Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-110

Armando Oliu

Technical Memorandum – 2005-212558 March 2005

DEBRIS/ICE/TPS ASSESSMENT and
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF SHUTTLE MISSION STS-110

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OF
SHUTTLE MISSION STS-110

April 8, 2002

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TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF PHOTOS

FOREWORD

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

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

Photo 1: Launch of Shuttle Mission STS-110

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-110 consisted of OV-104 Atlantis (25th flight), ET-114, and BI-112 SRB's on MLP-3 and Pad 39B. Atlantis was launched at 4:44:19 pm EDT on 8 April 2002. Landing was at 12:27 a.m. local/eastern time on 19 April 2002.

Post landing inspection of Orbiter tiles showed a total of 110 hits, of which 22 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 70 total hits, of which 18 had a major dimension of 1-inch or larger, both numbers are within family. The area from the nose landing gear to the main landing gear wheel wells sustained 30 hits with 11 greater than 1-inch. Approximately 15 of the total lower surface hits were around the LH2 umbilical area. 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.

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.

2.0 PRE-LAUNCH BRIEFING

The Debris/Ice/TPS and Photographic Analysis Team briefing for launch activities was conducted at 3:30 p.m. EDT on 3 April 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.

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S. Otto	LMMSS	ET Processing
M. Eastwood	Thiokol-LSS	SRM Processing

2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The pre-launch inspection of the MLP-3, Pad B FSS and RSS was conducted on 3 April 2002 from 1600 to 1830 hrs EDT.

No facility items were documented in Appendix K of S0007VL4. The MLP, FSS, and RSS appeared in excellent condition. Minor clean-up items were in-work.

No vehicle items were noted with the exception of two small pieces of grass/twigs observed on the upper surface of the 2nd stiffener ring of the RH SRB. The items were located on both the –Z and +Z side of the systems tunnel. The items are very small and are not a debris concern.

3.0 SCRUB

3.1 EXTERNAL TANK LOADING – LH2 Leak in MLP Line

Approximately 13 minutes into the LH2 fast fill portion of the ET loading a large vapor cloud was detected on MLP Side 4 using the OTV system. A 16-inch MLP hydrogen vent line was identified as the origin of the leak. ET loading was halted and a drain initiated. The ET was only partially loaded. No anomalies had been detected, via OTV, on the ET during the loading process. The loading of cryogenics into the ET began at approximately 6:17 am on halted after a leak was detected on a LH2 line on the MLP.

3.1.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed.

3.1.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed.

This attempt to launch STS-110 was scrubbed due to the hydrogen leak on the LH2 vent line on the MLP.

Photo 2: Hydrogen Leak in LH2 Vent Line.

3.2 POST DRAIN INSPECTION

The post drain inspection of STS-110, MLP-3, and Pad B FSS was conducted on April 4, 2002 from 1230 to 1330 hours. The launch scrub was called at 0927 hours due to a massive hydrogen leak on the hydrogen vent line running along the MLP east side. The team performed a preliminary inspection of this line from the pad surface using binoculars. An approximately 1/8 inch wide crack was observed at the leak location.

No MLP deck or facility anomalies were detected.

Likewise, no anomalies were observed on the SRB's.

Orbiter tiles, RCC panels, and SSME's were in nominal configuration. RCS thruster paper covers were intact.

The GOX vent arm was in the extended position with the hood up. OTV monitoring from LCC Firing Room 2 was performed prior to and during GVA retraction and had verified no anomalies with the vent system or the ET nose cone and forward LO2 tank TPS. The post drain Pad inspection also verified no anomalies in this area. No topcoat was missing from the nose cone area within the GOX vent seal footprint.

The External Tank was in excellent condition. Bipod jack pad standoff closeouts were in nominal condition. All PDL repairs were intact with none protruding. No crushed foam or debris was detected in the LO2 feedline support brackets.

The only ice remaining was located in the lower EB fittings and on the LH2 ET/ORB umbilical purge vents.

In summary, no IPR conditions and no flight hardware concerns were detected during the post drain inspection. Other than the Hydrogen Vent line crack there are no constraints for the next cryoload.

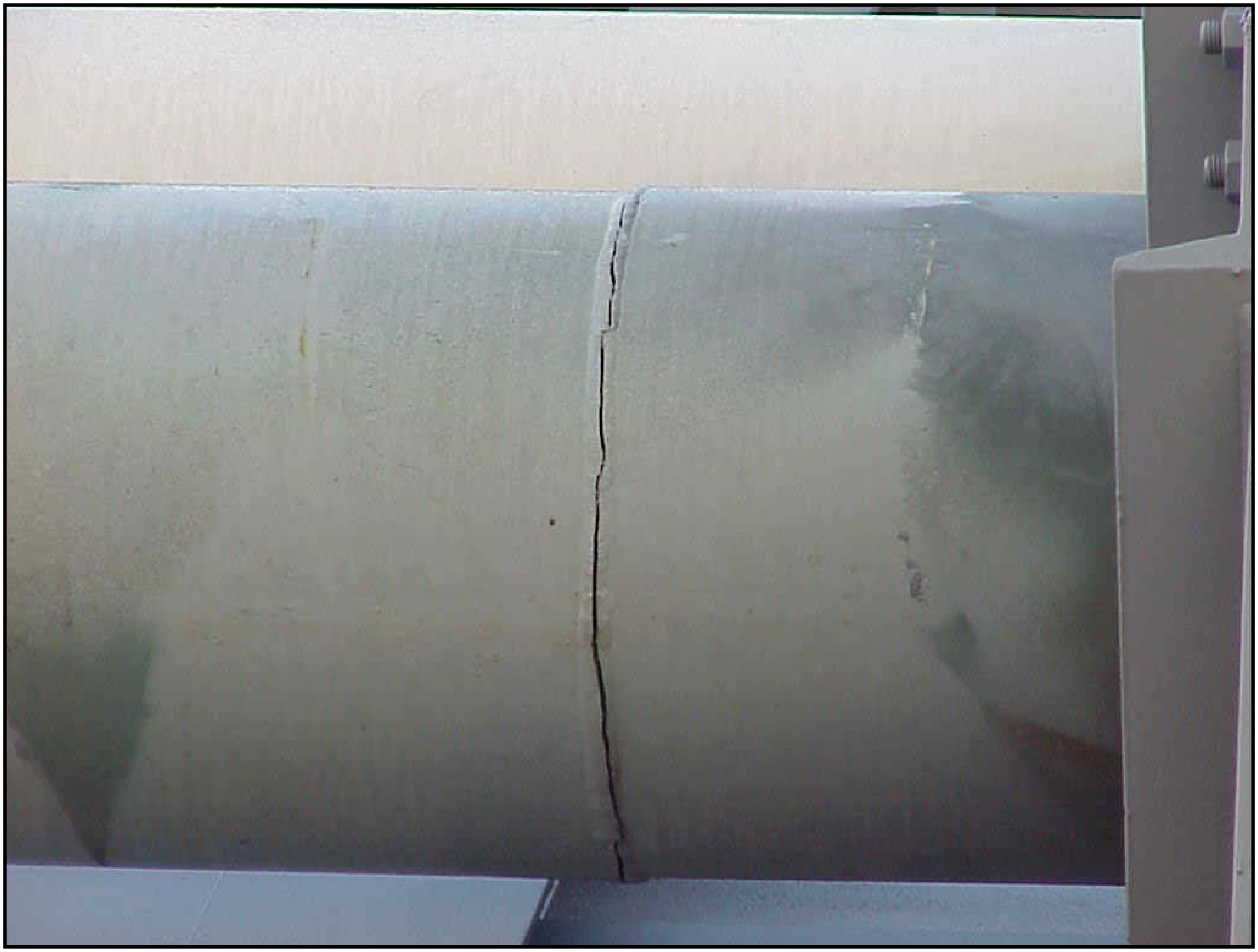


Photo 3: Crack in Hydrogen Vent line on MLP.

4.0 LAUNCH

4.1 PRE-LAUNCH SSV/PAD INSPECTION

The pre-launch inspection of the MLP-3, Pad B FSS and RSS was re-performed on 7 April 2002 from 1600 to 1730 hrs EDT.

No facility items were documented in Appendix K of S0007VL4. The MLP, FSS, and RSS appeared in excellent condition. Minor clean-up items were in-work.

No vehicle items were noted.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 1030 to 1230 hrs on 8 April 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.

4.2.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact though covers for thrusters F3L, R1R, R2D and L4D were discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface.

4.2.2 SOLID ROCKET BOOSTERS

No SRB case, closeout, or protuberance anomalies were observed. SRB case temperatures measured by the STI radiometers were close to ambient temperatures, ranging from 68 to 71 degrees F. All measured temperatures were above the minimum requirement.

4.2.3 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run as a comparison to infrared scanner point measurements. The program predicted temperatures above the 32 degrees F throughout ET cryoload. The following table shows ambient condition, SURFICE prediction and IR surface temperatures at the start of FIT walkdown. The SURFICE Ice Prediction Program does not take into account the effect the sun has on the ET surface temperatures.

Ambient conditions – 1100hrs	SURFICE Predictions	IR Surface Readings
73 Degrees F.	LO2 ogive 61 Degrees F	LO2 Tank 58-72 Degrees F
61% RH	LO2 barrel 56 Degrees F	
15 knots	LH2 upper 54 Degrees F	LH2 Tank 55-68 Degrees F
106 degrees	LH2 lower 62 Degrees F	

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

No significant anomalies were present in the intertank TPS. Four cracks in the intertank stringer valley TPS were observed (1st valley –Z of –Y thrust panel, 1st valley +Z of –Y thrust panel, 1st valley –Z of +Y thrust panel, and 2nd valley +Y of the LH2 PAL ramp). The cracks exhibited no ice, frost, or offset. Therefore, the cracks were acceptable for flight per the NSTS-08303 criteria. Ice and frost accumulations on the GUCP were typical.

The LH2 tank was dry with no condensate. A small, 2-inch diameter frost spot was detected on the aft side of the +Y vertical strut to LH2 tank interface. This frost formation is acceptable per NSTS-08303. There were no acreage TPS anomalies.

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

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 were typical. There was less than typical amount of ice/frost accumulation on the LH2 ET/ORB umbilical purge barrier. 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.

4.2.4 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.

4.3 T-3 HOURS TO LAUNCH

After completion of the Final Inspection on the pad, surveillance continued from the Launch Control Center. Twenty-two remote-controlled television cameras and two infrared radiometers were utilized to perform scans of the vehicle. No anomalies were detected during this timeframe.

STS-110 launched at 4:44:19 pm EDT on 8 April 2002.

Photo 4: LO2 tank acreage.

No condensate was present on the LO2 tank acreage. Surface temperature ranged from 58-72 degrees Fahrenheit. There were no acreage TPS anomalies.

Photo 5: LH2 tank acreage.

The LH2 tank was dry with no condensate. Surface temperature ranged 55 to 68 degrees Fahrenheit. There were no acreage TPS anomalies.

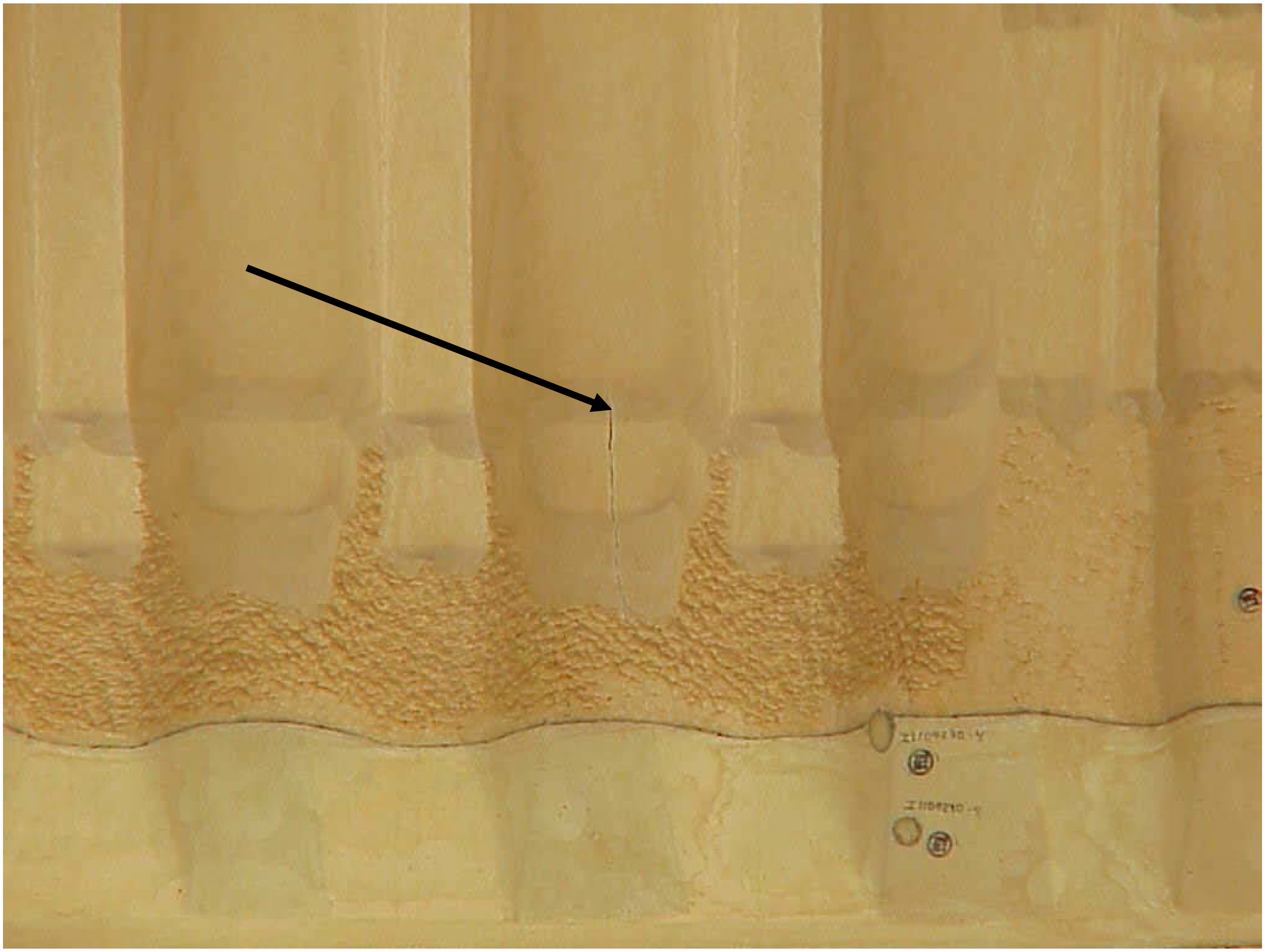


Photo 6: Crack in Intertank Valley

Photo 7: Frost ball.
2-inch diameter frost spot on the aft side of the +Y vertical strut to LH2 tank interface.

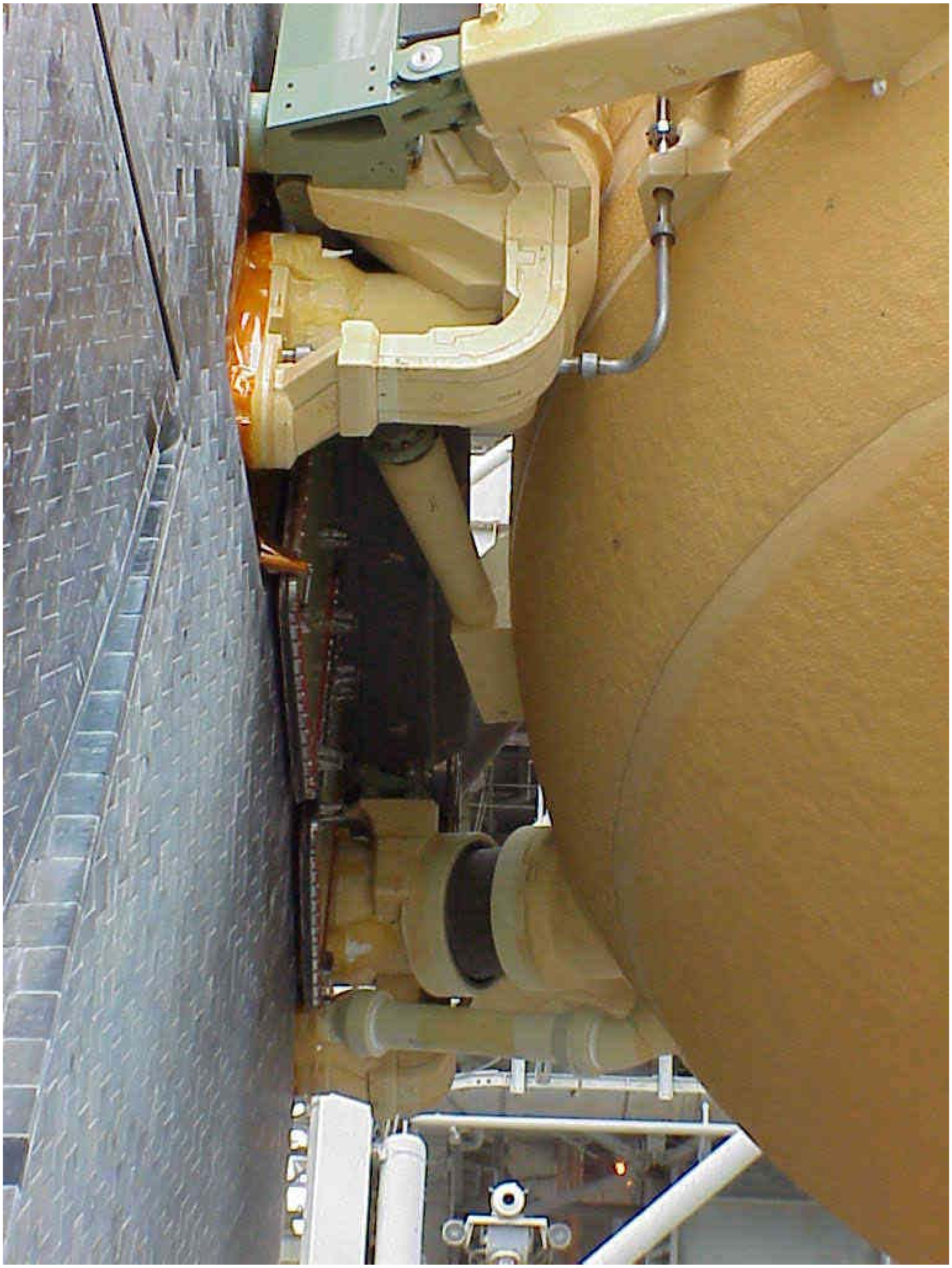


Photo 8: Umbilical area.

Typical ice/frost finger on pyro canister vent and on LH2 recirculation line bellows.

5.0 POST LAUNCH PAD DERBIS INSPECTION

The post launch inspection of the MLP-3, Pad B FSS and RSS was conducted on 8 April 2002 from Launch + 1.75 to 3.75 hours (1815 to 2015 EDT).

No flight hardware was found.

Orbiter liftoff lateral acceleration data to predict stud hang-ups received from Boeing-Huntington Beach indicated that no SRB holddown stud hang-up had occurred, the reported value was 0.14G. Evaluation of the MLP 0-level was performed and the south holddown studs were visually assessed as having no indication of hang-up. Erosion was typical for the north posts with some evidence of missing RTV at the HDP haunch interface. North holddown post blast covers and T-0 umbilical exhibited minimal exhaust plume damage. Both SRB aft skirt GN2 purge lines were intact, protective tape layering was partially eroded on the RH side and the metal braid was exposed on the LH purge line.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged; the LO2/LH2 bonnets were observed to be fully closed. The MLP deck was in generally good shape. All MLP deck communication connector caps were found intact and secured. Removable handrail support on Side 4 was found to have been partially displaced; the floor plate was missing one fastener and fastener was loose (not torqued) in place.

The GH2 vent line latched on the 4^{th} tooth of the FSS latching mechanism. The vent line was displaced to the south and contacted the north stabilizer rod. Inspection of the area did not reveal any indication of the vent line having made contact with the FSS. GUCP and 7-inch QD exhibited no damage, the poppet was observed to be intact. The deceleration cable was in nominal configuration, and the vent line blanket was sooted and torn.

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 good shape with no indications of plume damage.

Debris findings included:

- FSS 235’ level - loose uni-strut clamp and fasteners found
- Pad surface SW near RSS truck – Z shaped metal panel flashing 9’ (long) x 4” (wide)
- North Flame Trench – Metal Object ~ 5’- 8” x 3”(half round) believed to MLP flame hole panel batten

Overall damage to the pad appeared to be minimal.

6.0 FILM REVIEW

Two pieces of facility debris appears from under the raise deck adjacent to the SSME exhaust hole and near the LH2 TSM during SSME ignition. Shortly after T-0 the debris is blown across the MLP deck (away from the flight hardware) until it leaves the field of view. The debris appears to be two portions (1 to 3 foot in length) of either electrical cable or tygon tubing. (E-3)

6.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 71 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). GH2 vent line appeared to contact deceleration cable slightly south of center. Positive capture was achieved on the vent line latch with the latching mechanism centered in latching plate. (E-39, E-43) The hydrogen vent line pivot arm showed no rebound. (E-61)

Several ice particles from the GH2 disconnect fell at T-0. (E-33, E-34, E-61, E-64) Two ice particles contacted LH SRB shortly after T-0. No damage noted. (E-33)

Umbilical purge barrier baggie material fell during and after roll maneuver. (E-52, E-54, E-207, E-213, E-222) One piece of purge barrier detached from the umbilical and was caught in turbulent flow directing it toward ET aft dome and then under the body flap, in between SSME's #2 and #3 prior to being ejected aft in the exhaust of SSME #1. Additional large purge barrier baggie portion was observed falling past body flap at GMT 20:44:47.956.

