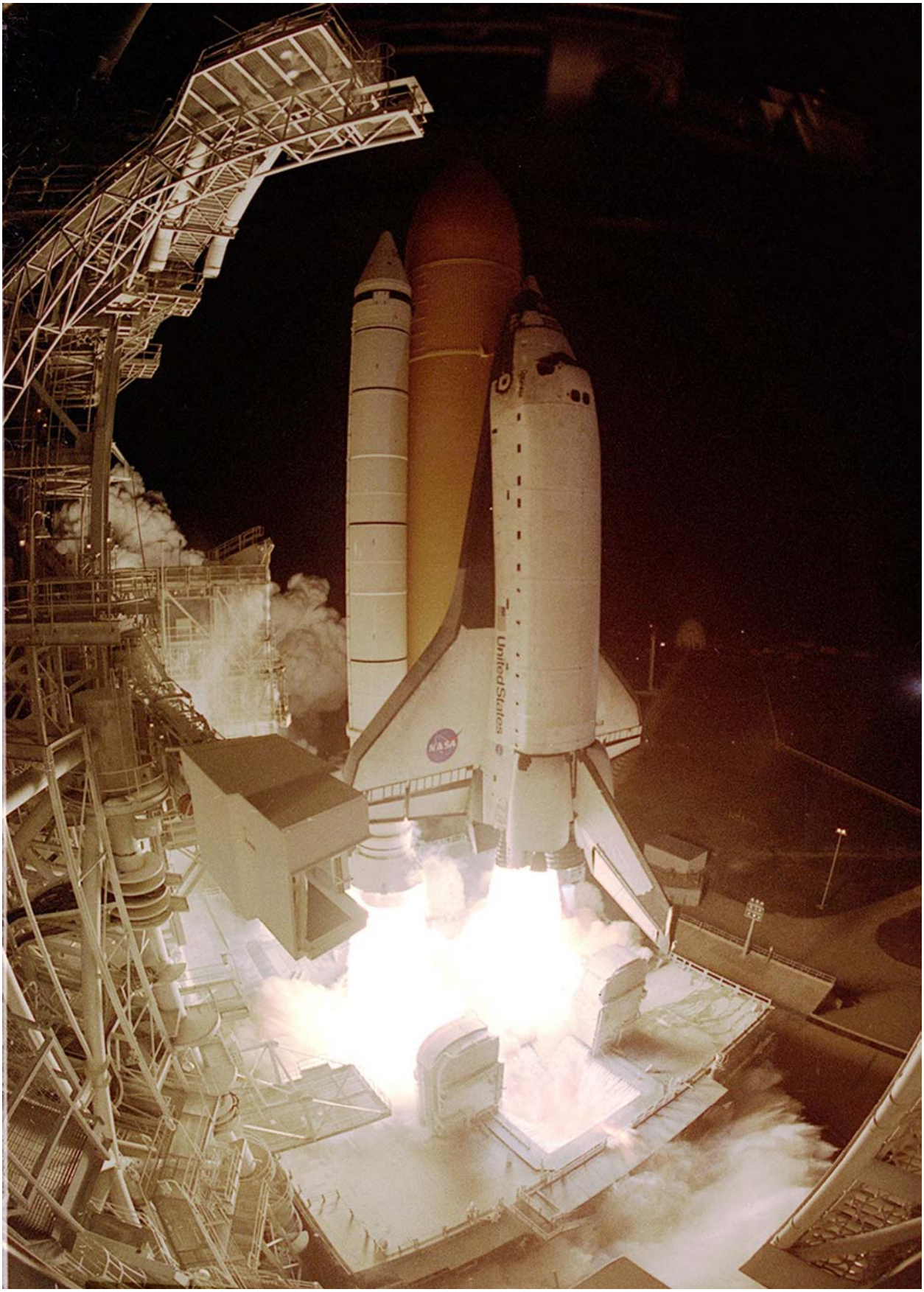

Photo 1: Launch of Shuttle Mission STS-109

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-109 consisted of OV-102 Columbia (27th flight), ET-112, and BI-111 SRB's on MLP-2 and Pad 39A. Columbia was launched at 06:22:02 EDT on 1 March 2002. Landing was at 04:32 a.m. local/eastern time on 12 March 2002.

Post landing inspection of Orbiter tiles showed a total of 98 hits, of which 18 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 63 total hits, of which 14 had a major dimension of 1-inch or larger. The majority of the hits (34 total with 7 having a dimension larger than 1-inch) were located in the area from the nose landing gear to the main landing gear wheel wells. Approximately 13 of the total lower surface hits were around the LH2 and LO2 umbilical areas. Most of the damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical baggie flailing in the airstream and contacting tiles before pulling loose and falling aft.

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 0615 on 27 February 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
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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
D. Leggett	Boeing	Systems Integration
B. Atkinson	Boeing	Systems Integration
T. Wilson	Boeing	Systems Integration
S. Otto	LMMSS	ET Processing
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A. Khodaoust	Boeing	Shuttle Aerodynamics
M. Eastwood	Thiokol-LSS	SRM Processing

3.0 LAUNCH

3.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the launch pad and Shuttle vehicle was performed on 27 February 2002. The walkdown of Pad 39A and MLP-2 included the flight elements OV-102 Columbia (27th flight), ET-xxx, and BI-111 SRB's. Four facility items were documented in Appendix K of S0007VL4:

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

Two vehicle IPR's were generated:

- IPR109V-405 Two areas of damaged External Tank foam on the LO2 tank. One area is located at Xt-760, approximately 39 degrees +Y of the +Z axis. The other is located at Xt-600, approximately 31 degrees –Y of the +Z axis.

- IPR109V-408 Small deposit of RTV-133 on the –Z side of the LH SRB forward center segment, at approximately Xb-1060.

Both IPR's were dispositioned to use-as-is with Material Review Board (MRB) approval.

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

3.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 0030 – 0210 hrs on 1 March 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 but two covers (R1U and R3R) were slightly discolored, with no liquid indications observed. Ice/frost had formed on all the way around the SSME #2 heat shield-to-nozzle interface and from the 4 to 12 o'clock position on SSME #1

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 48 to 53 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 slightly above the 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown.

Ambient conditions – 1100hrs	SURFICE Predictions	IR Surface Readings
56 Degrees F.	LO2 ogive 43 Degrees F	LO2 Tank 28-47 Degrees F
61% RH	LO2 barrel 35 Degrees F	
9 knots	LH2 upper 36 Degrees F	LH2 Tank 28-48 Degrees F
046 degrees	LH2 lower 41 Degrees F	

The Final Inspection Team observed no condensation on the LO2 tank acreage. Very light frost was noted on the LO2 tank acreage (-Y+Z and -Y-Z quadrants) as well as frost on the interface between the ice/frost ramps and the acreage. No ice/frost was noted in the two damaged foam areas documented in the IPR's generated during the pre-launch inspection. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. Five cracks were observed in the intertank stringer valley TPS (1st, 7th, 11th, and 13th valley –Z of the –Y thrust panel and 1st valley +Z of the –Y thrust panel). Ice and frost accumulations on the GUCP were typical.

The LH2 tank was dry with no condensate on the TPS. Some patches of light frost were observed on the LH2 tank acreage, in all four quadrants. Surface temperatures ranged from 28 to 35 degrees Fahrenheit. Light frost was also observed at the PAL ramp and –Y bipod ramp to acreage interface. There were no acreage TPS anomalies.

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

An 8 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 typical. Likewise, a typical amount of ice/frost had accumulated on the LH2 ET/ORB umbilical purge barrier outboard side, forward, and aft surfaces. Typical ice/frost fingers were present on the pyro canister and plate gap purge vents. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

3.2.4 FACILITY

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

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-109 was launched at 06:22:02 EDT on 1 March 2002.

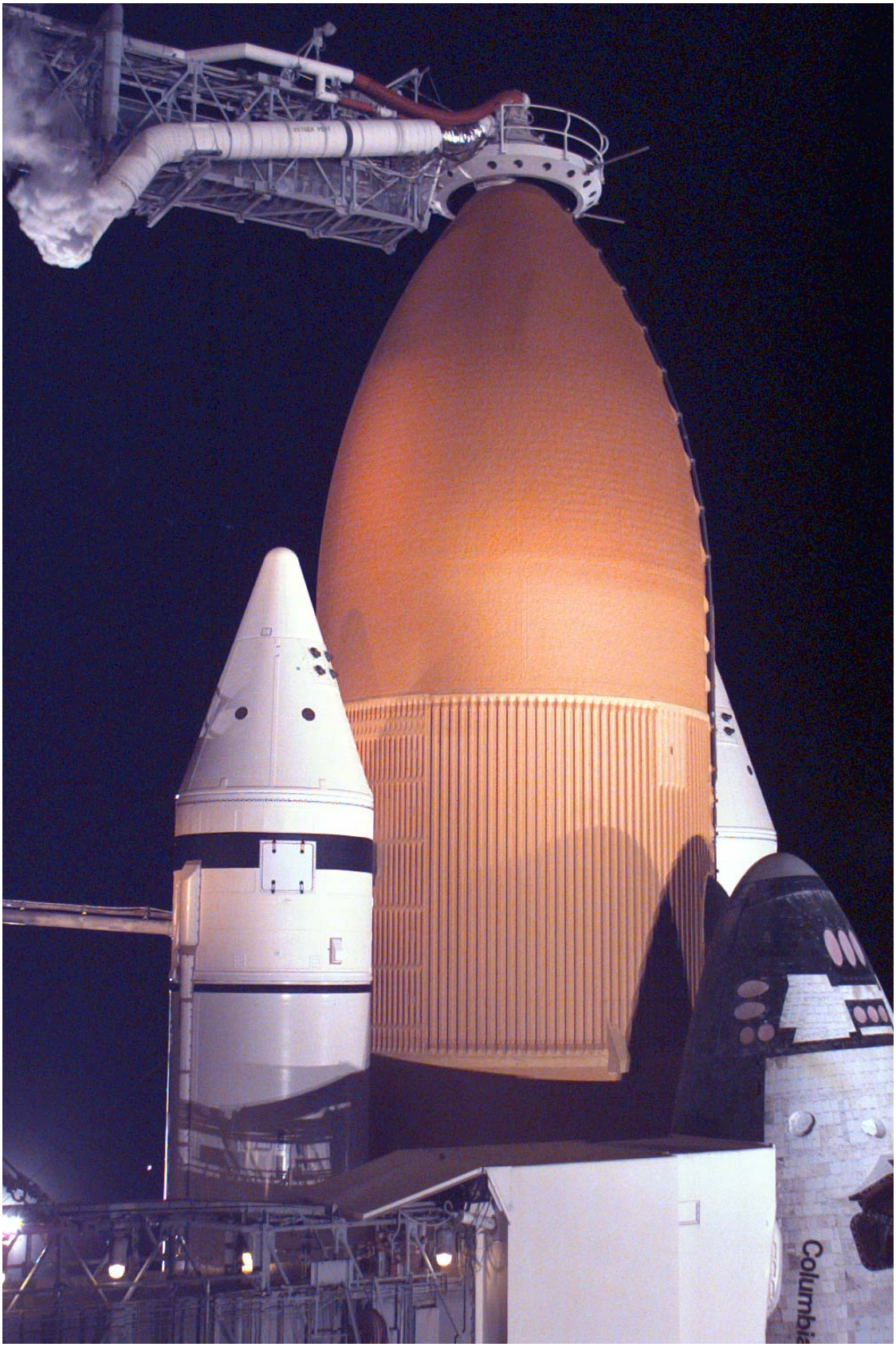


Photo 2: LO2 tank acreage.

No condensate was present on the LO2 tank acreage. Surface temperature ranged from 28 to 47 degrees Fahrenheit. There were no acreage TPS anomalies.

Photo 3: LH2 tank acreage.

No condensate was present on the LH2 tank acreage. Surface temperature ranged 28 to 48 degrees Fahrenheit. Light frost was present in all quadrants. There were no acreage TPS anomalies.

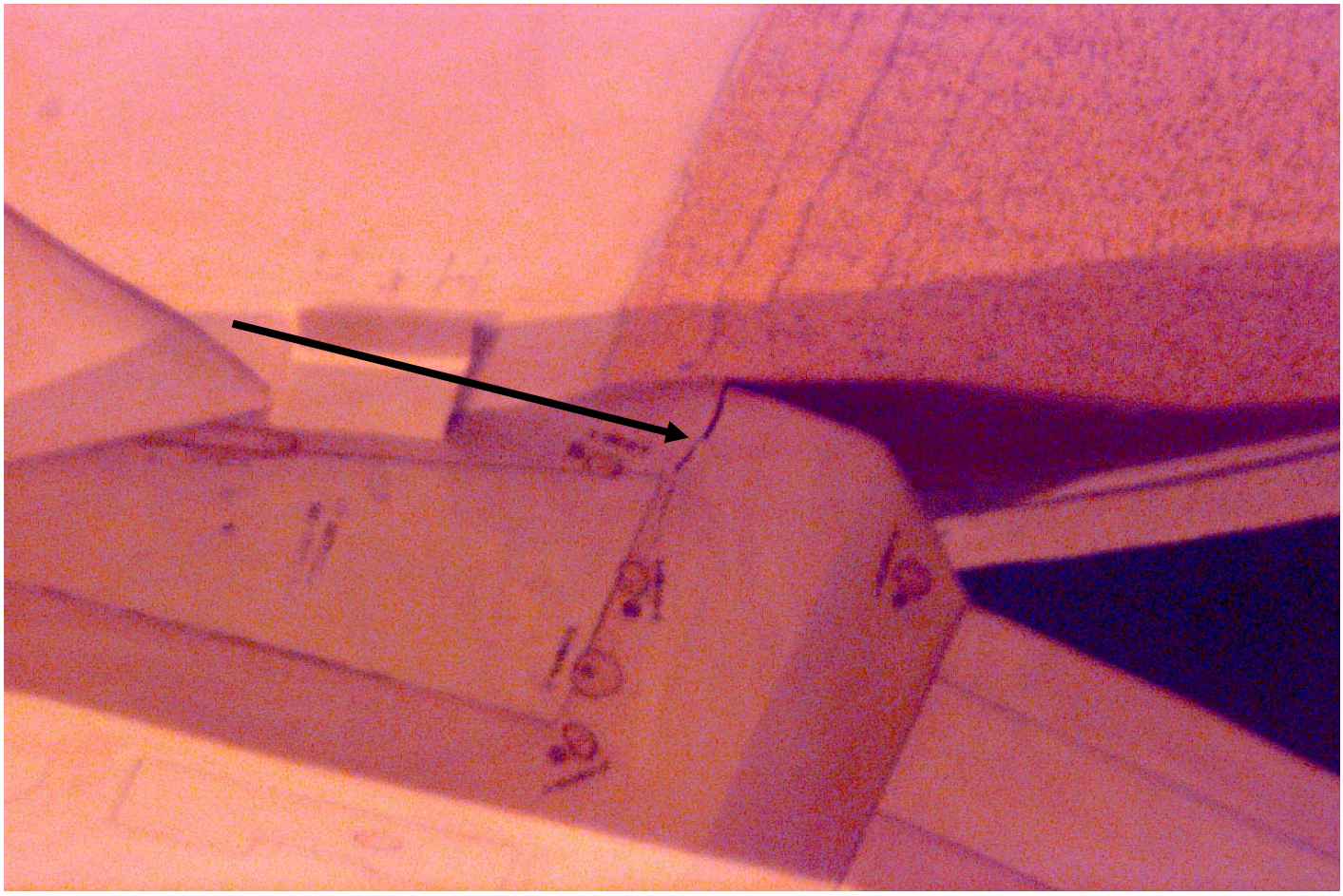


Photo 4: Crack in –Y Vertical Strut TPS

An 8 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.

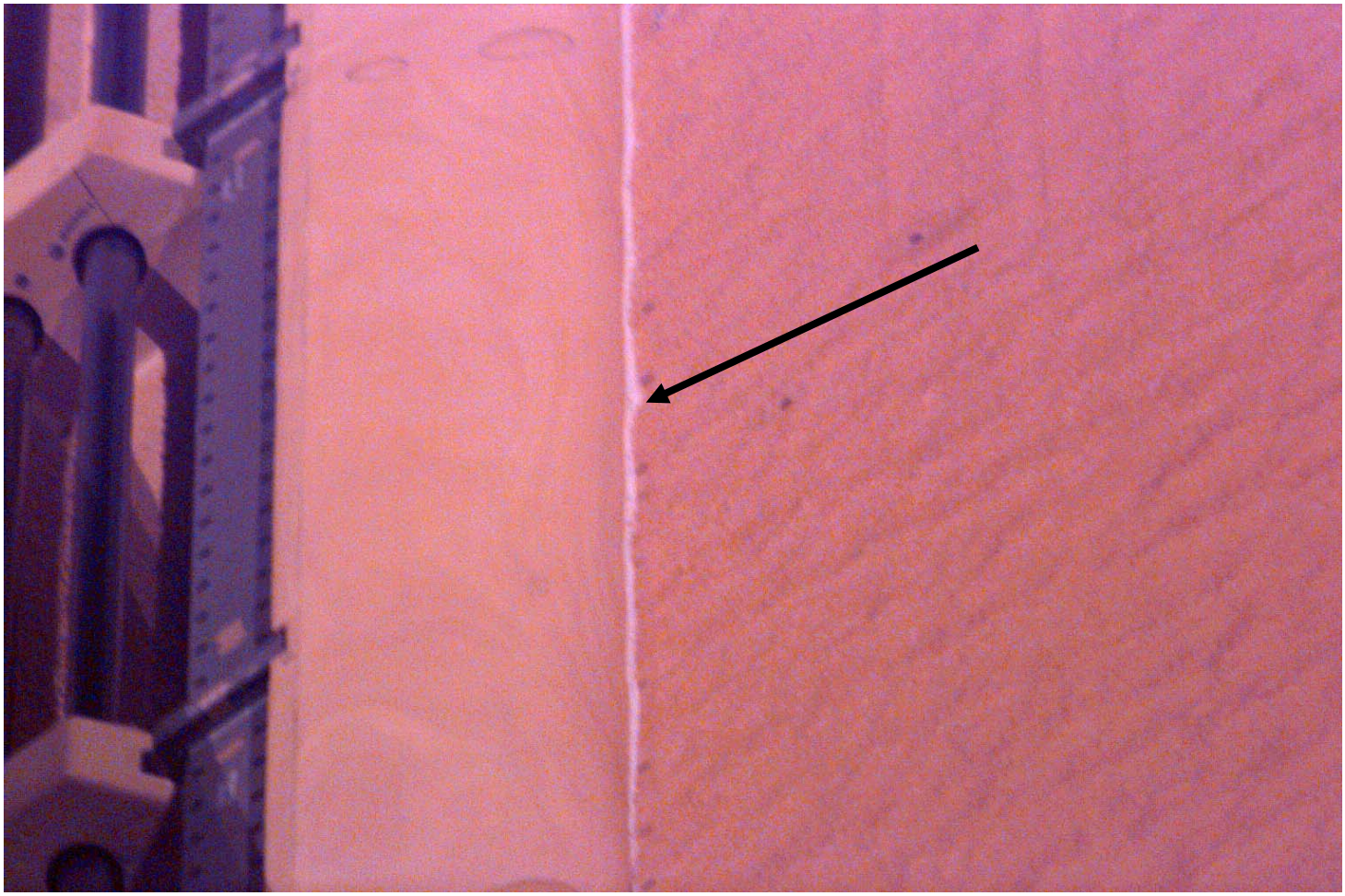


Photo 5: Frost on PAL ramp to LH2 tank acreage

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-2, Pad A FSS, north flame trench, and Pad A apron was conducted on 01 March 2002 from Launch + 1.5 to 3.5 hours (0800 to 1000 EST).

No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach reported a value of 0.08G which indicated that no SRB holddown stud hang-up had occurred. Evaluation of the MLP 0-level was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for both the north and south posts. North holddown post blast covers and T-0 umbilical exhibited nominal exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, protective tape layering was partially eroded on both the RH and LH sides.

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. All MLP deck communication connector caps were found intact and secured.

The GH2 vent line latched on the eighth of eight teeth on the latching mechanism. The restraint 'catch' cable that had paint applied for indication of first contact point was in contact with the retracted line and witness mark could not be identified. 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 and torn. Film review should provide additional data for the assessment of vent line retract position.

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 shape with a broken ground strap at the GOX vent arm console. The GOX vent seals were inspected and found to be in good shape.

Debris findings included:

- FSS 115' level had one or two broken water lines (RSS side).
- FSS 175' level Regulator knob fell off panel 'GN2/GHE crossover panel #5'.

Overall damage to the pad appeared to be normal.

5.0 FILM REVIEW

No significant anomalies were observed during the review of the STS-109 Films/videos that required notification to the Mission Management Team, Shuttle managers, vehicle systems engineers, and to Program Integration.

5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 82 films and videos, which included 16mm films, 35mm films, and Operational Television Video (OTV) camera videos, were reviewed starting on launch day.

GUCP separation and retraction appeared normal (E-33, E-34). GH2 vent line contacted deceleration cable south of center. Latch mechanism hit the North stabilizer rod initially and came to rest adjacent to the South stabilizer rod. Positive capture was achieved on the vent line latch. (E-39, E-43)

Vapors visible from flex hose support block web area. Most likely caused by moisture on structure. (E-36)

Vapor trail was observed off of wing tips during and after roll maneuver. (E-52, E-207, E-213, E-222, E-223, E-224)

SRB water trough baggie material was noted exiting the RH SRB exhaust hole. (E-36)

Several birds came into field of view after SSME startup. No contact with vehicle was noted. (E-63, E-77, E-224)

SRB separation appeared normal. (E-207, E-208, E-212)

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

Free-burning GH2 blown toward vertical stabilizer by wind. (E-52, E-63, E-76, E-77)

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

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-34, E-36, E-52, E-63)

Charring on the ET aft dome was typical. (E-208, E-212, E-222, E-223)

Umbilical purge barrier baggie material fell during roll maneuver. (E-213, E-222)

Forward RCS paper covers were observed falling aft during early ascent. (E-207, E-223)

Pieces of facility debris entered field of view during liftoff, no vehicle impacts. (E-31, E-36, E-40).

Small ice/frost particles from the flight-half of GH2 vent were observed falling alongside the –Z side of the ET shortly after T-0. (E-207)

North Hydrogen Burn Igniters on LH2 TSM sputtered momentarily. (E-76)

SRB holddown post shoe rocked slightly on HDP's #1, #2, and #6. (E-8, E-9, E-13)

GSE Tile shim material shaken loose by SSME ignition acoustics/vibration from the base heat shield near SSME #1. GMT 11:21:59.349 (E-20)

Deluge water pipe leaking near HDP 8. (E-16)

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

Ice from LO2 feedline bellows or support bracket seen falling between ET and Orbiter. No contact with orbiter noted. (E-52)

RTV noted on LH SRB during L-24 hour inspection was still intact after T-0. (E-33)

Several flashes in SSME plume were observed during ascent. (E-222, E-223)

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 19 March 2002.

SRB separation from the External Tank appeared nominal.

ET separation from the Orbiter was normal. The EO-3 separation bolt appeared to be very slightly protruded.

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.

There was an approximately 20 inches by 30 inches of foam loss/erosion on the -Y thrust strut.

Several TPS blisters and divots on the +Y thrust strut. Largest area near the +Y thrust strut flange.

Two small divots near the +Y thrust panel on the intertank to LH2 tank flange.

Three divots observed on the intertank-to-LH2 tank flange between the bipods. One of the divots extends into the acreage foam.

No anomalies were detected in the LO2 tank acreage. The two locations documented on IPRs IPR109V-405 and -408 showed no degradation. The BSM burn scars were typical. The Ogive and the nose cone appeared be in excellent condition.

The ablation/erosion of LO2 feedline flange closeouts was typical. Plug pull repairs on the feedline looked good.

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.

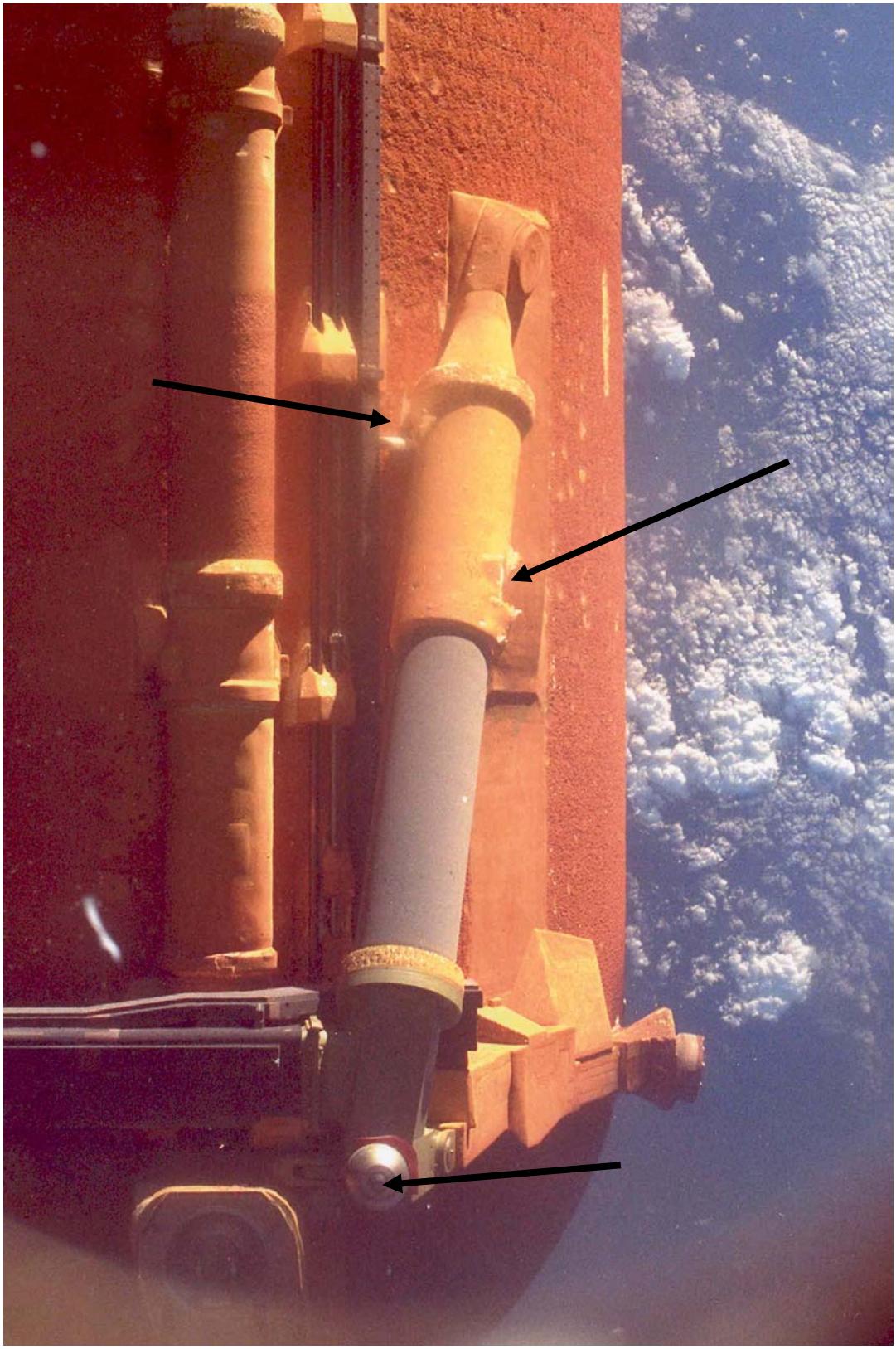


Photo 6: External Tank post separation

Large divots on +Y thrust strut TPS. EO-3 separation bolt protruding slightly.