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

Particles of SRB aft-skirt instafoam fell along side the SRB plume. (E-207, E-208, E-212, E-223)

OMS-assist firing was visible shortly after SRB separation. (E-207, E-212)

Localized flow condensation at various points on the vehicle were typical. (E-207, E-208, E-212, E-213, E-222)

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

Free-burning GH2 blown south under body flap. (E-52, 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-34, E-36, E-52, E-63)

Charring on the ET aft dome was typical. (E-207, E-208, E-213, E-223, E-224)

Forward RCS paper covers were observed falling aft during early ascent. (E-52, E-54, E-207, E-213, E-222, E-223)

Numerous small debris particles entered field of view well after vehicle clears tower. (E-63).

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

Numerous flashes in SSME plume were observed during ascent. (E-207, E-212, E-220, E-222, E-223)

No stud hang up were observed on any of the SRB hold-down posts.

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

Small pieces of FSS facility debris enters field of view prior to T-0. No contact with vehicle. (E-42)

Deluge water pipe leaking near HDP 3. (E-7, E-10)

Two tile surface chips were noted from base heat shield. Largest one appeared between SSME #1 and #2. Tile surface coating loss was also observed from the aft face of the RH RCS stinger. This is a common occurrence due to SSME ignition acoustics.

Vapors on ET aft dome and SRB stiffener rings were observed after T-0.

Ice particles fell from LH2 / LO2 TSM T-0 disconnects.

Small particles of deck debris were blown across MLP deck.

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

The 35mm still images from the LO2 ET/ORB umbilical camera and the 16mm film motion picture films from the LH2 umbilical cameras were reviewed.

SRB separation from the External Tank appeared nominal.

ET separation from the Orbiter was normal. However, the imagery showed what appeared to be a relative yaw movement in the ET in respect to the Orbiter. Subsequent investigation revealed that yaw movement was on the Orbiter. This was probably due to the new OI-29 alpha-beta management maneuver. This new Orbiter software update may affect future capabilities of ET post-separation imagery.

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.

Two divots, approximately 5 inches by 5 inches, were observed on the intertank-to-LH2 tank flange closeouts between the bipods. One of the divots encompasses a significant portion of the +Y Jack Pad closeout.

No anomalies were detected in the LO2 tank acreage. 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 acreage appeared to be in nominal condition.

6.3 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 additional anomalies were detected from touchdown through rollout.

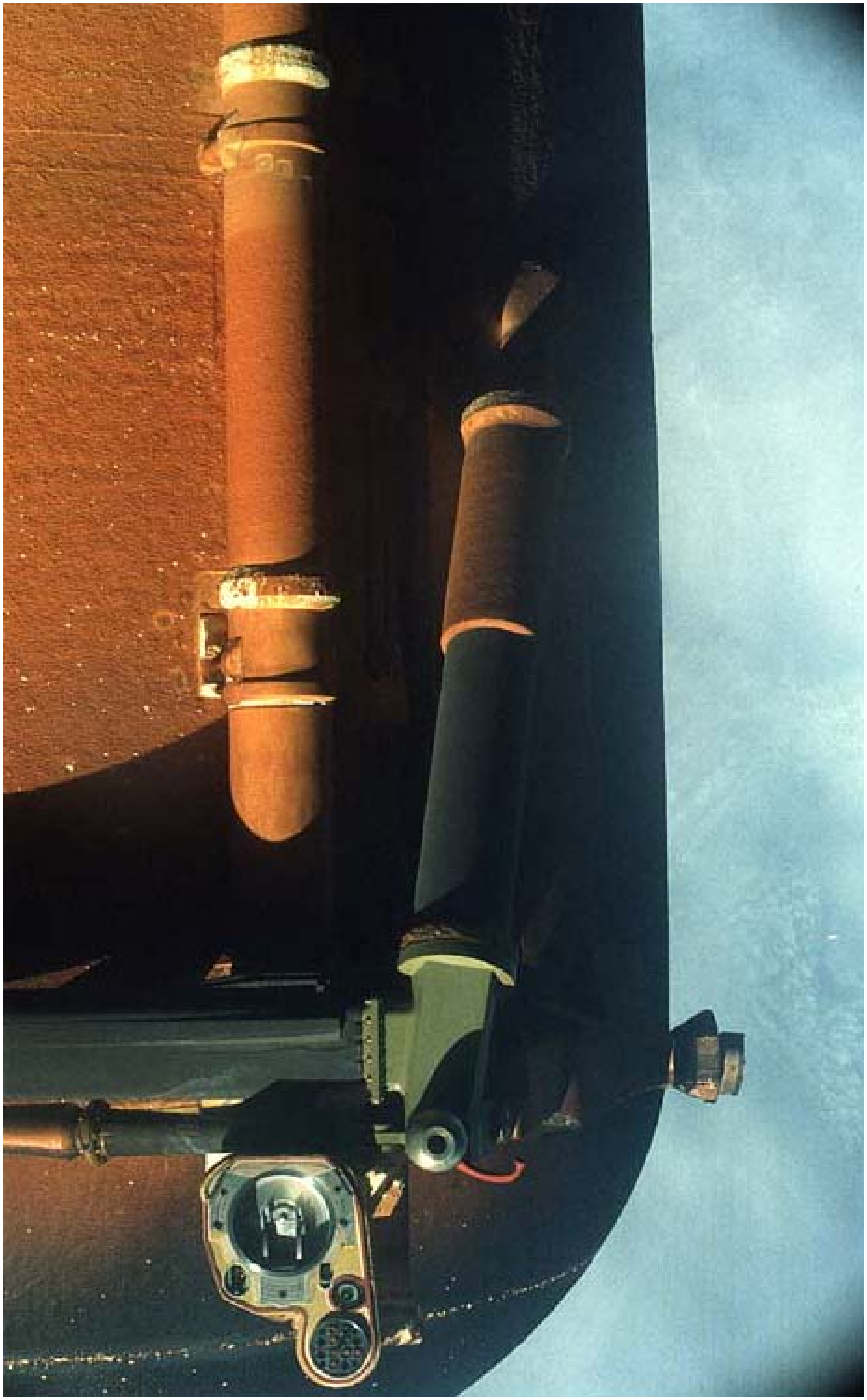


Photo 9: ET Post Separation.

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

Photo 10: ET Post Separation.

Two divots, approximately 5 inches by 5 inches, were observed on the intertank-to-LH2 tank flange closeouts between the bipods. One of the divots encompasses a significant portion of the +Y Jack Pad closeout.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-112 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 11 April 2002. Generally, 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, but two RH and two LH cover attach rings 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 with the exception of two missing pins and retainer clips on the left SRB. Parachute riser entanglement most likely caused this.

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.

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

No indication of stud hang up was observed.

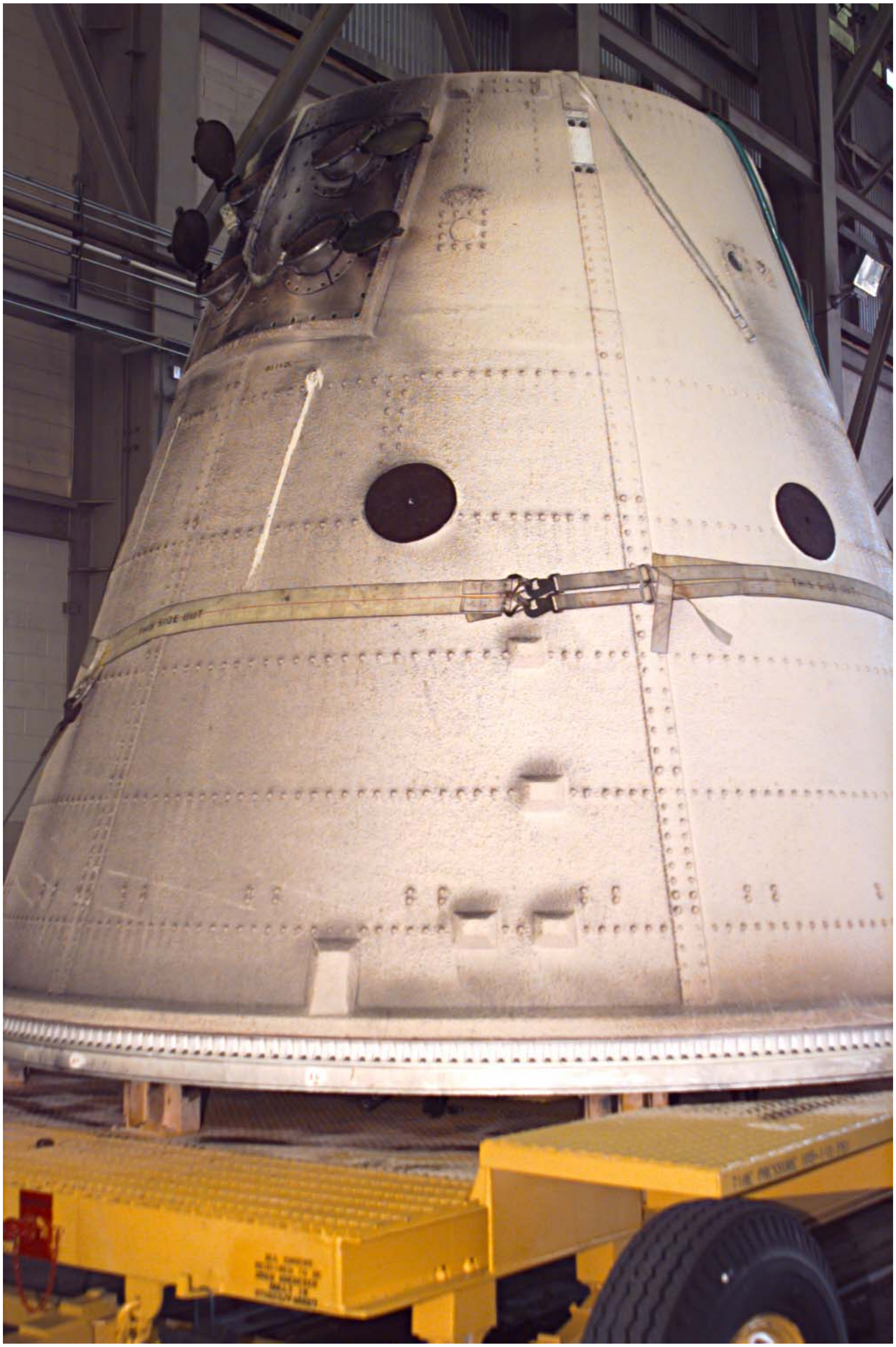


Photo 11: LH Frustum Post Flight Condition
The LH SRB frustum exhibited no debonds/unbonds or missing TPS.

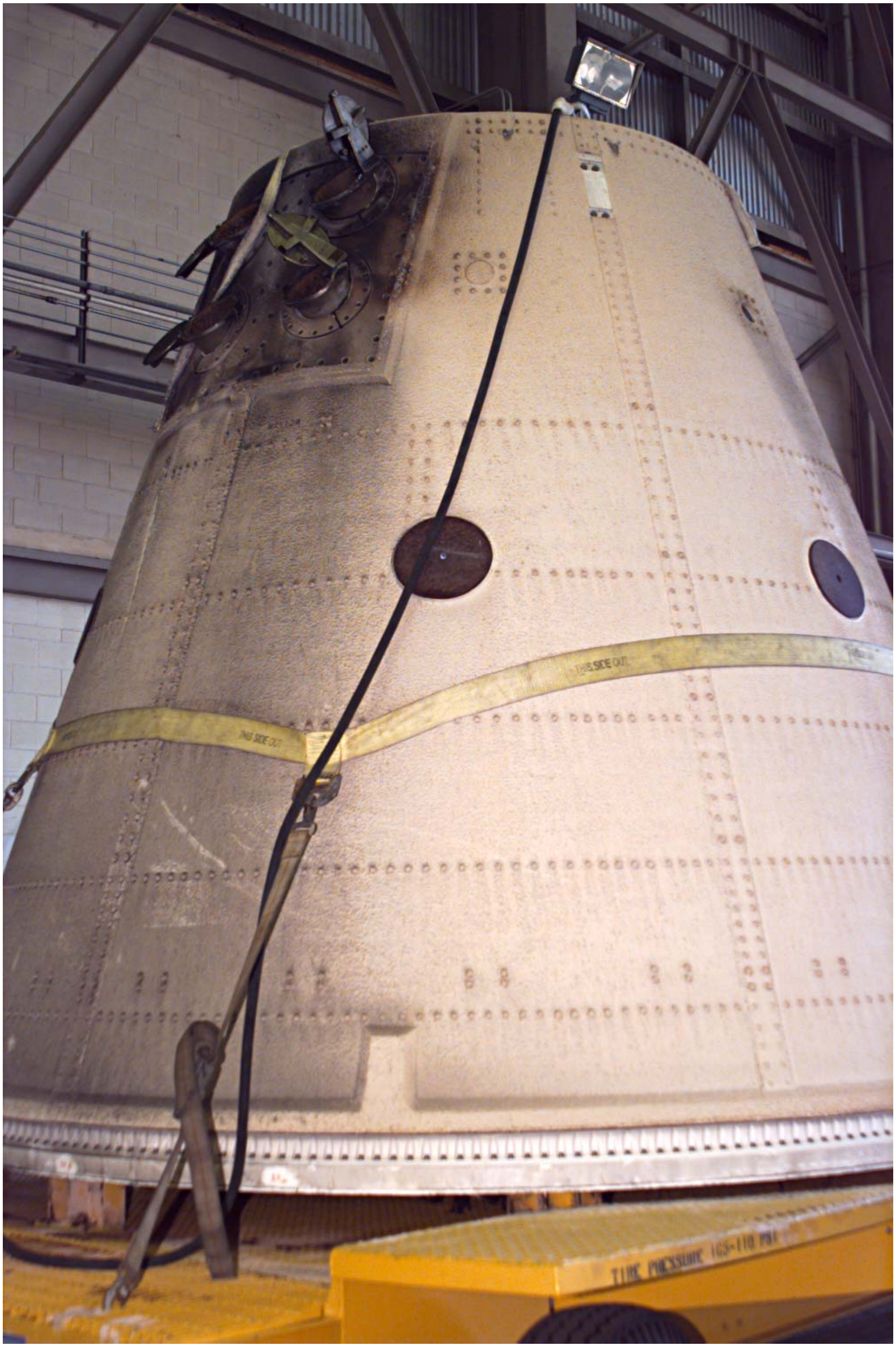


Photo 12: RH Frustum Post Flight Condition
The RH SRB frustum exhibited no debonds/unbonds or missing TPS.

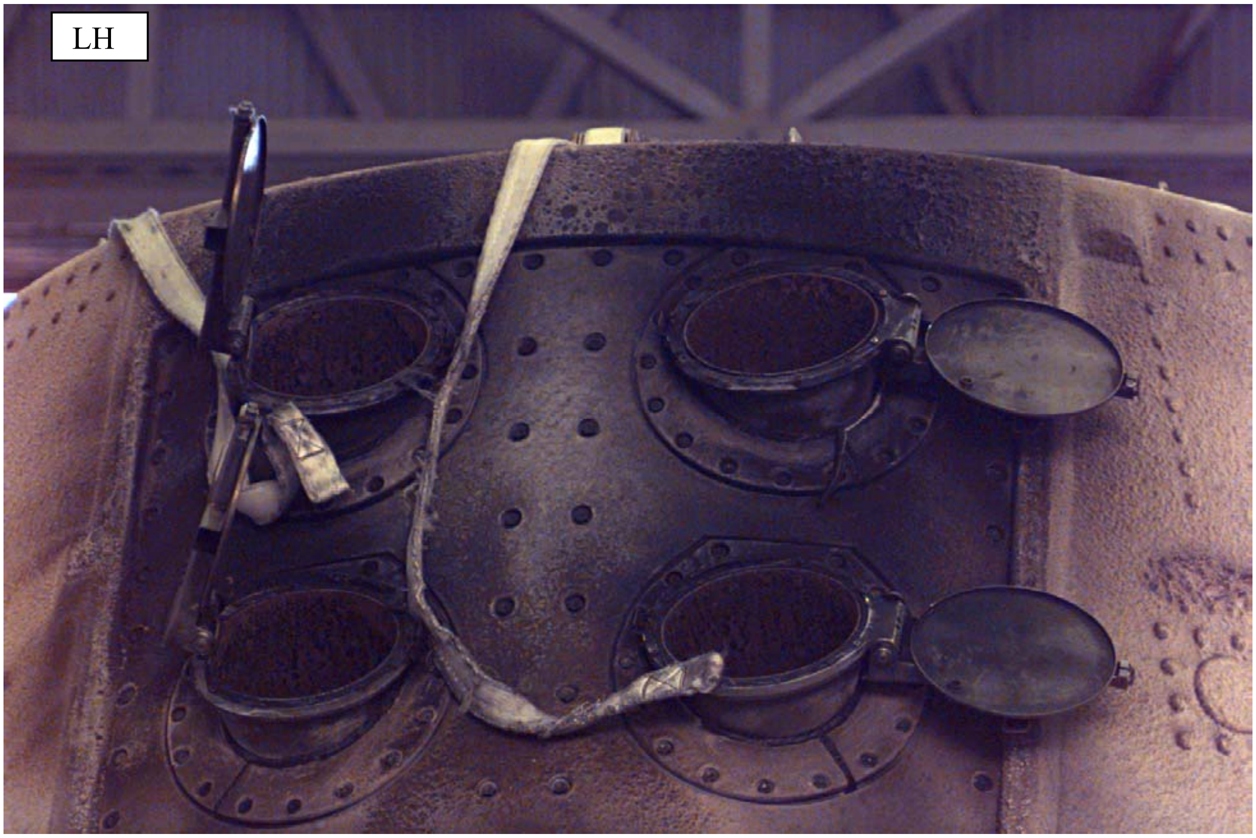


Photo 13: BSM Cover Condition

Two RH and two LH cover attach rings had been bent at the hinge by parachute riser entanglement.

Photo 14: SRB Post Flight Condition

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

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 12:26 pm local/eastern time landing on 19 April 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 2. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 110 hits of which 22 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-110 Orbiter damage hits by area:

	HITS > 1-inch	TOTAL HITS
Lower Surface	18	70
Upper Surface	0	0
Window Area	4	34
Right Side	0	6
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	0	0
TOTALS	22	110

The Orbiter lower surface sustained 70 total hits, of which 18 had a major dimension of 1-inch or larger, both numbers are well within family. The area from the nose landing gear to the main landing gear wheel wells sustained 30 hits with 11 greater than 1-inch. Approximately 15 of the total lower surface hits were around the LH2 umbilical area. 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 just forward of the RH main landing gear wheel well, measured 3-1/2 inches long by 3/4-inches wide by 5/8-inches deep. The cause of this damage has not been determined yet.

Gap filler material was found protruding from in between tiles on the LH OMS pod eyeball area.

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 34 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 heavier greater than normal. There is a window ding, 1/4-inch diameter, approximately at the center of window #2.

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.