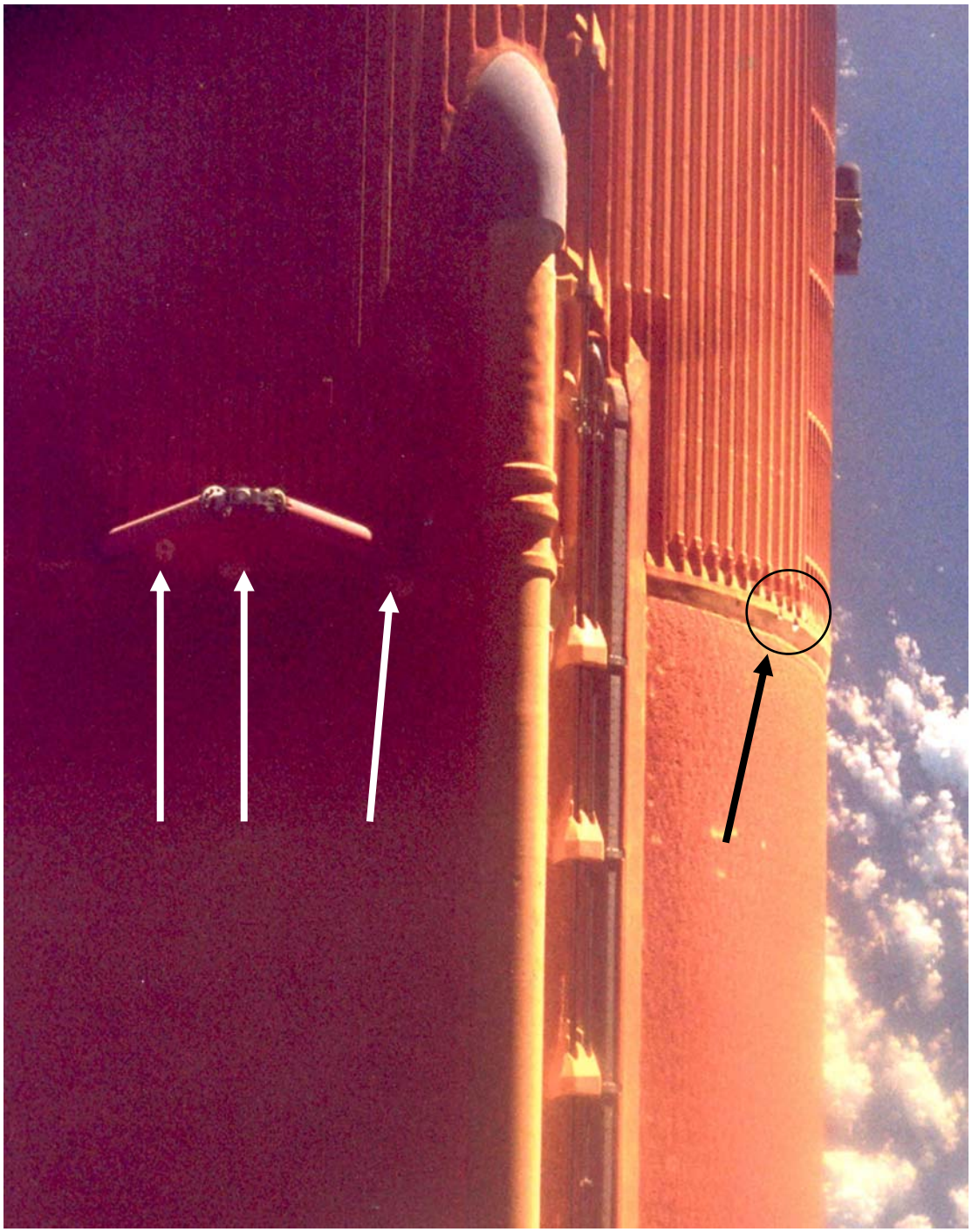


Photo 7: External Tank post separation
Two small divots near the +Y thrust panel on the intertank to LH2 tank flange. Three divots observed on the intertank-to-LH2 tank flange between the bipods. One of the divots extends into the acreage foam.

6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-111 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 5 March 2002. Both boosters were in excellent condition.

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.

The forward skirts exhibited no debonds or missing TPS. RSS antennae covers/phenolic base plates were intact.

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

Separation planes 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.

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally on all HDP's.

No indication of stud hang up was observed.

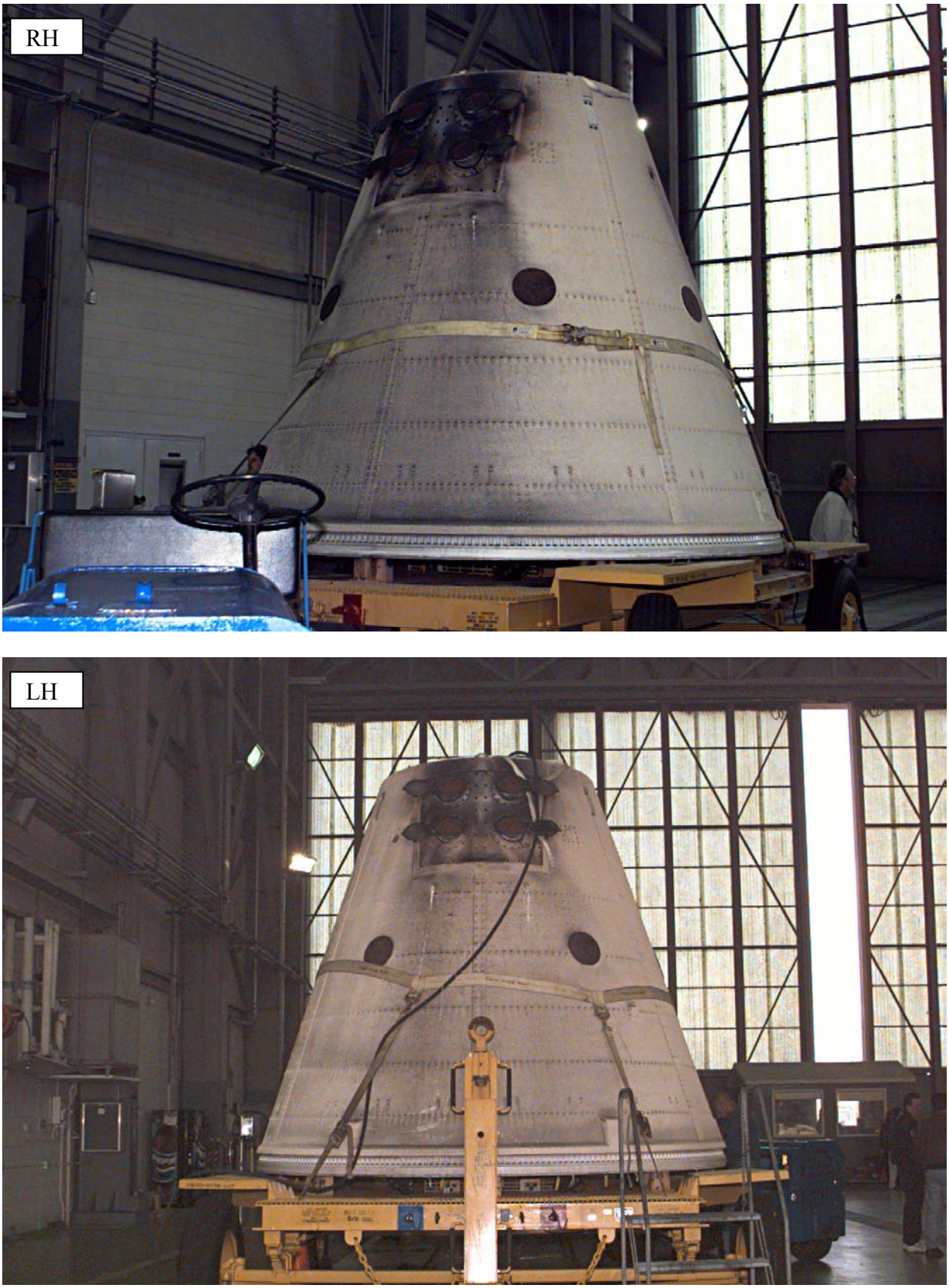


Photo 8: Frustum Post Flight Condition

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

Photo 9: SRB Post Flight Condition

Both SRBs were found in good condition regarding debris assessment

7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 4:32 a.m. local/eastern time landing on 12 March 2002, a post landing inspection of OV-102 Columbia was conducted at the Kennedy Space Center on SLF runway 33 and in Orbiter Processing Facility bay 3. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 98 hits of which 18 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-109 Orbiter damage hits by area:

	HITS > 1-inch	TOTAL HITS
Lower Surface	14	63
Upper Surface	0	1
Window Area	4	29
Right Side	0	4
Left Side	0	1
Right OMS Pod	0	0
Left OMS Pod	0	0
TOTALS	18	98

The Orbiter lower surface sustained 63 total hits, of which 14 had a major dimension of 1-inch or larger, both numbers are well within family. The majority of the hits (34 total with 7 greater than 1-inch) were located in the area between the nose landing gear and the main landing gear wheel wells. Approximately 13 of the total lower surface hits were around the LH2 and LO2 umbilical areas. Most of these damage sites around the ET/ORB umbilical were most likely caused by pieces of the umbilical purge barrier flailing in the airstream and contacting tiles before pulling loose and falling aft.

The largest lower surface tile damage site, located on the LH chine area, measured 3-1/2 inches long by 2-inches wide by 1/8-inches deep. The cause of this damage has not been determined yet.

Gap filler material was found protruding from in between tiles at two locations on the lower surface; LH wing near the elevon and LH outboard elevon

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 29 hits, with 4 having one dimension greater than 1-inch, on the window perimeter tiles. Hazing and streaking of forward-facing Orbiter windows appears to be slightly greater 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. The potential identification of debris damage sources for mission STS-109 will be based on the laboratory analysis of Orbiter post landing microchemical samples, inspection of the recovered SRB components, film analysis, and aerodynamic debris particle trajectory analysis.

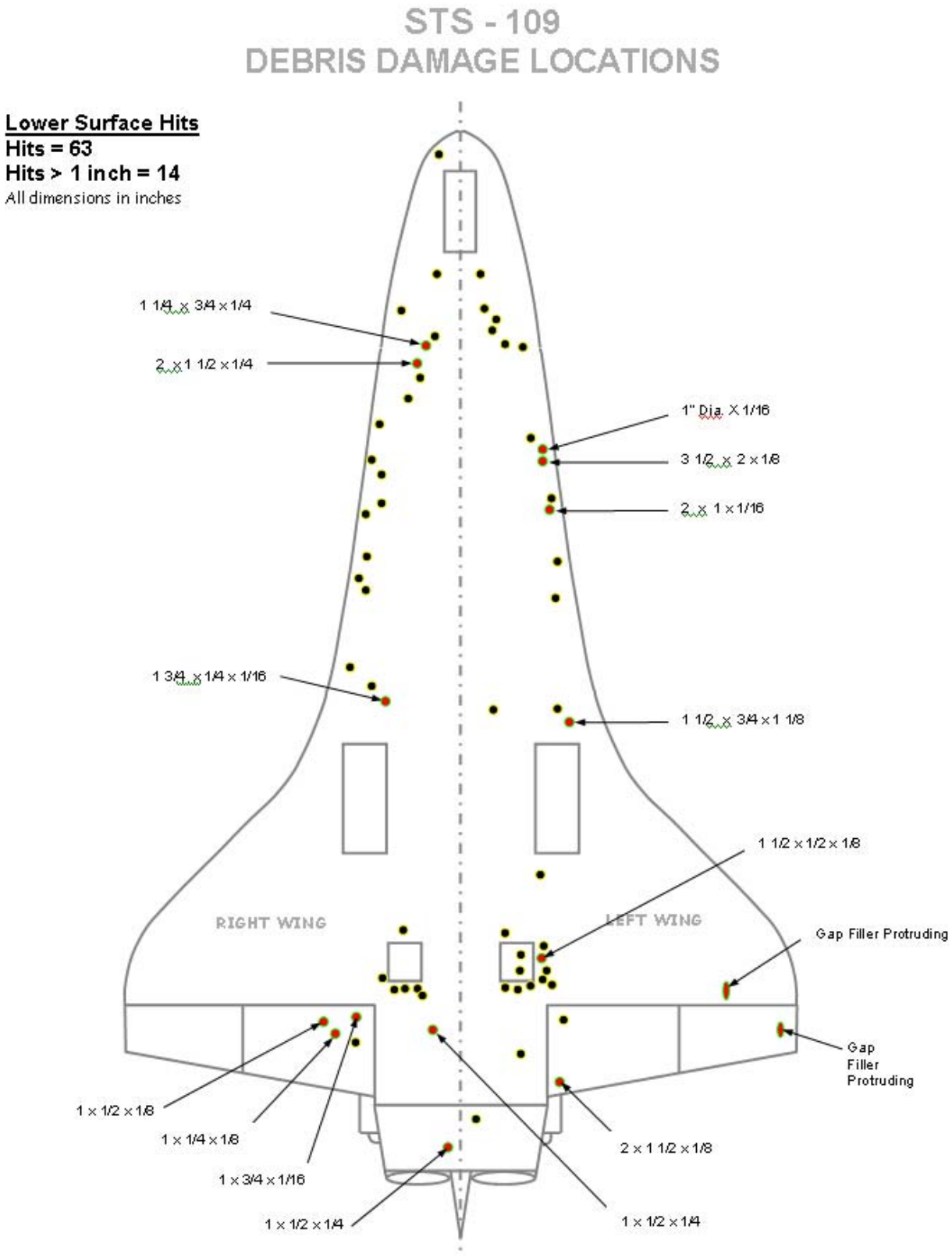


Figure 1: Orbiter Lower Surface Debris Damage Map

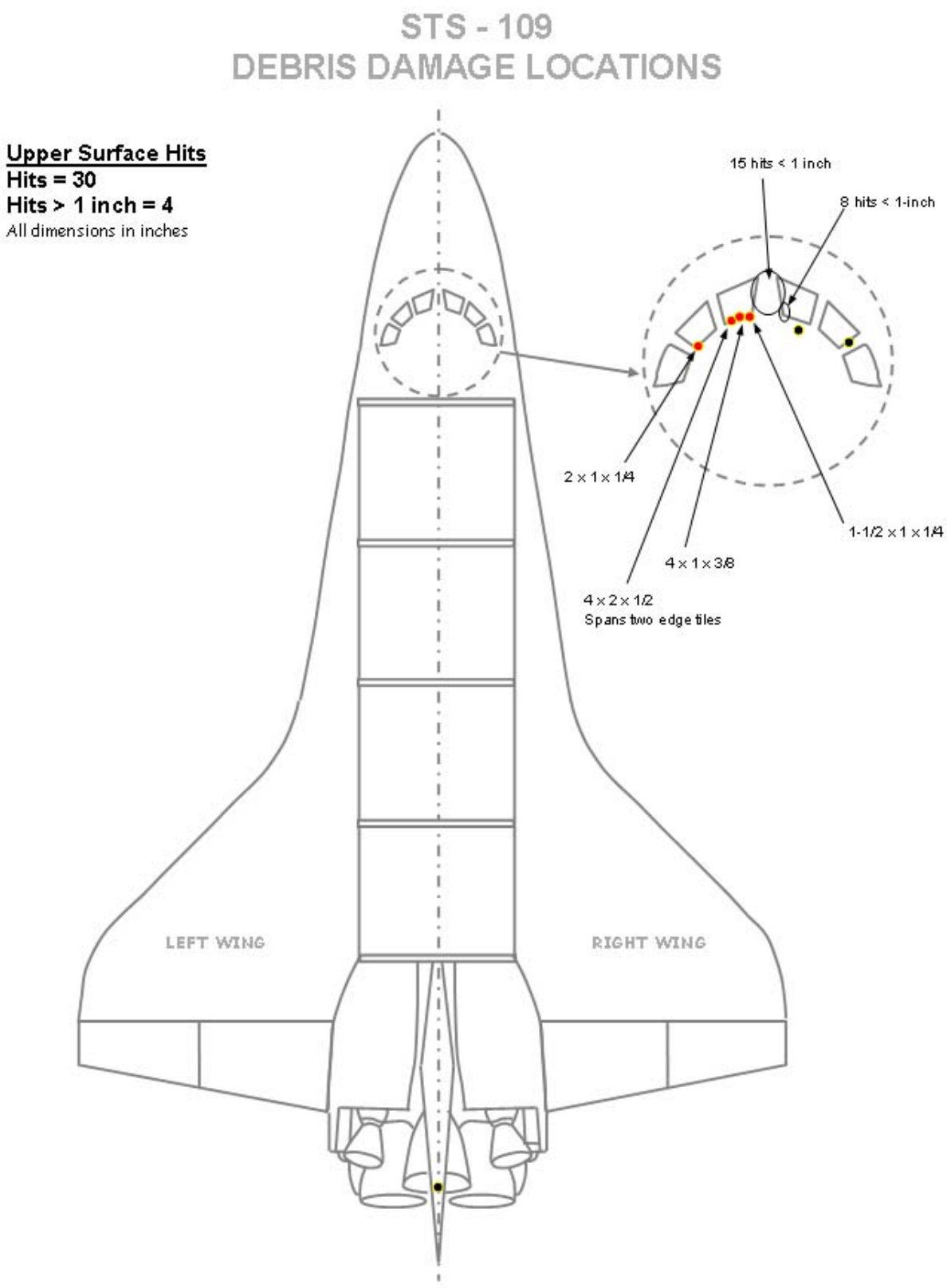


Figure 2: Orbiter Upper Surface Debris Damage Map

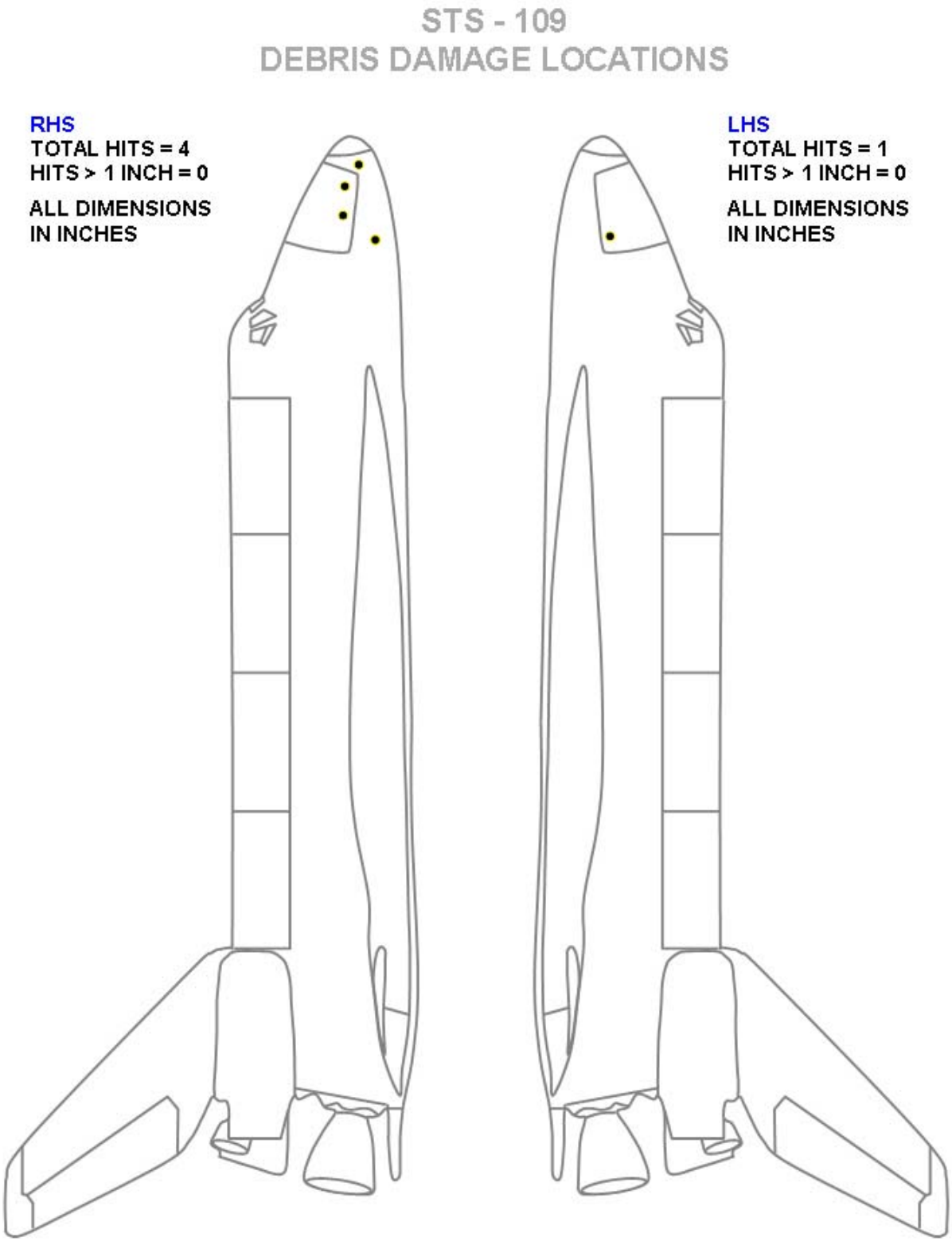
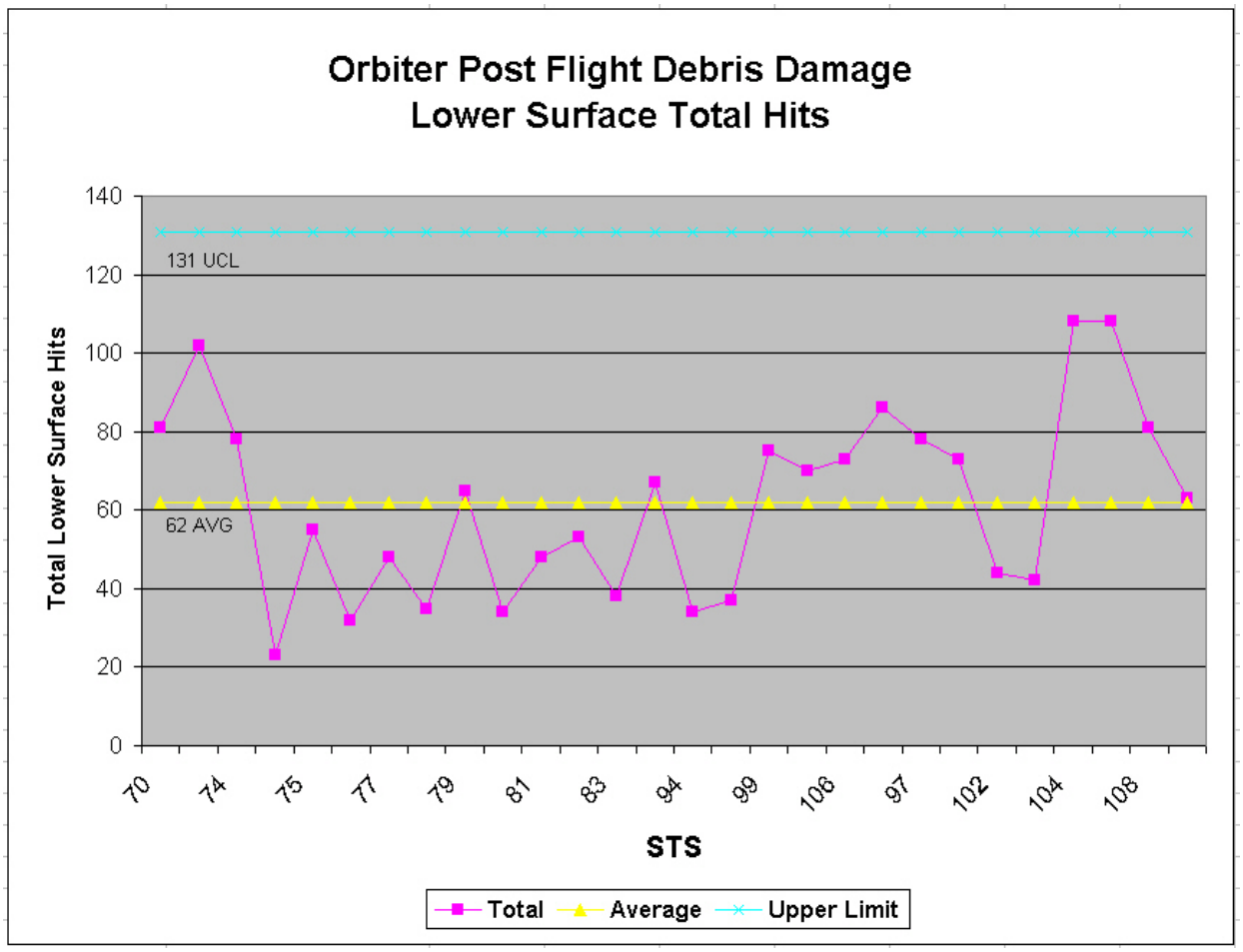


Figure 3: Overall View of Orbiter Sides

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
AVERAGE	11.9	65.8	16.8	104.5
SIGMA	6.0	32.0	6.3	27.5
STS-109	14	63	18	98

MISSIONS STS-86,87,89,90,91,95,88,96,93,103 ARE NOT INCLUDED SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES

Figure 4: Orbiter Post Flight Debris Damage Summary



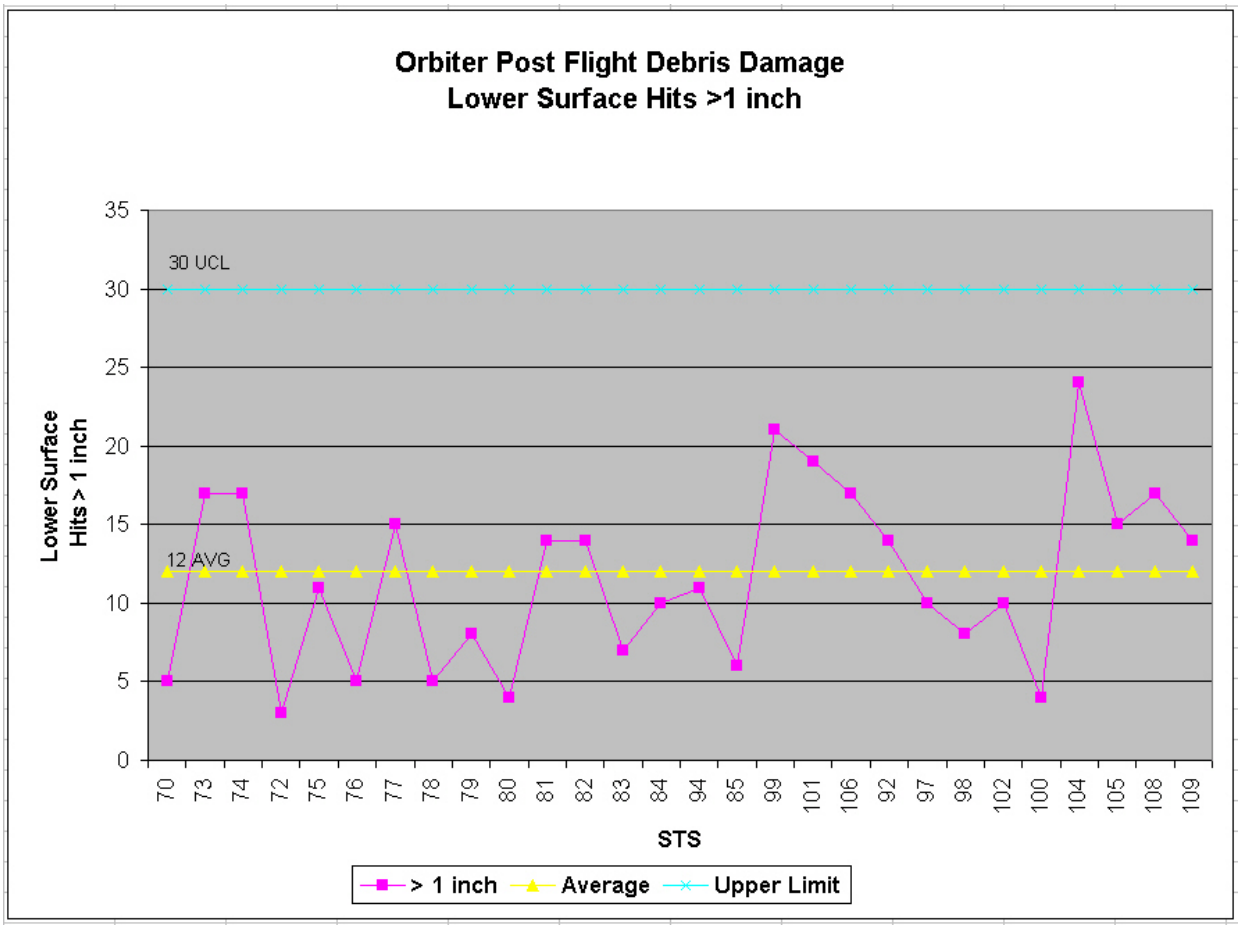
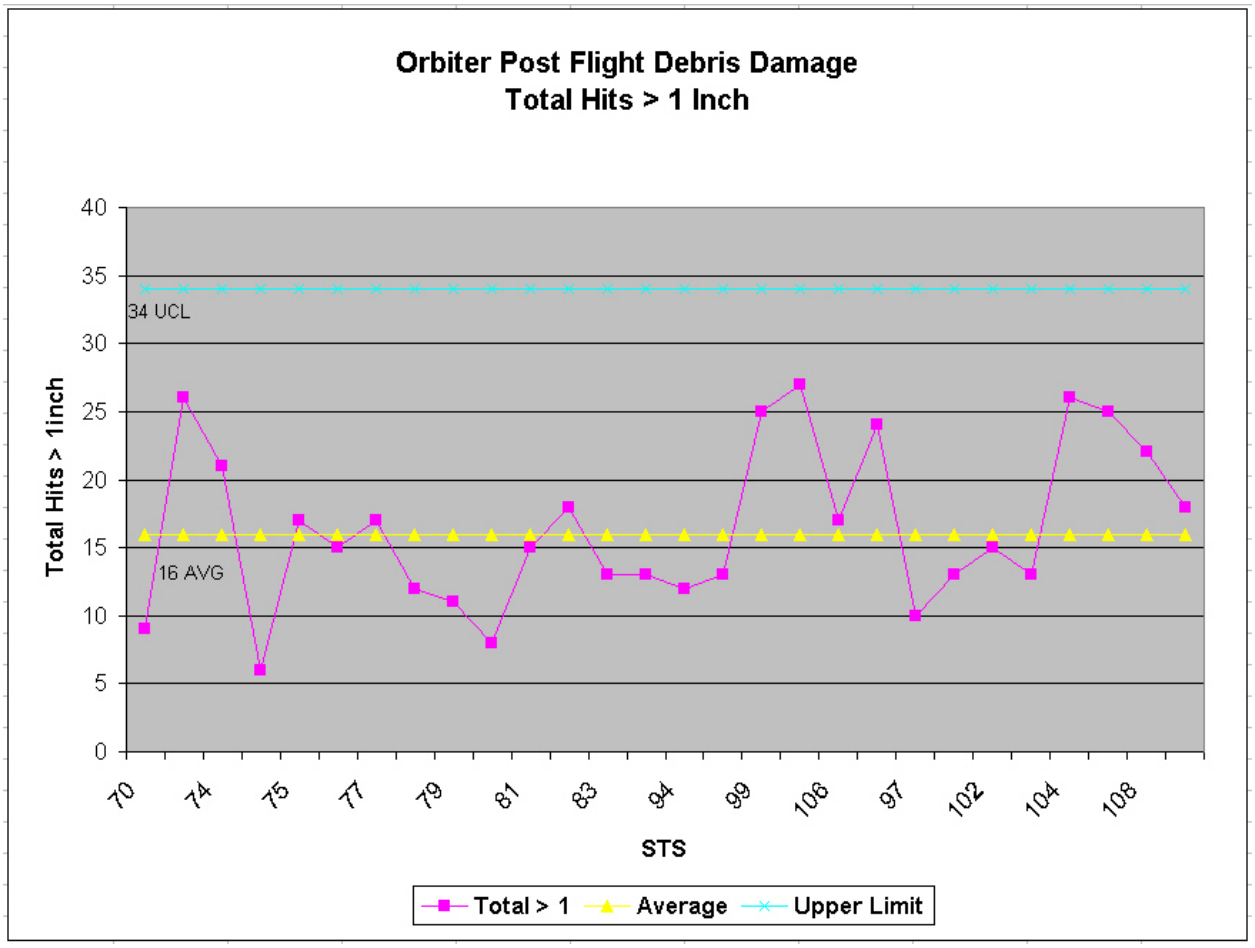


Figure 5: Control Limits for Lower Surface Hits



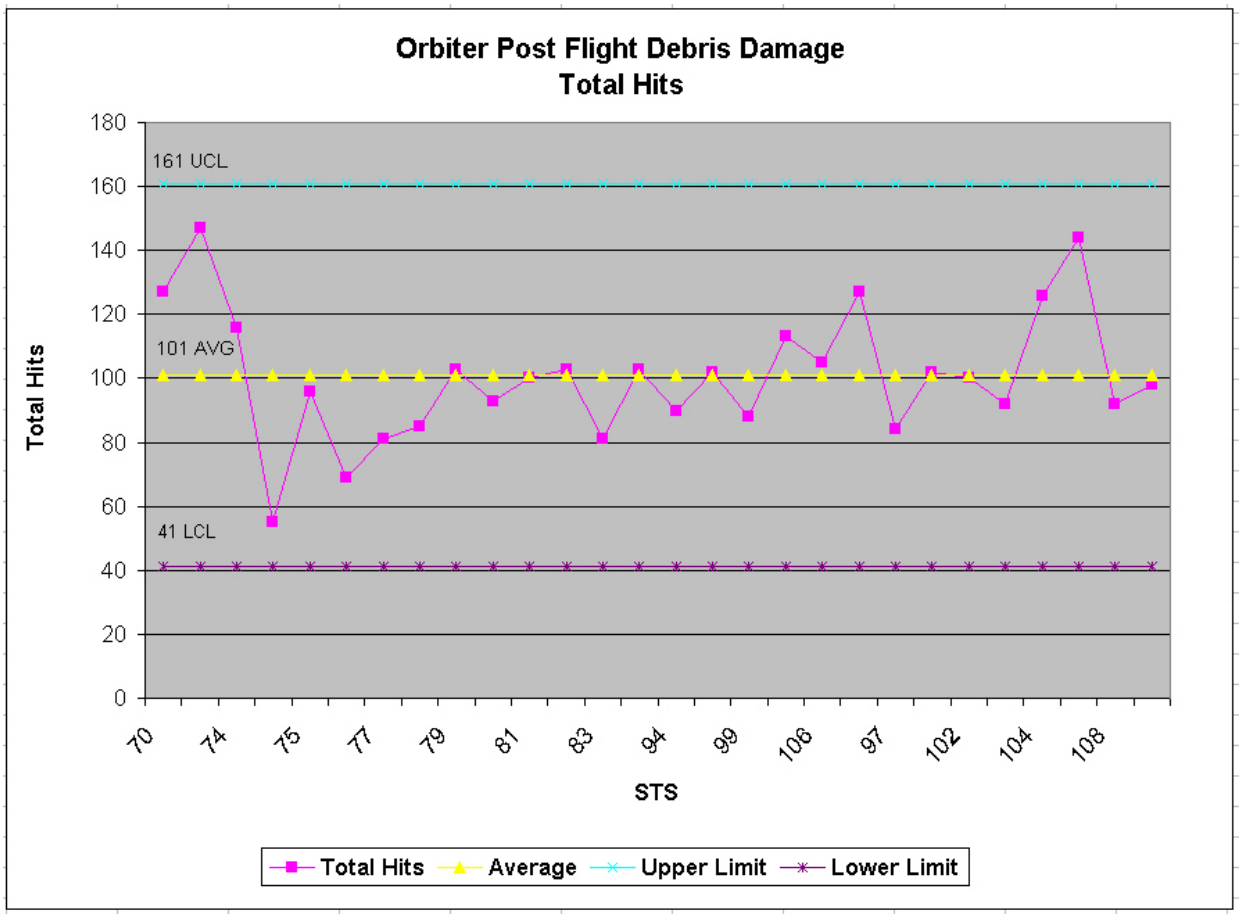


Figure 6: Control Limits for Total Hits

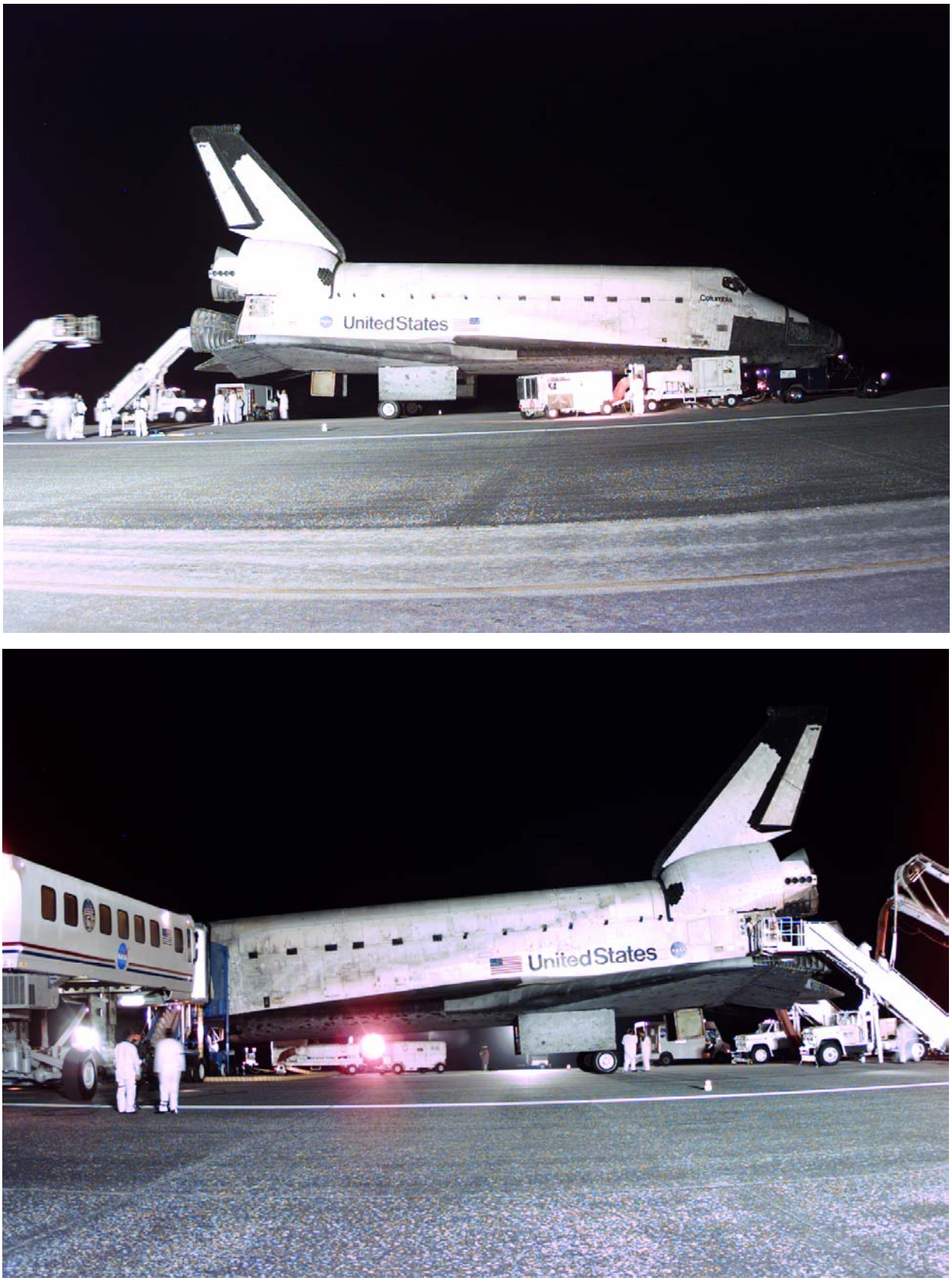


Photo 10: Overall View of Orbiter

The Orbiter TPS sustained a total of 98 hits of which 18 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.

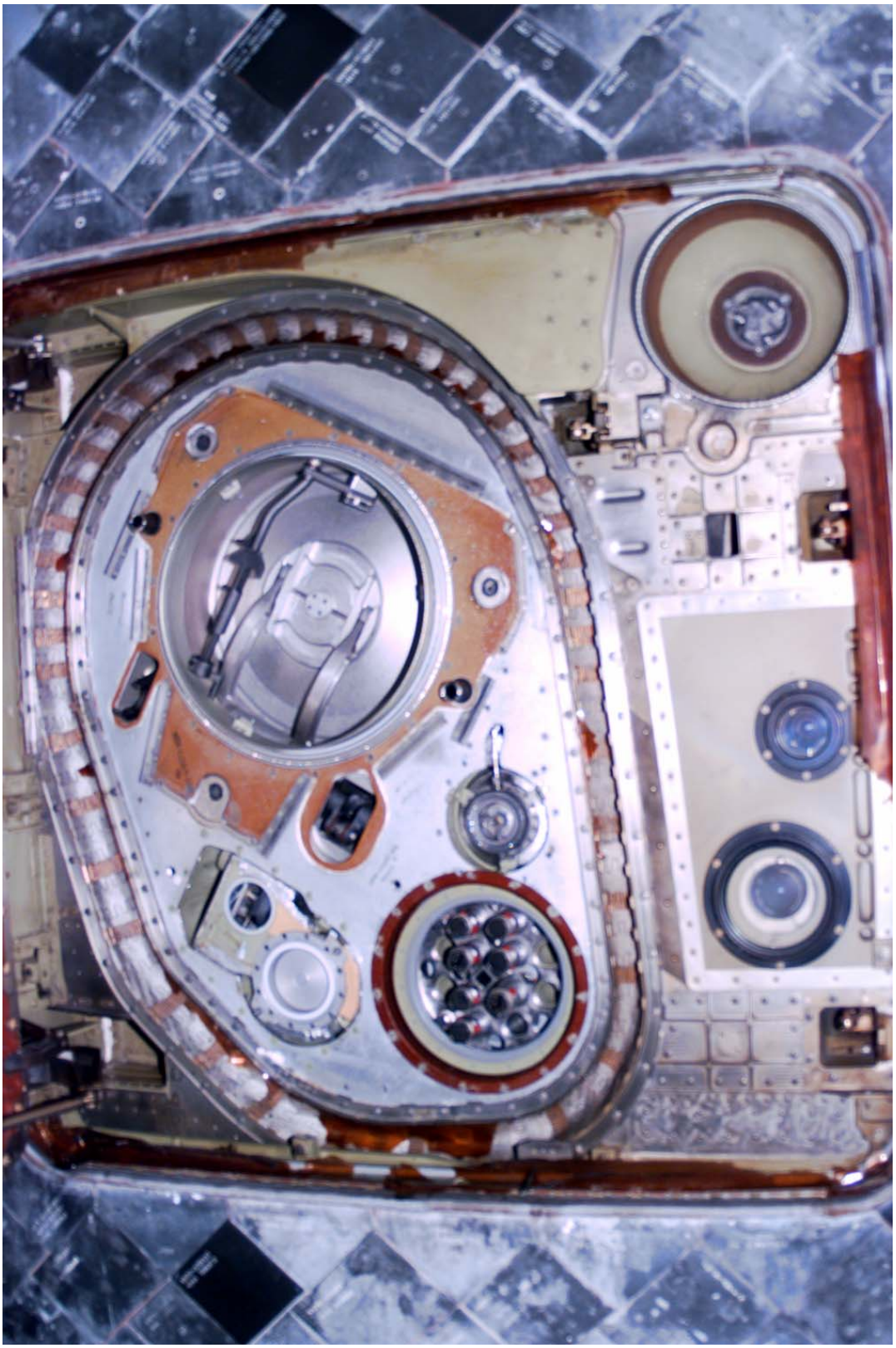


Photo 11: ORB/ET LH2 Umbilical

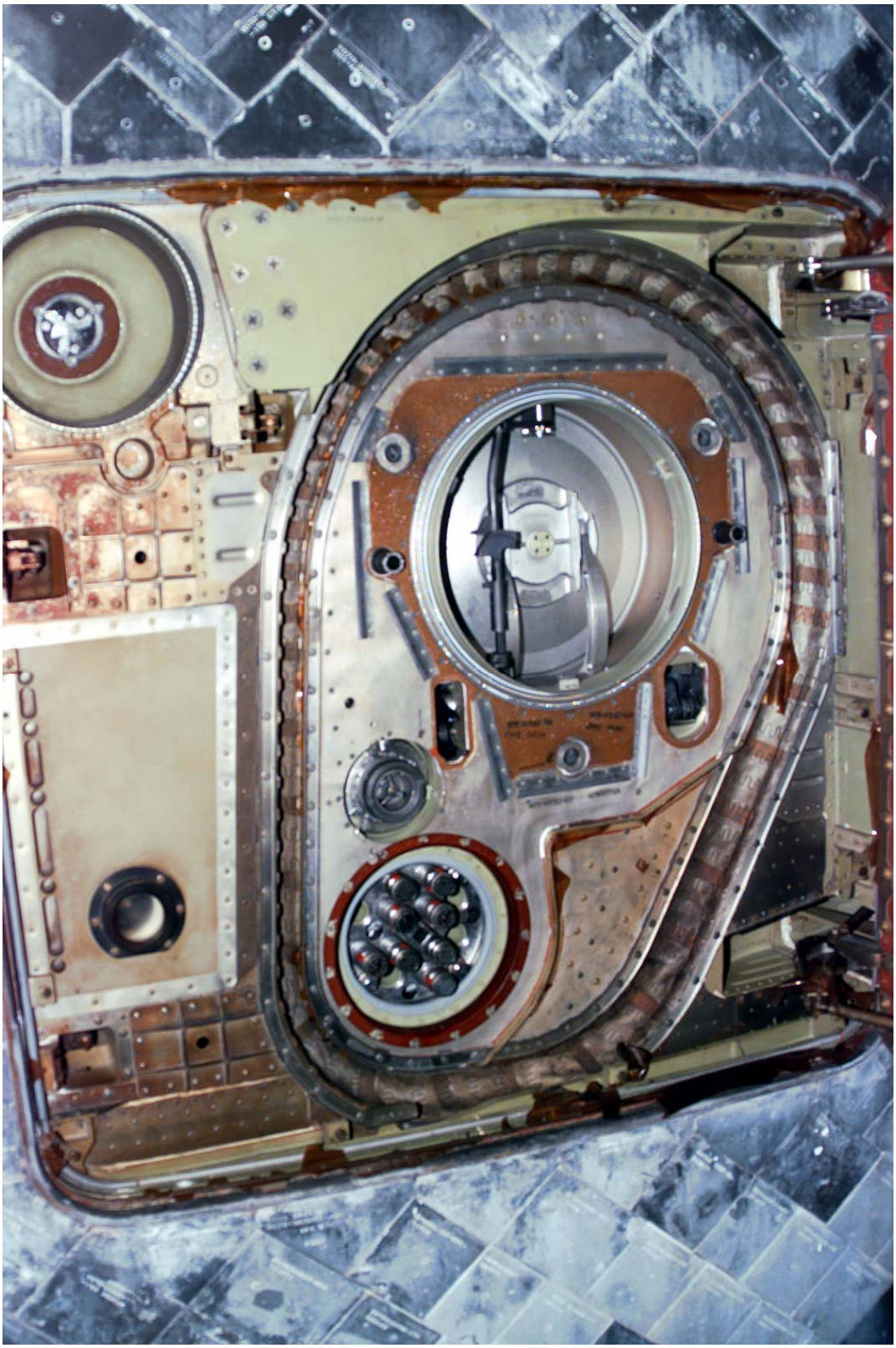


Photo 12: ORB/ET LO2 Umbilical

8.0 DEBRIS SAMPLE LAB REPORTS

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

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

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

9.0 POST-LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, no post-launch anomalies were observed on the STS-109 mission.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Table of Contents

Tables and Figures

1 STS-109 (OV-102): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-109 launch of Columbia (OV-102) from Pad A occurred on March 1, 2002 at 060:11:22:02.032 UTC as seen on camera E7. SRB separation occurred at approximately 11:24:07.284 UTC as seen on camera E207.

On launch day, 24 videos were received and screened. The long range tracking video camera ET207 did not have the IRIG timing with the video. The focus is soft on the long range tracking views (probably due to atmospheric haze).

Twenty-six launch films were screened and a report was sent to the Shuttle Program distribution on March 5, 2002. Twenty-two additional films were received for contingency support and anomaly resolution. This includes four films (E39, E43, E61, and E64) that were provided in support of the previous mission (STS-108) hydrogen vent umbilical anomaly (SR-1652). (Camera film E204 was not provided.)

No anomalous events were seen during the review of the STS-109 launch films and videos that were elevated to the Launch + 4 Day or the Landing + 3 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Reports. (These reports consolidate the multi-center post flight photo reviews into a single list of observations for engineering review. This integrates the photo review process into the IFA / PRACA process to ensure that the identified observations are assessed and dispositioned prior to the next flight per established problem reporting criteria). 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 new 35mm umbilical well TPS camera flew on STS-109. See section 2.4. Crew handheld still photography and video of the External Tank was also acquired on STS-109.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested.

Pre-planned, real-time image analysis support was provided to the Hubble SM-3B program on STS-109. The Hubble SM-3B image analysis support will be documented in the IS&AG SM-3B imagery summary reports.

1.1.3 Landing

Columbia made a night landing on runway 33 at the KSC Shuttle Landing Facility on March 12, 2002 (071:09:31:51.870 UTC). Nine videos and ten 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. During the deployment of the drag chute, a downward motion of the chute was noted as the chute grabbed air.

Post landing, a sink rate analysis of the STS-109 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 and Landing + 3 Day Intercenter Consolidated Film Review Reports

No anomalous events were seen during the review of the STS-109 launch films and videos that were elevated to the Launch + 4 Day or the Landing + 3 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Reports.

2.2 Special Interest Observation

One special interest observation was noted that involved similar hardware to an anomalous event seen previously on the STS-108 mission.

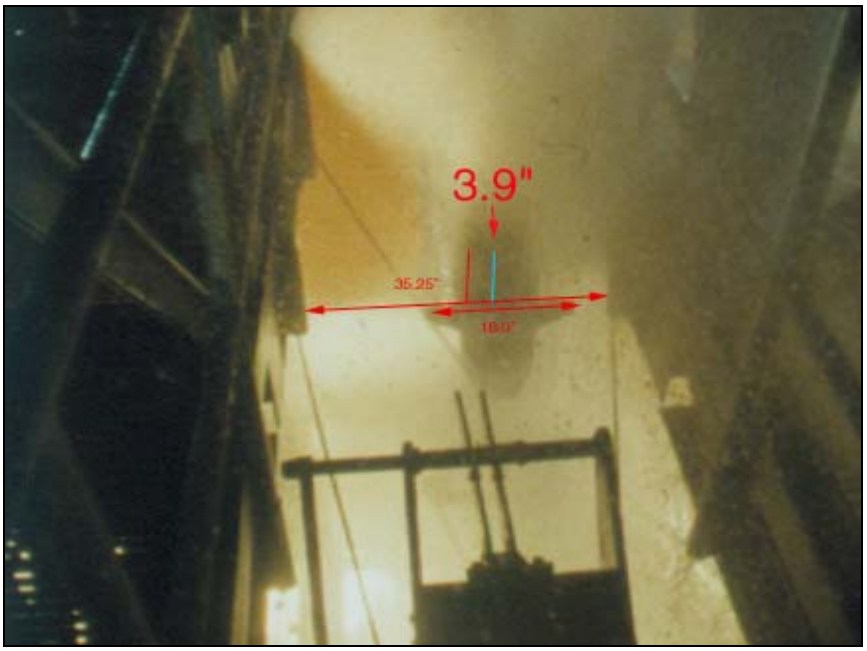


Figure 2.2 GH2 Vent Arm South of Center Contact with the Deceleration Cable During Latchback (Camera E39)

GH2 Vent Arm Latch Back (Camera E39, E43) – As reported by KSC, the GH2 vent arm was seen to contact the deceleration cable south of the center position during the rotation of the arm downward during retraction. The north stabilizer rod of the GH2 vent arm struck the FSS latch mechanism and moved southward before coming to a stop adjacent to the GH2 vent arm south stabilizer rod. Positive capture was achieved on the vent line latch. The times of these events were:

11:22:03.505 UTC - GH2 vent line contacted the deceleration cable south of center.

11:22:03.871 UTC - The north stabilizer rod on the GH2 vent arm contacted the latch-back mechanism south of center.

11:22:04.274 UTC - Approximate time of latch-back of the GH2 vent arm.

Vapors obscured the view of the GH2 vent arm on the image frame when the arm contacted the deceleration cable. Therefore a measurement of the distance from center could not be made. However, after the vapors cleared, analysts were able to make measurements of the arm position from the camera E39 film. The center of the vent arm on an image 0.175 seconds after contact with the deceleration cable was measured to be 3.9 inches to the right of the channel centerline. (The error was estimated to be +/- 0.1 inches.)