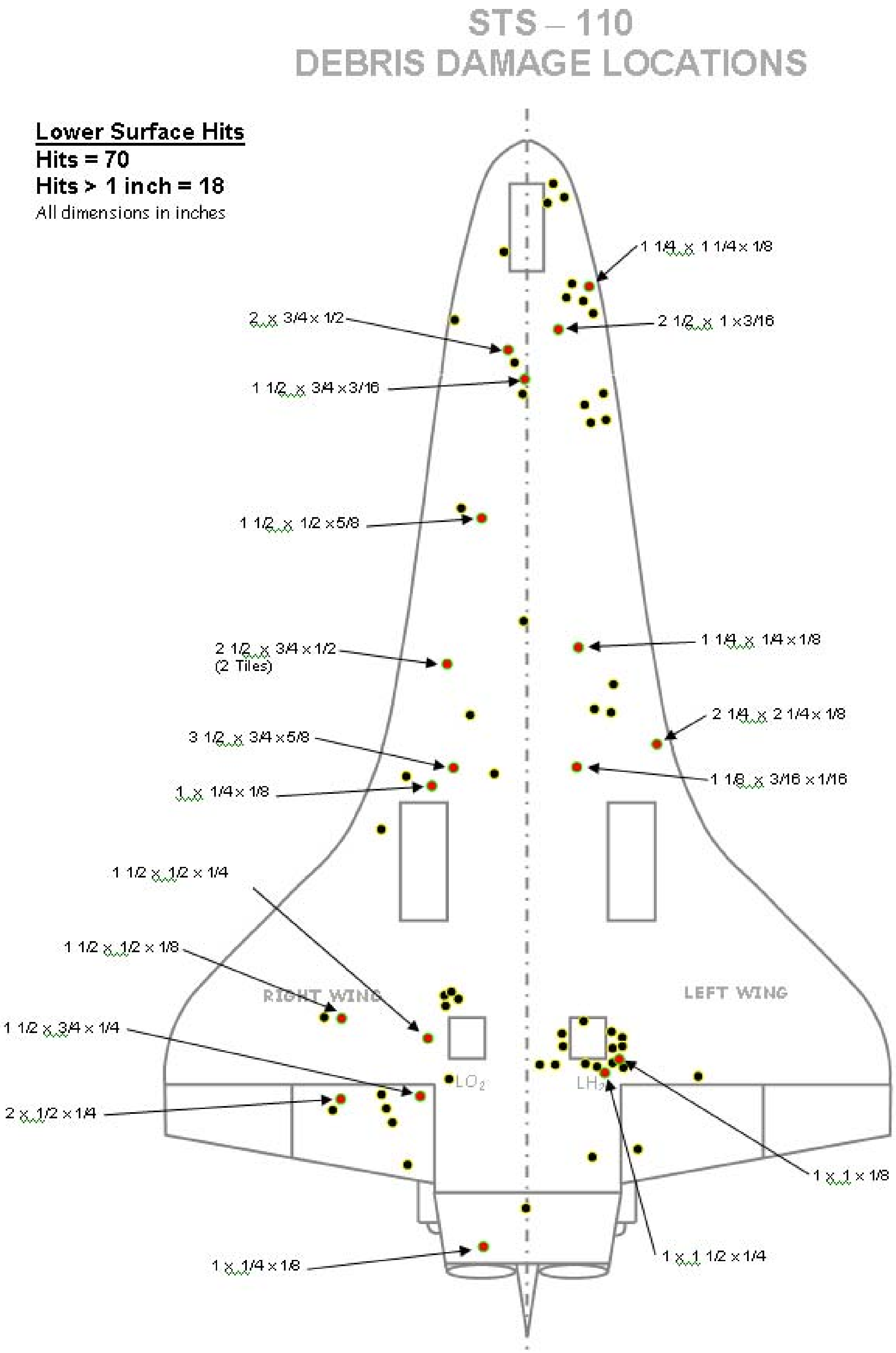


Figure 1: Orbiter Lower Surface Debris Damage Map

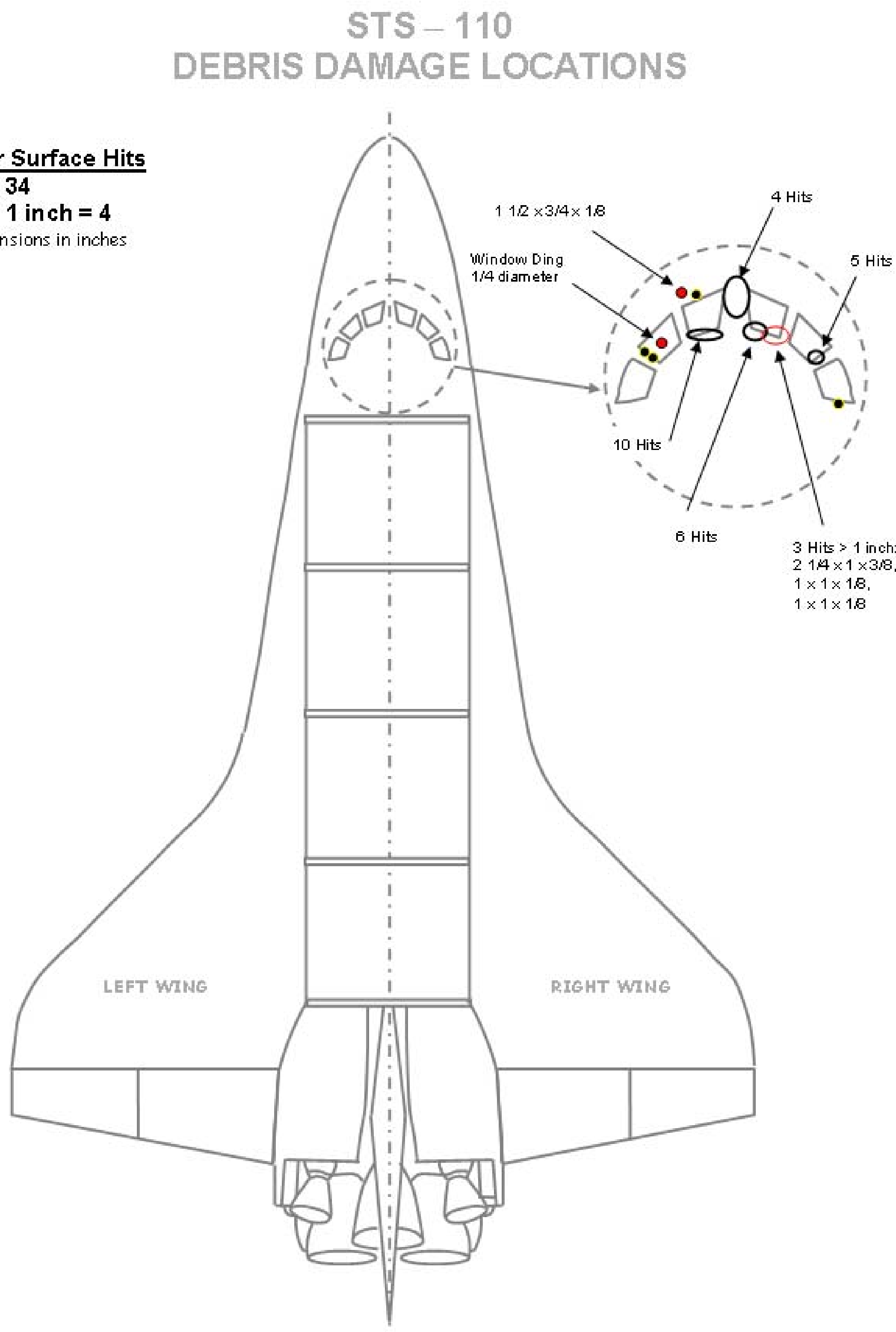


Figure 2: Orbiter Upper Surface Debris Damage Map

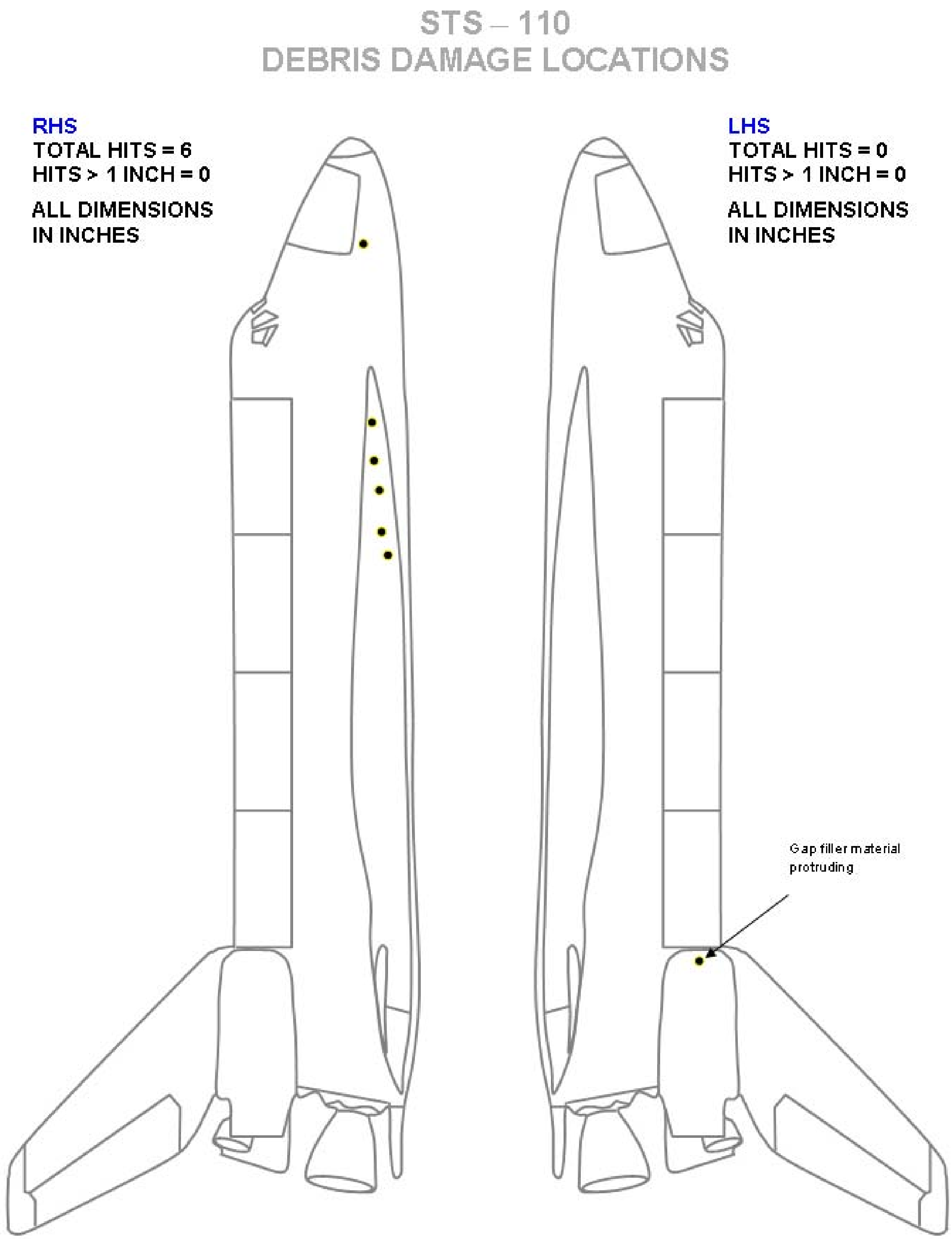
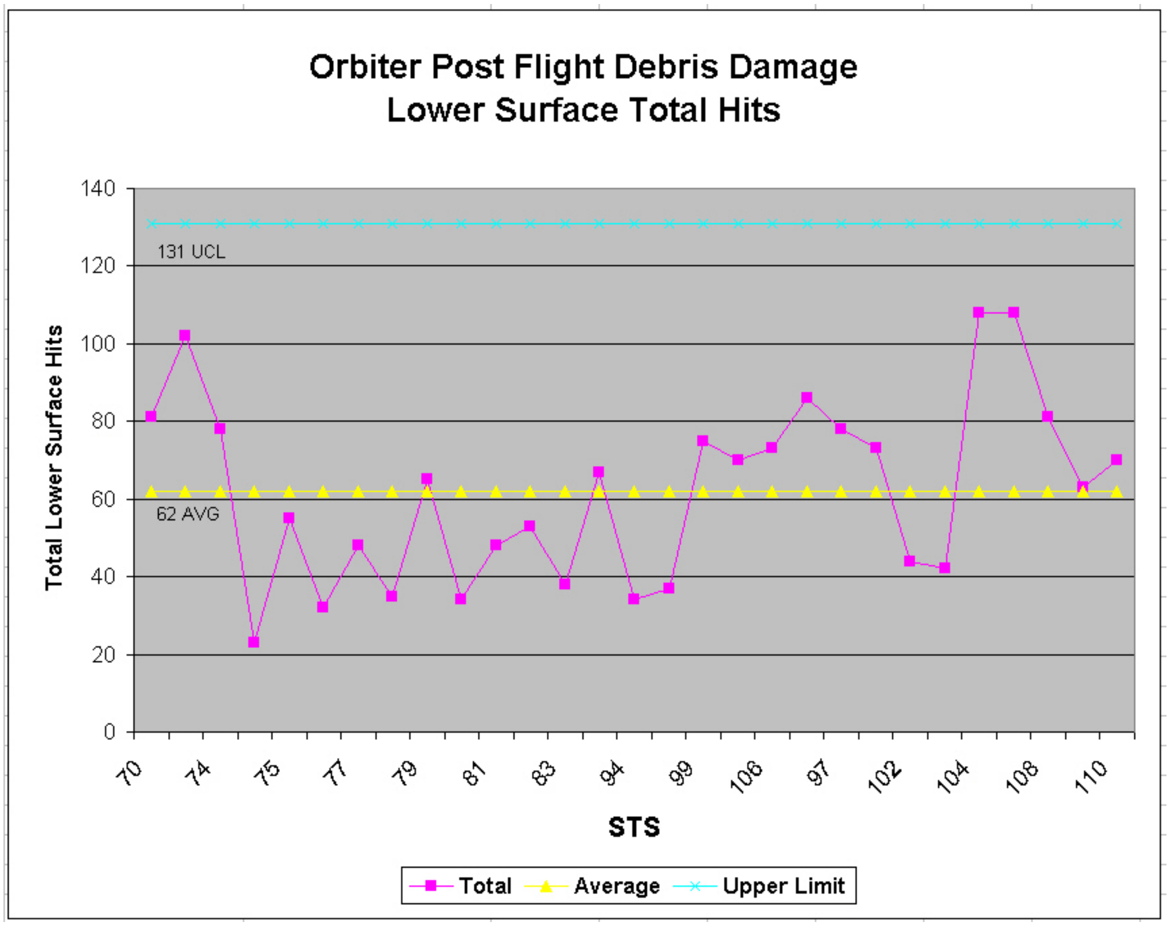


Figure 3: Overall View of Orbiter Sides

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
AVERAGE	12.0	65.7	16.8	104.2
SIGMA	5.9	31.4	6.2	27.0
STS-110	18	70	22	110

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



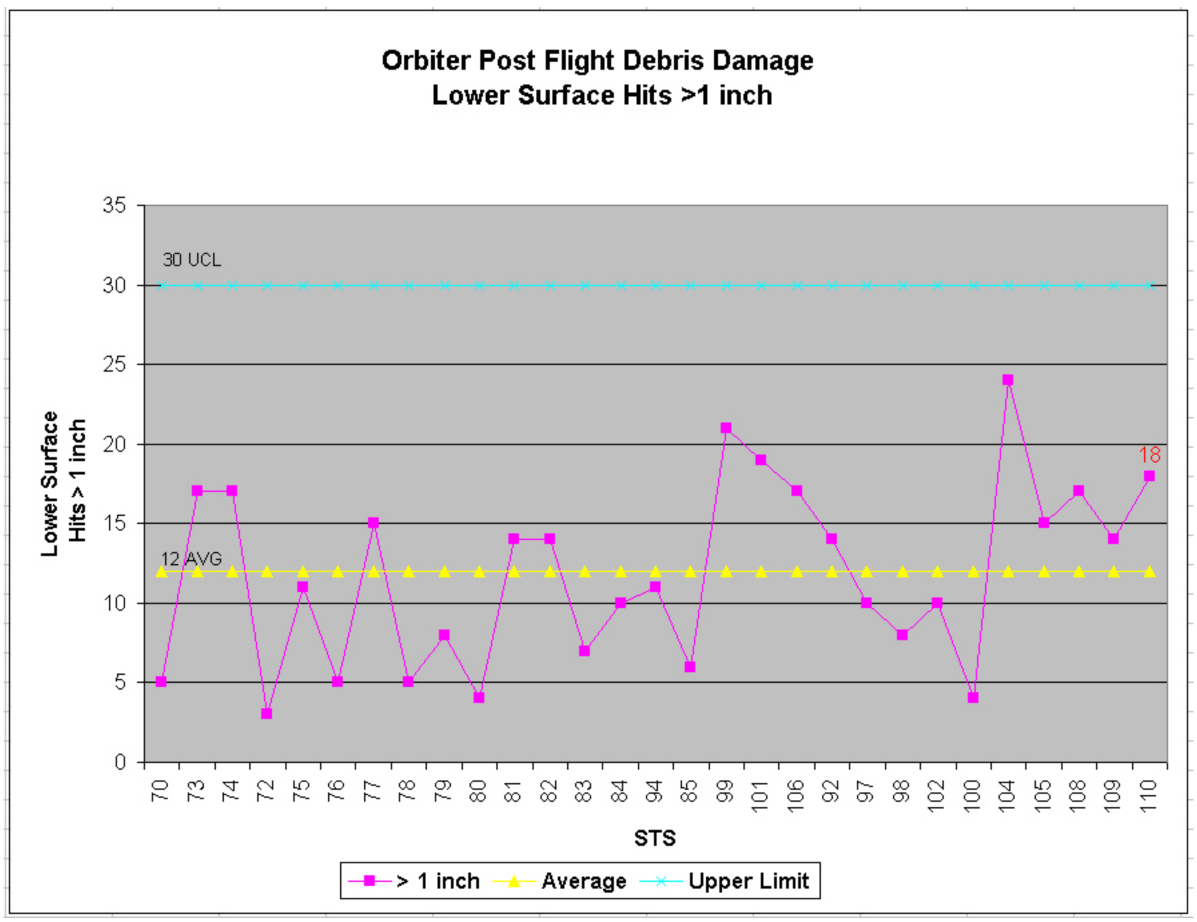
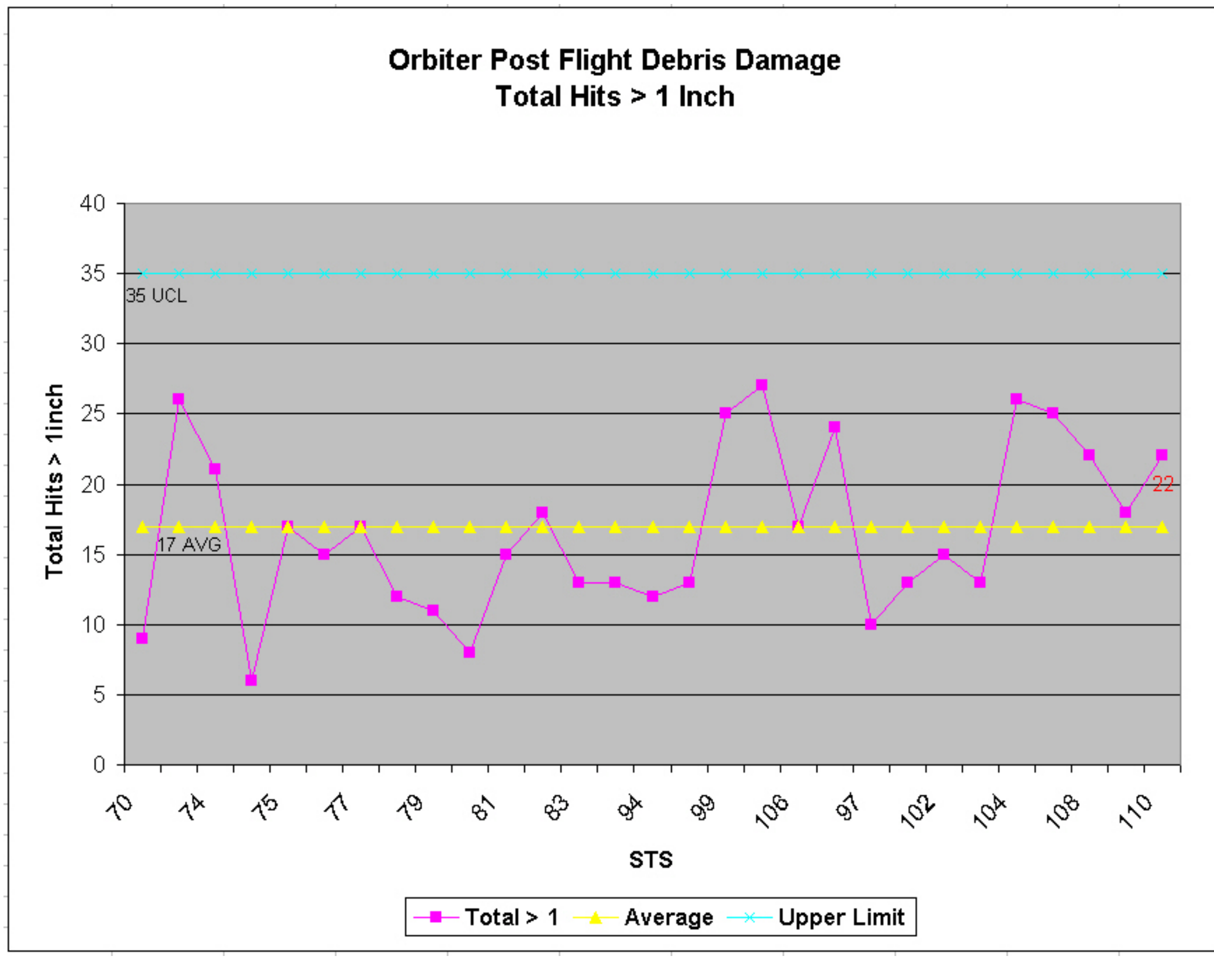