The GH2 vent arm retraction from the ET at liftoff appeared normal (11:22:02.031 UTC) on the launch pad camera views. On camera E41, vapors were seen coming from the GH2 vent arm bridle during the arm retraction. Ice and vapors were seen falling aft along the ET during the vent arm retraction. (Cameras E33, E34, E41, E36, E54, E223)

2.3 Other Launch Observations

2.3.1 Debris from SSME Ignition through Liftoff

A rectangular-shaped, red-colored piece of debris (probably a tile shim) appeared to detach from the base heat shield between the left RCS stinger and the left OMS nozzle and fell aft between the SSME cluster during SSME ignition (11:21:58.546 UTC). The same object was seen on camera E19 coming from behind SSME #1 and then falling aft between the SSME cluster at 11:21:59.725 UTC. On camera E76, this same object was seen falling aft near the rim of SSME #1 (11:21:59.942 UTC). (Cameras E19, E20, E76)

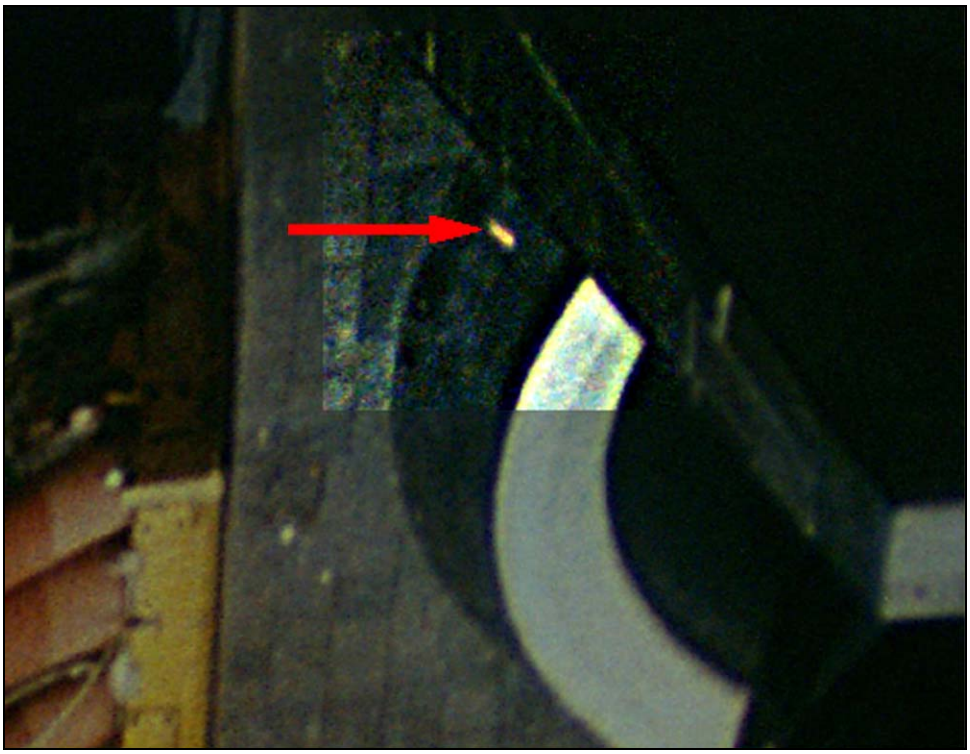


Figure 2.3.1 (A) Red-colored Debris near Base Heat Shield (Camera E17)

A second, rectangular-shaped, red-colored debris object (also probably a tile shim) was seen falling aft of SSME #3 at 11:22:00.237 UTC. On camera E17, this second possible tile shim was seen near the base heat shield outboard of SSME #3 before falling aft along the –Z side of the body flap (11:22:00.109 UTC). See Figure 2.3.1(A). (Cameras E17, E19)

What appeared to be a piece of ET / Orbiter purge barrier material tape was seen falling aft along the body flap prior to liftoff (11:22:00.8 UTC). (Camera E31)

A piece of ice debris was seen to contact the –Z side of the SSME #3 bell prior to liftoff (11:21:59.649 UTC). No damage to the SSME #3 engine bell was noted. (Camera E17)

A small dark-colored piece of debris appeared to originate from the RSRB holddown post #5 bolt hole as the RSRB holddown post foot lifted off the holddown post shoe. This object may have been a piece of debris from the debris containment system (DCS) (11:22:02.554 UTC). (Camera E12)

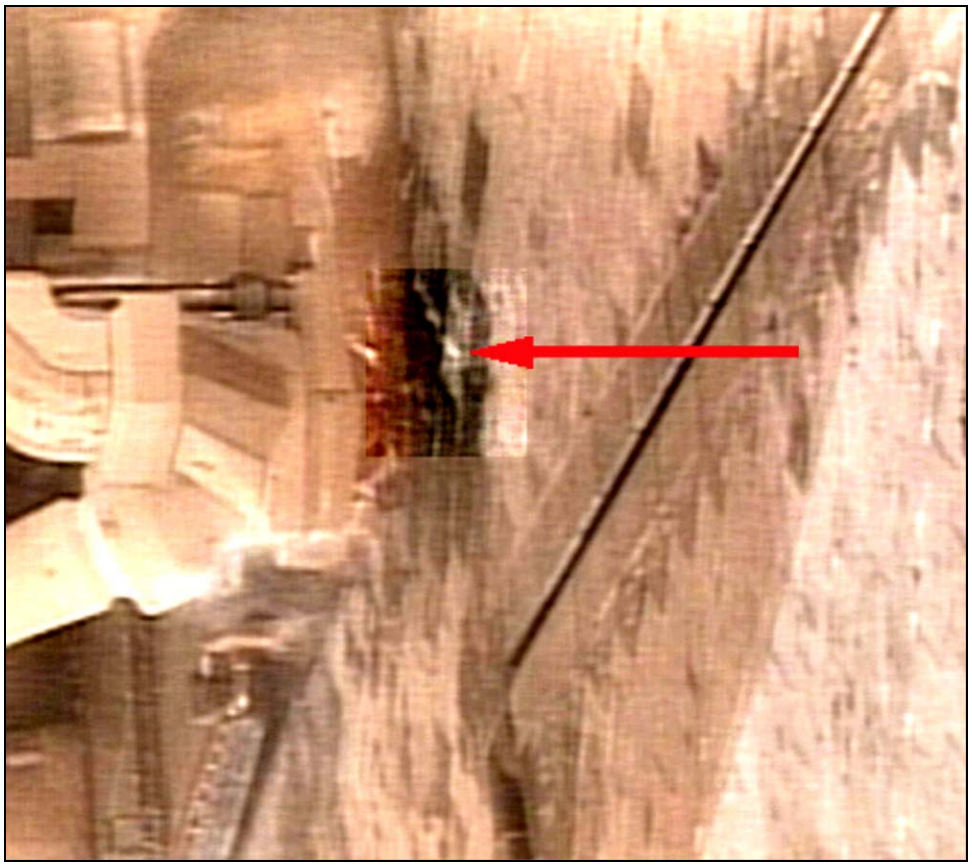


Figure 2.3.1 (B) Ice Contacts Orbiter Tiles Near LH2 Umbilical (Camera OTV009)

Multiple pieces of ice debris were seen falling from the ET/Orbiter umbilicals and along the –Z side of the body flap during SSME ignition through liftoff. A single piece of ice debris contacted the LO2 umbilical well doorsill during SSME ignition (11:21:58.506 UTC). A single piece of ice debris contacted the Orbiter tiles close to the LH2 umbilical during SSME ignition (11:22:01.676 UTC). See Figure 2.3.1 (B). A single piece of light-colored debris (probably ice) was seen near the flange on the LH2 umbilical 17 inch feedline before falling aft during liftoff (11:22:02.277 UTC). No damage to the vehicle was observed. Umbilical ice debris contacting the Orbiter surfaces has been seen on previous missions. (Cameras OTV009, OTV054, E1, E4, E5, E18, E19, E20, E31, E34, E36, E52, E63, E76)

Light-colored debris (possibly ice) was seen falling aft of the ET along the RSRB during SSME ignition (11:21:58.870 UTC). A dark-colored piece of debris (probably RCS paper) was seen near the right RCS stinger prior to liftoff (11:21:59.658 UTC). (Camera E2)

A light-colored piece of debris seen between SSME #2 and SSME #3 near the base heat shield fell aft along the + Z side of the body flap after SSME ignition. This debris appeared to be RCS paper (11:22:00.208 UTC). At approximately the same time, a second piece of light-colored debris (probably RCS paper) was seen near the +Z aft edge of the body flap. (Camera E5)

A small, light-colored, unidentified piece of debris was seen above the LO2 TSM before falling aft along the LO2 TSM T-0 disconnect prior to liftoff (11:21:59.463 UTC). (Camera E17)

A dark-colored piece of debris was seen falling along the –Y side of the Orbiter fuselage above (+Z) the left inboard elevon prior to liftoff (11:21:59.455 UTC). (This object appeared out of focus and may have been near the camera). On camera E76, a light-colored piece of debris (origin unknown) was seen falling aft along the –Z side of the right inboard elevon during liftoff (11:22:03.431 UTC). (Camera E31, E76)

A light colored piece of rectangular-shaped debris (possibly tape) was seen falling from behind the LH2 umbilical during SSME ignition. This debris appeared flexible and thin and appeared to "float" aft along the Orbiter (11:22:01.109 UTC). (Camera OTV009)

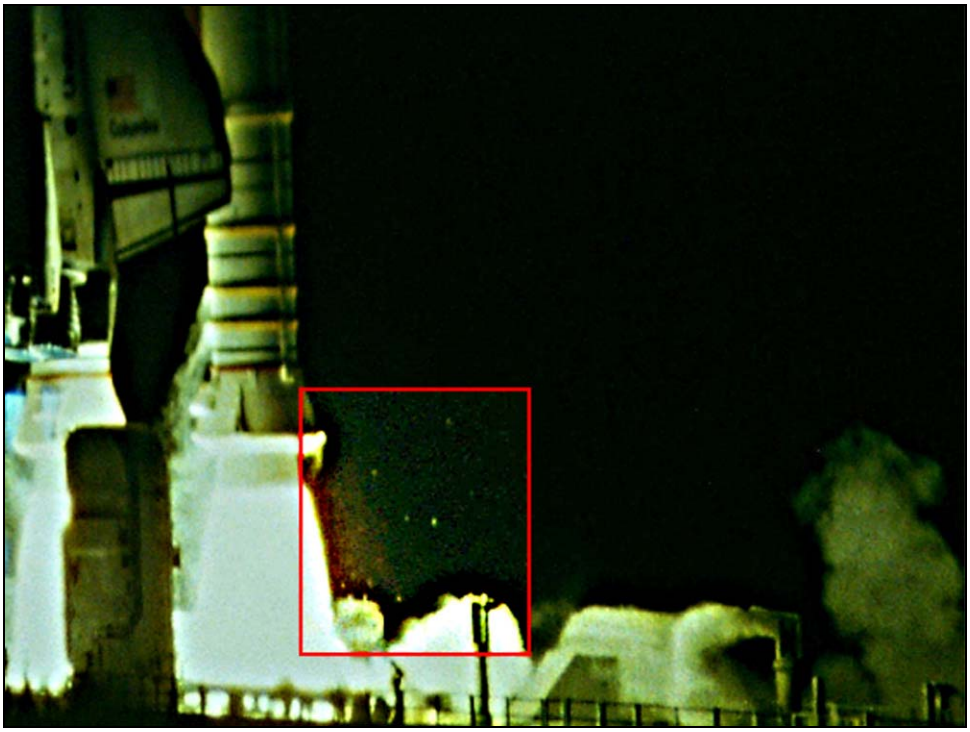


Figure 2.3.1 (C) Debris Seen North of MLP During Liftoff (Camera E1)

Multiple pieces of SRB throat plug and/or SRB flame duct debris were seen near the right and left SRBs during liftoff. None of this debris was seen to contact the launch vehicle. See Figure 2.3.1 (C) and Table 2.3.1. (Cameras E1, E5, E17, E19, E41, E52, E63, E76, E222)

Camera	Time (UTC)	Description
OTV071	(liftoff)	Two pieces of light colored debris between Orbiter and FSS
OTV063	11:22:02.511	Unidentified, light-colored piece of debris seen coming from behind the ET aft dome traveling toward the Orbiter before falling aft
E5	11:22:02.745	Two light-colored pieces of debris (first seen on the outboard sides of both SRB's) traveled inboard toward the –Z side of the body flap before falling aft
E17	11:22:02.812	A light-colored piece of debris was seen near the LO2 TSM before falling aft
E63	(liftoff)	SRB flame duct debris seen outboard of the LSRB during liftoff
E52	11:22:02.932	Multiple pieces of debris were seen on the –Z side of the RSRB exhaust plume during liftoff
E17	11:22:03.045	Single light-colored piece of debris seen traveling past the LO2 TSM before falling aft near the right RCS stinger
KTV4A, KTV7A, E41, E222	11:22:03.266, 11:22:04.067	Multiple pieces of debris north of MLP during liftoff
E76	11:22:04.081	Several light-colored pieces of probable instafoam debris were seen moving laterally in a –Y direction from near the LSRB aft skirt
E76	11:22:04.081	Several pieces of light-colored debris were seen traveling toward the LO2 TSM from near the LSRB aft skirt
E19	11:22:04.451	Single piece of debris seen near the LSRB aft skirt moving in a +Y direction and then fell aft

Table 2.3.1 SRB Throat Plug / Flame Duct Debris at Liftoff

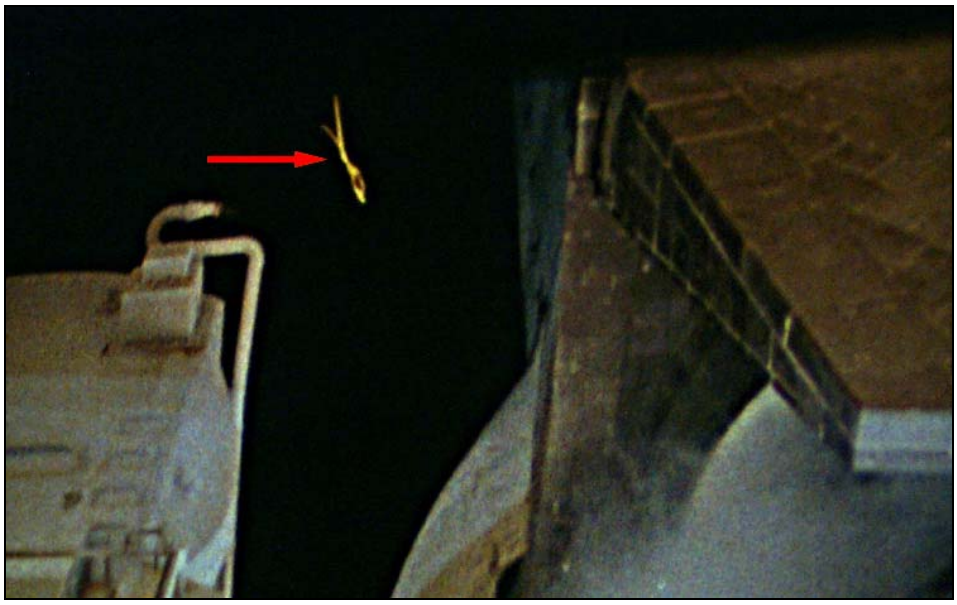


Figure 2.3.1 (D) Unidentified Debris seen above LO2 TSM (Camera E17)

A long, unidentified, linear-shaped debris object (with a fork-shaped appearance on one end) appeared to be above the LO2 TSM (in the image view) and traveled toward the +Y edge of the body flap before falling aft during liftoff (11:22:02.905 UTC). See Figure 2.3.1 (D). (Camera E17)

Several pieces of orange-colored debris (probably ET/Orbiter umbilical well purge barrier material) were seen falling aft along the body flap, along with pieces of ET/Orbiter umbilical well ice, at liftoff (11:22:00.229 UTC). (Camera E18)

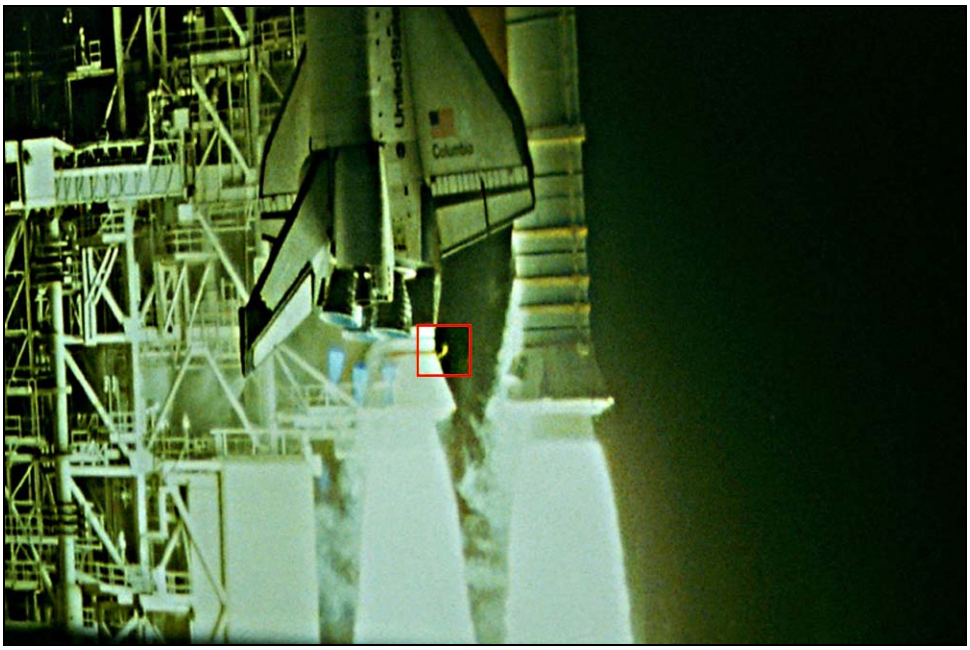


Figure 2.3.1 (E) Umbilical Purge Barrier Material seen Falling Aft During Liftoff (Camera E76)

A large piece of ET/Orbiter umbilical purge barrier material and several smaller pieces of purge barrier material were seen falling aft from the ET / Orbiter umbilical area along the body flap during liftoff (11:22:04.1UTC). See Figure 2.3.1 (E). On camera E222 and E223, a large, orange-colored, piece of debris (probable ET/ Orbiter purge barrier material) was seen between the –Z side of the body flap and the aft end of the LSRB before falling aft into the exhaust plume (11:22:05.010 UTC). ET/Orbiter purge material debris during ascent has been seen on previous mission imagery. (Cameras E1, E5, E18, E36, E52, E63, E76, E222, E223)

An unidentified, light-colored, long, thin, rectangular-shaped debris object was seen falling aft along the south side of the LH2 TSM during liftoff (11:22:03.961 UTC). (Camera E18)

2.3.2 Debris During Ascent

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. See Table 2.3.2 (A).

Event Time	Event Description
11:22:10.964 UTC	RCS paper debris was seen near the left OMS nozzle at the beginning of the roll maneuver (Camera E52)
11:22:13.462 UTC	Forward RCS paper debris was seen falling along the +Z side of the left wing and over the left inboard elevon (Camera E52)
11:22:20.119 UTC	Probable RCS paper debris was seen forward of the LSRB aft skirt near the ET (Camera 52)
11:23:23.279 UTC	A white-colored streak was seen coming from near SSME rim #1 (possibly RCS paper debris or a condensation streak) (Camera KTV13)
11:23:23.346 UTC	Several light-colored pieces of debris were seen aft of the vertical stabilizer (probable forward RCS paper debris) (Camera KTV13)

Table 2.3.2 (A) RCS Paper Debris During Ascent

As on previous missions, debris was seen exiting the SRB exhaust plumes. The debris exiting the SRB exhaust plumes during the majority of ascent was probably instafoam from the aft end of the SRB's. The more dense appearing debris near the time of tail-off, just prior to SRB separation, was probably SRB slag debris. Examples of this debris can be seen in Table 2.3.2 (B).

Event Time (UTC)	Camera
11:22:16.605	E52
11:22:54.120	E222
11:23:11.841	E223
11:23:14.907	E223
11:23:15.181 – 11:23:18	E223
11:23:16.206	KTV4
11:23:22.879	KTV4
11:24:02.183	ET207

Table 2.3.2 (B) Debris Seen Exiting the SRB Exhaust Plume

2.3.3 Mobile Launch Platform (MLP) Events

The SSME ignition appeared normal. During SSME start-up, the SSME Mach diamonds formed in the expected sequence (3, 2, 1). (Cameras E19, E20, E76) The times for the Mach diamond formation given in Table 2.3.3 are from film E19:

SSME	Time (UTC)
SSME #3	11:21:58.705
SSME #2	11:21:58.860
SSME #1	11:21:58.989

Table 2.3.3 SSME Mach Diamond Formation Times

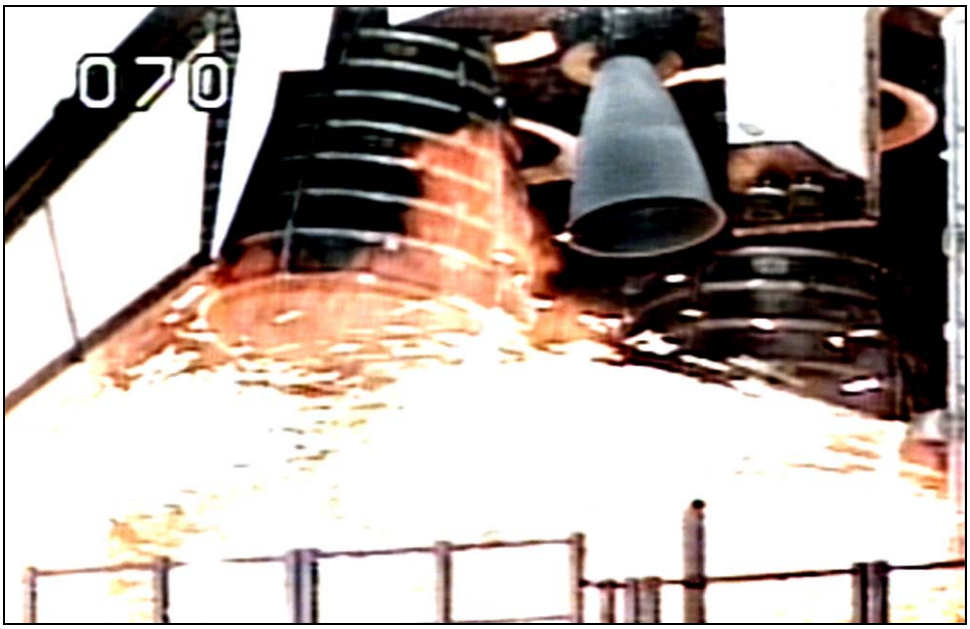


Figure 2.3.3 (A) Orange Vapor Seen Above SSME Rims Prior to Liftoff (Camera OTV070)

Orange vapor (possibly free burning hydrogen) was seen forward of the base of the vertical stabilizer, near the base heat shield, forward of the trailing edge of the OMS pods, and on the –Z side of the body flap during SSME ignition (11:21:56.471 UTC). See Figure 2.3.3 (A). Orange vapor forward of the aft end of the Orbiter during SSME ignition has been seen on previous mission films and videos. (Cameras OTV070, E1, E2, E5, E18, E19, E20, E52, E63, E76)

Frost was seen on the ET nose cone vent louvers prior to and during liftoff. Frost on the ET vent louvers has been seen on previous mission imagery. (Cameras OTV060, OTV061)

Light-orange-colored streaks were seen in the SSME exhaust plumes, possibly debris induced,

after SSME ignition and prior to liftoff at the times shown below (CamerasE2, E19, E52, E76):
SSME #1 - 11:22:00.521, 11:22:00.092, 11:22:01.137, 11:22:01.176, 11:22:01.821 UTC,
11:22:02.744, 11:22:02.918 UTC
SSME #2 - 11:22:01.293 UTC
SSME #3 - 11:22:00.098, 11:22:02.757 UTC

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

Typical of previous missions, small areas of tile surface coating material erosion were seen on the tip of the right RCS stinger (11:21:57.3 UTC), on the base of the left RCS stinger (11:22:57.4 UTC), two areas on the base heat shield outboard of SSME #3 (11:21:57.2 and 11:21:58.561 UTC), and on the base heat shield outboard of SSME #2 (11:21:57.3 UTC) during SSME ignition. (Cameras E17, E19, E20)

No significant movement of the OMS pod tiles during SSME ignition was detected on the STS-109 camera films. (Cameras E17, E18)

SRB ignition was at 11:22:02.032 UTC based on the observation of the PIC firing at RSRB holddown post M-4. (Camera E7)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 11:22:04.172 UTC (right purge line) and 11:22:04.279 UTC (left purge line). (Cameras E8, E13)

2.3.4 Ascent Events

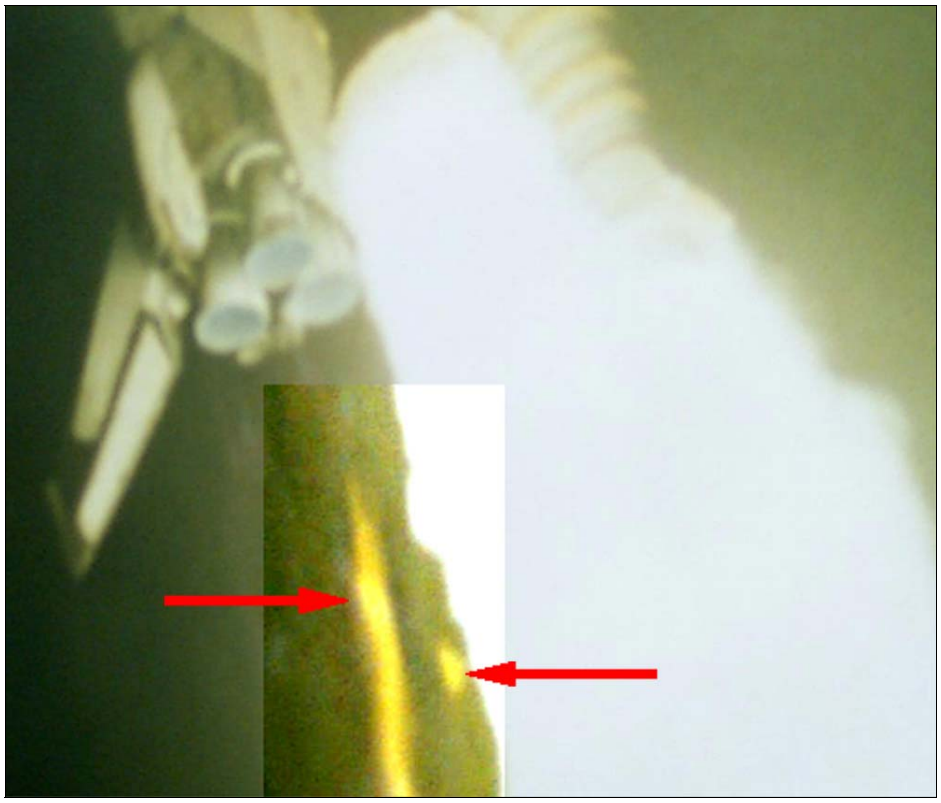


Figure 2.3.4 Flares Seen in SSME Exhaust Plume (Camera E223)

Multiple light-orange-colored flares (possibly debris induced) were noted in the SSME exhaust plume during ascent on the long range tracking camera films. See Figure 2.3.4. 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-109 can be seen in Table 2.3.4.

Time (UTC)	Event	Camera
11:22:14.830	Flare seen in SSME exhaust plume	ET204
11:22:16.997	Flare seen in SSME exhaust plume	ET204
11:22:18.033	Flare seen in SSME exhaust plume	ET204
11:22:18.967	Flare in SSME exhaust plume	ET204
11:22:20.201	Flare in SSME exhaust plume	ET204
11:22:33.592	RCS paper debris seen prior to and after flare in SSME exhaust plume. See Figure 2.3.4.	E223
11:22:33.614	Flare in SSME exhaust plume	E212

Table 2.3.4 Flares Seen in SSME Exhaust Plumes During Ascent

2.4 Onboard Photography of the External Tank (ET-112)

2.4.1 35mm Umbilical Well Camera Film (Roll 412)

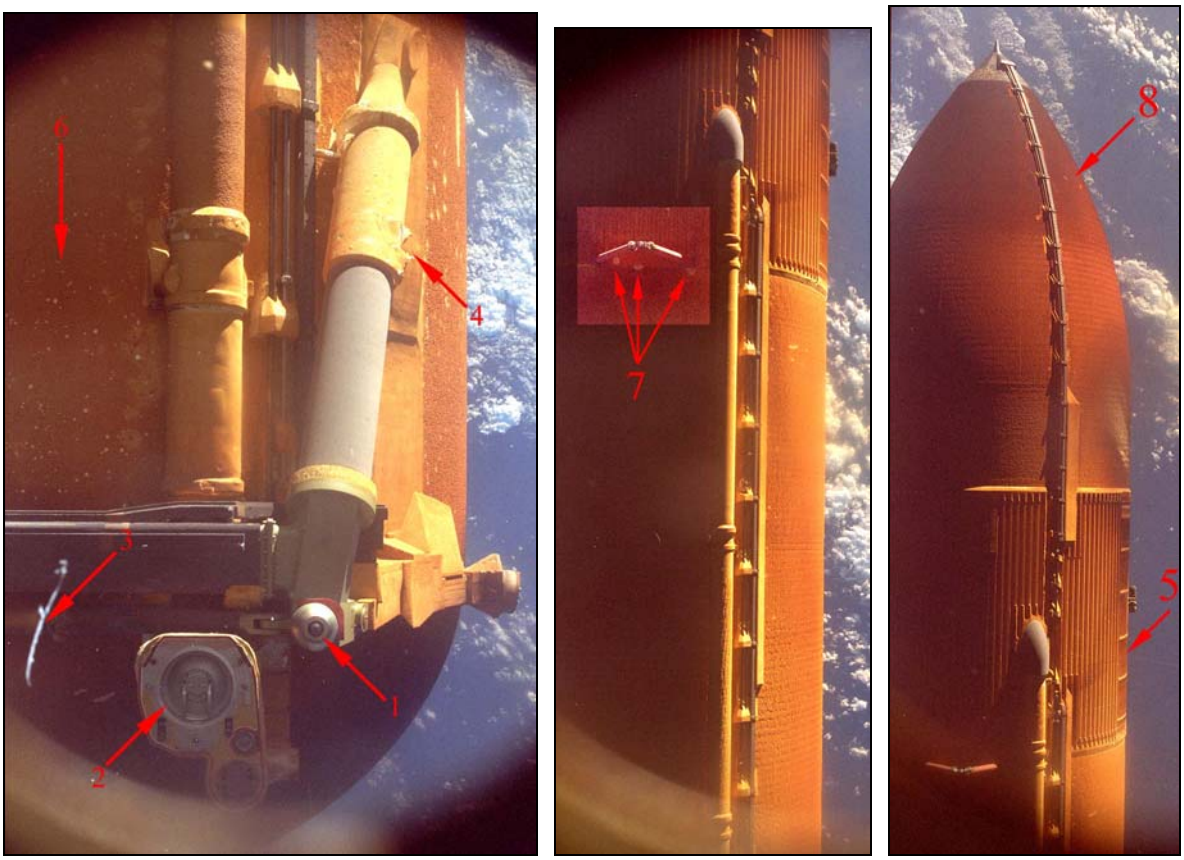


Figure 2.4.1 35mm Images of the External Tank during Separation

The separation bolt between the ET and the aft end of the Orbiter (EO-3 fitting near the liquid oxygen umbilical) appeared to be flush or, at the most, very slightly protruded. See Figure 2.4.1, annotation 1. (A Shuttle Program investigation of the STS-106 bolt extension was previously conducted in October, 2000). The red-colored purge seal on the EO-3 ball joint fitting was in place.

A small piece of debris was visible aft of the EO-3 fitting just after ET separation. A second light-colored, rectangular-shaped piece of probable TPS debris was seen in the +Y direction from the EO-3 fitting (frame 3).

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 2.4.1, annotation 2.

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

A linear-shaped, light-colored piece of debris with small, finger-like protrusions was seen. This debris appeared to be a piece of white RTV or possibly a piece of frozen hydrogen. See Figure 2.4.1, annotation 3.

A light-colored mark (possible TPS erosion) was noted between the +X end of the +Y thrust strut and the LO2 press line. A tear in the TPS near the forward end of the +Y thrust strut was noted. See Figure 2.4.1, annotation 4. Also, a light-colored mark was seen on the LH2 tank TPS in the –Y direction from a LO2 feed line.

No damage was seen on the visible portion of the +Y thrust panel. See Figure 2.4.1, annotation 5. However, two probable divots were seen near the –Y aft corner of the +Y thrust panel on the LH2 / intertank close-out flange. No exposed substrate material was noted.

Typical of previous missions, small "popcorn" divots were seen on the aft LH2 tank TPS forward of the cross beam. See Figure 2.4.1, annotation 6.

Three light-colored marks (probable divots) appeared to be present in the shadow area under the forward bipod on the LH2 / intertank close-out. One of the light-colored marks was in the position of the –Y jack pad closeout on the LH2 tank-to-intertank closeout flange. The larger mark, centered between the legs of the forward bipod was estimated to be approximately six inches in diameter. No exposed substrate material was noted. See Figure 2.4.1, annotation 7.

The visible portion of the LO2 tank / Ojive TPS and the nose cap appeared to be in excellent condition. The aero friction and aero heating marks visible on the TPS just aft of the nose cone appeared typical to that seen on previous missions. See Figure 2.4.1, annotation 8.

Notes: STS-109 was the first mission with imagery of the ET using the new Nikon F5 35mm umbilical camera (that replaced the Nikon F4 camera), a 50 mm lens (vs. the previously used 55 mm lens), and the Kodak Royal Gold 100 color negative film (vs. the previously used color positive film). Coverage was complete from the aft end of the ET to the tip of the ET nose. The focus is good. The exposure on the Sun lit portions of the ET is good. The exposure in the shadow areas of the ET is better on the color negative film than was seen on previous missions using color positive film.

Shadows from the back lighting from the early morning Sun limited the 35 mm umbilical camera views in the -Y direction of the ET by shadow and could not be analyzed on the 35mm umbilical film.

Thirty-seven frames imaging the ET were acquired. The images were excellent quality except for the areas obscured by shadow.

The +X translation maneuver was performed on STS-109 to facilitate the imaging of the ET with the umbilical well cameras.

2.4.2 16 mm Umbilical Well Camera Films with the 5mm and 10mm Lenses (FL101 and FL102)

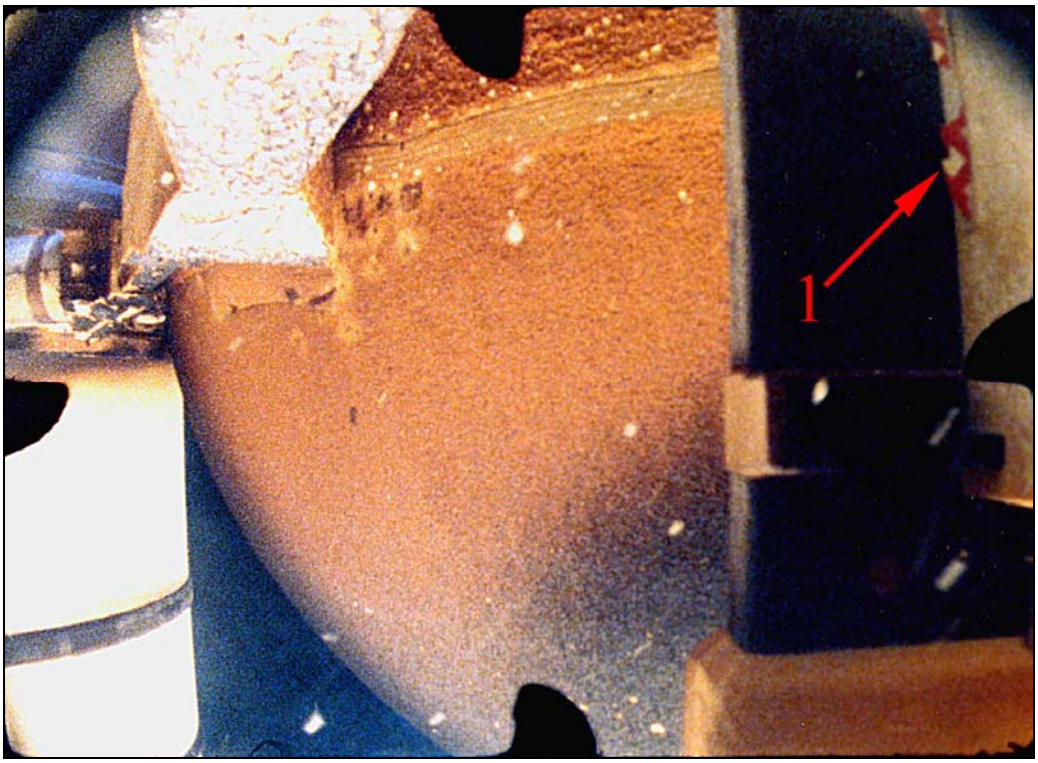


Figure 2.4.2 (A) 16mm Umbilical Well Camera Imagery

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

A red-colored object was seen lodged near the +Y side of the electric cable tray. The object was irregular-shaped with a white mark near the center. This object may have been a piece of RCS paper. The object was still present at the beginning of the ET film sequence. See Figure 2.4.2 (A), annotation 1.

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. Typical blistering of the fire barrier material on the outboard (-Y) side of the LH2 umbilical was seen. The amount of ablation of the TPS on the aft dome was less than that typically seen on previous flights, although several of the TPS ablation marks were very obvious. No anomalies were seen on the left and right SRB nose caps during SRB separation.

The ET separation from the Orbiter appeared normal (the view was very dark because of the back lighting from the early morning Sun).

A red-colored, somewhat square-shaped object, with a white-color on the backside, tumbled in the +X/-Y direction across the face of the LH2 umbilical carrier plate after ET separation. This may be related to the red-colored object seen during the SRB separation sequence on the same films.

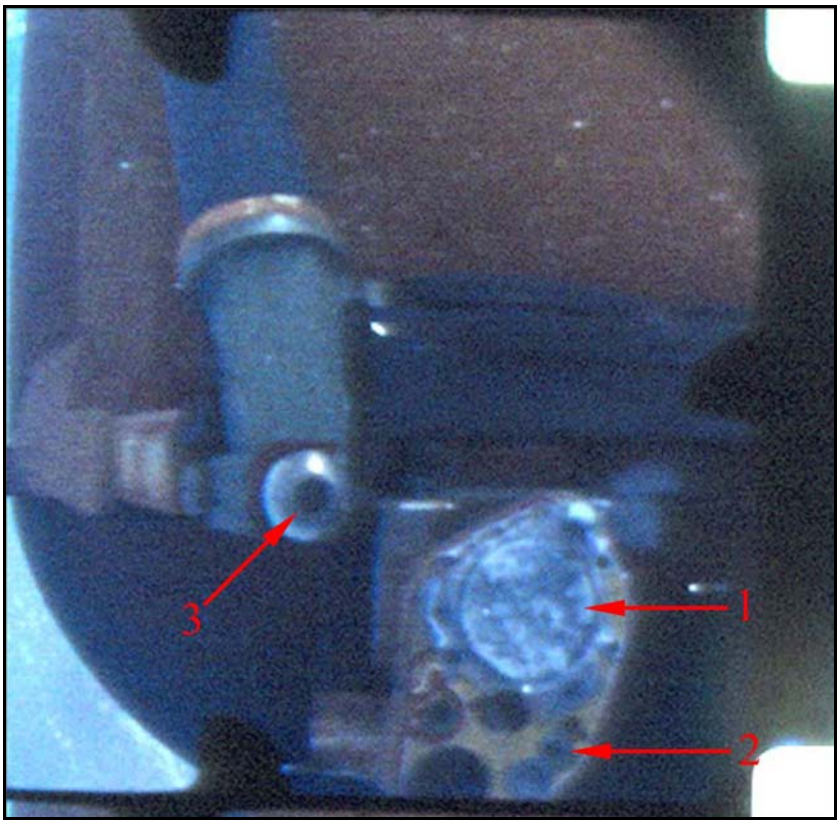


Figure 2.4.2 (B) 16mm Umbilical Well Camera Imagery

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 2.4.2 (B), annotation 1. A white-colored, linear, S- shaped, object seen on the –Y side of the LH2 17 inch orifice was probably a piece of frozen hydrogen. Frozen hydrogen was visible between the 1 o'clock position of the LH2 umbilical and the –Y end of the ET cross beam.

Although the orifice of the ET 4-inch hydrogen recirculation line was dark and difficult to see on the 16 mm umbilical well camera films, nothing unusual was noted on or near this connection point. The valve appeared closed and no frozen hydrogen was seen on the face of the 4-inch line connection. See Figure 2.4.2 (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 2.4.2 (B), annotation 3. The red-colored purge seal on the EO-2 ball joint fitting was in place. TPS erosion was seen on the aft flange of the –Y thrust strut. A large band of white-colored possible TPS erosion was seen on the forward end of the –Y thrust strut.

The LH2 tank TPS appeared to be in good condition on the 16mm camera views.
Note: No timing data was present on the 16 mm umbilical well camera films.

2.4.3 35 mm Crew Handheld Film (Roll 410)

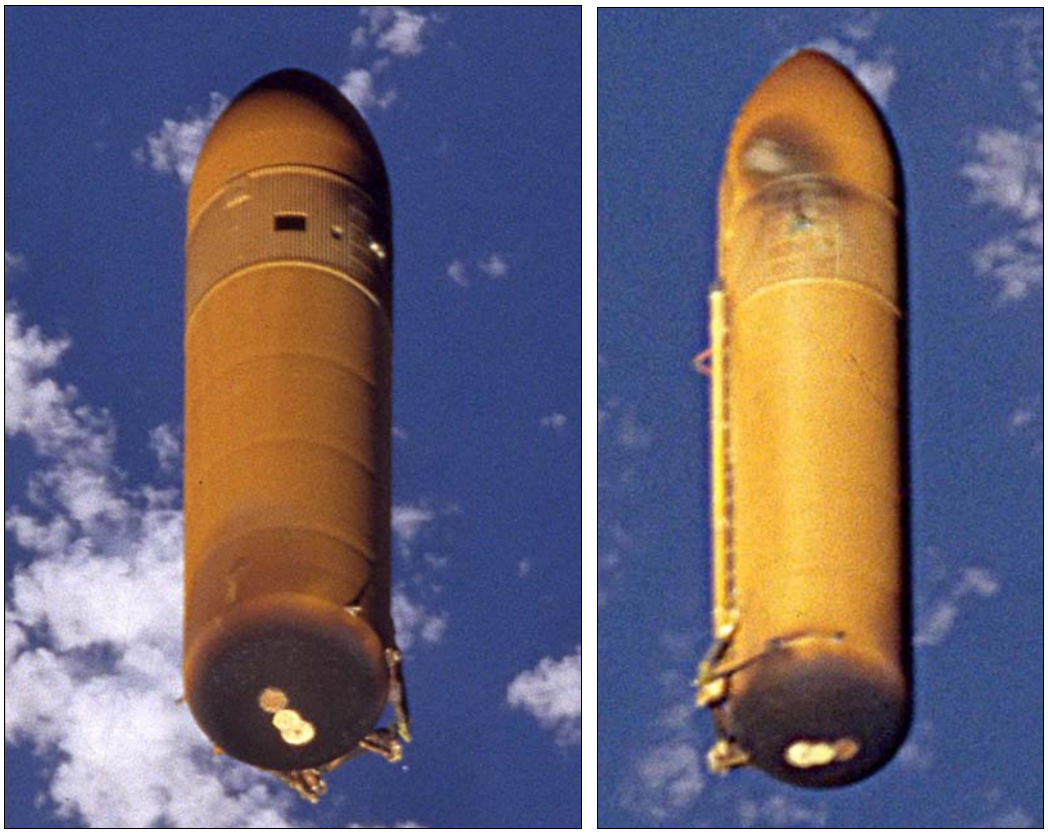


Figure 2.4.3 Handheld images of the External Tank (Frames 1 and 11)

No anomalous or unusual observations were noted on the handheld film views. Excellent quality views of all sides of the ET, the ET aft dome, and ET nose were acquired. See Figure 2.4.3. The +Y and –Y thrust panels appeared to be in good condition on the hand held film views.

The distance of the ET was calculated to be approximately 1.9 km's on the first photographic frame acquired. A total of thirty-seven pictures of the ET were obtained using the handheld Nikon F5 camera with a 400 mm lens. Timing data is present on the film. The first picture was taken at approximately 18 minutes MET. The astronauts performed a manual pitch maneuver from the heads-up position to bring the ET into view in the Orbiter overhead windows for the handheld video and photography.

2.4.4 Crew Handheld Video

Approximately eleven minutes of video imaging the External Tank using the PD-100 camcorder was acquired. All aspects of the ET were imaged. No anomalous or unusual observations were noted on the video views. No venting from the ET intertank gaseous hydrogen vent or the aft ET umbilicals was seen on the STS-109 video.

2.5 Landing Events Timing

The time codes from videos were used to identify specific events during the screening process. The STS-109 landing event times are provided in Table 2.5

Event Description	Time (UTC)	Camera
Left main gear door opening	**071:09:31:30.054**	**EL17IR**
Right main gear door opening	071:09:31:30.321	EL17IR
Left main gear tire touchdown	071:09:31:51.870	EL17IR
Right main gear tire touchdown	071:09:31:51.903	EL17IR
Drag chute initiation	071:09:31:54.570	EL17IR
Pilot chute at full inflation	071:09:31:55.471	EL17IR
Bag release	071:09:31:56.381	KTV33L
Drag chute inflation in reefed configuration	071:09:31:57.482	KTV33L
Drag chute inflation in disreefed configuration	071:09:32:01.985	KTV33L
Nose gear tire touchdown	071:09:32:01.210	EL17IR
Drag chute release	~071:09:32:27.339	EL17IR
Wheel Stop	~071:09:33:02.995	KTV11L

Note: ~ Denotes that the time shown is approximate.

Table 2.5 Landing Event Times

2.6 Landing Sink Rate Analysis

Image data from the SLF centerline video 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 (30 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. A trendline for the midpoint between the main gear was determined considering the height of the Orbiter above ground with respect to time. Sink rate equals the slope of each regression line.

The main gear sink rate for the STS-109 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.6. The trends for the main gear sink rate for these same times are shown in Figure 2.6.

Time Prior to Touchdown	Main Gear Midpoint Sink Rate	Estimated Error (1σ)
1.00 Sec.	2.5 ft/sec	± 0.2 ft/sec
0.50 Sec.	2.0 ft/sec	± 0.2 ft/sec
0.25 Sec.	0.9 ft/sec	± 0.3 ft/sec

Table 2.6 Main Gear Midpoint Landing Sink Rate

Figure 2.6 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-109 vehicle was reported to be 222,160 lbs.

2.7 Other

2.7.1 Normal Events

Normal events observed included:

- elevon motion prior to liftoff
- ice / frost on SSME purge drain-line vents
- birds near the launch vehicle during liftoff
- 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
- condensation off the Orbiter wing tips 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

2.7.2 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-109

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

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

March 26, 2002
Marshall Space Flight Center,
Huntsville, AL 35812

Contents

Figures

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Engineering Photographic Analysis Report for STS-109

Launch of the one-hundred-eighth Space Shuttle mission STS-109, the twenty-seventh flight of the Orbiter Columbia (OV-102), occurred March 1, 2002 at 5:22 AM CST from launch complex 39-A, Kennedy Space Center (KSC), Florida. Launch time was reported as 2002:060:11:22:02.021 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

STS-109 Photographic Analysis Summary:

The Intercenter Consolidated Film/Video "STS-109 Launch+4 Day" Report, March 6, 2002 reported no anomalous events during the screening of launch film and video. The "STS-109 Landing+3 Day" Report, March 18, 2002 also reported no anomalous events.

Photographic Analysis Website:

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

http://photo4.msfc.nasa.gov/STS/sts109/sts109.html

Information available on the MSFC Engineering Photographic Analysis website includes:

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

Photographic Coverage:

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

Seventy 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-109 is illustrated in the following table.

	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	6
Tracking	0	10	11
Onboard	2	2	1
Other	0	0	0
Totals	26	19	25

Table 1. STS-109 Camera Coverage

Due to cloudy conditions, some film and video cameras frequently did not image the vehicle during portions of the ascent (E212, E213, E220, E222, and E223) and apparently vehicle tracking was lost due to clouds by other cameras (E52, E213, ET213, E222 and E224). Film camera E204 and video camera ET204 lose the vehicle in the clouds but reacquire the vehicle again after SRB separation. Film cameras E205 and E213 had problems centering the vehicle in the frame.

Little detail was observed on video cameras OTV041, OTV048, and OTV070 due to high contrast exposures. Imagery was overexposed from film camera E54 after rollover and video camera ET213 after clearing the tower. Film was very blurred on film camera E4. The focus on film camera E208 was soft, probably due to atmospheric haze.

T-Zero Timing:

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

Holddown Post	Camera	Time (UTC)
M-1	E9	060:11:22:02.031
M-2	E8	060:11:22:02.032
M-5	E12	060:11:22:02.030
M-6	E13	060:11:22:02.031

Table 2. STS-109 T-0 Timing

SRB Separation Timing:

SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E207, occurred at 060:11:24:07.268 UTC.

Anomalous Events:

No anomalous events were observed in launch film or video reviewed at MSFC.

Observations:

Video Camera TV21A: Flash on MLP

A bright, bluish colored flash was observed on the MLP during SSME ignition.

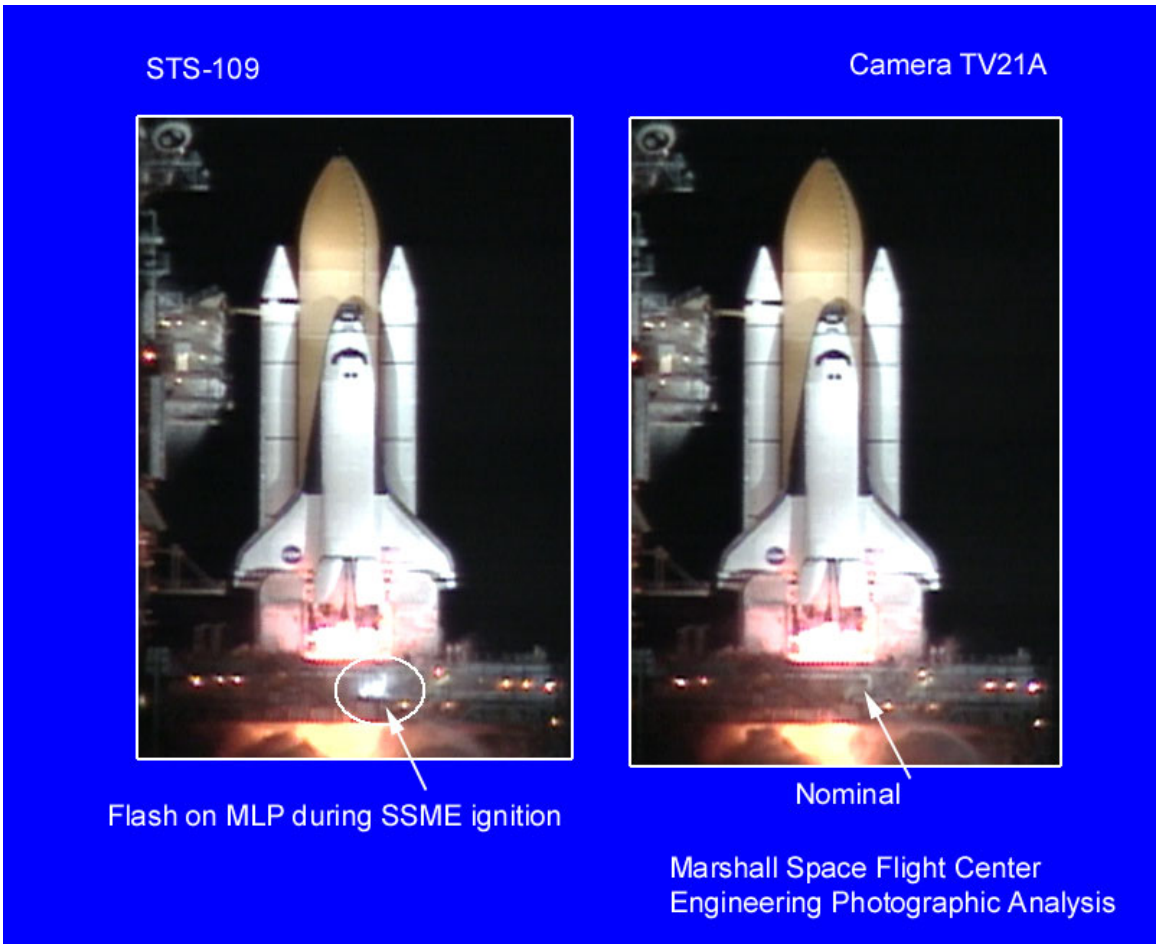

Figure 1. TV21A: Flash on MLP

Film Camera E63: Flash on MLP

A bright bluish colored flash was observed on the MLP during SSME ignition. It appears that the flash was a Xenon bulb burnout.

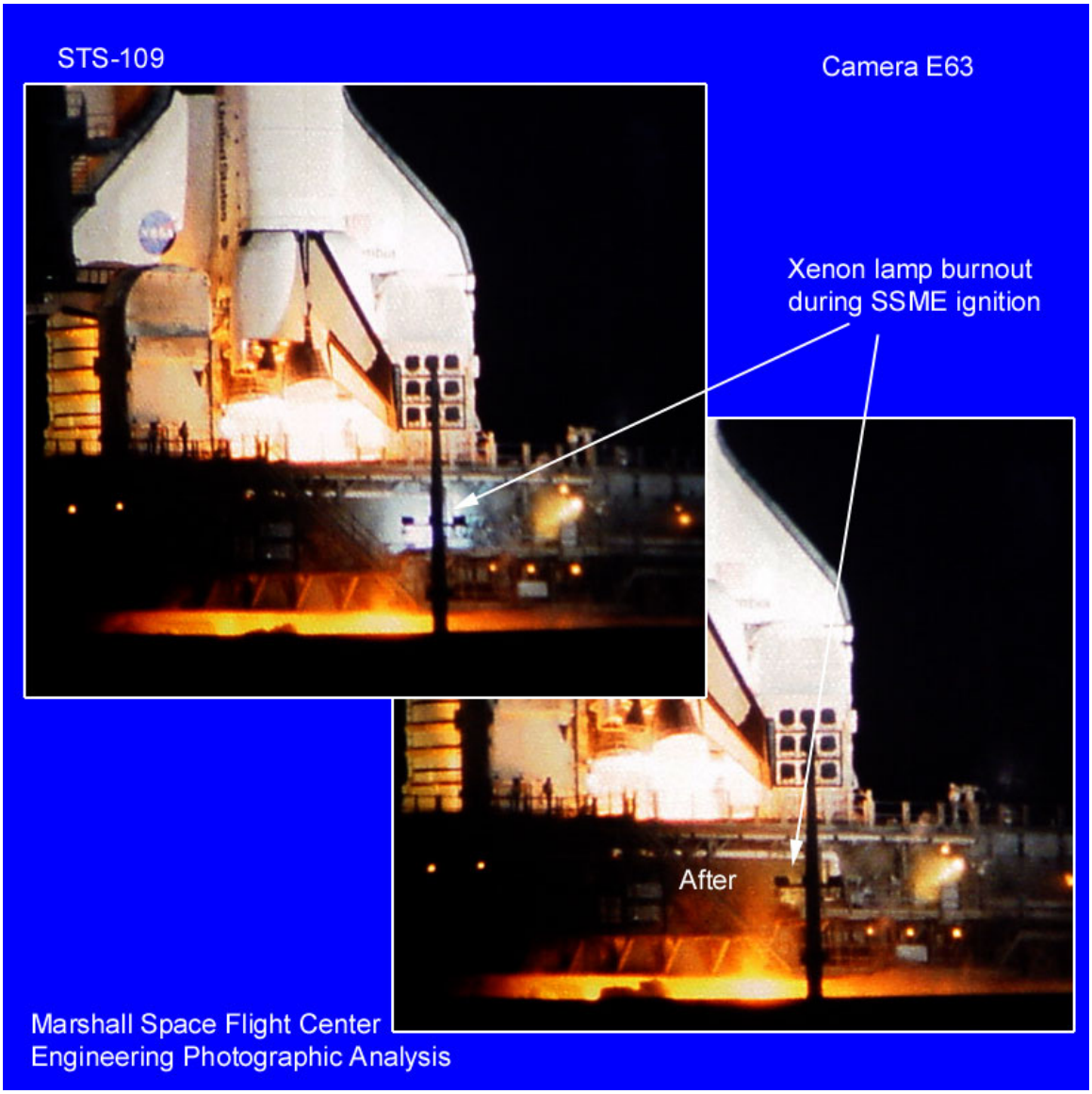

Figure 2. Film Camera E63: Flash on MLP

Video Camera OTV063: Yellow Colored Debris

A yellowish colored debris item was observed at liftoff. Another view of this debris item was captured by Video Camera TV009, Figure 4.

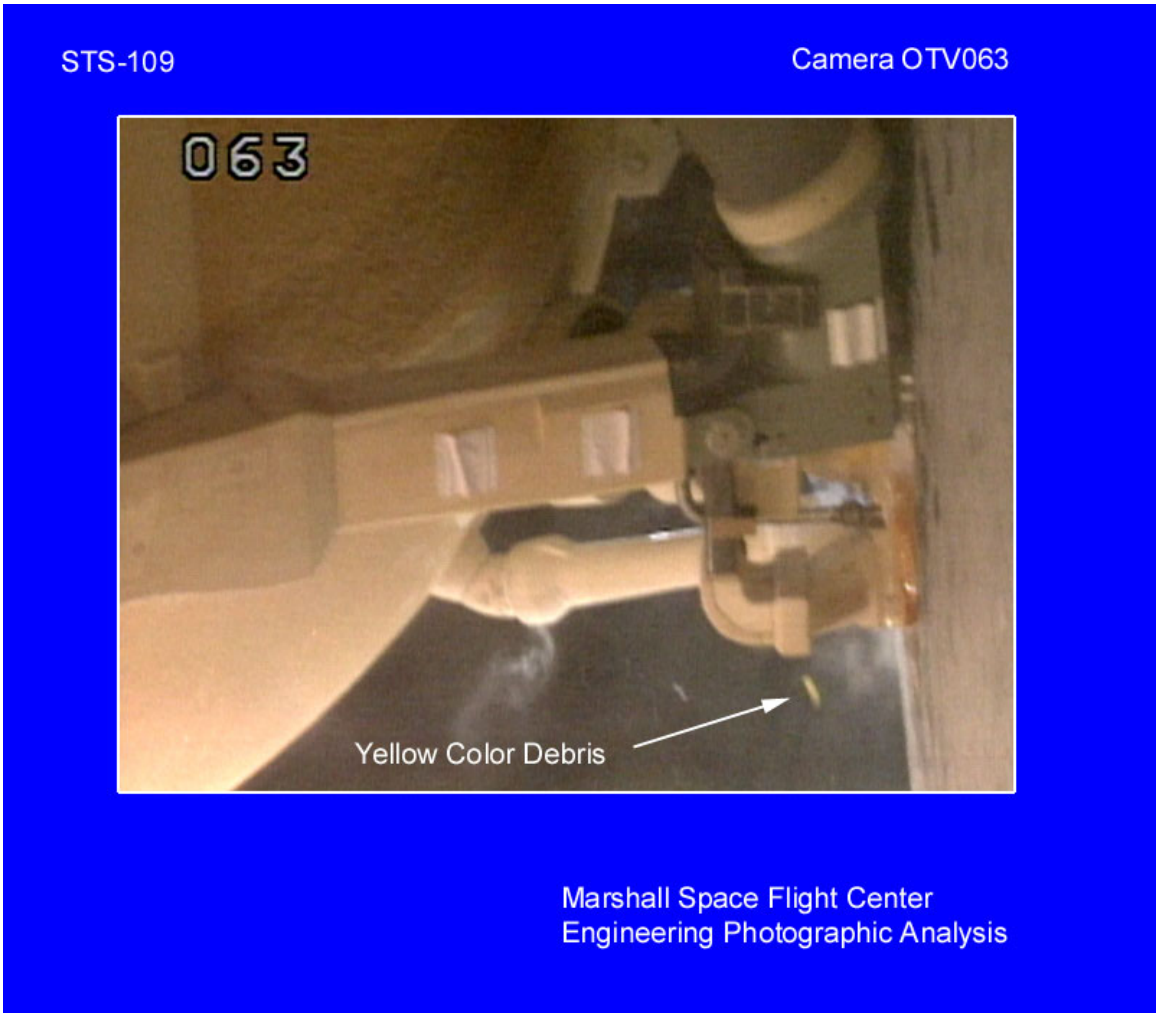

Figure 3. Video Camera OTV063: Yellow-Colored Debris

Video Camera TV009: Yellow Colored Debris

A yellowish colored debris item was observed at liftoff.