Figure 5: Control Limits for Lower Surface Hits



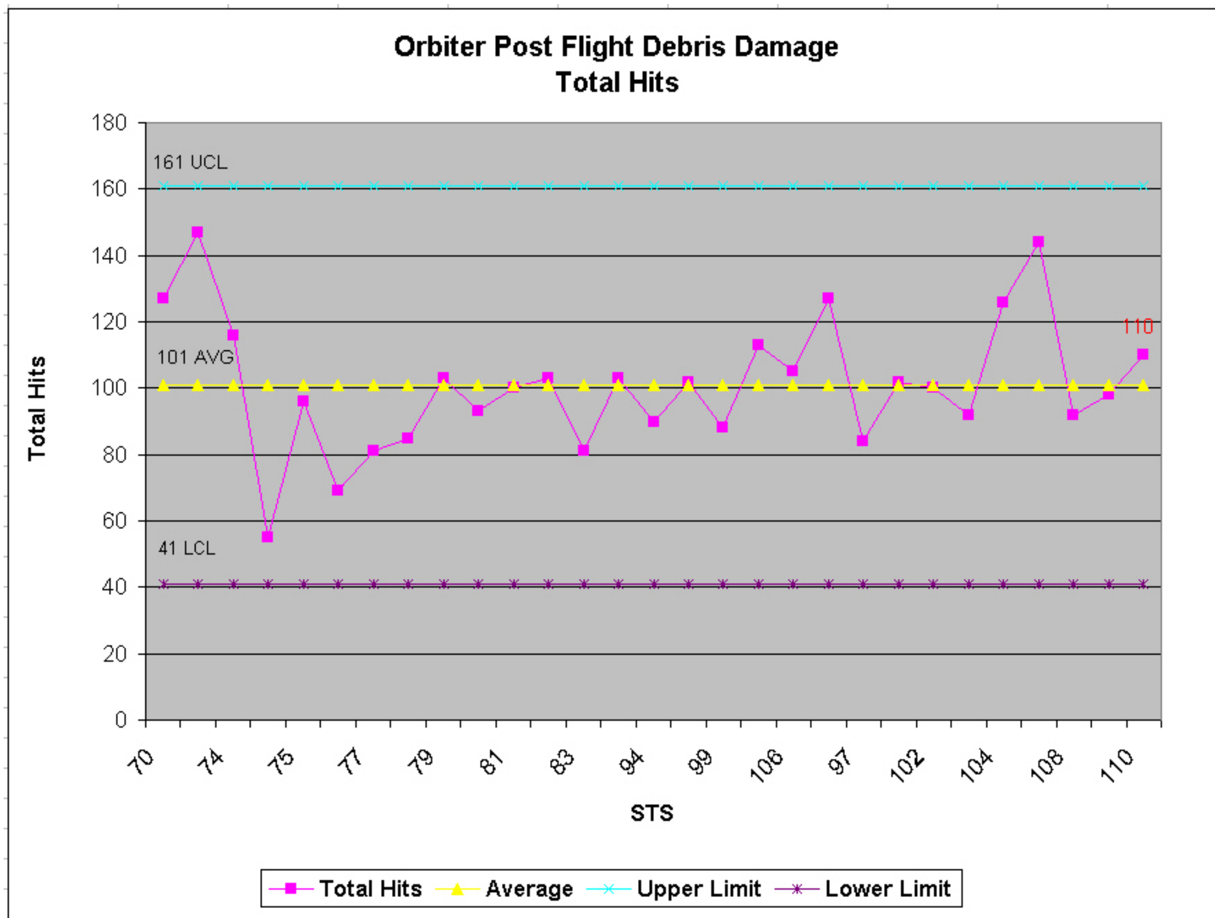


Figure 6: Control Limits for Total Hits

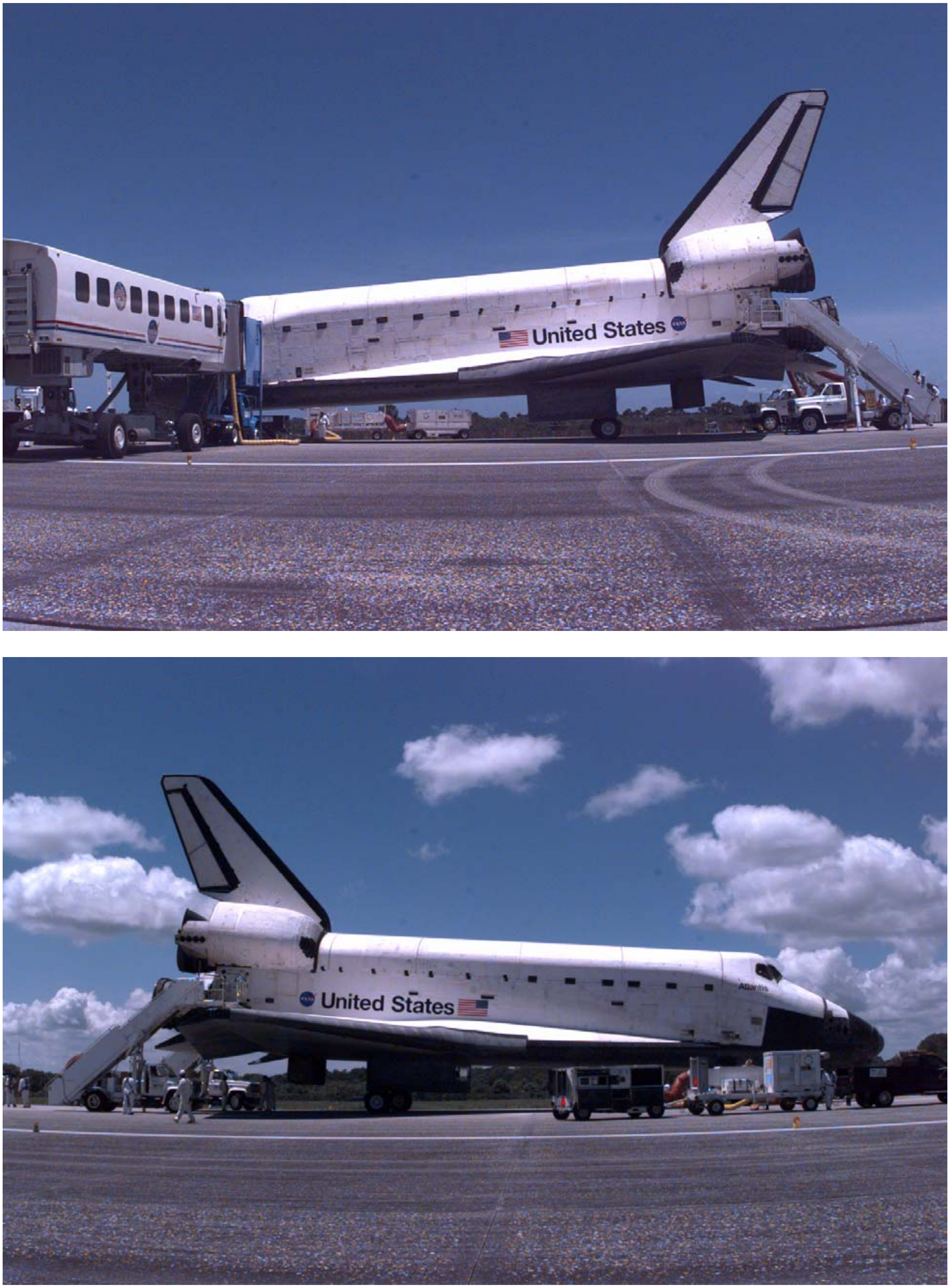


Photo 15: Overall View of Orbiter sides

The Orbiter lower surface sustained 70 total hits, of which 18 had a major dimension of 1-inch or larger, both numbers are well within family.

Photo 16: Overall View of Orbiter Windows

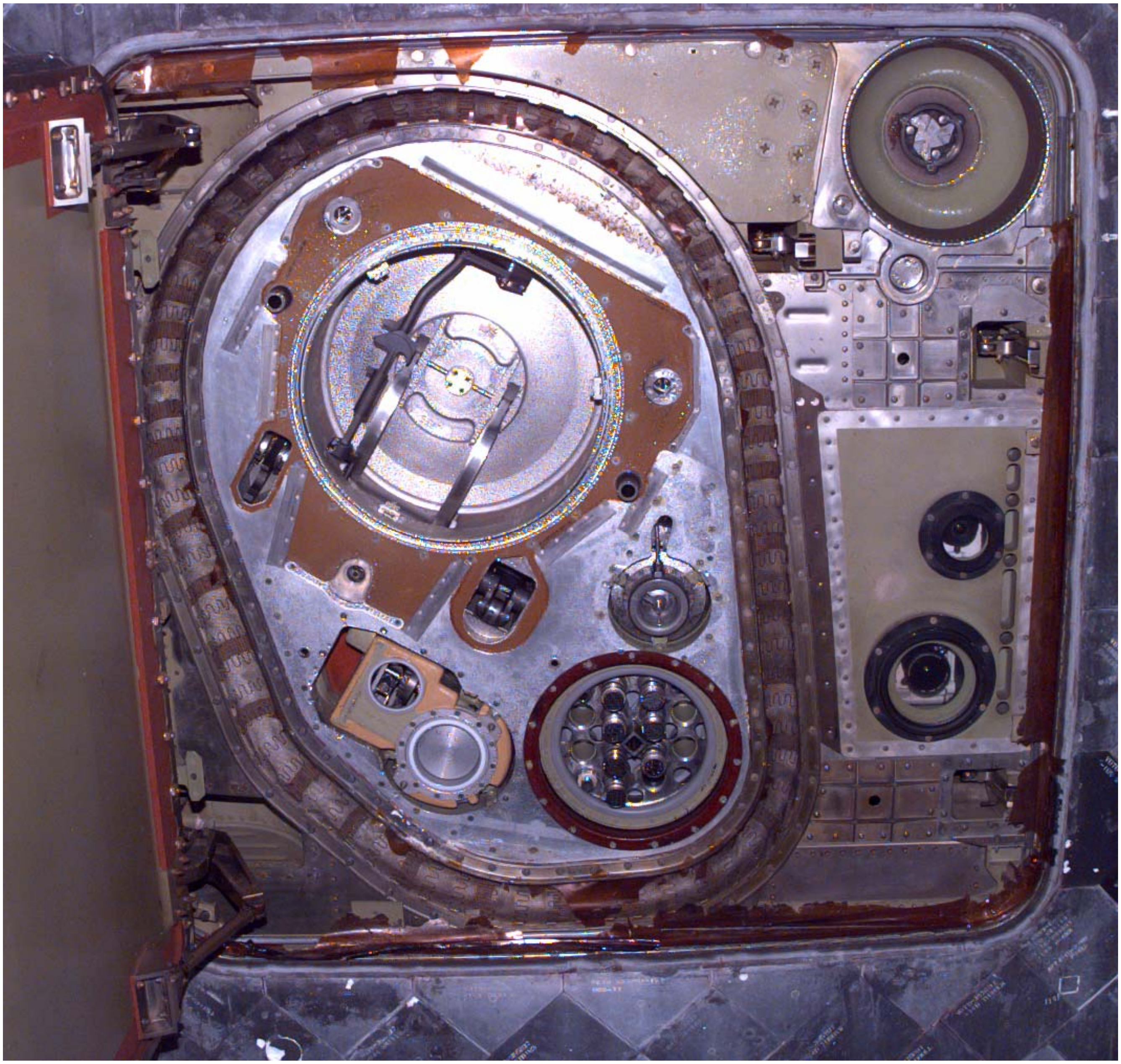


Photo 17: ORB/ET LH2 Umbilical

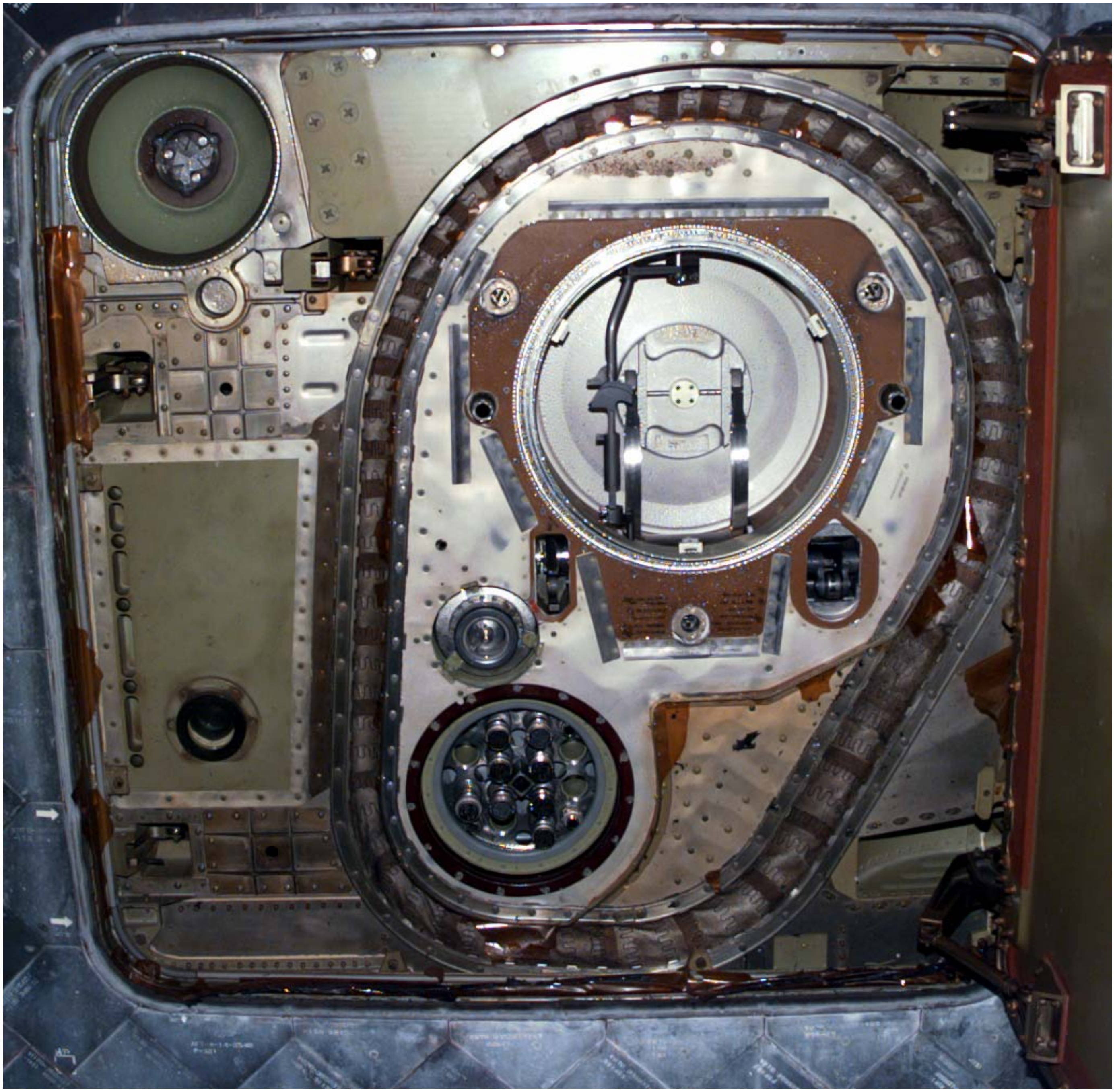


Photo 18: ORB/ET LO2 Umbilical

9.0 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.

Sample residuals provided indication of Orbiter Thermal Protection System (TPS) materials, metallics and metallic corrosion, paint, natural landing site, and organic materials.

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

10.0 POST-LAUNCH ANOMALIES

Based on the debris walkdowns and film/video review, no post-launch anomalies were observed on the STS-110 mission.

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APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Table of Contents

1 STS-110 (OV-104): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-110 launch of Atlantis (OV-104) from Pad B occurred on April 8, 2002 at 098:20:44:18.991 UTC as seen on holddown post camera E8. SRB separation occurred at approximately 20:46:22.325 UTC as seen on the camera E207 film.

On launch day, 24 videos were received and screened. The long range tracking views (second engineering replays) did not have the IRIG timing. The focus is soft on the long range tracking views (probably caused by atmospheric haze).

Twenty-six launch films were screened and a report was sent to the Shuttle Program distribution on April 9, 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 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-110 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 35mm umbilical well TPS camera flew on STS-110 (the new 35mm umbilical well camera was not used on STS-110). See section 2.4. Crew handheld still photography of the External Tank was also acquired on STS-110. Crew handheld video of the External Tank was not acquired on STS-110.

1.1.2 On-Orbit

No unplanned on-orbit Shuttle support tasks were requested. Pre-planned, real-time analysis support was provided to the ISS AF-8A Space Station photographic and television external survey. The Space Station image analysis support will be documented in the AF-8A Imagery Overview Report.

1.1.3 Landing

Atlantis made a day landing on runway 33 at the KSC Shuttle Landing Facility on April 19, 2002 (109:16:26:57.270 UTC).   Eleven 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. The drag chute appeared to deploy straight aft on the landing imagery views.

Post landing, a sink rate analysis of the STS-110 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-110 launch films and videos that were elevated to the Launch + 4 Day or the Landing + 3 Day KSC, JSC, MSFC Film/Video Analysis Team Consolidated Film Review Reports.

2.2 Special Interest Observation

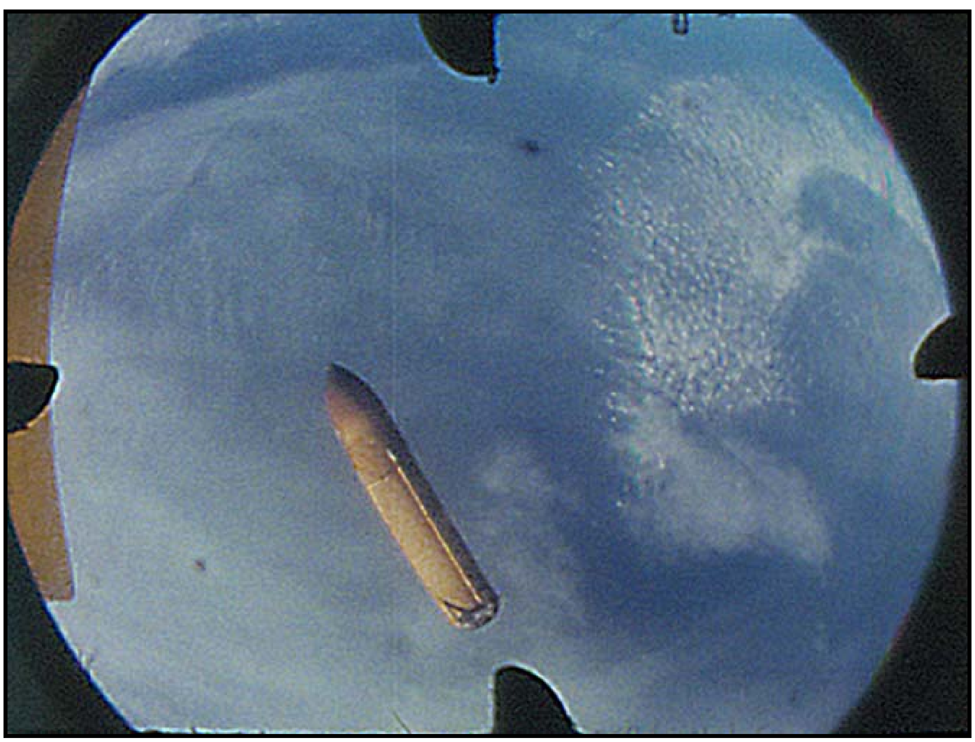

Figure 2.2 (A) Apparent -Y Tilt to the External Tank

After ET separation, the ET began tilting in a –Y direction on the umbilical well camera films. At the end of the 16mm film sequence, the ET appeared tilted to the left (-Y) approximately 30 to 35 degrees. 16mm prints from previous missions since STS-28 were examined and in all cases the ET appears relatively straight or to have a right (+Y) tilt after separation (STS-28 appeared almost straight but slightly left of center). Most often the tilt to the right was crudely estimated to be less than 5 or 10 degrees. On STS-57 and STS-58, the tilt to the right was estimated to be approximately 20 degrees. ET engineers at JSC were contacted about the unusual left (-Y) lean to the ET on STS-110.

Boeing Integrated Ascent GN&C personnel reported that the apparent –Y movement of the ET on the umbilical well films was caused by residual angular velocity of the Orbiter due to the new OI-29 alpha-beta management (SCR 92353D) and is considered nominal behavior for STS-110 (and subsequent launches). Therefore, the apparent motion of the ET seen on the umbilical well films was due to the Orbiter's relative motion and was not an IFA condition.

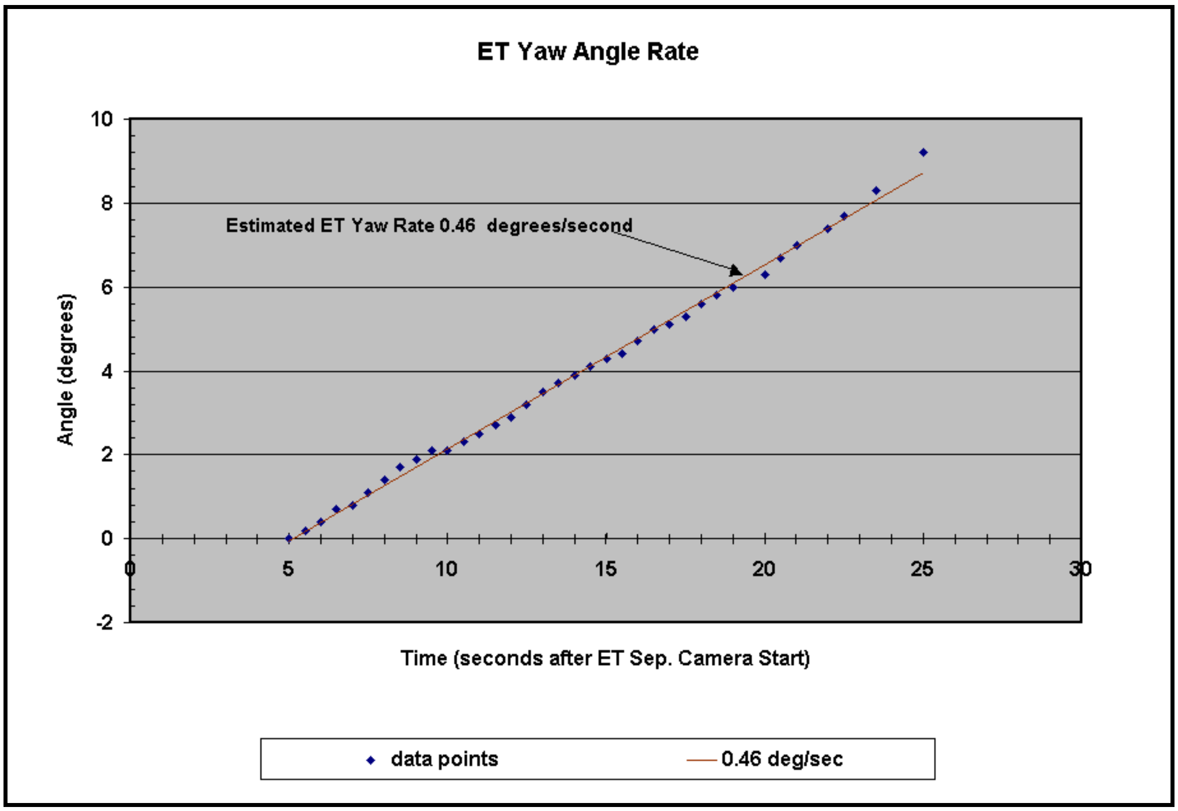

Figure 2.2 (B) External Tank Yaw Angle vs. Time from the 35mm Umbilical Well Camera Film

The apparent yaw angle of the ET vs. time was measured to be 0.46 +/- 0.04 degrees/sec from the 35mm umbilical well camera film. See Figure 2.2 (B). This was comparable to

Boeing's 0.3 to 0.6 deg / sec relative yaw rate quotes due to the OI-29 alpha-beta management.