Figure 4. Video Camera TV009: Yellow Colored Debris

Film Camera E20: Rectangular Shaped Debris

Ice was observed on SSME#2 eyelid. Also, a reddish colored rectangular shaped debris item was observed at liftoff.

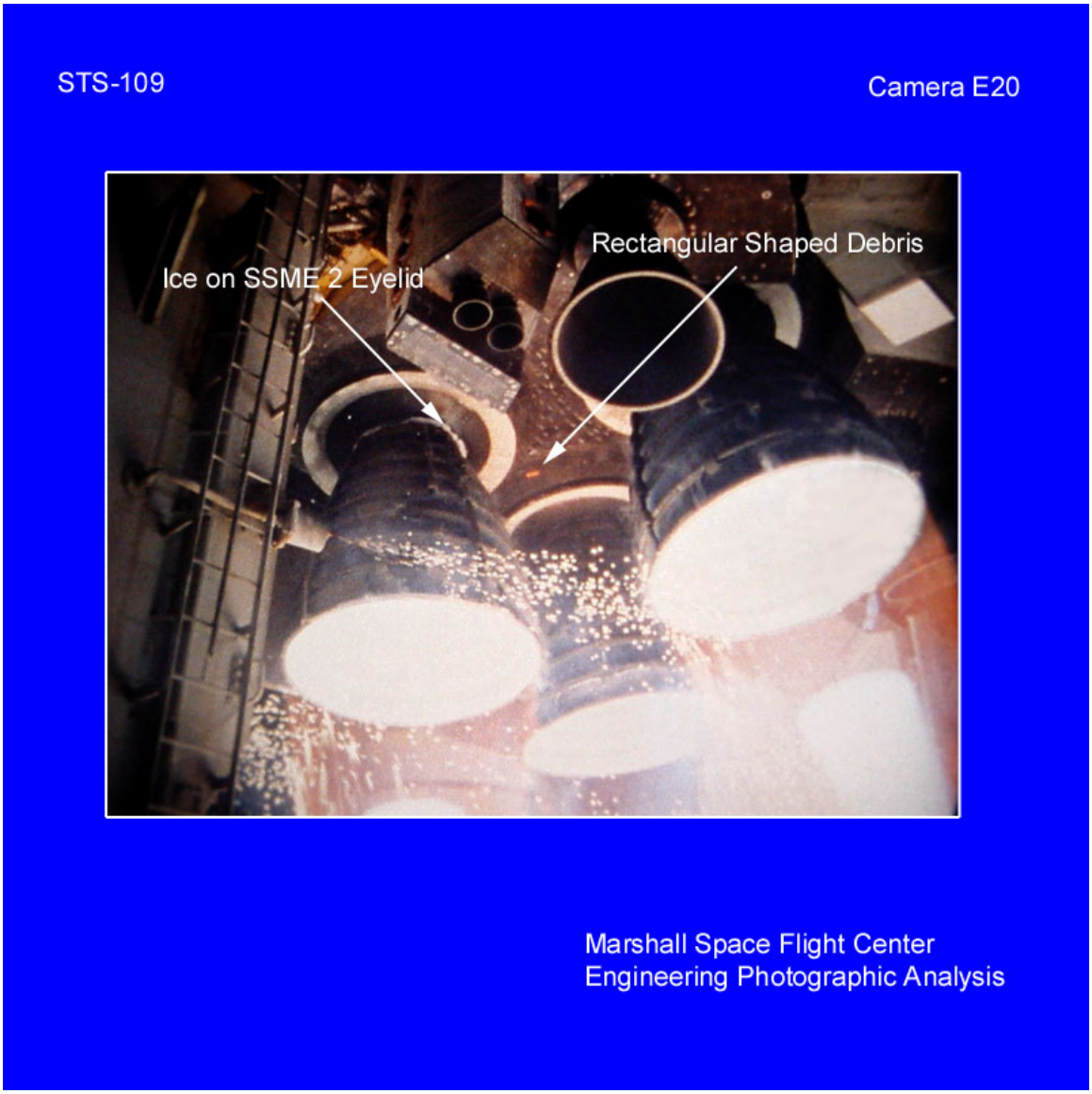

Figure 5. Film Camera E20: Rectangular Shaped Debris

Film Camera E18: Rectangular Shaped Debris

A flexible rectangular shaped debris item was observed at liftoff.

Figure 6. Film Camera E18: Rectangular Shaped Debris

Film Camera E31: Rectangular Shaped Debris

A long thin rectangular shaped debris item was observed falling apparently on the +Z side of the left Orbiter wing.

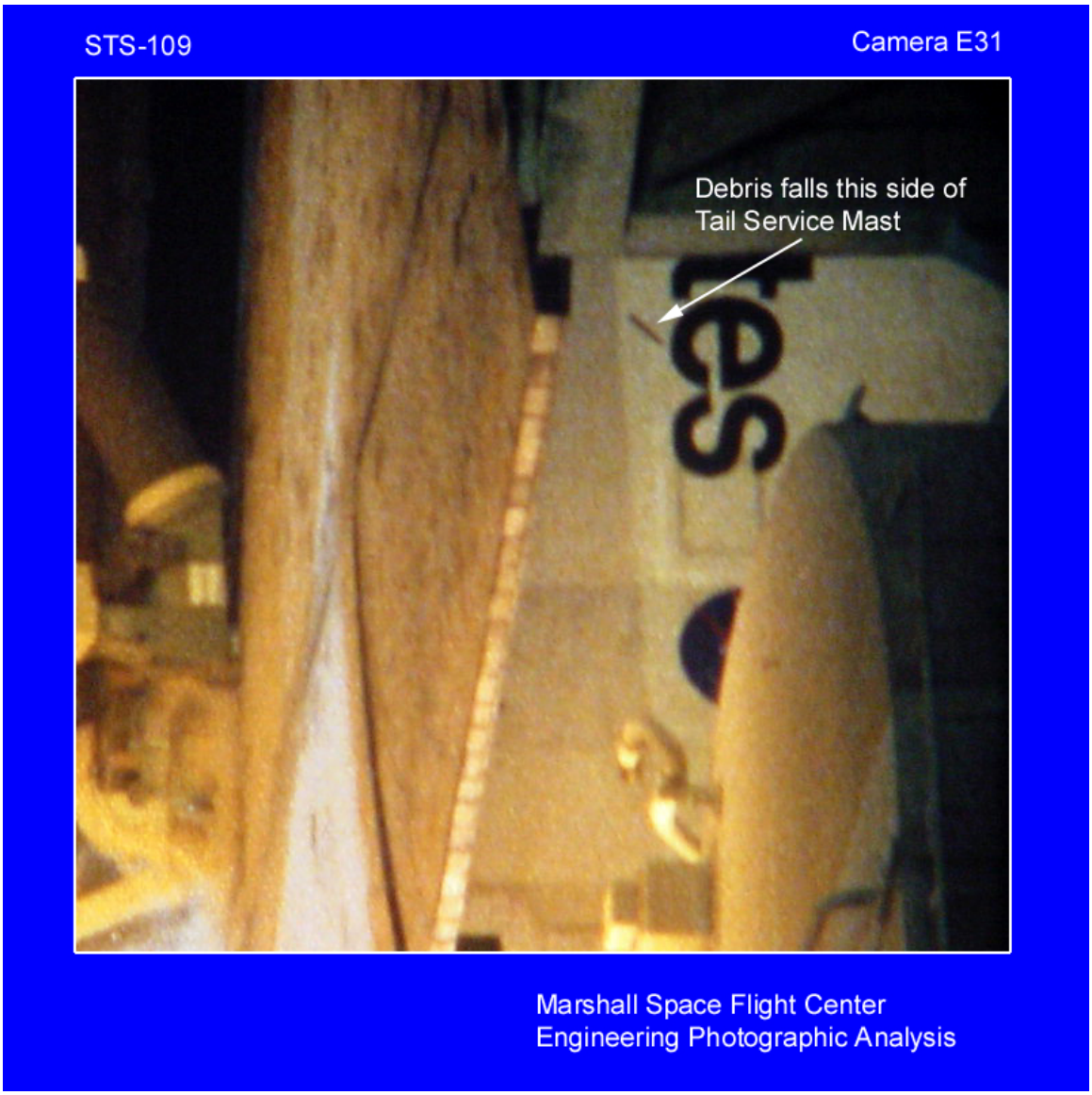

Figure 7. Film Camera E31: Rectangular Shaped Debris

Film Camera E17: Debris

A rope-like debris item and a rectangular shaped debris item were observed during liftoff.

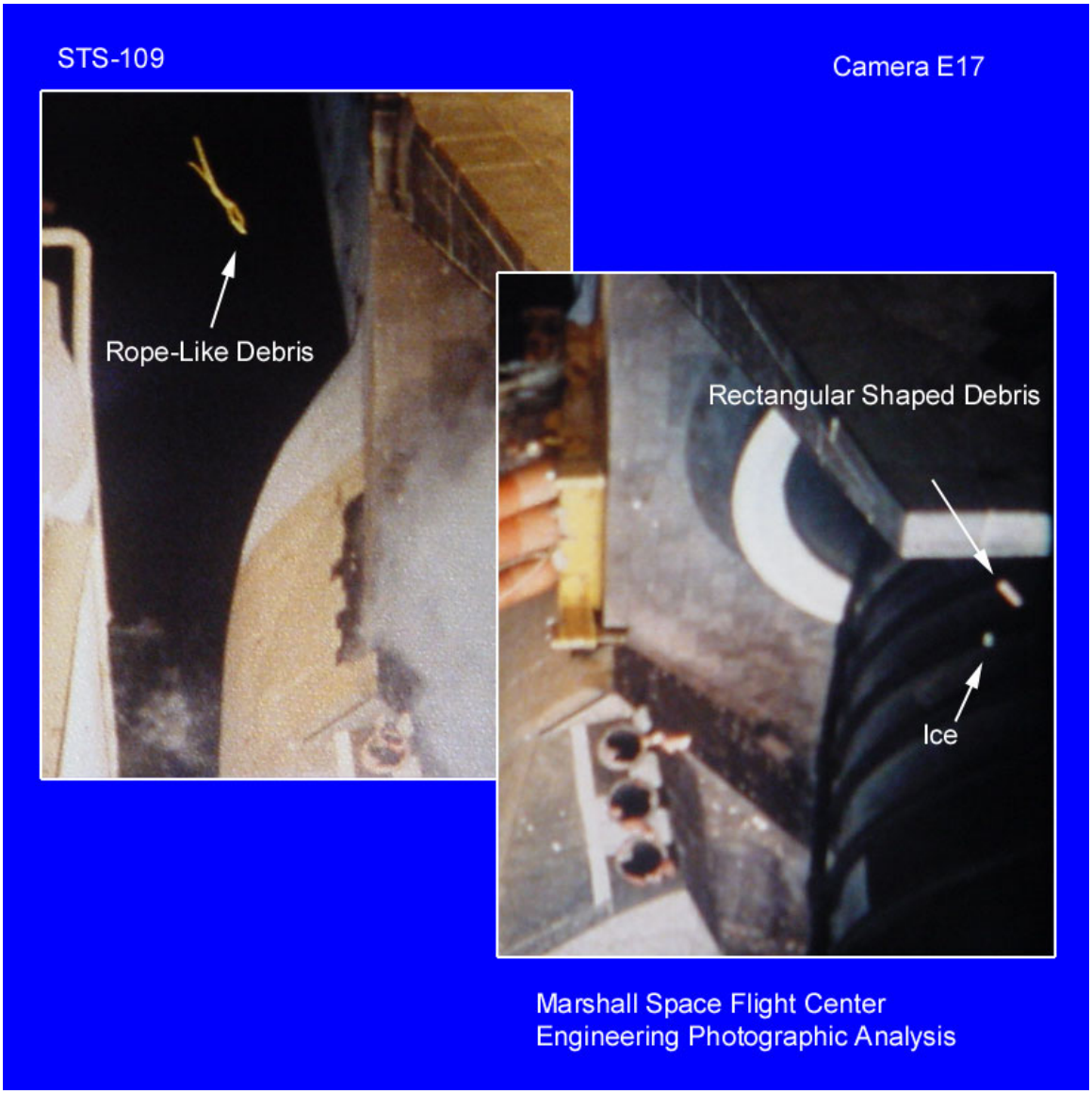

Figure 8. Film Camera E17: Debris

Video Camera TV4A: Pad Debris at Liftoff

Typical pad debris was observed at liftoff.

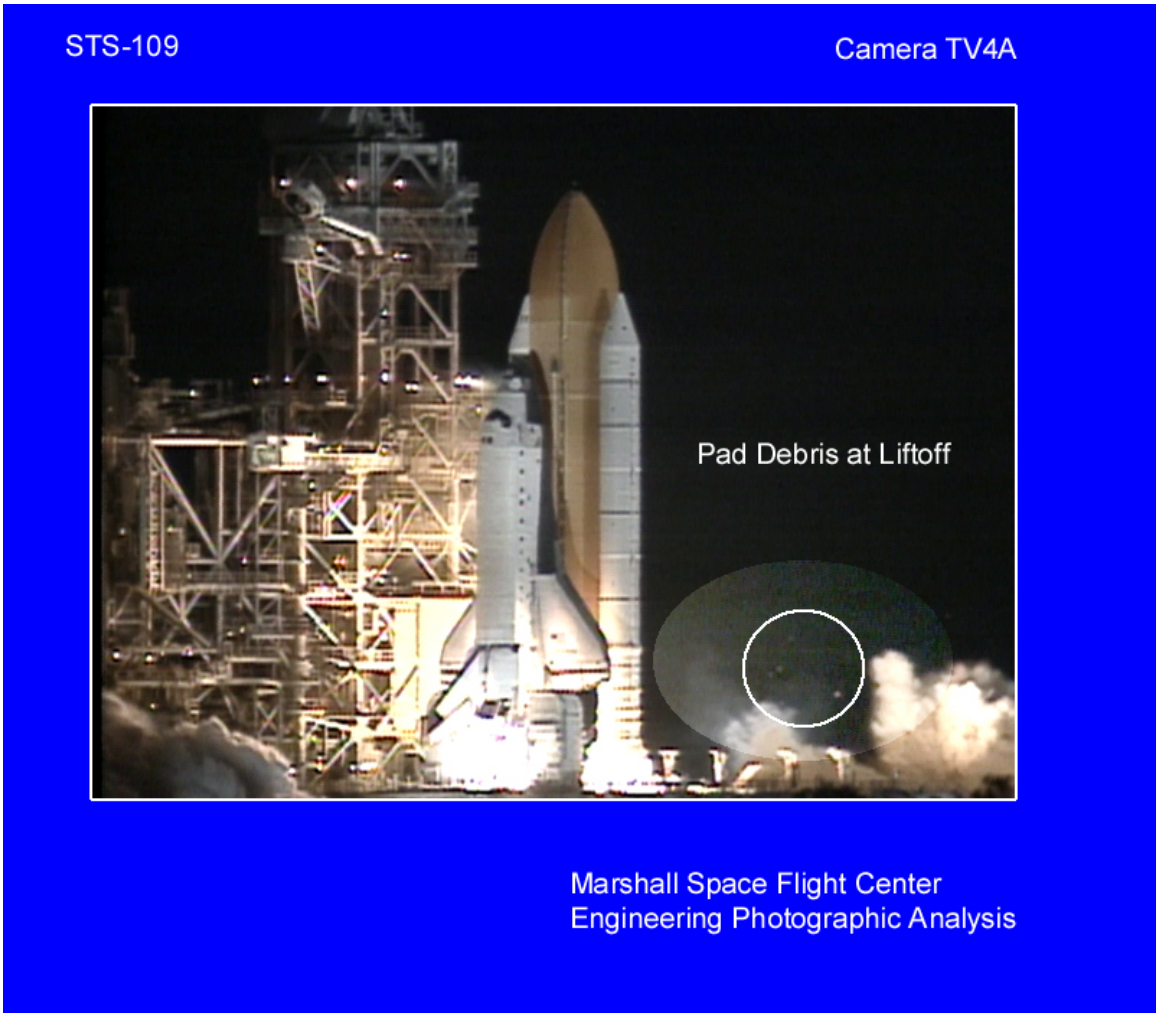

Figure 9. Video Camera TV4A: Pad Debris at Liftoff

Film Camera E8: HDP M2 Debris

A small debris object was observed falling from Holddown Post M2 hole just after liftoff. Also, but not imaged, debris was noted falling from Holddown Post M5 hole (Film Camera E12).

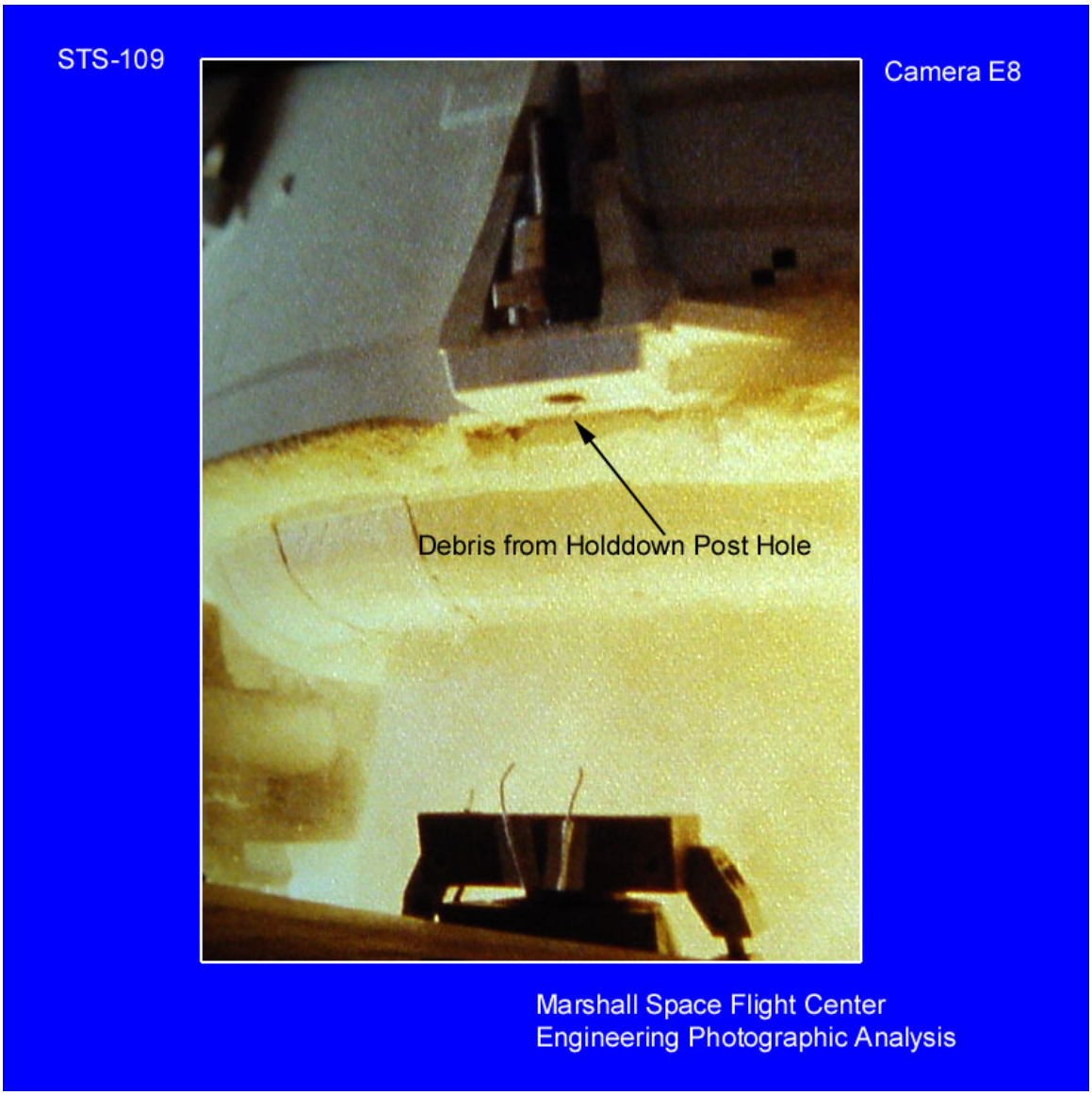

Figure 10. Film Camera E8: HDP M2 Debris

Film Camera E63: Debris Falling Aft

Debris falling aft of vehicle was noted during liftoff. This debris was probably purge barrier material. Other views of this debris was obtained from Film Camera 223, Figure 12, and Film Camera E62, Figure 13.

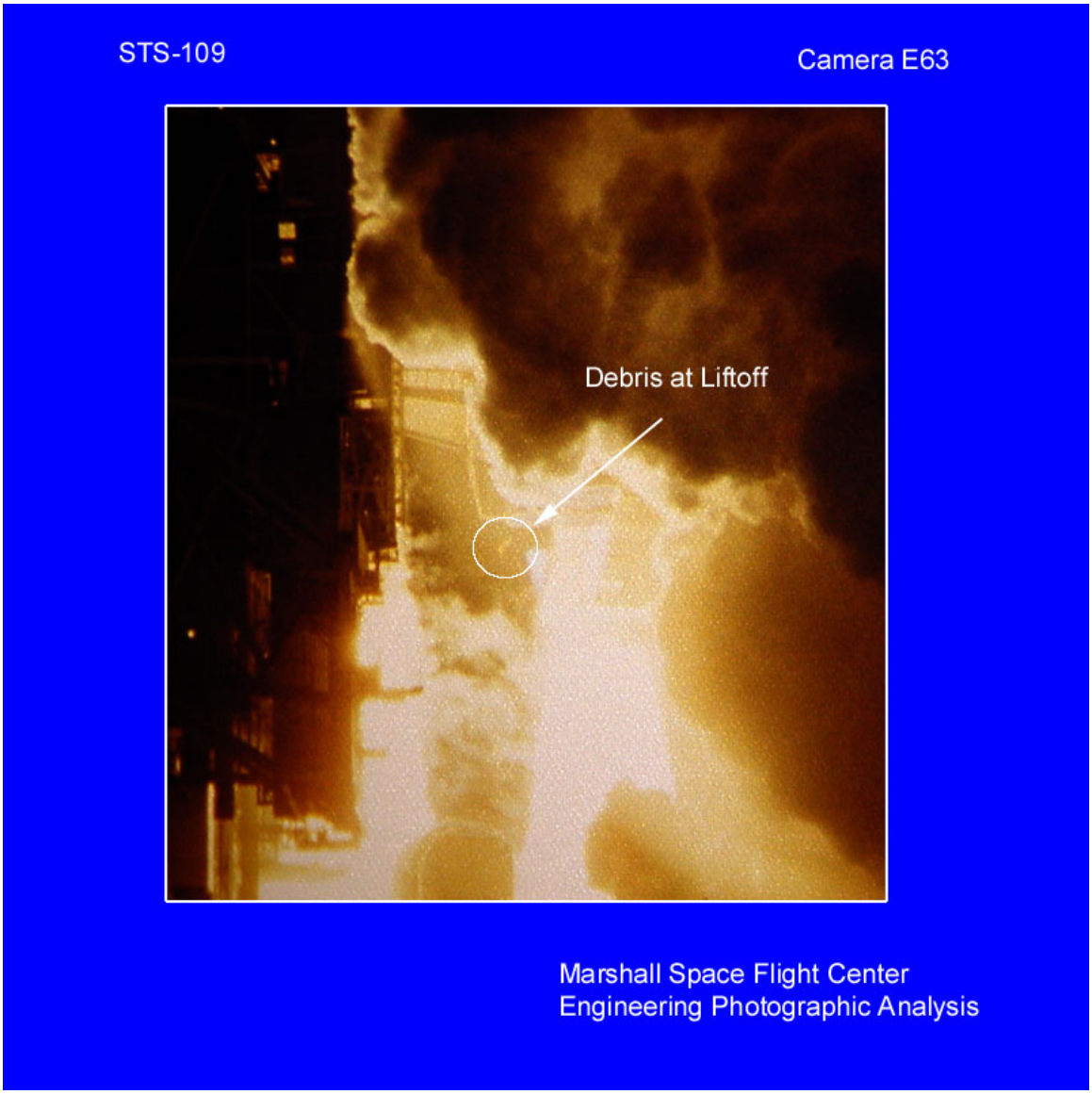

Figure 11. Film Camera E63: Debris Falling Aft

Film Camera E223: Debris Falling Aft

Debris object observed falling aft of the Orbiter after liftoff and before Orbiter clears the tower. Object has a paper-like quality and yellowish color and is presumed to be purge barrier material.

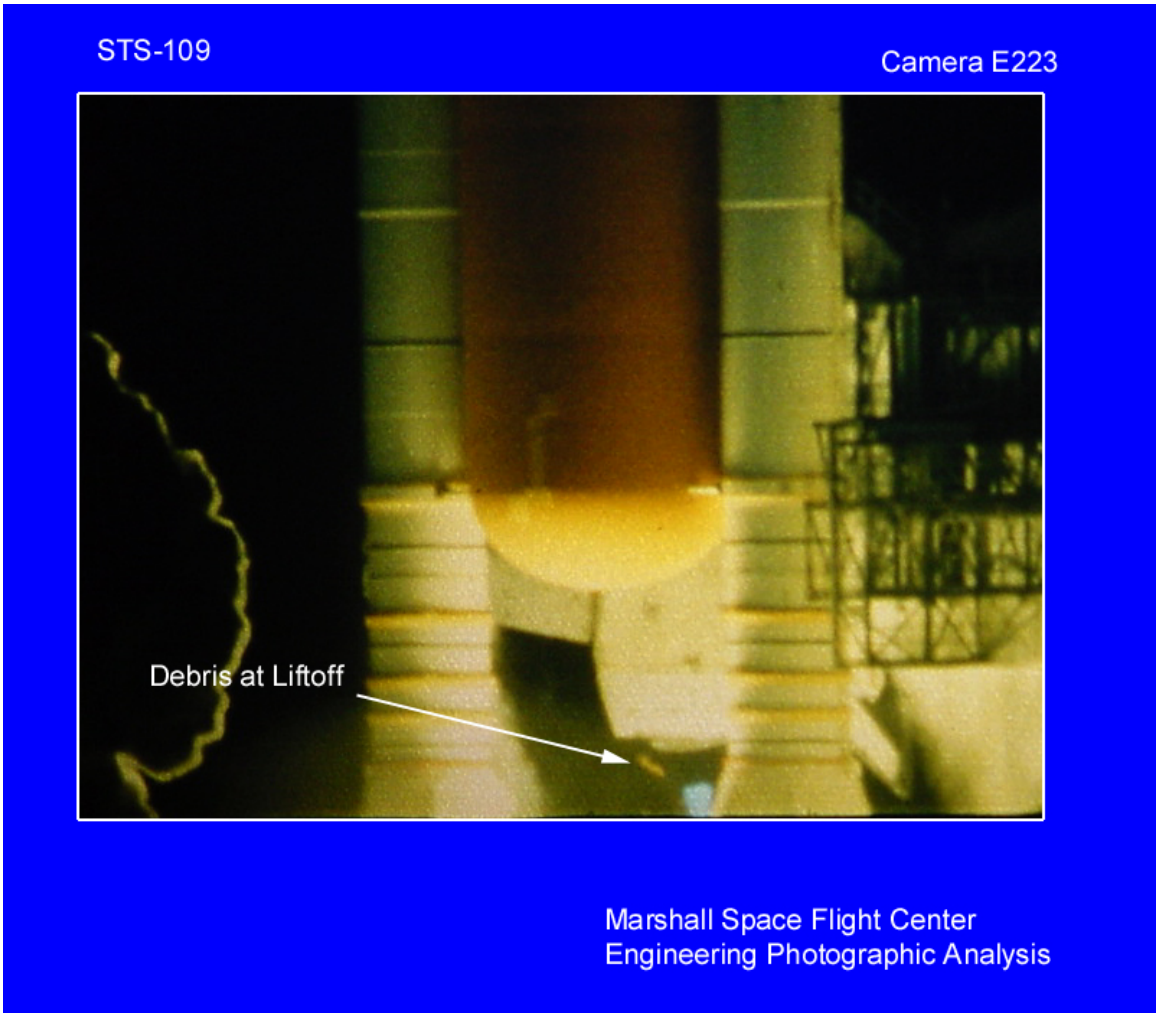

Figure 12. Film Camera E223: Debris Falling Aft

Film Camera E62: Debris Falling Aft

Another view of the debris object noted in Figure 12.