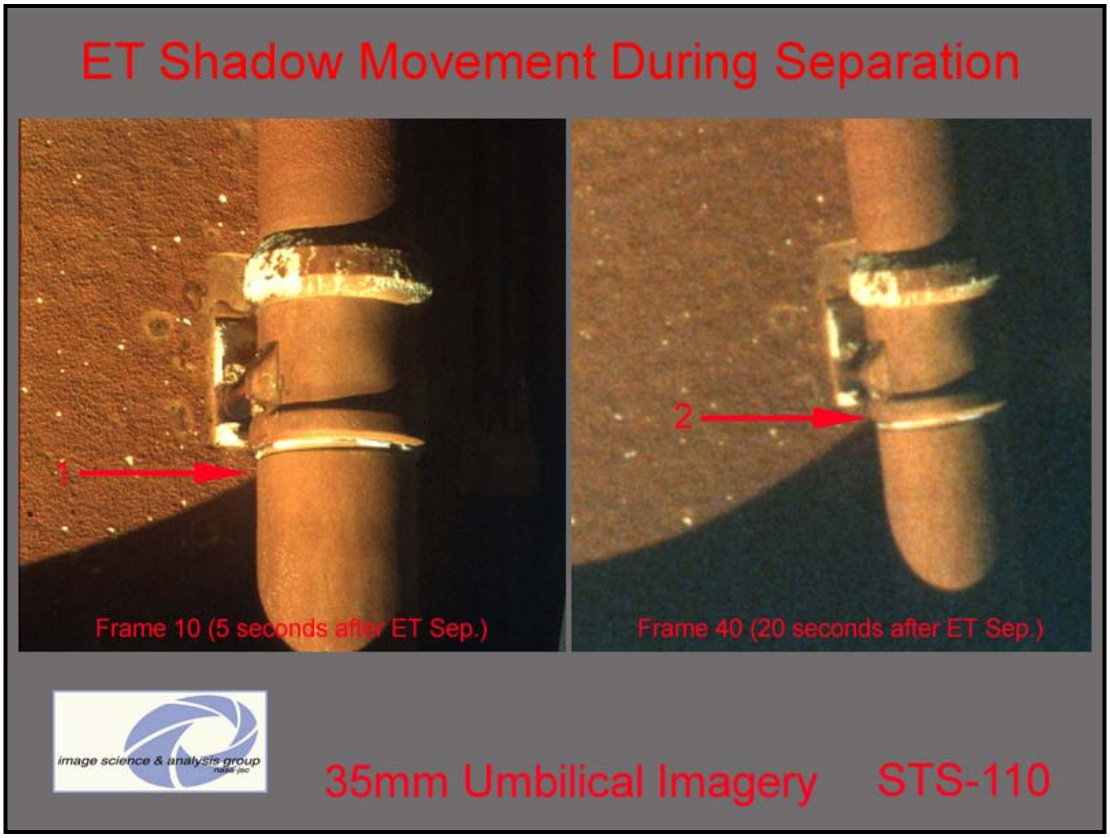

Figure 2.2 (C) Shadow Movement on the ET after ET Separation

The amount of movement of the shadow on the STS-110 ET was found to be comparable to the shadow movement seen on the STS-109 ET after separation. The change in movement of the STS-110 shadow on the ET during a fifteen second period can be seen in Figure 2.2 (C). This is consistent with the orbiter moving rather than the ET since the ET angle with respect to the sun is remaining relatively unchanged.

2.3 Other Launch Observations

2.3.1 Debris from SSME Ignition through Liftoff

Figure 2.3.1 Debris Seen on MLP Deck During Liftoff (Camera E3)

Several pieces of facility debris were seen on the MLP deck near the LH2 TSM and the SSME exhaust hole during SSME ignition. During liftoff, the debris were blown in a westerly direction across the MLP deck. The debris were long and linear-shaped and appeared to be pieces of either cable or tubing. The debris moved away from the launch vehicle and were not seen to contact the vehicle. See Figure 2.3.1. (Camera E3)

The GH2 vent arm retraction from the ET at liftoff appeared normal (20:44:18.967 UTC). 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. Ice debris that fell aft from the GUCP during the GH2 vent arm retraction was seen to contact the LSRB and break into several pieces. Also, two pieces of falling ice debris may have contacted the ET. No damage to the LSRB or the ET protective foam was noted. (Cameras E33, E34, E41, E36, E61, E64) The GH2 vent arm was seen to contact the deceleration cable near the center position but slightly south during the rotation of the arm downward during retraction. Positive capture was achieved on the vent line latch. The times of these events were (Cameras E39, E43):

20:44:20.472 UTC - GH2 vent line contacted the deceleration cable.

20:44:20.921 UTC - Approximate time of latch-back of the GH2 vent arm.

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. Several pieces of umbilical ice debris were seen to detach from the LO2 umbilical and contact the +Y surface of the LO2 electric cable tray during SSME ignition (20:44:15:925, 20:44:15.958 UTC). No damage to the vehicle was observed. Umbilical ice debris contacting the Orbiter surfaces has been seen on previous missions. (Cameras OTV109, OTV154, E1, E4, E5, E17, E18, E20, E31, E34)

Ice debris was seen falling from the LH2 umbilical that contacted the LH2 four inch recirculation line during SSME ignition (20:44:15.892 UTC). Ice debris contacting this recirculation line has been seen on previous mission videos. (Camera OTV109)

Several pieces of umbilical ice debris were seen to detach from the LO2 umbilical and contact the +Y surface of the LO2 electric cable tray during SSME ignition (20:44:15:925, 20:44:15.958 UTC). No damage to the vehicle was noted. (Cameras OTV154, OTV109)

Several small pieces of ice / frost debris were seen falling aft from the ET end of the +Y ET / Orbiter aft attach brace during SSME ignition (20:44:14.657 UTC). Also, vapor was seen near the ET end of –Y ET / Orbiter aft attach brace. (Cameras OTV154, E5, E31)

Two pieces of ice debris first seen aft of the ET/Orbiter bipod fell between the Orbiter and the ET during liftoff. At 20:44:22.398 UTC, one piece of the ice debris contacted the Orbiter fuselage tiles and fell aft. This debris was probably frost / ice from the forward LO2 feedline bellows. No damage to the vehicle was observed. (Camera OTV161)

A large piece of ET/Orbiter umbilical purge barrier material and several smaller pieces of the purge barrier material were seen falling aft from the ET / Orbiter umbilical area and fell aft along the body flap during liftoff. ET/Orbiter purge material debris during liftoff has been seen on previous mission imagery. (Cameras E5, E34)

Multiple pieces of SRB throat plug and/or SRB flame duct debris were seen near the right and left SRBs during liftoff. On camera E1, debris was seen on the north side of the aft LSRB. Also on camera E1, a piece of debris was seen rolling along the MLP in a north direction. On camera E18, several pieces of probable throat plug debris were seen coming from the direction of the aft end of the LSRB. On camera E52, SRB flame duct debris was seen north of the MLP during liftoff. None of this debris was seen to contact the launch vehicle. (Cameras E1, E2, E4, E18, E41, E52, E63, E223)

2.3.2 Debris During Ascent

A light-colored piece of debris was seen aft of the left wing prior to tower clear and fell aft (20:44:23.270 UTC). (Camera E52)

A light-colored, flexible piece of debris was noted in the SRB exhaust plume after liftoff. This debris could have been paper or other debris moving across the view close to the camera (20:44:23.933 UTC). (Cameras OTV161, E31)

Orange-colored debris (probably ET/Orbiter umbilical well purge barrier material) were seen falling aft along the body flap during ascent. On camera E207, a single piece of debris, possibly purge barrier material, was noted falling aft of the vehicle along the body flap, and fell aft into the SSME exhaust plume during ascent (20:44:37.409 UTC). On camera E223, multiple pieces of probable purge barrier material were seen falling aft along the body flap during ascent (20:44:47.993 UTC). On cameras E222 and E223, multiple pieces of debris (probable purge barrier material) were noted falling aft along the body flap during ascent (20:44:43.740 UTC, 20:44:47.996 UTC). ET/Orbiter purge material debris during ascent has been seen on previous mission imagery. (Cameras ET207, E207, E222, E223)

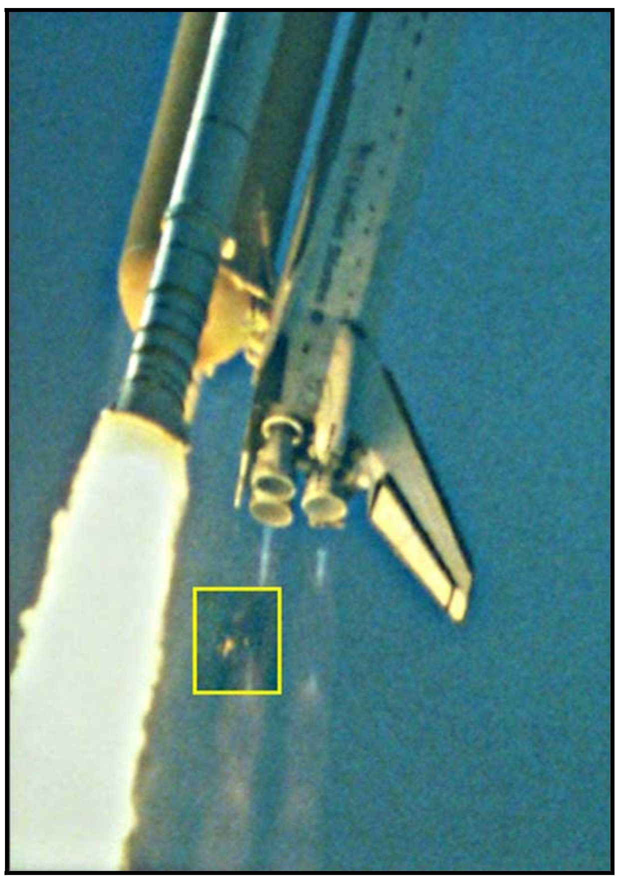

Figure 2.3.2 (A) RCS Paper Debris Spray Seen During Ascent (Camera E222)

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. Umbilical ice and RCS paper debris during ascent has been seen on previous mission films and videos. See Table 2.3.2 (A) for examples of debris seen during the STS-110 ascent. (Cameras E52, E54, E207, E222, E223)

Camera	Time (UTC)	Description
E207	20:33:39.837	RCS paper debris seen falling past vertical stabilizer
E52	20:44:40.000	RCS paper debris seeing falling aft over left wing
E52	-------	Forward RCS paper debris seen falling aft over right wing
E222	20:44:38.000	Several pieces of forward RCS paper were seen falling aft of the vehicle along the vertical stabilizer
E222	20:44:41.236	RCS paper debris seen falling aft in SSME exhaust plume
E52	20:44:41.229	Debris (probably ice) was seen falling aft of the right wing
E223	20:45:03.516	Light-colored debris was seen falling aft in the SSME exhaust plume

Table 2.3.2 (A) RCS Paper Debris during Ascent

Camera	Event Time (UTC)	Description
E207	20:45:02.258	Debris near base of RSRB at holddown post M-4 location
E223	20:45:30.552	Debris falling along SRB exhaust plume
KTV4B, E207, E223	20:45:38.251	Two pieces of debris falling along SRB exhaust plume
ET208	SRB Separation	Debris falling along SRB exhaust plume

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

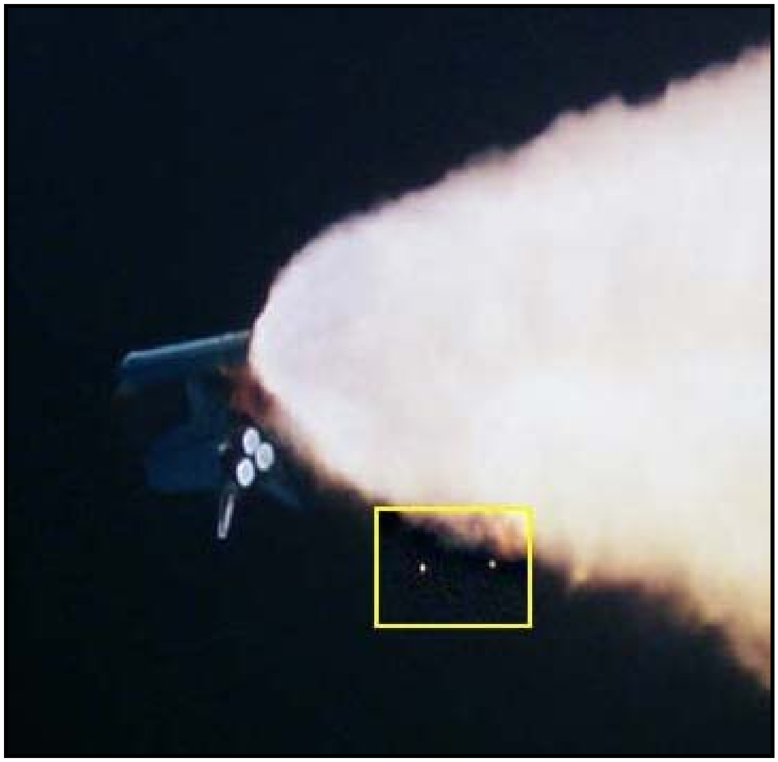

Figure 2.3.2 (B) Debris Seen Exiting the SRB Exhaust Plume During Ascent (Camera E222)

As on previous missions, debris was seen exiting the SRB exhaust plumes during ascent. 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 are provided in Table 2.3.2 (B). (Cameras KTV4B, ET207, ET208)

A single piece of light-colored debris was seen falling from near the +Y/-Z side of the RSRB near stiffener ring #2 during ascent. The debris then fell aft along the SRB exhaust plume (20:45:04.209 UTC). (Cameras E207, E223)

2.3.3 Mobile Launch Platform (MLP) Events

The SSME ignition appeared normal. However, during SSME start-up, the SSME Mach diamonds did not form in the expected sequence (3, 2, 1). The SSME #2 Mach diamond formed prior to the SSME #3 Mach diamond. (Cameras OTV170, E19, E20, E76) The times for the Mach diamond formation given in Table 2.3.3 are from film E19:

SSME	Time (UTC)
SSME #2	20:44:15.808
SSME #3	20:44:15.848
SSME #1	20:44:16.150

Table 2.3.3 SSME Mach Diamond Formation Times

(STS-110 was the first flight using all three of the new Space Shuttle Block II main engines. A comparison of the times between the engine mach diamond formations of the three STS-110 engines was made with the equivalent Mach diamond formation times on the previous eight missions. The STS-110 mach diamond formation times were found to be comparable to the previous mission times.)

Figure 2.3.3 Orange Vapor Seen Forward of SSME Rims Prior to Liftoff (Camera OTV170)

Orange vapor (possibly free burning hydrogen) was seen forward of the SSME rims, 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 (20:44:13.790, 20:44:13.923 UTC). See Figure 2.3.3. Also, orange vapor was seen near the left and right SRB holddown posts (M-2, M-3, M-4, M-5, M-6, and M-7) during SSME ignition. Orange vapor forward of the SSME rims during SSME ignition has been seen on previous mission films and videos. However, the orange vapor appeared to be more extensive on the STS-110 films than was typically seen on previous mission films and videos. (Cameras OTV170, OTV163, E1, E2, E3, E4, E5, E8, E12, E13, E15, E16, E17, E18, E19, E20, E41, E52, E63, E76, E222)

Vapor from the +Y and –Y ET vent louvers was seen prior to liftoff. Vapor from the ET vent louvers has been seen on previous mission videos. (Camera OTV160)

Ringing of the SSME #3 engine bell was very noticeable during SSME ignition (20:44:15.558 UTC). Ringing of the engine bells has been seen on previous mission videos. (Camera OTV170)

Faint, 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 (Cameras E1, E19, E20):

SSME #1 – 20:44:16.685, 20:44:16.718, 20:44:16.914, 20:44:16.924, 20:44:16.949, 20:44:17.141, 20:44:17.166, 20:44:17.342, 20:44:18.780 UTC

SSME #2 – 20:44:17.631 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 (20:44:14.5 UTC), on the base of the left RCS stinger, on the base heat shield on the +Z side of SSME #3 near the Dome Mounted Heat Shield (DMHS), on the base heat shield outboard of SSME #2, and on the base of the left OMS nozzle during SSME ignition. (Cameras E17, E18, E19, E20)

No significant movement of the OMS pod tiles during SSME ignition was detected on the STS-110 camera films. (Cameras E17, E18)

SRB ignition was at 20:44:18.991 UTC based on the observation of the PIC firing at RSRB holddown post M-2. (Camera E8)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 20:44:21.203 UTC (right purge line) and 20:44:21.150 UTC (left purge line). (Cameras E8, E13)

Significant rocking of the RSRB hold down post M-2 was visible during liftoff. A leak in a MLP water supply pipe was seen near the RSRB hold down post M-4. (Cameras E7, E8, E12, E13, E15, E16)

2.3.4 Ascent Events

Figure 2.3.4 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. Many of these flares appeared to originate on the +Z side of the SSME exhaust plume near the trailing edge of the body flap. This could indicate that the flares were possibly induced by purge barrier material or pieces of tile material. 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-110 can be seen in Table 2.3.4. Flares in the SSME exhaust plumes have been seen on previous missions films and videos.

Camera	Time (UTC)	Event
KTV4B	20:44:37.390	Flare in SSME Exhaust Plume
E222	20:44:37.409	Debris induced flare in SSME exhaust plume from possible baggie material.
E223	20:44:53.513	Flare noted in SSME #2/#3 exhaust plume. Debris noted prior to flare
E223	20:44:58.351, 20:44:58.392	Flares noted in SSME #1 exhaust plume.
E223	20:44:59.331	Flare noted in SSME #2/#3 exhaust plume well aft of the SSMEs
E223	20:44:59.331-20:45:00.872	Multiple, light-colored, very faint flares noted in the SSME #2/#3 plumes well aft of the SSMEs
E223	20:45:01.750	Flare noted in SSME #2/#3 exhaust plume well aft of the SSMEs that lasted for two frames
E223	20:45:04.670	Bright flare noted in SSME #2/#3 exhaust plume near SSME rims
E223	20:45:06.252	Flare noted in SSME #2/#3 exhaust plume that appears to be debris induced that lasted for three frames
E207	20:45:07.119	Flare in SSME exhaust plume
E222, KTV4B	20:45:08.890	Flare in SSME exhaust Plume
E207, E223	20:45:08.975	Flare seen in SSME exhaust plume
KTV4B, E223	20:45:10.051	Debris induced flare noted in SSME exhaust plume that lasted for three frames
E207, E223	20:45:11.200	Large flare in SSME exhaust plume aft of the body flap
KTV4B, E207, E223	20:45:13.216-20:45:13.280	Multiple flares noted in SSME exhaust plume

Table 2.3.4 Flares Seen in SSME Exhaust Plumes During Ascent

At 20:44:41.527 UTC, what appeared to be a condensation streak was noted off the trailing edge of the body flap during ascent. Condensation was also observed on the forward end of the Orbiter during ascent (20:44:59.479 UTC). Condensation plumes and condensation streaks off the launch vehicle have been seen on previous mission videos. (Camera KTV4B, E222, E223)

Body flap motion typical of that seen on previous missions was seen during ascent (20:44:56.5-20:45:27.5 UTC). (Camera ET207, E207)

An orange-colored flash from the early OMS-2 assist burn was seen approximately ten seconds after SRB separation (20:46:32.627 UTC). (Cameras KTV13, ET207, ET208, E207, E212)

2.4 Onboard Photography of the External Tank (ET-114)

2.4.1 35mm Umbilical Well Camera Film (Roll 384)

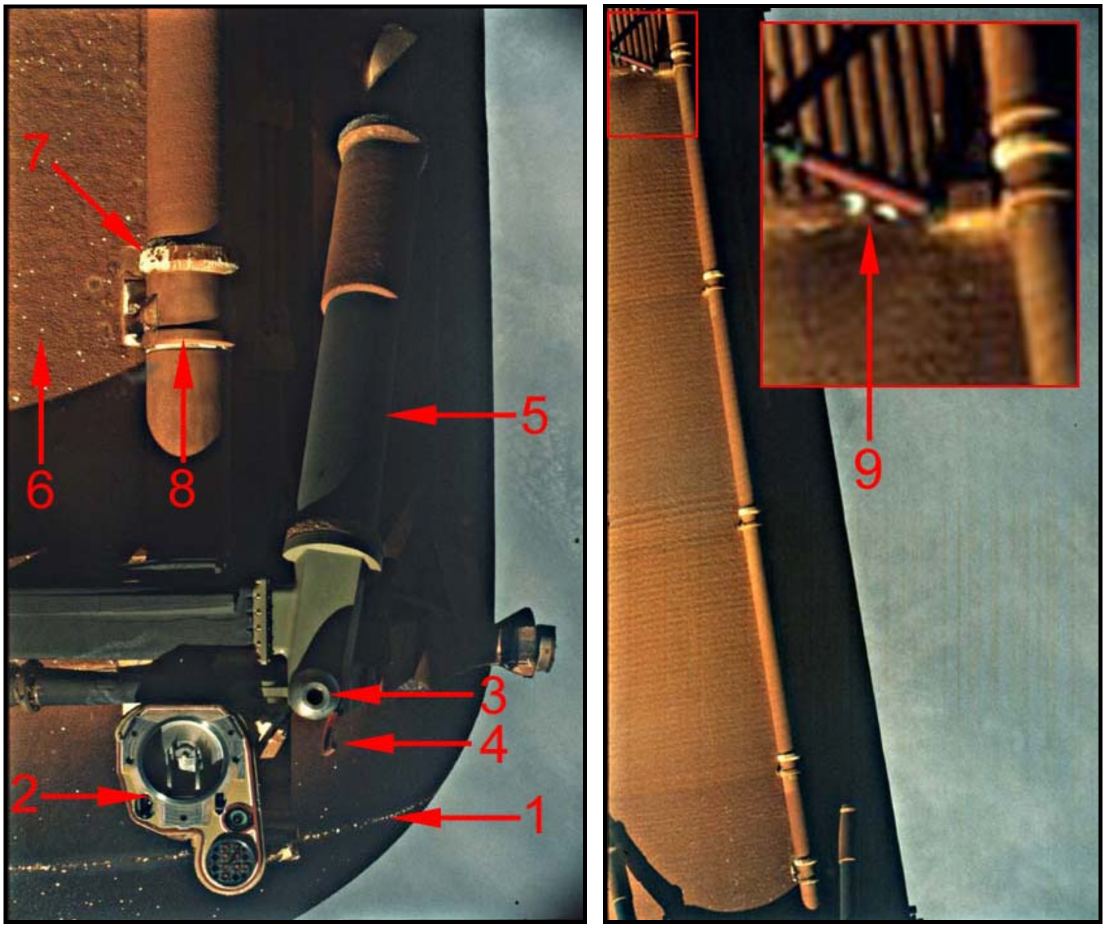

Figure 2.4.1 35mm Images of the External Tank during Separation

A long band of small, white-colored divots is visible on the ET aft dome TPS at the same level as the base of the LO2 umbilical. See Figure 2.4.1, annotation 1. Randomly located "pop-corn" divots have been typically seen on the ET aft dome on previous mission films. However, a long band of divots is not typically seen. Engineers at Michoud reported that this band of divots occurred at the interface of a spray gun stop and restart that took place during the application of the foam to the ET aft dome.