Figure 13. Film Camera E62: Debris Falling Aft

Film Camera E207: Vapors off Orbiter Wingtips

Vapors were noted off the Orbiter wingtips during ascent.

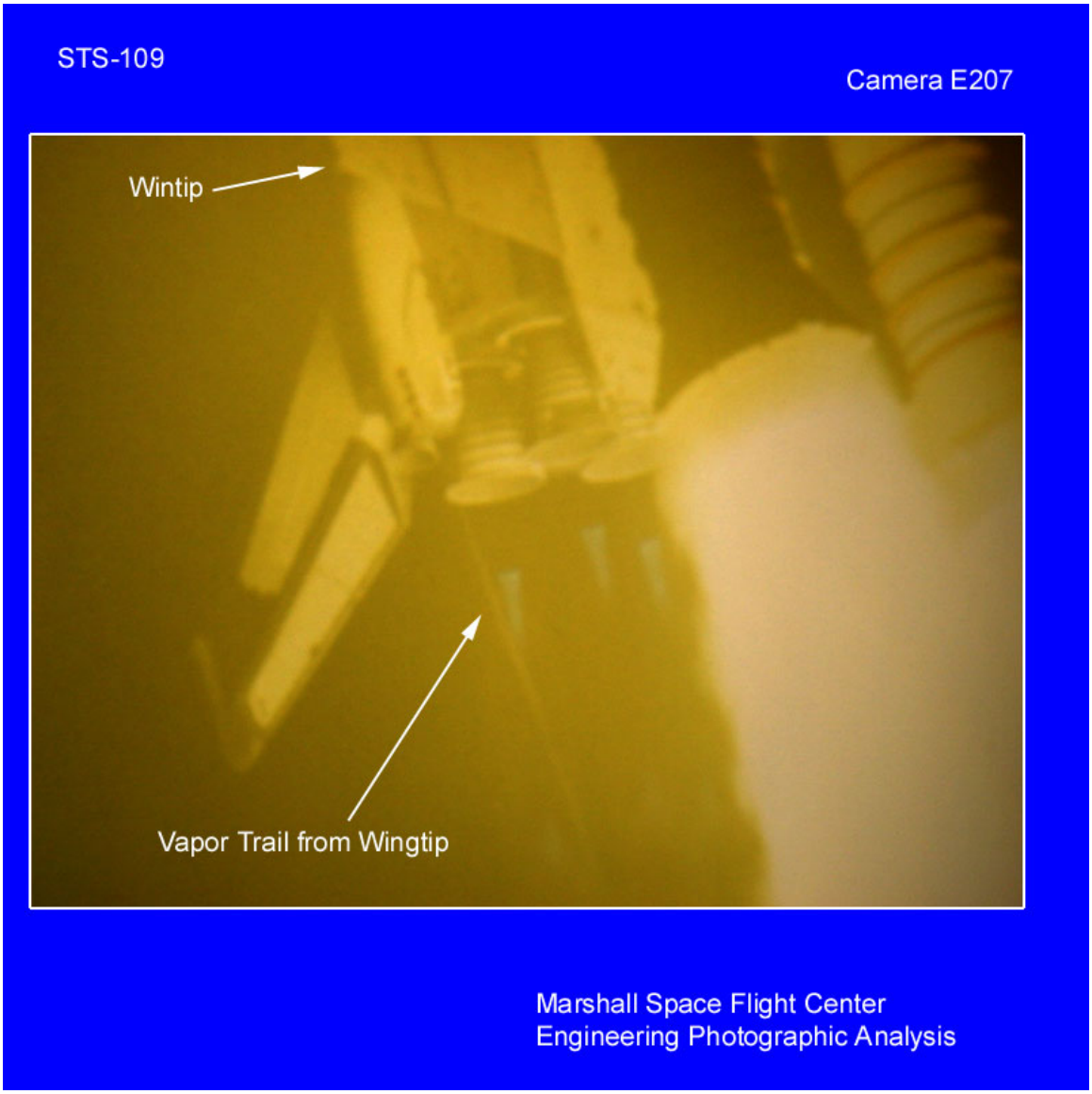

Figure 14. Film Camera E207: Vapors off Orbiter Wingtips

Film Camera ET204: Streak in SSME Plumes

Debris induced streaks were observed in SSME plumes during ascent.

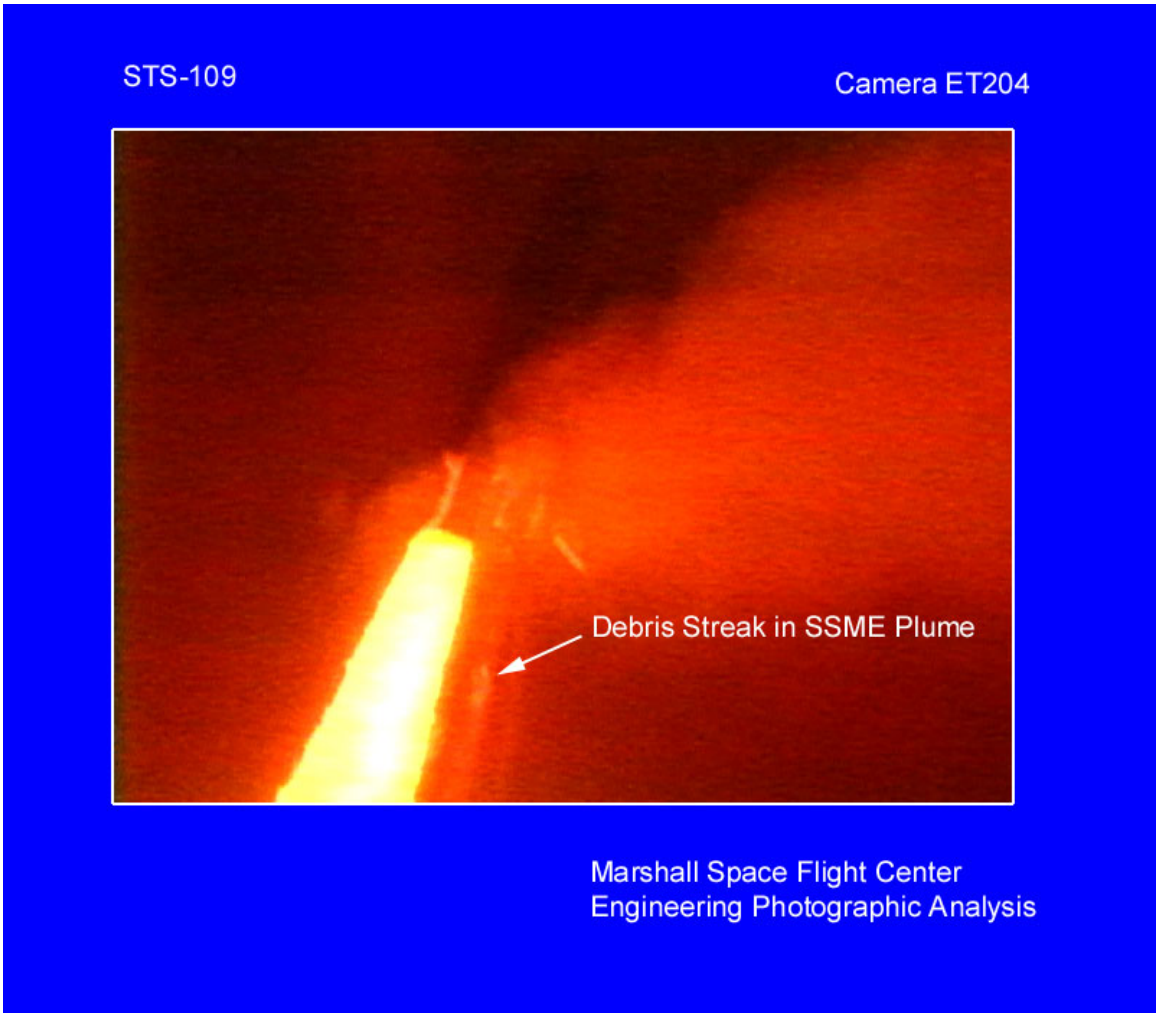

Figure 15. Film Camera ET204: Streak in SSME Plumes

Film Camera E223: Streak in SSME Plumes

Another view of the streaks in the SSME plumes shown in Figure 15.

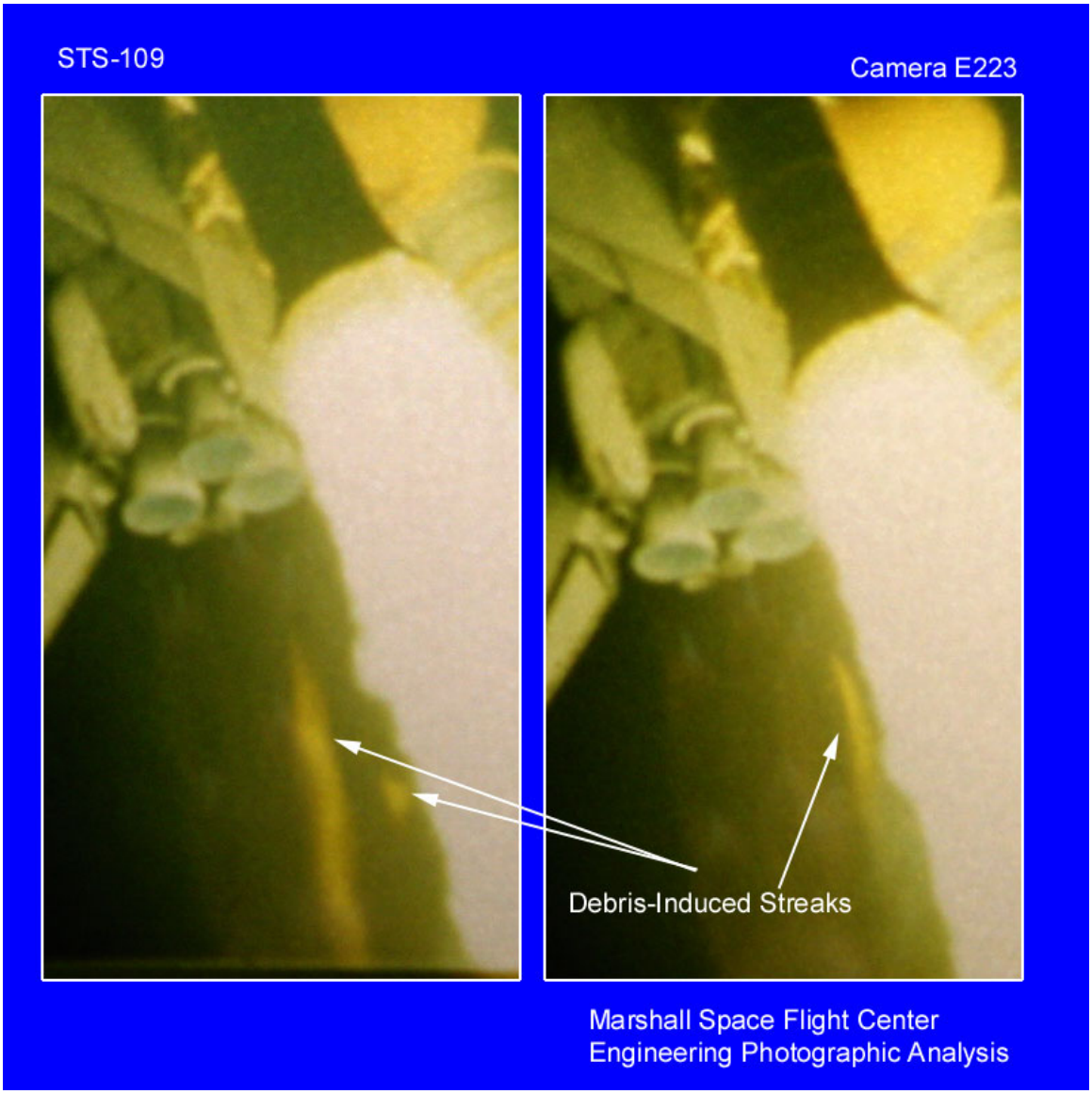

Figure 16. Film Camera E223: Streak in SSME Plumes

Film Camera E207: Debris Falling Aft

A view of typical debris falling aft of the vehicle during ascent. This debris is probably RCS paper from forward on the Orbiter.

Figure 17. Film Camera E207: Debris Falling Aft

Video Camera TV4A: Debris Ejected from SRB Plumes

Typical debris ejected from the SRB plumes during ascent.

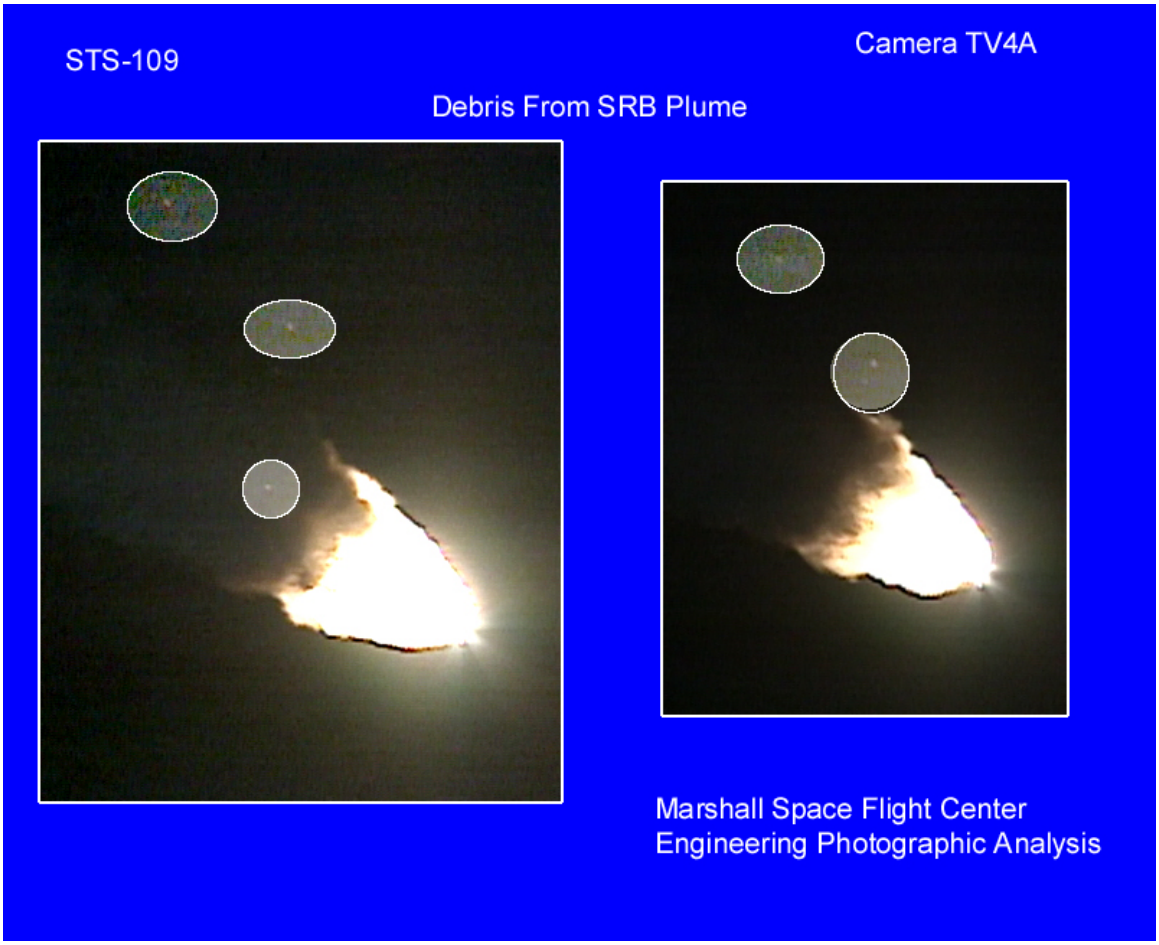

Figure 18. Video Camera TV4A: Debris Ejected from SRB Plumes

Film Camera FL101: Butcher Paper at SRB Separation

Butcher Paper was still attached to the vertical strut at SRB separation.

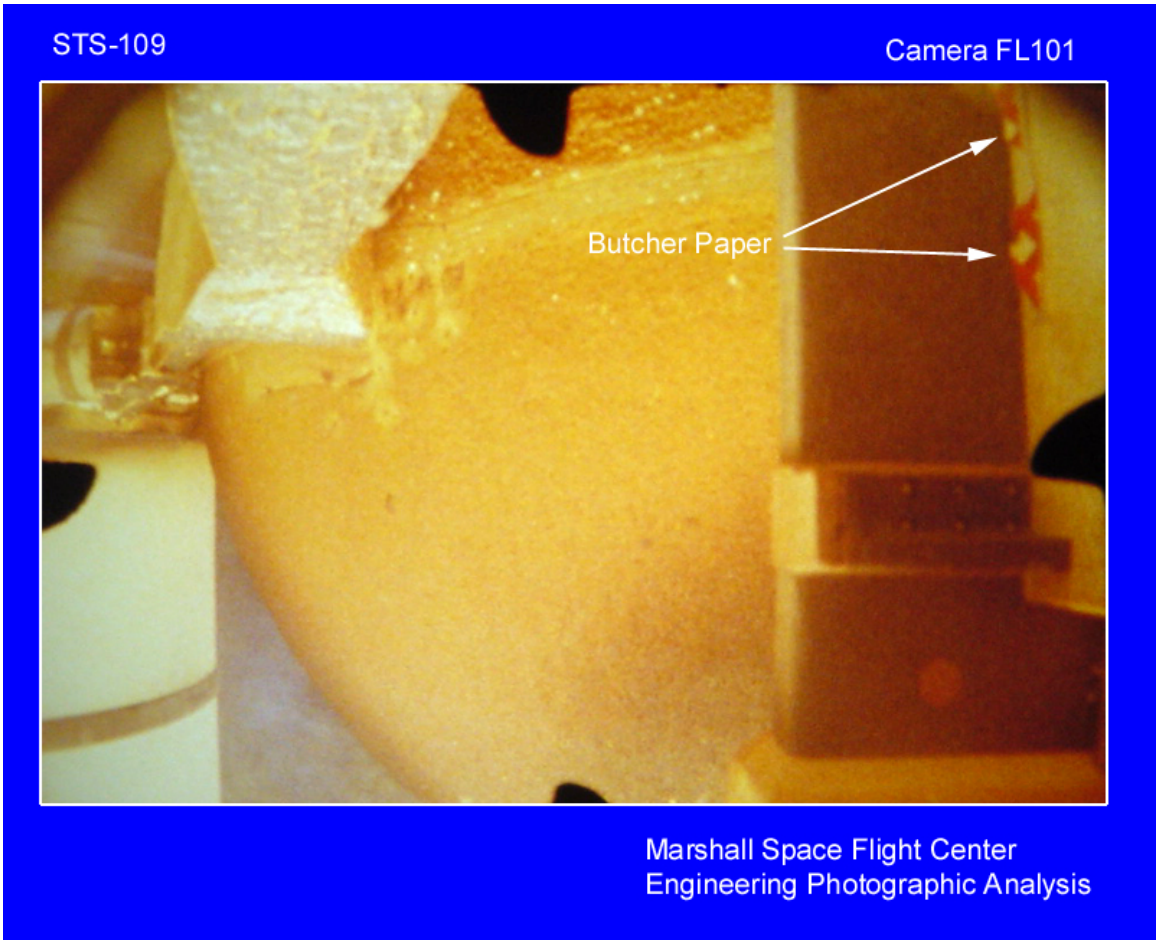

Figure 19. Film Camera FL101: Butcher Paper at SRB Separation

Film Camera FL101: Debris at ET Separation

A red colored debris item was noted just after ET Separation.

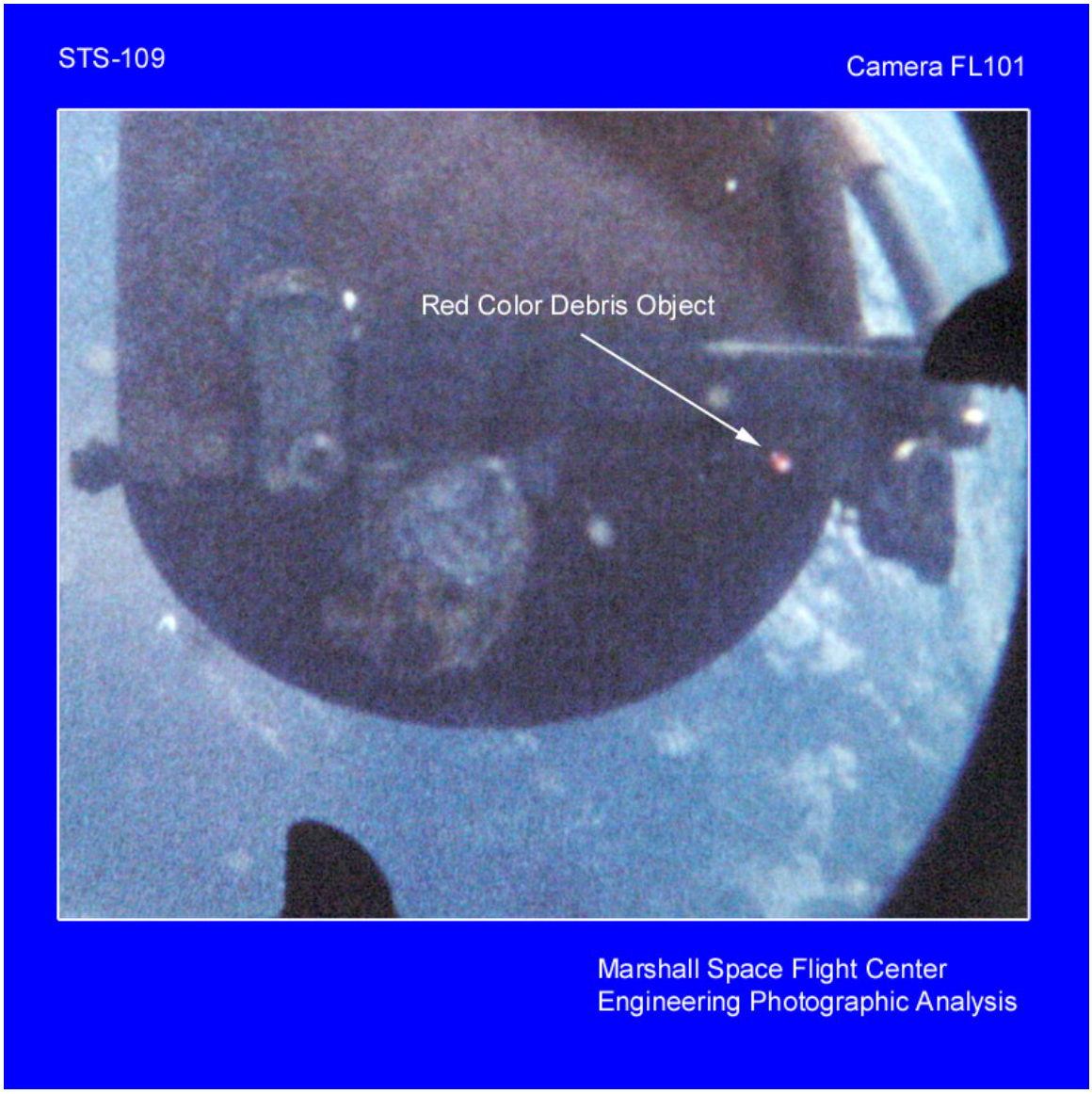

Figure 20. Film Camera FL101: Debris at ET Separation

Film Camera FL101: Vapors at SRB Separation

Vapors were noted during SRB separation at the pull-away electrical interface EB-9, located on the aft top stabilization strut.

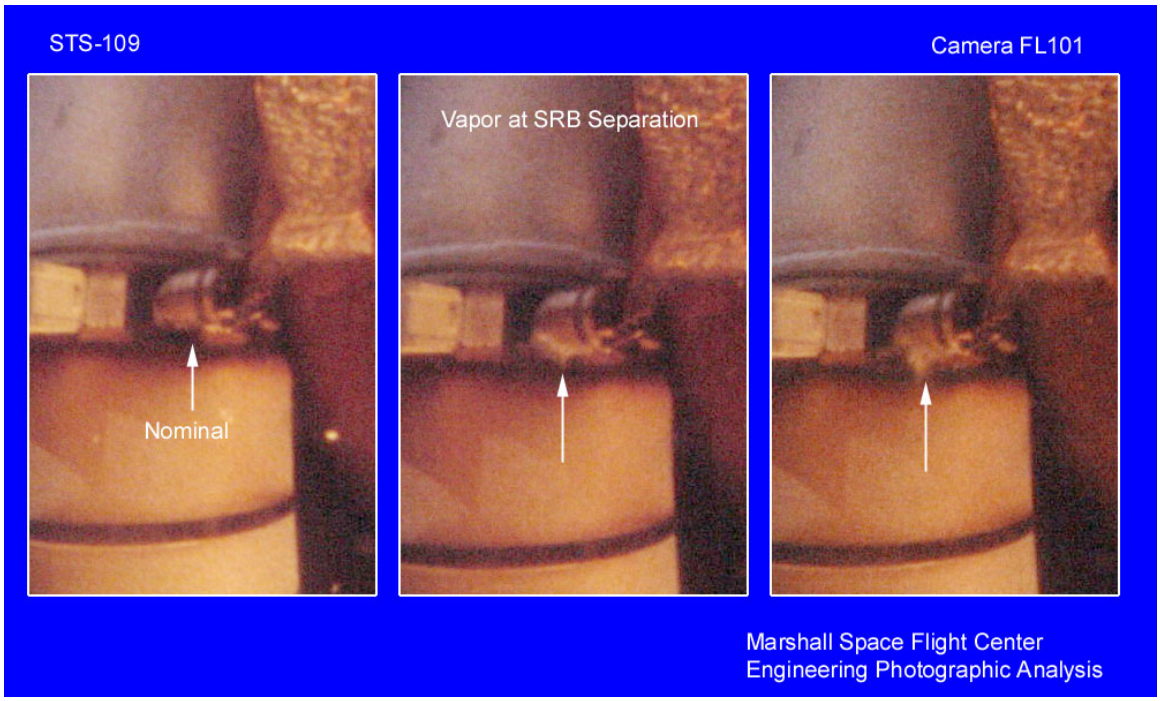

Figure 21. Film Camera FL101: Vapors at SRB Separation

Film Camera FL102: Missing TPS from Thrust Strut

TPS was noted missing from the left aft thrust strut just after ET separation.

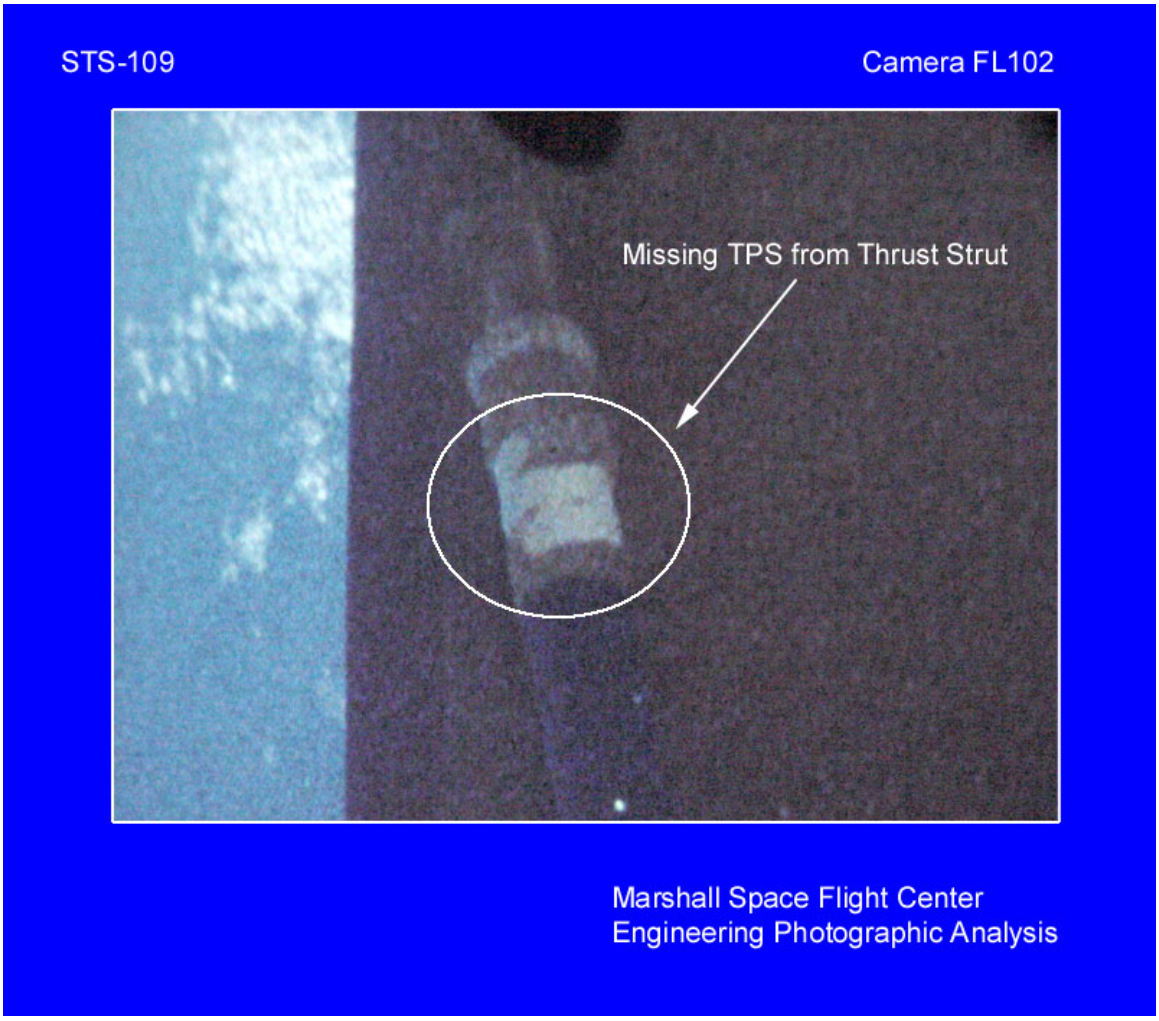

Figure 22. Video Camera TV4A: Missing TPS from Thrust Strut

35mm Umbilical Well Camera: Bipod and Intertank Divoting

From the 35mm Umbilical camera, two large divots were observed in the ET TPS under the ET/Orbiter forward attach bipod and one divot just aft of the bipod near the LO2 Feedline. Other divots were noted on the Intertank aft flange TPS.

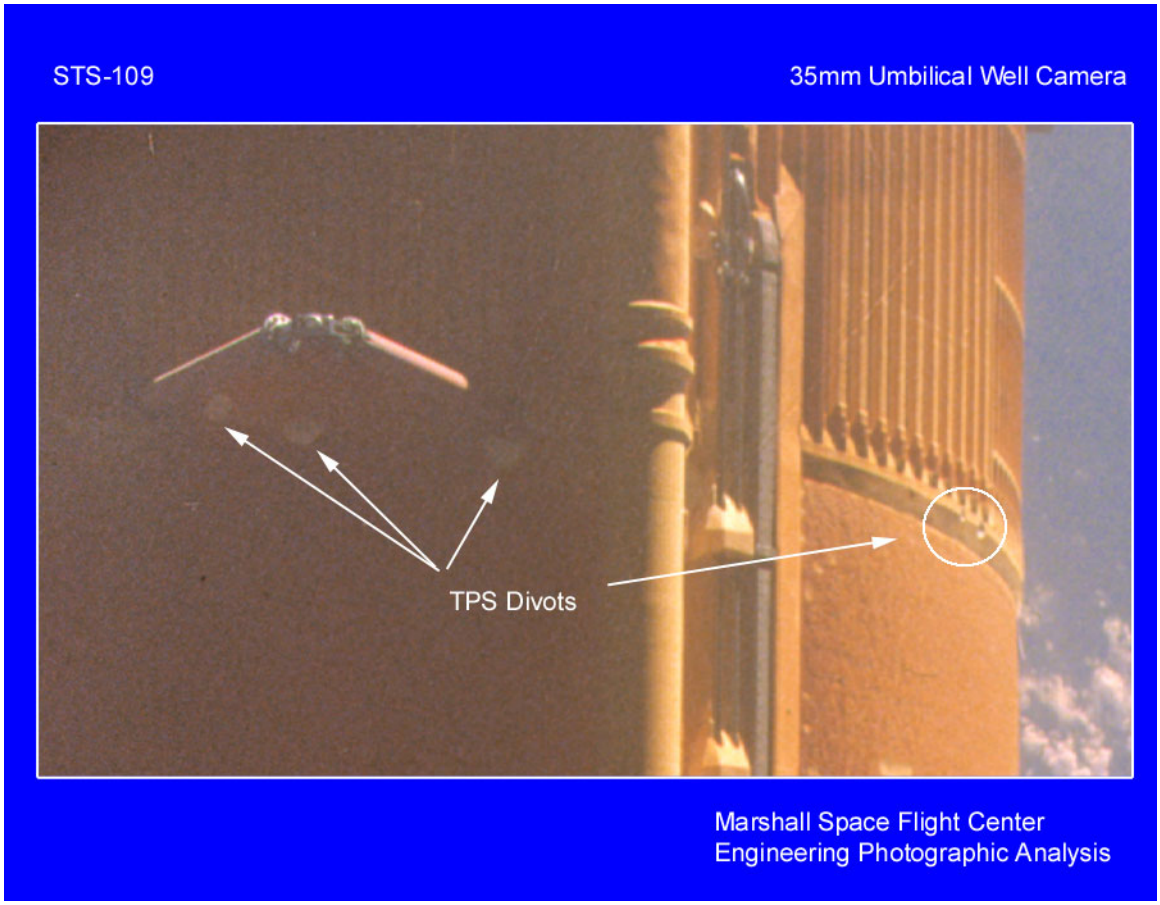

Figure 23. 35mm Umbilical Well Camera: Bipod and Intertank Divoting

35mm Umbilical Well Camera: EO-3 Bolt Protrusion

The EO-3 ET/Orbiter Interface Bolt appears to be slightly protruding after ET/Orbiter separation. Not shown are images of the EO-2 ET/Orbiter Interface Bolt which appeared to move from inside the bore to a position barely protruding from the bore.

Figure 24. 35mm Umbilical Well Camera: EO-3 Bolt Protrusion

35mm Astronaut Handheld Camera: ET After Separation

Typical BSM burn scars and aft dome charring were observed.

Figure 25. 35mm Astronaut Handheld Camera: ET After Separation

Video Camera TV13: Debris at SRB Separation

Debris was observed falling aft of the vehicle at SRB separation. Image resolution of this event was poor and a movie was created to allow recognition of the object by its motion. The movie may be found on the website.

Figure 26. Video Camera TV13: Debris at SRB Separation

Special Investigations

GH2 Vent Arm Investigation Continuation for STS109

Work continued for the GH2 Vent Arm analysis for mission STS109. Analysis indicates that the GH2 Vent Arm motion in the XZ plane was similar to motion experienced by previous missions, Figure 27, Figure 28, and Figure 29. The 2D separation angle, as measured directly from the image, for the GUCP fall-away from the ET surface also appeared in-family, Figure 30. There are differences between Pad A, mission STS109, and Pad B, all other analyzed missions, which may account for the apparent steeper separation angle noted in the comparison with other missions, Figure 31.

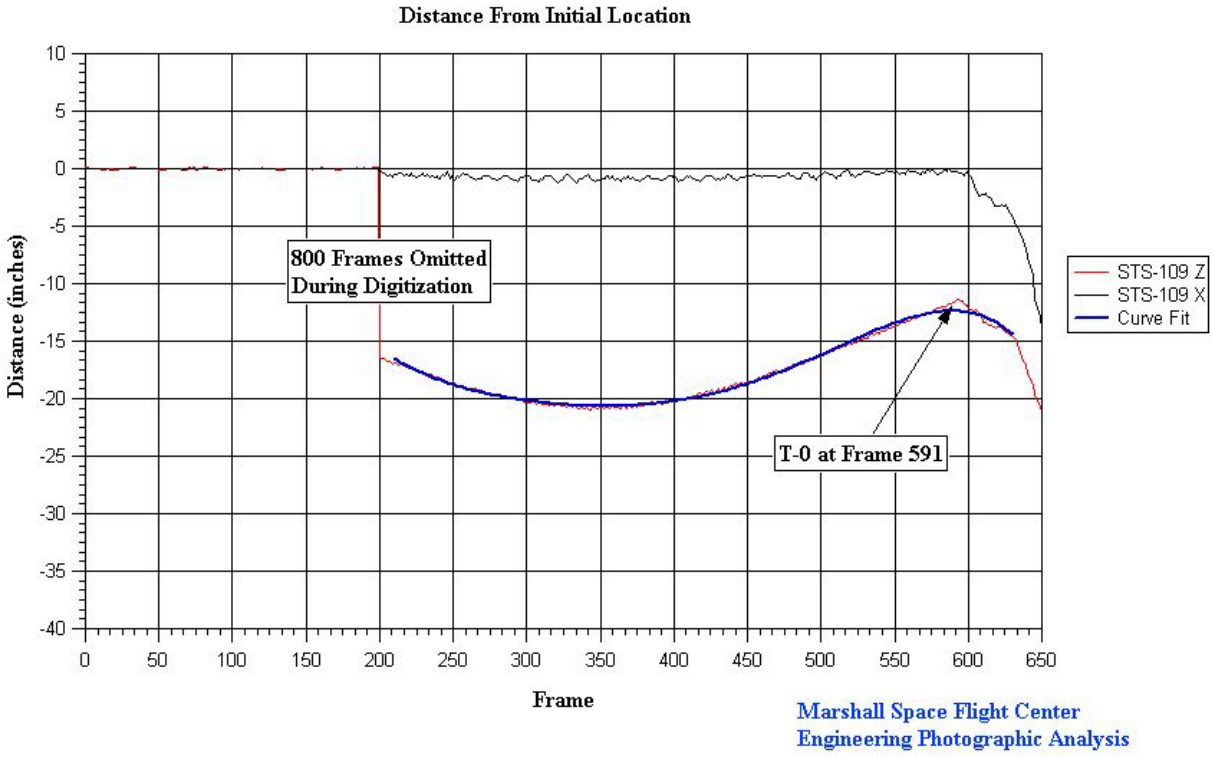

Figure 27. GUCP Motion in Z and X Directions

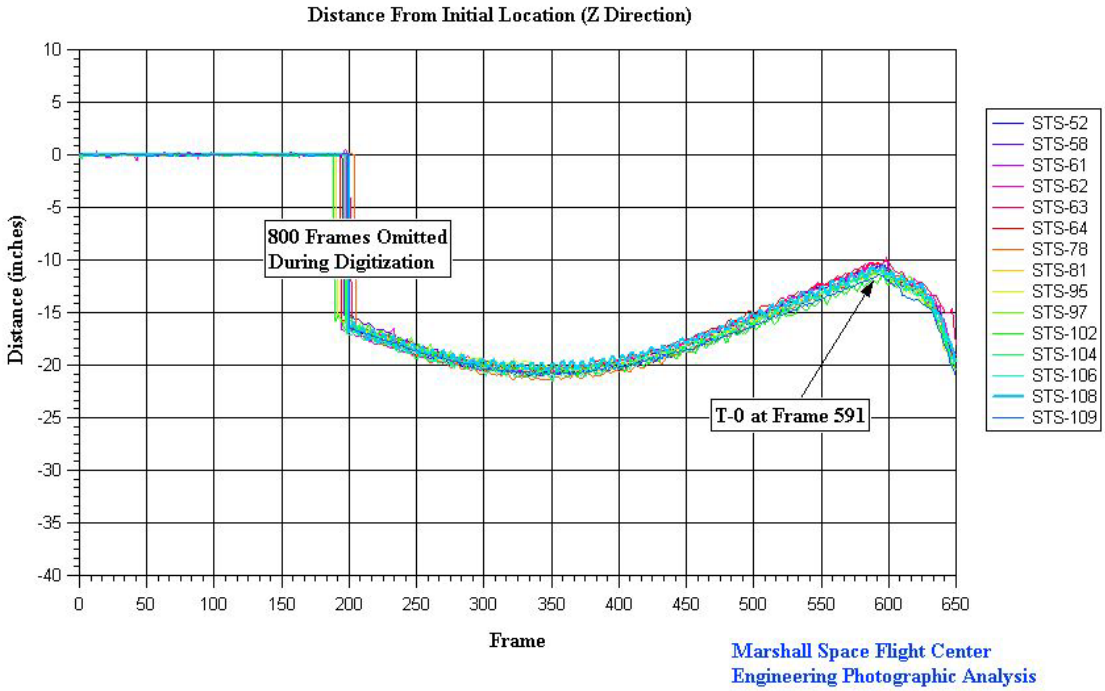

Figure 28. Z Direction Motion Comparison with Other Missions

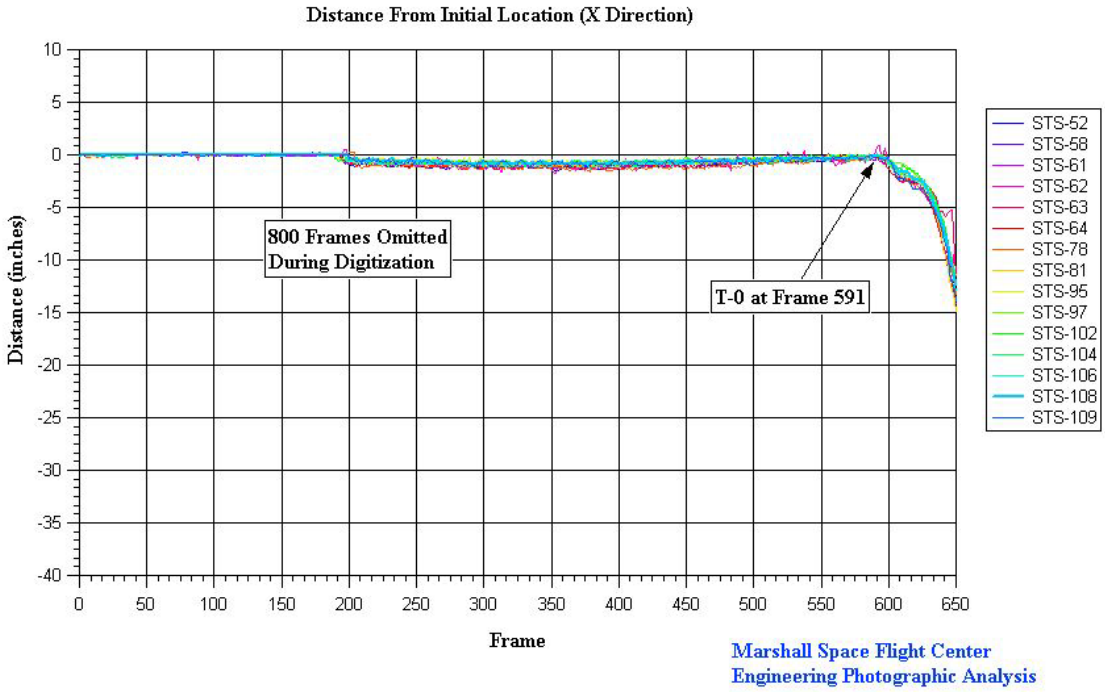

Figure 29. X-Direction Motion Comparison with Other Missions

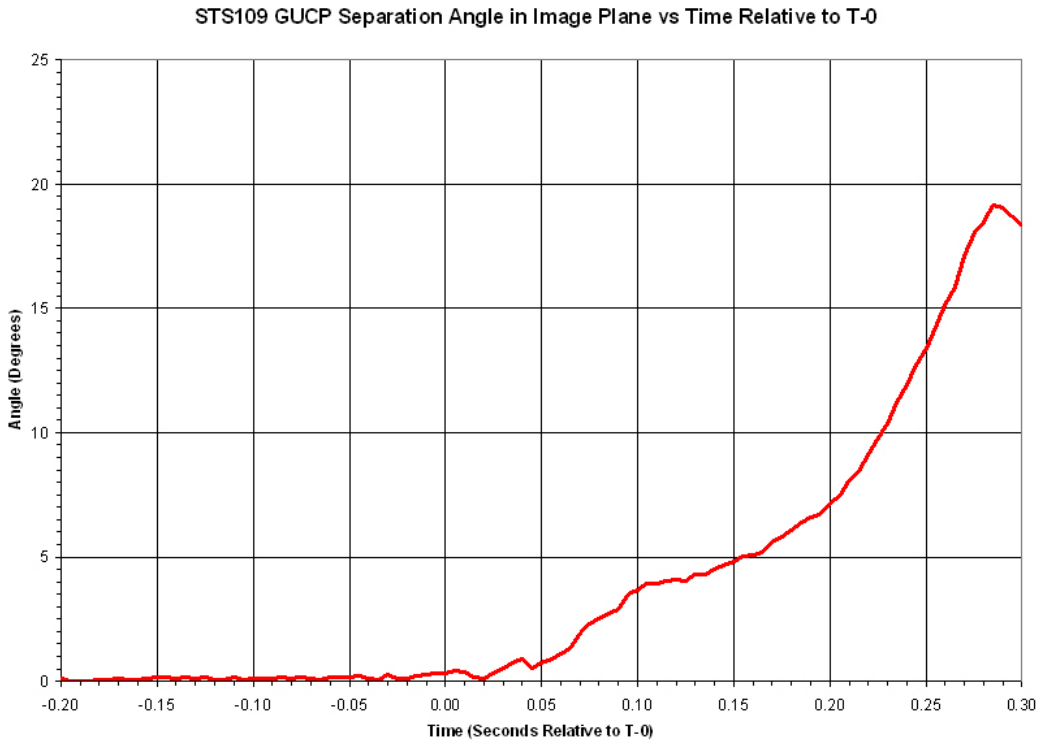

Figure 30. 2D Separation Angle for GUCP from ET Surface

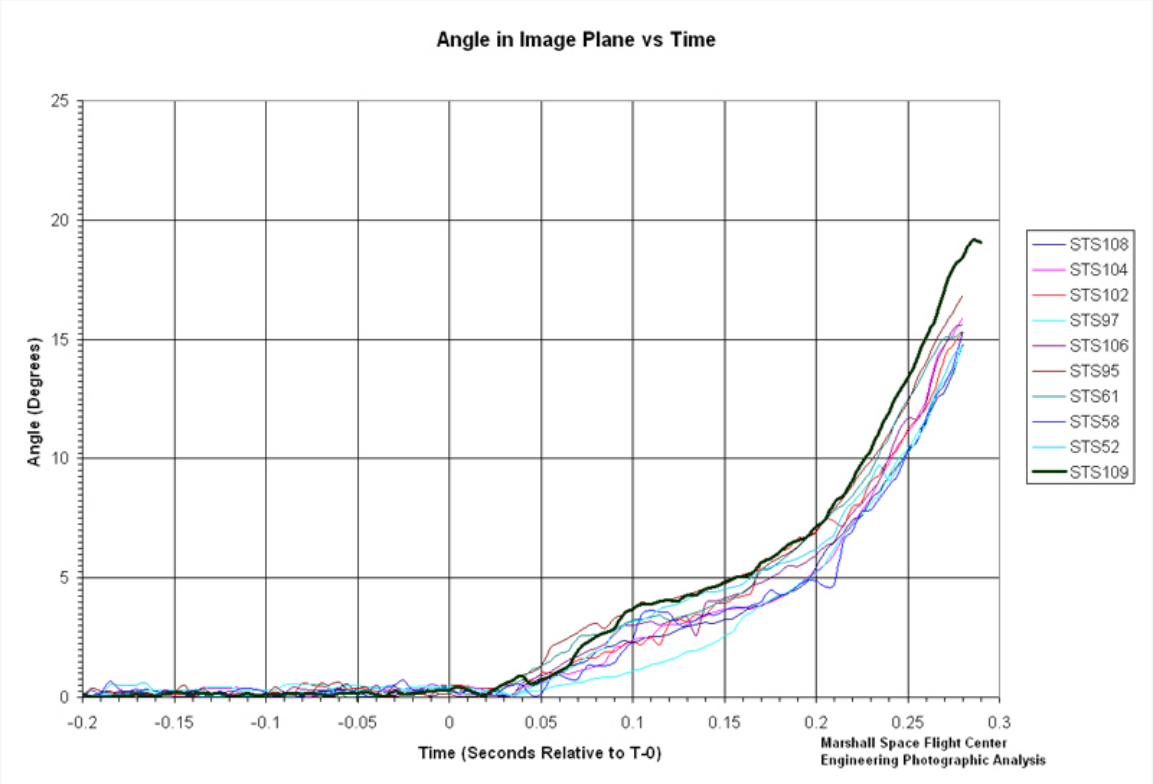

Figure 31. 2D Separation Angle Comparison with Other Missions

Individual Camera Assessments:

Assessments for individual cameras are listed below. The assessments for all individual cameras including camera characteristics as noted in the Photographic Acquisition Disposition Document (PADD) for flight STS-109 may also be found on the website.

Video Camera Assessments

TV13 Typical debris observed falling aft of vehicle. Linear optical distortions noted. Flow recirculation noted. SRB separation: 060:11:24:07.3 UTC. Forward RCS motor plumes observed at SRB separation.

TV4A Pad debris noted rising and falling. Free burning Hydrogen observed. Glowing debris ejected from SRB plumes during ascent.

TV7A Pad debris noted rising and falling.

ET204 Debris-induced streak observed in SSME plume. Camera loses track of vehicle in clouds and reacquires vehicle after separation.

ET207 Typical debris observed falling aft of vehicle. RCS motor plumes visible during SRB separation. Glowing debris particles ejected from SRB plumes during and after separation.

ET208 Glowing debris particles ejected from SRB plume after separation. Flow recirculation noted. RCS motor plumes observed at SRB separation.

ET212 Glowing debris particles ejected from SRB plume prior to separation.

ET213 Camera loses track vehicle after vehicle enters clouds. Video overexposed after vehicle leaves tower.

TV21A Free burning Hydrogen observed. Flash noted on MLP at liftoff.

OTV009 Typical ice/frost from 17-inch disconnects.

OTV041 Little detail of vehicle could be observed due to high contrast exposure.

OTV048 Little detail observed due to high contrast exposure.

OTV051 Free burning Hydrogen observed. Mach diamonds appear to form in 3-2-1 order.

OTV054 Typical ice/frost from 17-inch disconnects.

OTV063 Ice/frost strikes umbilical well doorsill. Yellowish debris noted near aft of disconnects.

OTV070 Free burning Hydrogen observed. Little detail observed due to over-exposure.

OTV071 Pad debris noted rising and falling. Free burning Hydrogen observed.

Astronaut Handheld Video Camera Resolution was such that fine detail could not be ascertained. All sides of the ET were imaged. No anomalous TPS damage was noted. BSM burn scars and aft dome charring were visible. No venting was noted.

Film Camera Assessments

E1 Typical ice/frost from 17-inch disconnects.

E2 Free burning Hydrogen observed.

E3 Pad debris observed.

E4 Film was blurred.

E6 Typical ice/frost from LO2 disconnect. Rectangular shaped debris noted falling between Orbiter and ET.

E7 Numerous pieces of debris emanating from SRB blast hole observed.

E8 SRB Holddown Post M2 PIC firing time at 11:22:02.032 UTC. Elongated debris particle falls from stud bore hole. Thin dark debris object falls through field of view, prior to PIC firing, 11:21:58.299 UTC.

E9 SRB Holddown Post M1 PIC firing time was 11:22:02.031 UTC.

E10 A tangle of water bagging ropes was observed near Holddown post.

E12 SRB Holddown Post M5 PIC firing time was 11:22:02.030 UTC. Small debris particle falls from stud bore hole.

E13 SRB Holddown Post M6 PIC firing time was 11:22:02.031 UTC.

E15 Pad debris noted rising and falling.

E16 Pad debris noted rising and falling. Water leak noted.

E17	Typical debris observed falling aft of vehicle. Rectangular debris observed falling past +Z side of body flap. Rope-like debris item observed falling through field of view.
E18	Typical ice/frost from LH2 disconnect. Free burning Hydrogen observed. Ice observed on SSME#2 eyelid. Light-colored, thin, flexible debris observed falling through field of view. Chipped tiles noted on Orbiter base heat shield.
E19	Free burning Hydrogen observed. Ice on SSME#2 eyelid noted. Mach diamond formation in 3-2-1 order. Faint streaks observed in SSME plumes.
E20	Ice on SSME#2 eyelid noted. Rectangular yellow-orange colored debris item observed coming from boat tail or base heat shield region.
E31	Typical ice/frost from 17-inch disconnects. Light-colored debris noted falling between Orbiter and ET. A dark, rigid, rectangular object and smaller dark object observed falling through field of view on +Z side of Orbiter. Objects do not impact the vehicle. Ice observed on SSME#2 eyelid.
E33	Typical ice/frost was noted on GUCA.
E34	Typical debris observed falling aft of vehicle. Faint streaks noted in SSME plumes.
E36	Typical debris observed falling aft of vehicle. Purge barrier material observed falling aft of vehicle. Vapors noted coming from GUCP during vent arm descent.
E40	Typical debris observed falling aft of vehicle.
E52	Typical debris observed falling aft of vehicle. Vapors from Orbiter wingtip noted early in flight. Typical ice/frost from 17-inch disconnects. Camera loses track of vehicle in clouds.
E54	Imagery overexposed after Rollover.
E57	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Bright debris material ejected from SRB plumes during ascent. Acoustic waves were visible during ascent.
E62	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. A Xenon light flash was noted on MLP. Large debris object observed falling aft of vehicle between SRB's on -Z side of vehicle.
E63	Flash was observed on MLP, prior to liftoff, at 11:21:58.166 UTC. Flash appears to be a Xenon light bulb burnout. Unidentified debris observed aft of body flap at 11:22:05.053 UTC.
E204	Typical debris observed falling aft of vehicle. Vapors from Orbiter wingtip noted during ascent. Camera loses image of vehicle in clouds for most of ascent.
E205	Linear optical distortions noted. SRB separation: 11:24:07.277 UTC. Vehicle not correctly framed or not imaged during most of ascent.
E207	Typical debris observed falling aft of vehicle. SRB separation: 11:24:07.268 UTC. Vapors noted off orbiter right wing during ascent. Debris ejected from SRB plumes prior to SRB separation, 11:24:02.344 UTC.
E208	Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. Flow recirculation noted. Body flap motion observed. Soft focus, probably due to atmospheric haze.
E212	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume after separation. Vehicle frequently obscured by clouds. RCS motor plumes noted at SRB separation.
E213	Typical debris observed falling aft of vehicle. Vapors from Orbiter wingtip noted early in flight. Vehicle not centered in frame, not all of vehicle imaged early in flight. Vehicle frequently obscured by clouds. Camera loses track of vehicle in clouds.
E220	Typical debris observed falling aft of vehicle. Linear optical distortions noted. SRB separation: 11:24:07.280 UTC. Vehicle frequently obscured by clouds. Several pieces of debris ejected from SRB plumes during ascent, 11:23:15.479 UTC.
E222	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Vapors noted off Orbiter wingtips during ascent. Camera appears to lose track of vehicle in clouds. Clouds frequently obscure vehicle.
E223	Typical debris observed falling aft of vehicle. SRB separation: 11:24:07.279 UTC. Large piece of debris noted below Orbiter Body Flap just after liftoff, 11:22:05.069 UTC. Clouds frequently obscure vehicle during ascent. Debris-induced streaks noted in SSME plumes: 11:22:33.592 and 11:22:34.119 UTC. Debris ejected from SRB plumes during ascent.

E224 Bird observed just after liftoff, 11:22:06.968 UTC. Camera apparently loses track of vehicle in clouds.

FL101 Vapors were noted from SRB upper aft attach at SRB separation. Typical TPS ablation observed.

FL102 Vapors observed from SRB upper aft attach at SRB separation. Slight twang noted at upper aft attach at SRB separation. Red colored debris observed traveling between camera and aft section of ET. TPS missing on aft left thrust strut. EO2 bolt appears to move from inside the bore to a position barely protruding from the bore. Two divots noted under bipod. Apparent divot on LH2 acreage.

35mm Umbilical Well Camera EO-3 bolt was observed to be protruding. TPS on thrust strut missing. Typical aft dome charring observed. Two divots under bipod and one divot between bipod and LO2 feedline noted. Two divots on LH2/Intertank flange TPS noted.

35mm Astronaut Handheld Camera Typical BSM scars observed. No unusual TPS damage noted.

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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