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.

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 slightly retracted. See Figure 2.4.1, annotation 3.

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

The red-colored purge seal on the EO-3 ball joint fitting was detached at one end. See Figure 2.4.1, annotation 4.

The TPS on the +Y thrust strut appeared to be in good condition. See Figure 2.4.1, annotation 5.

A white-colored area (probably frozen hydrogen) was seen on the aft dome TPS aft of the cross beam at the –Y end of the diagonal strut. White-colored marks at this location have been seen on previous mission films.

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.

Minor TPS abrasion on the LO2 feedline flange and brackets was visible. See Figure 2.4.1, annotation 7. As typically seen, a white-colored line (probably frost) was seen on the aft edge of the aft LO2 feedline bellows. See Figure 2.4.1, annotation 8.

Two light-colored marks (probable divots) were seen under the forward bipod on the LH2 tank-to-intertank close-out. These marks were estimated to be approximately six inches in diameter. No exposed substrate material was noted. See Figure 2.4.1, annotation 9.

Notes: On STS-110, the (old) Nikon F4 35mm umbilical camera with the 55mm lens and Kodak color positive film was flown. Coverage included the aft end of the ET and forward along the +Z side of the ET to the level on the forward bipod. The ET intertank, LO2 tank, and the ET nose cone were not imaged. (This is because the +X translation maneuver used to facilitate the imaging of the ET with the umbilical well cameras was NOT performed due to propellant concerns.) Shadows from the late afternoon Sun limited the 35mm umbilical camera views in the +Y direction of the ET LO2 feedline. The LO2 pressurization and electrical cable lines were obscured by shadow. The +Y ET Thrust Panel was not imaged.

Fifty frames were acquired with the 35mm umbilical camera which is fewer frames than is usually acquired. Usually there are 55 or more frames. Frames 39, 43, 46, 48, and 49 were blank. The ET appeared a little further away on the last frame than is normally seen. The ET was angled more to the left (-Y) on the last frame than is typically seen. The focus is good. The exposure on the Sun lit portions of the ET is good.

The processing and digital scanning of the 35mm umbilical well camera original flight film was completed. The images were excellent quality except for the areas obscured by shadow.

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

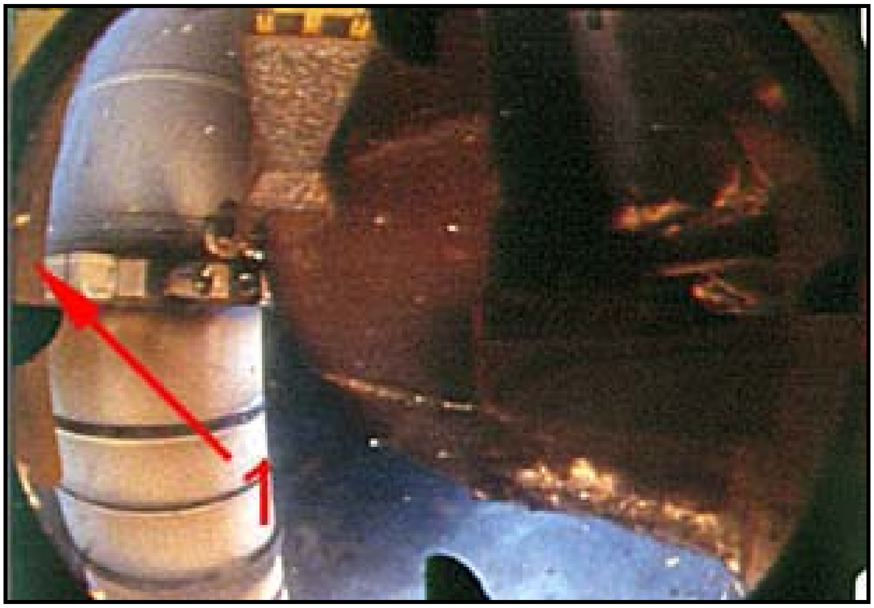

Figure 2.4.2 (A) 16mm Umbilical Well Camera SRB Separation Imagery

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.

A narrow, straight band of small divots / TPS erosion was seen extending in the +Y / -Y direction across the entire visible portion of the ET aft dome. Otherwise, the amount of ablation of the TPS on the aft dome was typical of that seen on previous flights.

A long, rectangular-shaped piece of orange-colored umbilical purge barrier material was visible on the left side of the camera view. A flexing motion of the purge barrier material was visible during both the SRB and ET separation views. See Figure 2.4.2(A), annotation 1.

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

Figure 2.4.2 (B) 16mm Umbilical Well Camera ET Separation Imagery

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).

After separation, the ET gradually began tilting in a –Y direction. At the end of the film sequence, the ET appeared tilted to the left (-Y) approximately 30 to 35 degrees. See Figure 2.2(A). Typically, the ET appears relative straight or to have a slight right (+Y) tilt after separation.

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. See Figure 2.4.2(B), annotation 1. As typically seen on previous missions, frozen hydrogen was visible on the orifice of the LH2 17 inch connect. 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 2.4.2(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 detached on one end.

Small divots / TPS erosion were seen on the forward flange of the –Y thrust strut. 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.

Notes: The 16mm umbilical camera film with the 10 mm lens (FL101) was out of focus. The soft focus was present across the entire view and for the entire film roll. The exposure was good on both of the 16mm umbilical films. Timing data was present on both of the umbilical well camera films.

2.4.3 35mm Crew Handheld Film (Roll 337)

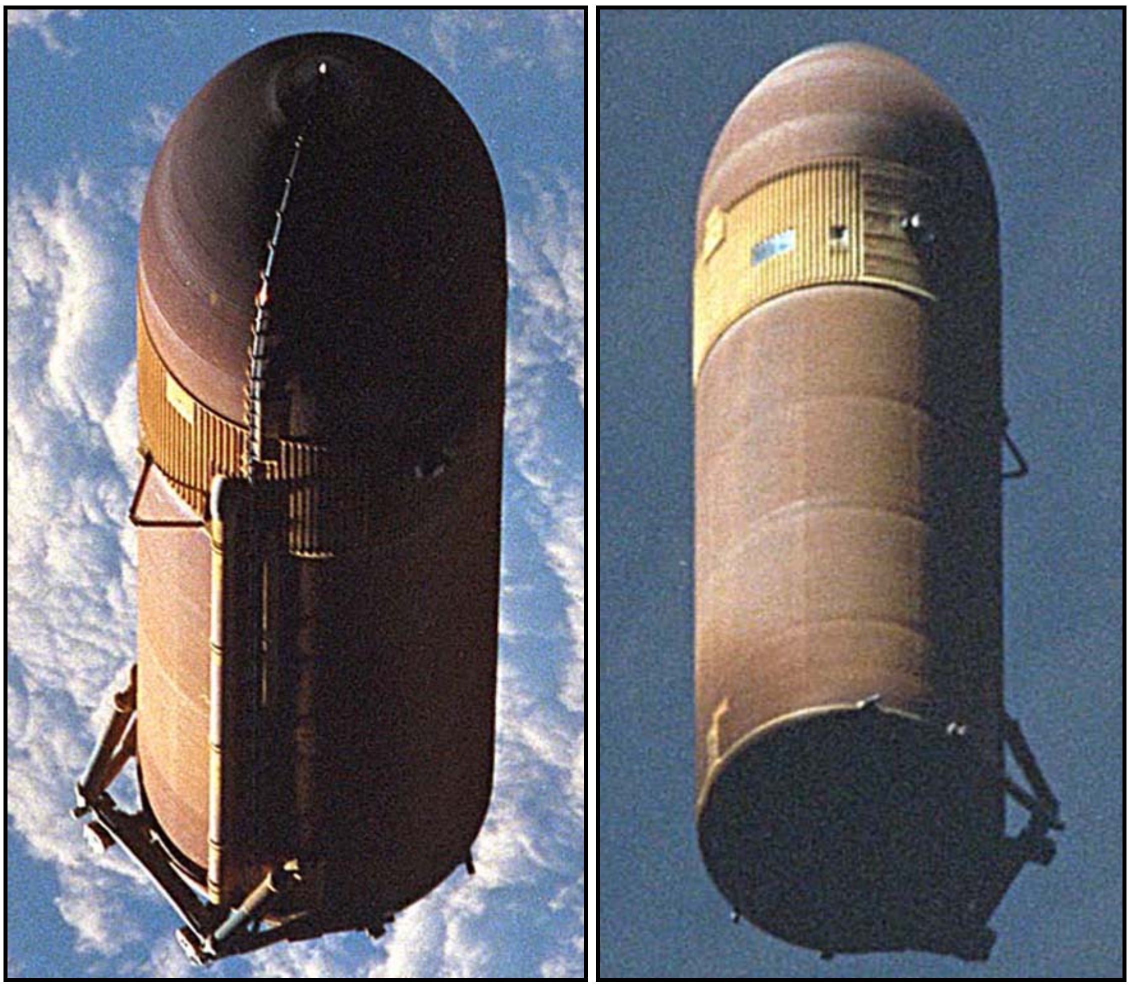

Figure 2.4.3 Handheld Images of the External Tank (Frames 1 and 11)

No anomalous or unusual observations were noted on the handheld film views. The analysis of the views was hindered because of the extensive shadows caused by the position of the ET relative to the late afternoon Sun. Eventually all sides of the ET, the ET aft dome, and ET nose were acquired as the ET rolled and pitched around it's center of mass before the ET disappeared across the sunset terminator. The overall ET TPS including the +Y and –Y ET thrust panels appeared to be in good condition on the handheld film views. No venting from the ET intertank gaseous hydrogen vent or the aft ET umbilicals was seen. See Figure 2.4.3.

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 12.4 minutes MET using the handheld Nikon F5 camera with a 400 mm lens. The distance of the ET was calculated to be approximately 1.1 km's on the first photographic frame acquired. A total of twenty-seven pictures of the ET were obtained. Timing data is present on the film.

2.4.4 Crew Handheld Video

The astronauts did not acquire handheld video of the ET on STS-110.

2.5 Landing Timing Events

The time codes from videos were used to identify specific events during the screening process. The STS-110 landing event times are provided in Table 2.5.

Event	Time (UTC)	Camera
Left Main Gear Door Opening	16:26:35.569	EL18 IR
Right Main Gear Door Opening	16:26:35.770	EL18 IR
Right Main Gear Tire Touchdown	16:26:57.270	EL17 IR
Left Main Gear Tire Touchdown	16:26:57.370	EL17 IR
Drag Chute Initiation	16:27:00.076	EL18 IR
Pilot Chute at Full Inflation	16:27:00.881	KTV33L
Bag Release	16:27:01.515	KTV33L
Drag Chute Inflation in Reefed Configuration	16:27:02.616	KTV33L
Drag Chute Initiation in Disreefed Configuration	16:27:06.187	KTV15L
Nose Gear Touchdown	16:27:08.301	EL18 IR
Drag Chute Release	16:27:42.122	KTV33L
Wheel Stop	~16:28:06.714	KTV15L

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 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 touchdown 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 touchdown 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 trend line 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-110 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.	2.7 ft/sec	+/- 0.2 ft/sec
0.50 Sec.	2.4 ft/sec	+/- 0.2 ft/sec
0.25 Sec.	3.3 ft/sec	+/- 0.4 ft/sec

Table 2.6 Main Gear Midpoint Landing Sink Rate

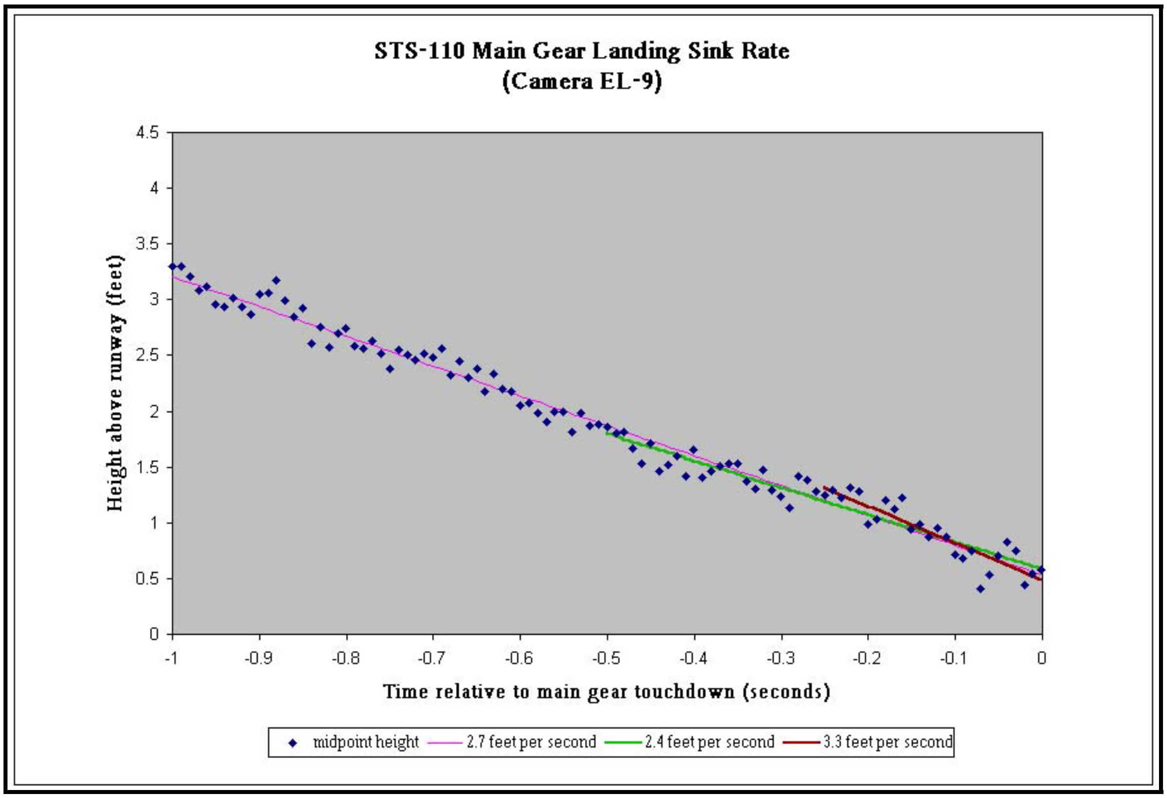

Figure 2.6 Main Gear Midpoint Landing Sink Rate

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-110 vehicle was reported to be 210,895 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
- 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

2.7.2 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-110

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)

May 14, 2002
Marshall Space Flight Center,
Huntsville, AL 35812

Contents

Figures

Tables

Engineering Photographic Analysis Report for STS-110

Launch of the one hundred-ninth Space Shuttle mission STS-110, the twenty-fifth flight of the Orbiter Atlantis (OV-104), occurred April 8, 2002 at 3:44 PM CDT from launch complex 39-B, Kennedy Space Center (KSC), Florida. Launch time was reported as 2002:098:20:44:18.983 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

Intercenter Film/Video Launch+4 Day and the Landing +3 Day Report:

The Intercenter Consolidated Film/Video "STS-110 Launch+4 Day" Report, April 15, 2002 reported no anomalous events during the screening of launch film and video.

The Intercenter Consolidated Film/Video "STS-110 Landing +3 Day" Report, reported no anomalous events during the screening of onboard and landing films and videos.

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/sts110/sts110.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-110 is illustrated in Table 1. Onboard films witnessing the –Y Yaw separation were not received at MSFC prior to the release of the Intercenter Consolidated Film/Video "STS-110 Landing +3 Day" Report. The MSFC review and analysis input, bringing this atypical event to attention, was not available for the report.

Video camera OTV148 does not track the vehicle. Sun degrades the image quality of video camera OTV141 early in ascent. Film cameras E57 and E59 move horizontally instead of vertically and lose track of the vehicle at liftoff. Film camera FL102 had soft focus.

	16mm	35mm	Video
MLP	19	0	4
FSS	3	0	3
Perimeter	0	7	5
Tracking	0	9	12
Onboard	2	1	0
Other	0	0	0
Totals	26	20	24

Table 1. STS-110 Camera Coverage

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	98:20:44:18.992
M-2	E8	98:20:44:18.991
M-5	E12	98:20:44:18.991
M-6	E13	98:20:44:18.992

Table 2. STS-110 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 98:20:46:22.308 UTC.

Anomalous Events:

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

Observations:

Video Camera OTV163: Free Burning Hydrogen

Free burning Hydrogen was observed on the -Z side of the body flap at SSME startup.

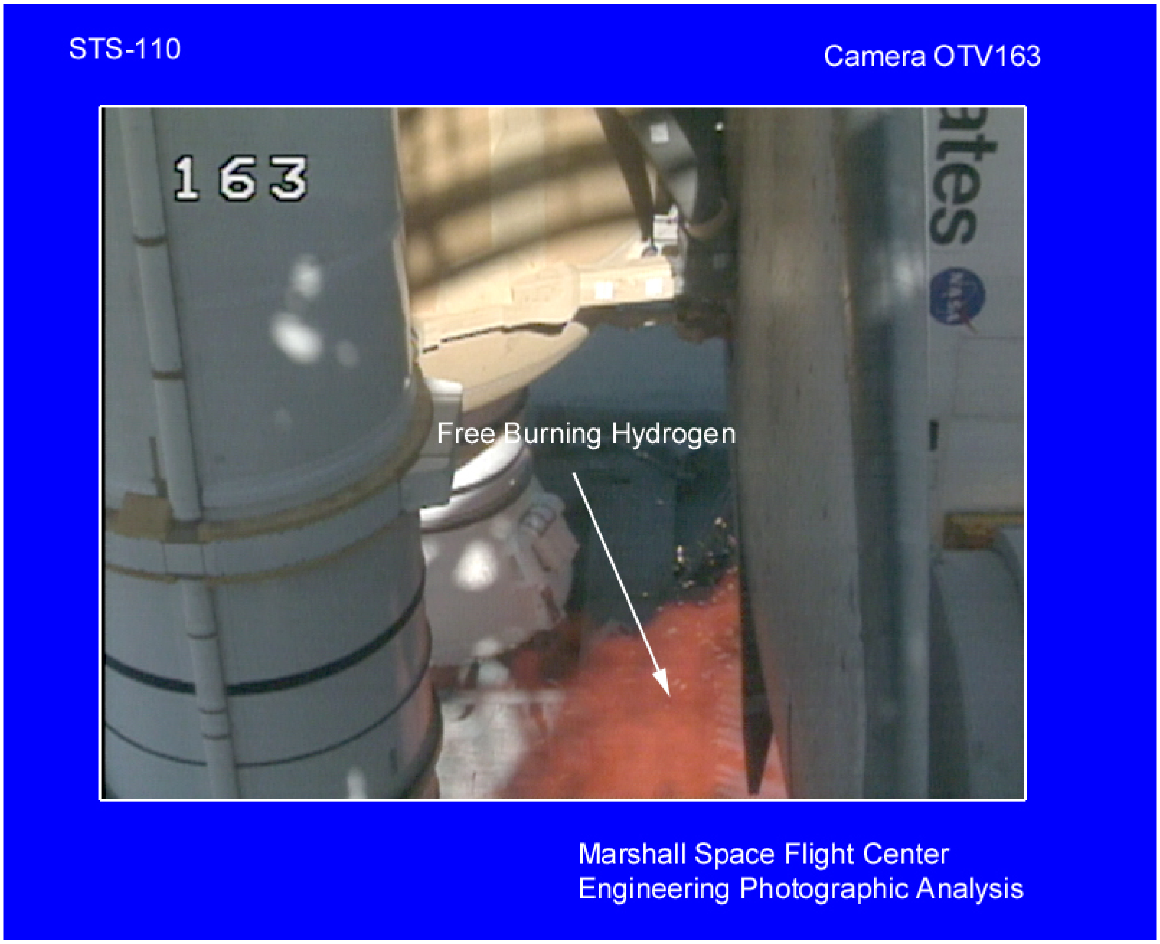

Figure 1. OTV163: Free Burning Hydrogen

Film Camera E20: Engine Streak in SSME Plumes

An engine-produced streak was noted in the SSME #1 plume prior to lift-off. This streak was imaged at 20:44:17.013 UTC. These faint streaks are common and are typically observed in SSME plumes just after SSME mainstage has been attained and prior to liftoff.

Figure 2. E20: Engine Streak in SSME Plumes

Film Camera E2: Engine Streak in SSME Plumes

An engine-produced streak observed in the SSME plumes prior to liftoff. This streak was imaged at 20:44:17.085 UTC.

Figure 3. E2: Engine Streak in SSME Plumes

Film Camera E3: Engine Streak in SSME Plumes

An engine-produced streak in the SSME plumes was observed prior to liftoff. This streak was imaged at 20:44:16.672 UTC.

Figure 4. E3: Engine Streak in SSME Plumes

Video Camera OTV109: Rectangular Debris Object

A yellowish rectangular shaped debris item was observed.

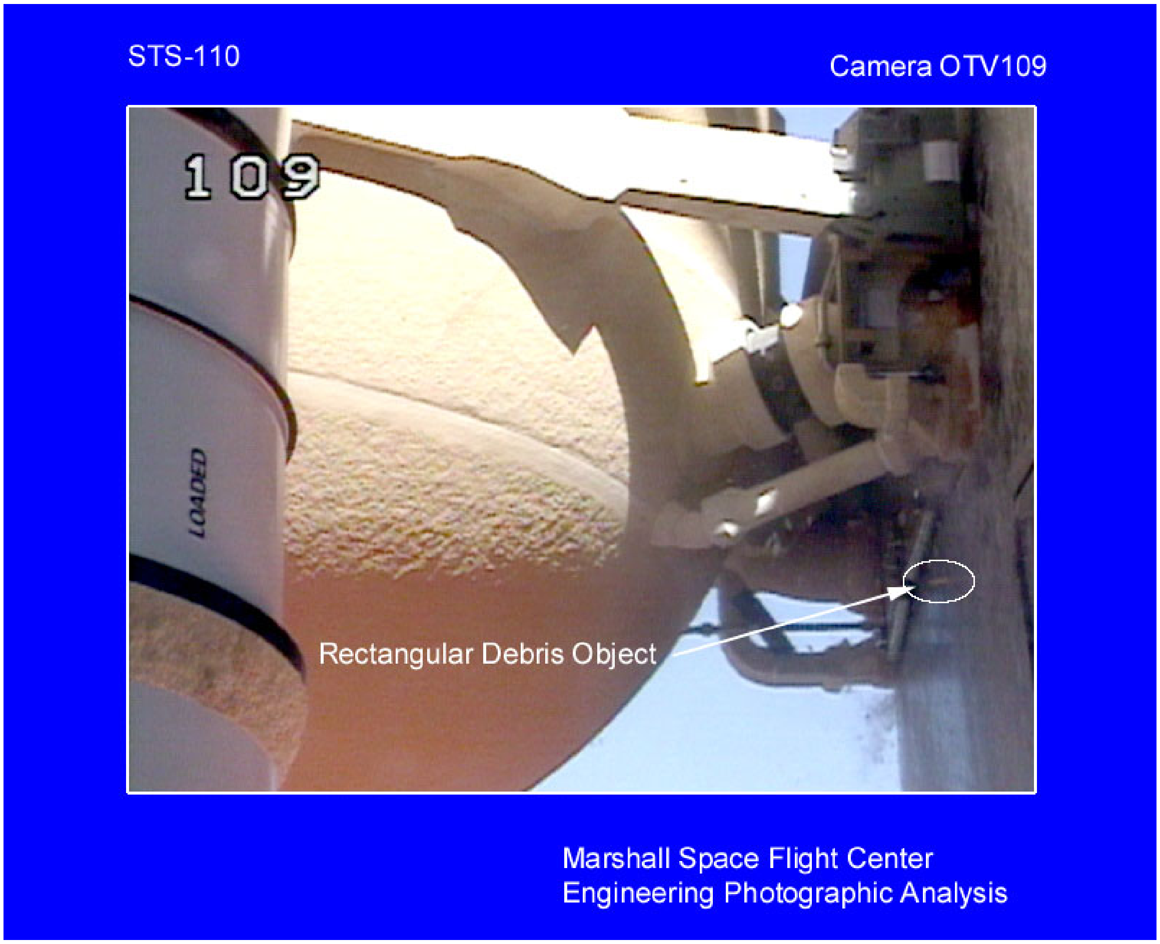

Figure 5. OTV109: Rectangular Debris Object

Video Camera OTV154: Ice Debris from External Tank

Ice/frost debris was noted falling from the +Y side of the External Tank at the vertical strut ET attach point.

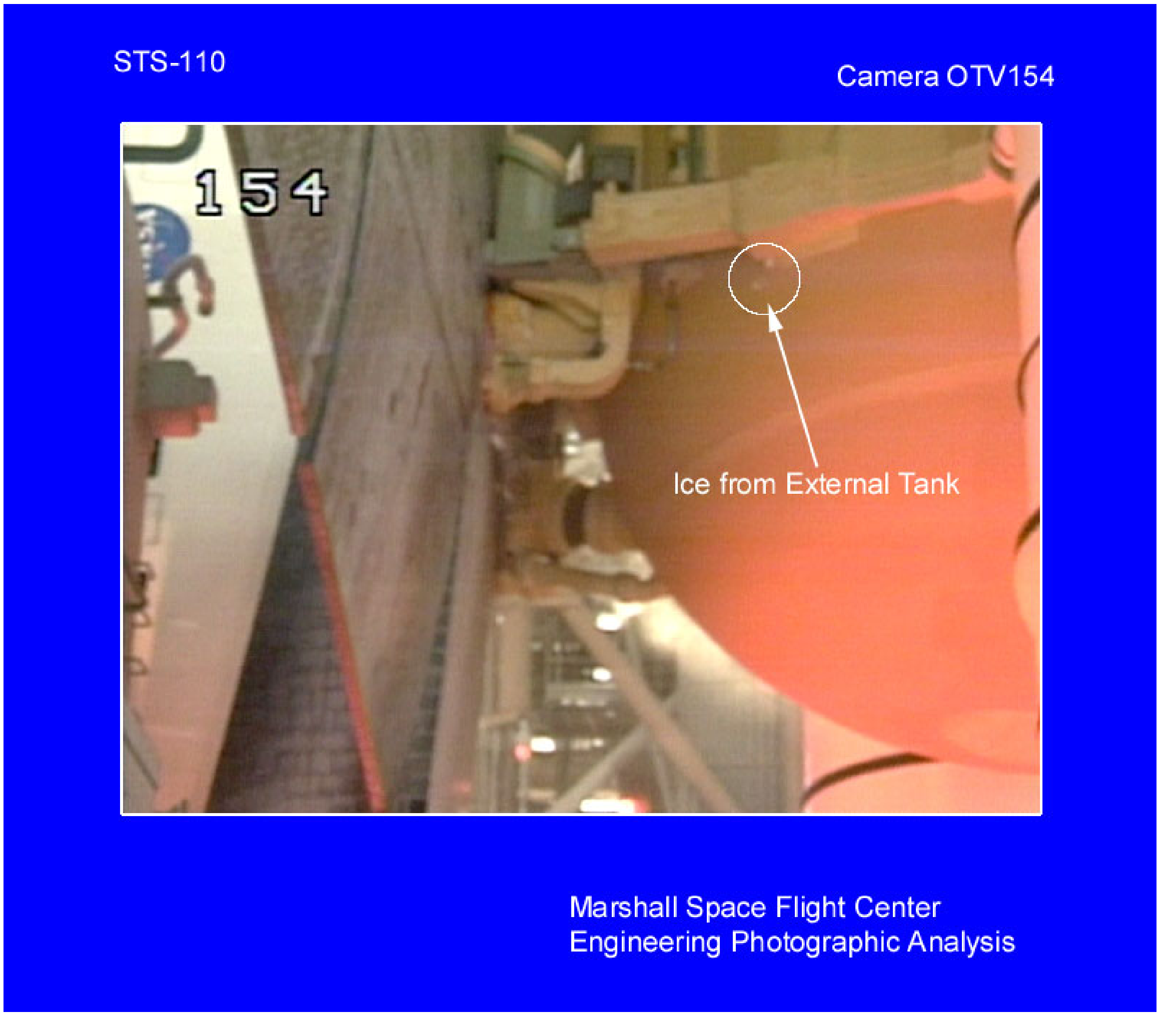

Figure 6. OTV154: Ice Debris from External Tank

Film Camera E14: Pad Debris

A large rectangular shaped debris item was ejected from the SRB blast hole.

Figure 7. E14: Rectangular Debris Ejected from SRB Blast Hole

Film Camera E3: Pad Debris

A rope-like piece of debris material was observed moving across the MLP deck. This debris moved in a direction away from the launch vehicle.

Figure 8. E3: Rope-like Debris on MLP Deck

Video Camera ET207: Flow Recirculation

Flow recirculation was observed during ascent.

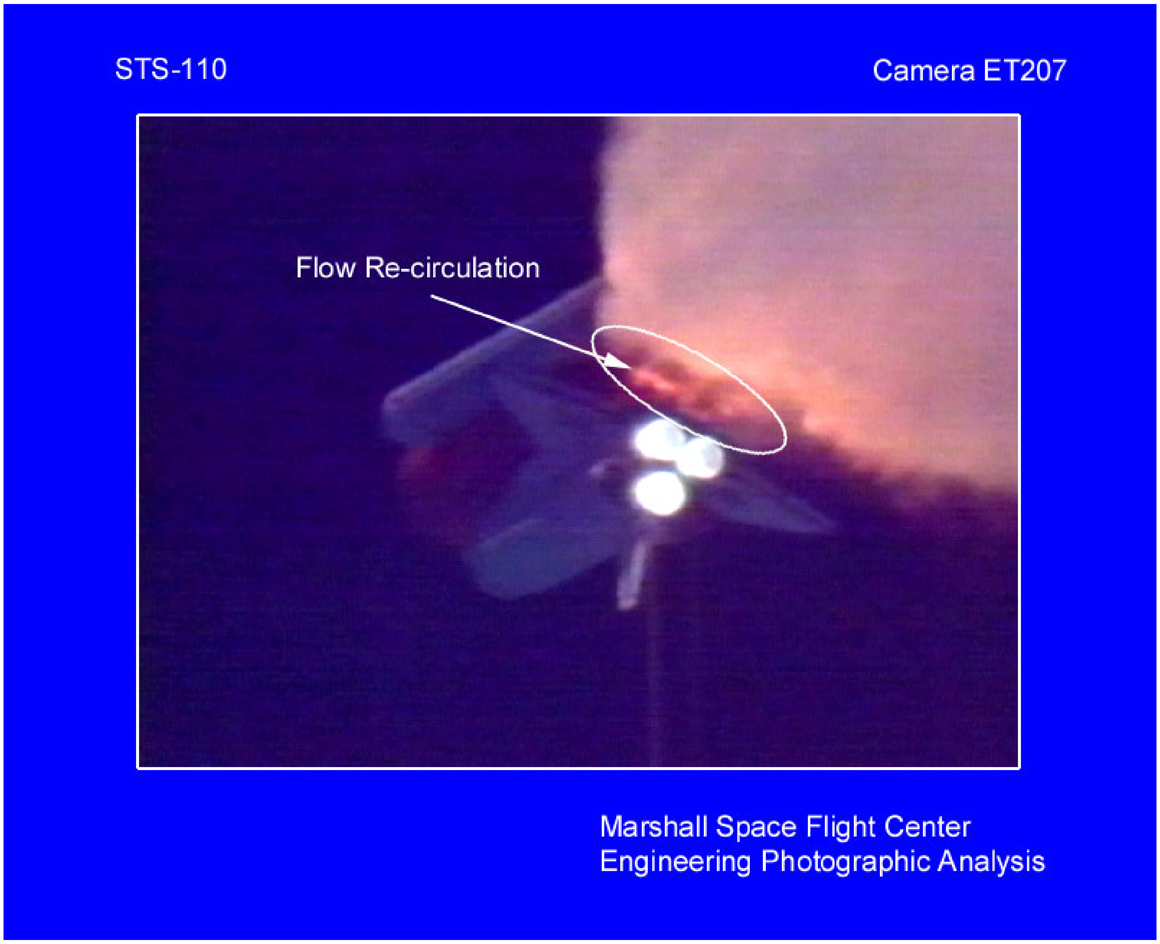

Figure 9. Video Camera ET207: Flow Recirculation

Video Camera ET207: Debris Induced Streaks in SSME Plumes

Debris-induced streaks were observed in the SSME plumes during ascent.

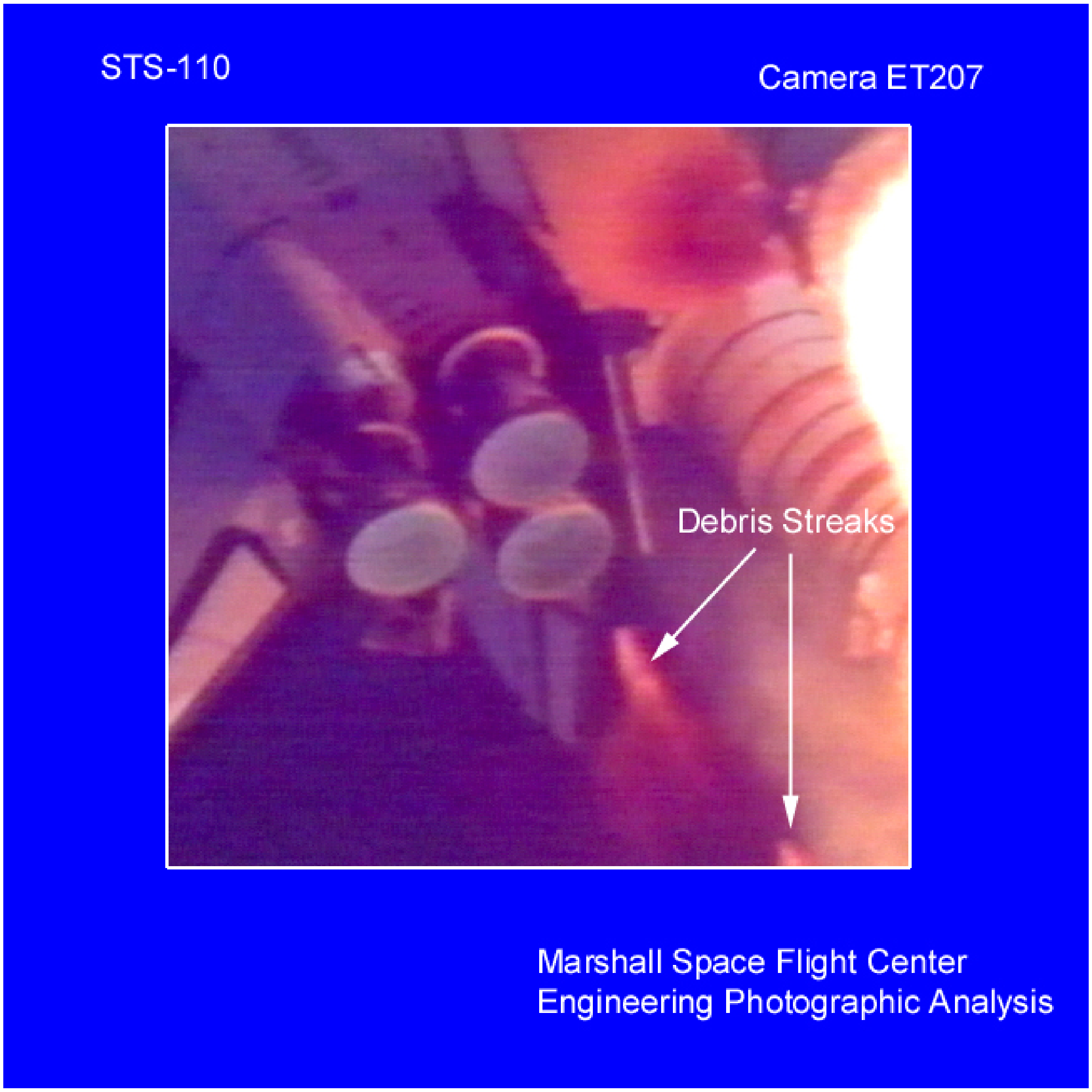

Figure 10. ET207: Debris Induced Streaks in SSME Plumes

Video Camera TV4B: Debris Under Body Flap

Debris material was observed emanating from under the body flap during ascent.

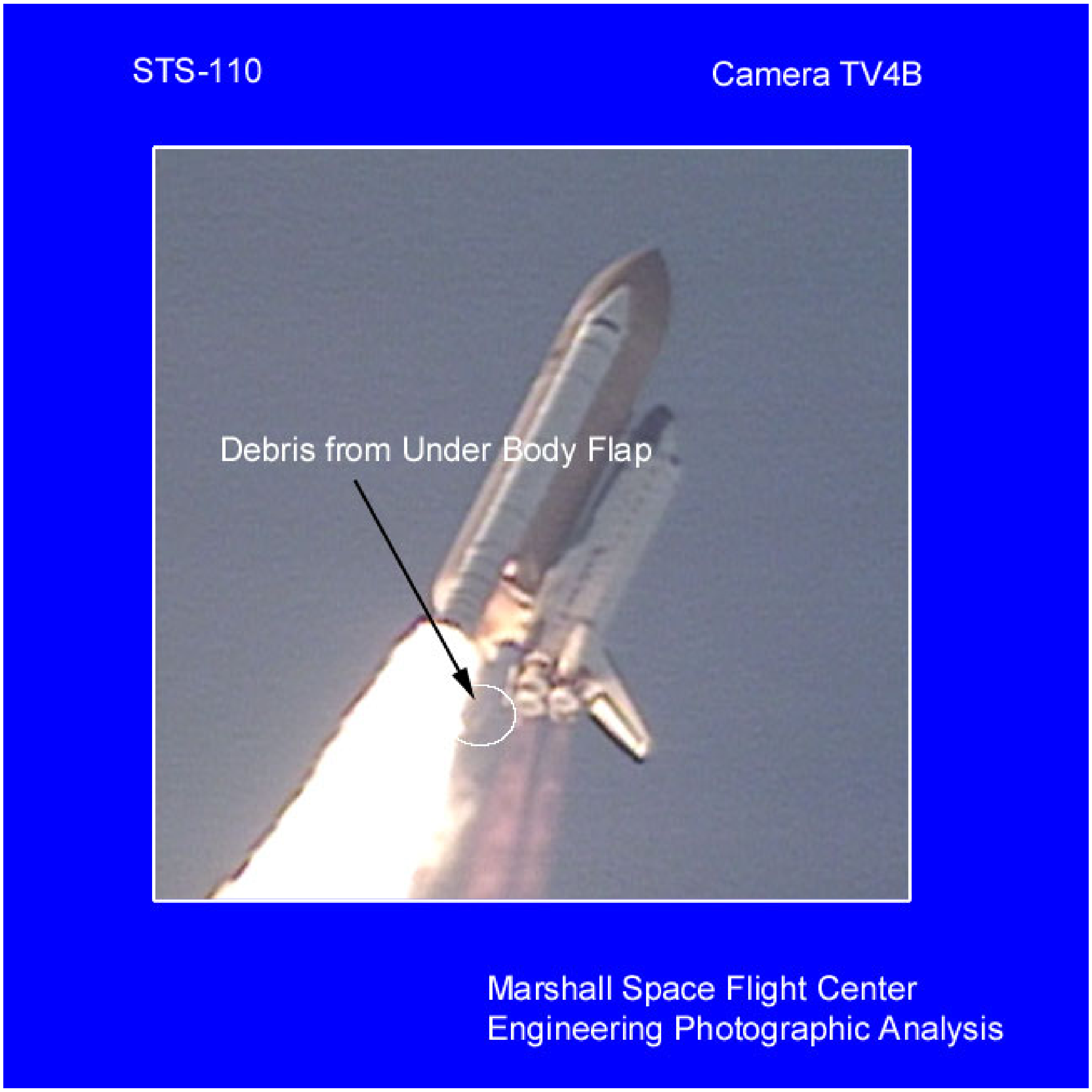

Figure 11. TV4B: Debris Under Body Flap

Video Camera TV4B: Streak in SSME Plume

A debris-induced streak was noted in the SSME plumes.

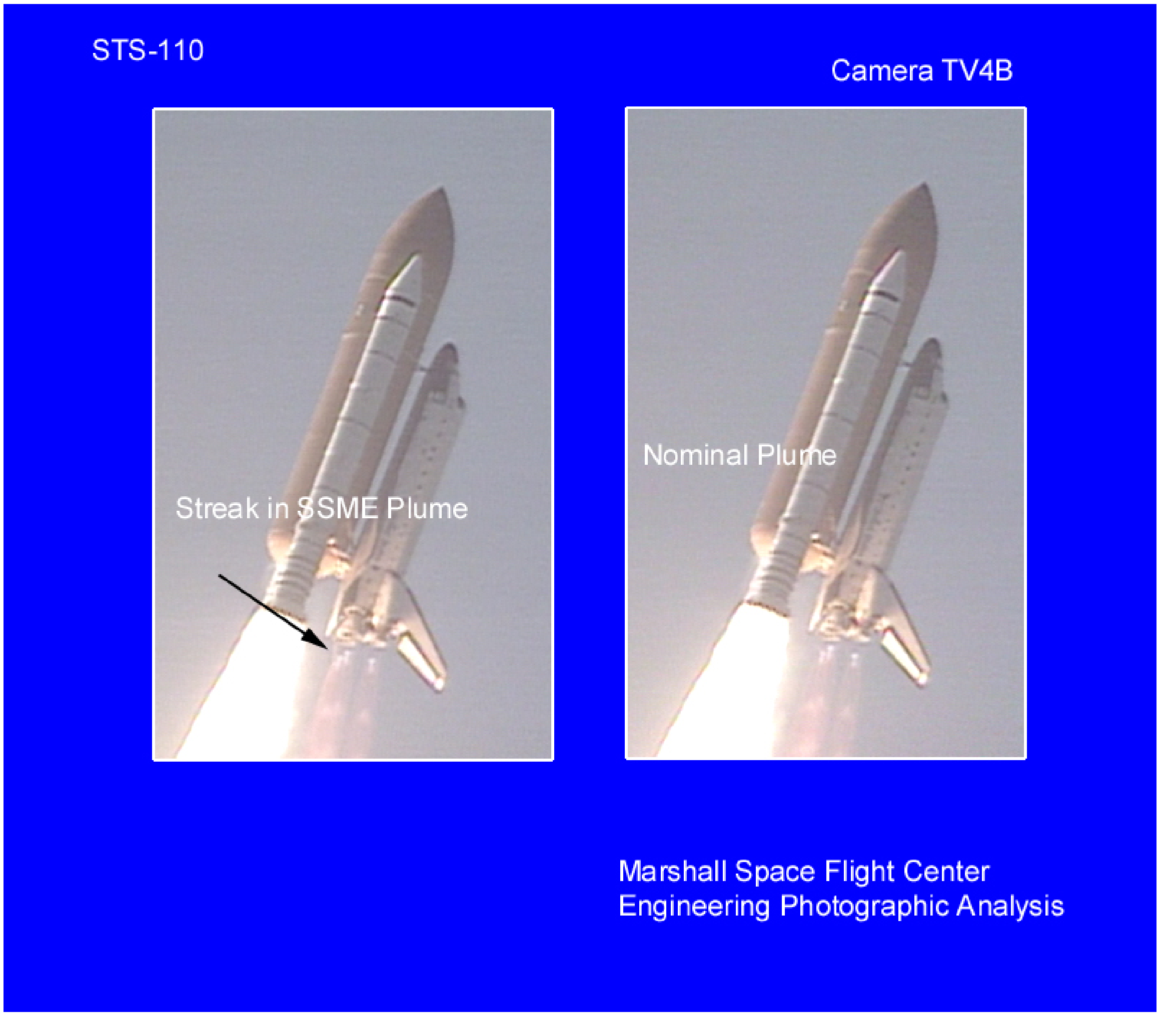

Figure 12. TV4B: Streak in SSME Plume

Video Camera TV4B: Streak in SSME Plume

A debris-induced streak was noted in the SSME plumes.

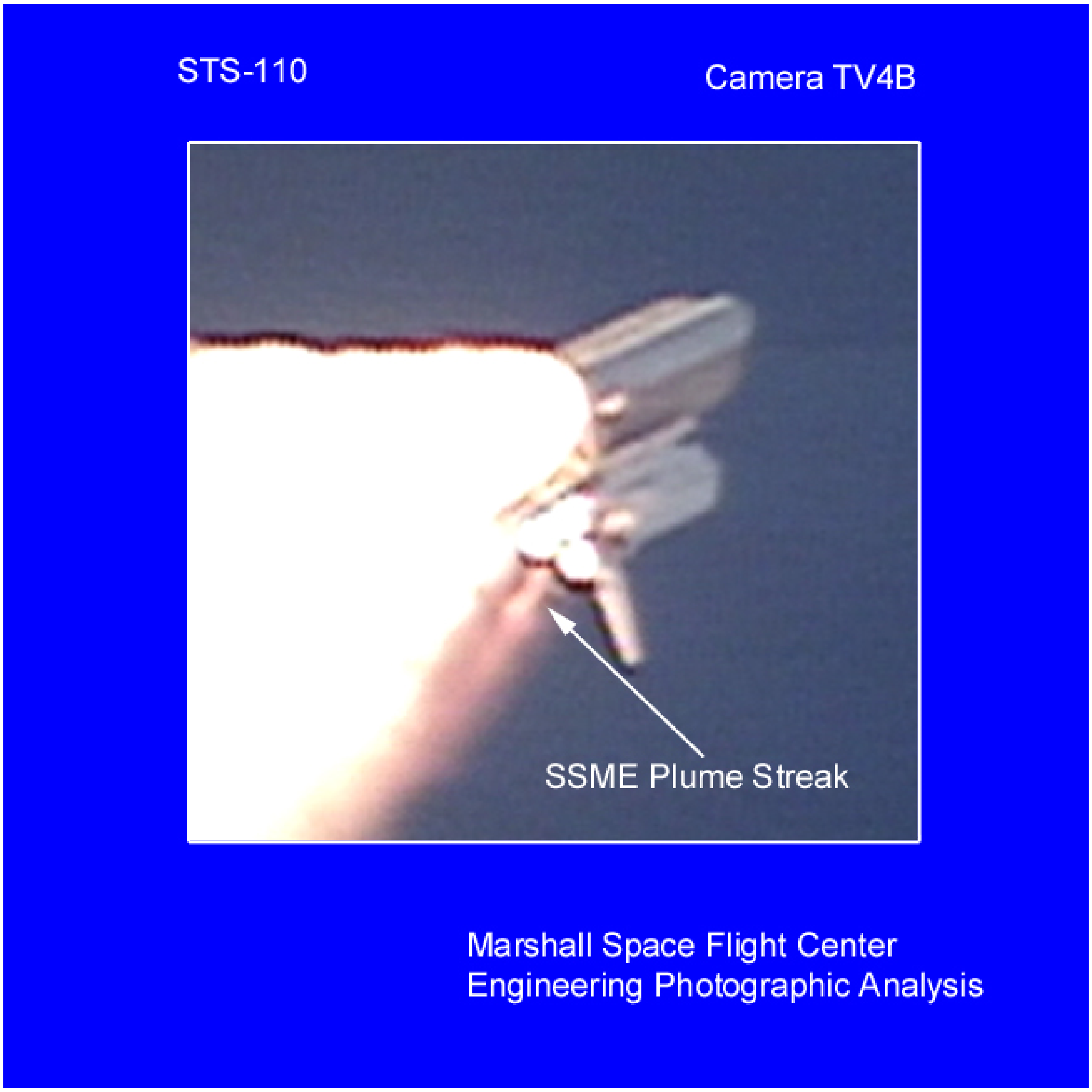

Figure 13. TV4B: Streak in SSME Plume

Video Camera ET212: Debris Induced Streak in SSME Plume

A debris-induced streak was noted in the SSME plumes.

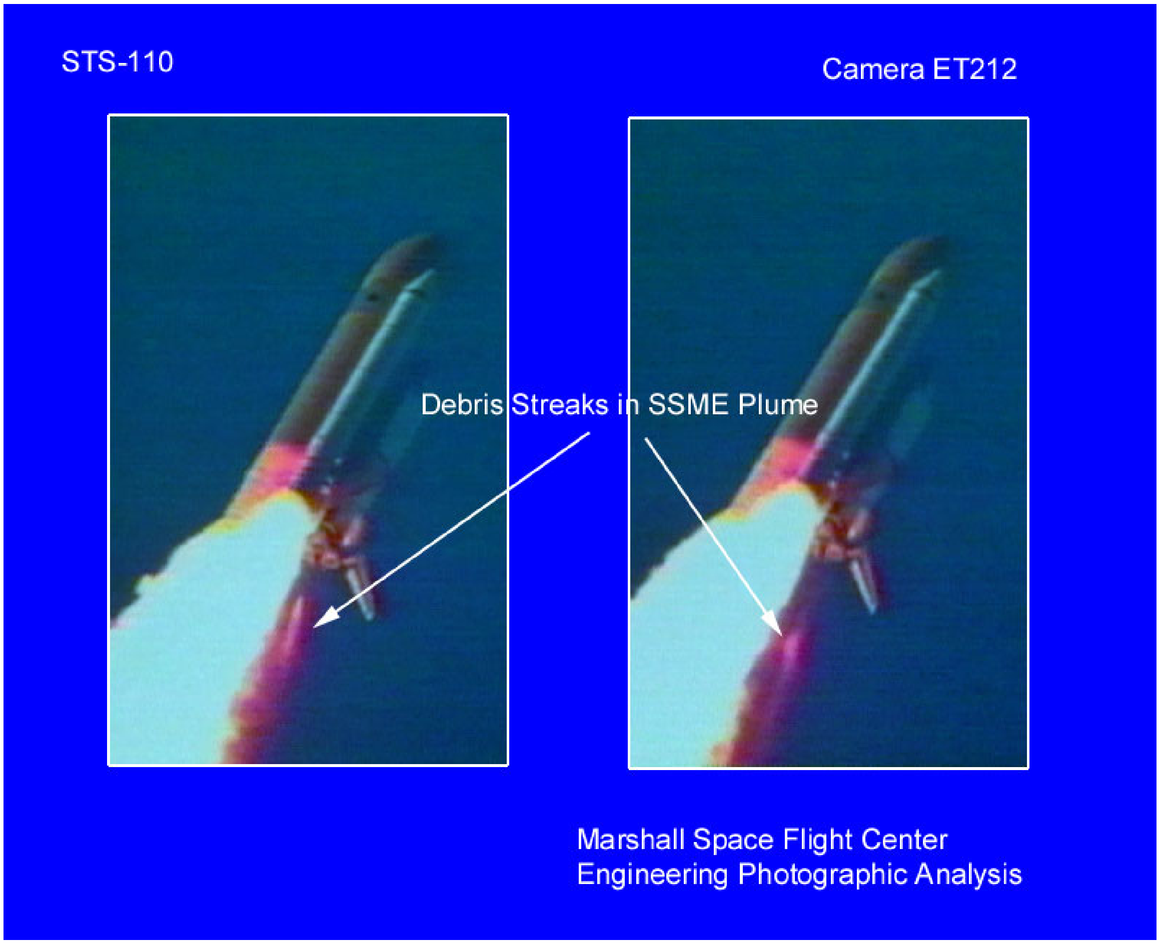

Figure 14. ET212: Debris Induced Streak in SSME Plume

Video Camera TV4B: Debris Ejected from SRB Plume

Debris was ejected from the SRB plumes during ascent.

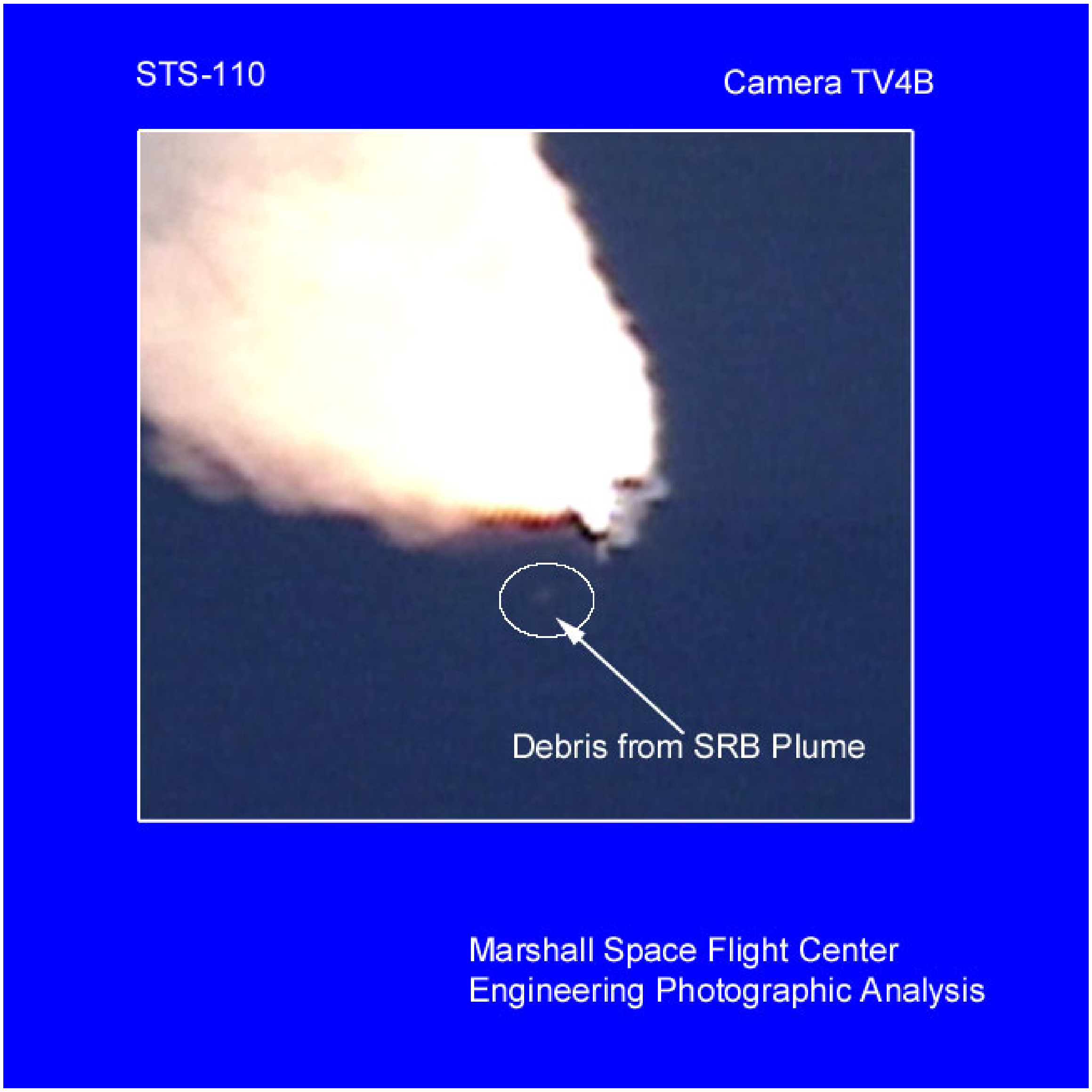

Figure 15. TV4B: Debris Ejected from SRB Plume

Film Camera E220: Debris Induced Streaks in SSME Plumes

Debris-induced streaks were noted in the SSME plumes.

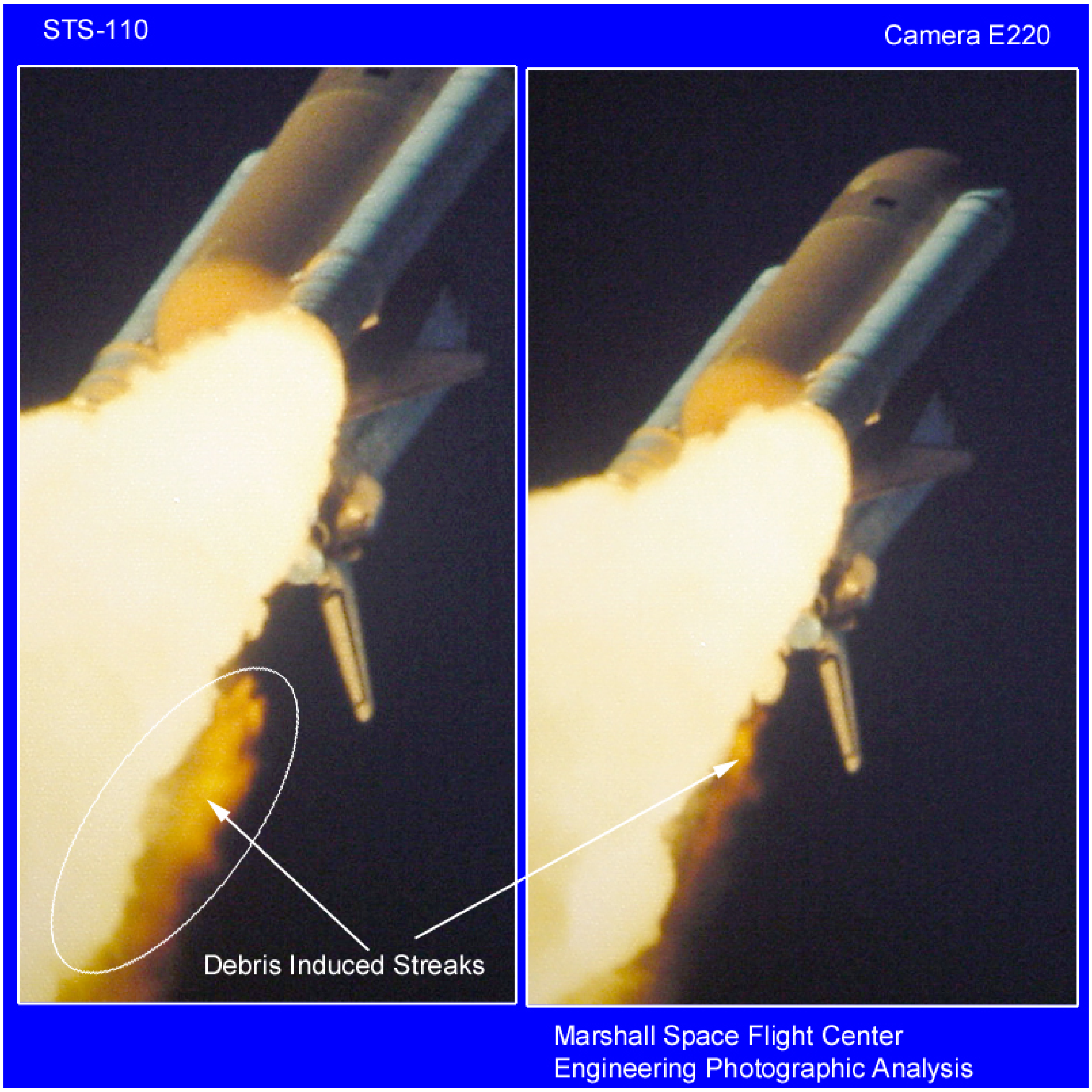

Figure 16. E220: Debris Induced Streaks in SSME Plumes

Film Camera E220: Debris from SRB

Debris observed falling along side of SRB.

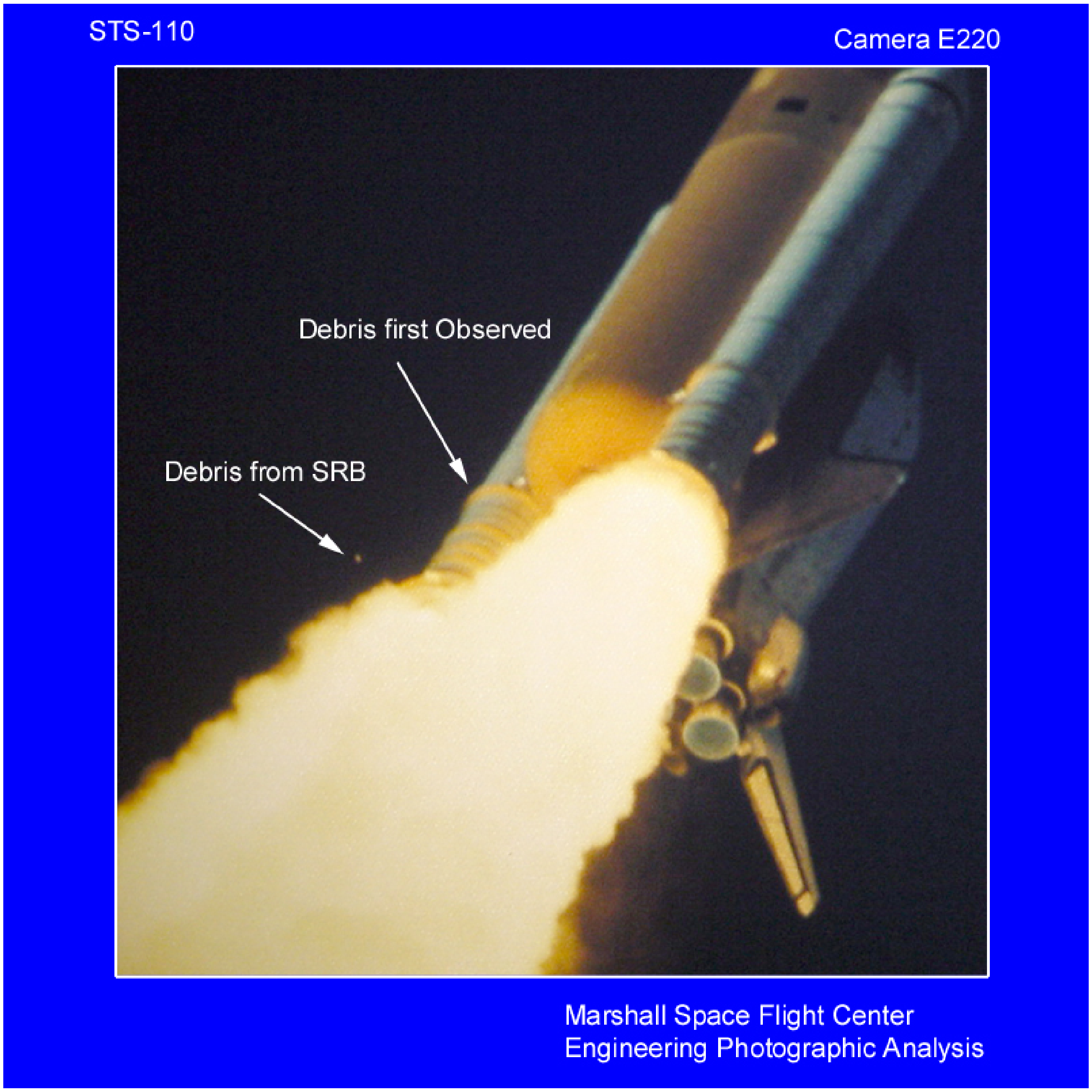

Figure 17. E220: Debris falling along side of SRB

Film Camera E220: RCS Butcher Paper Debris

Numerous pieces of forward RCS Butcher Paper were noted falling aft of the vehicle..

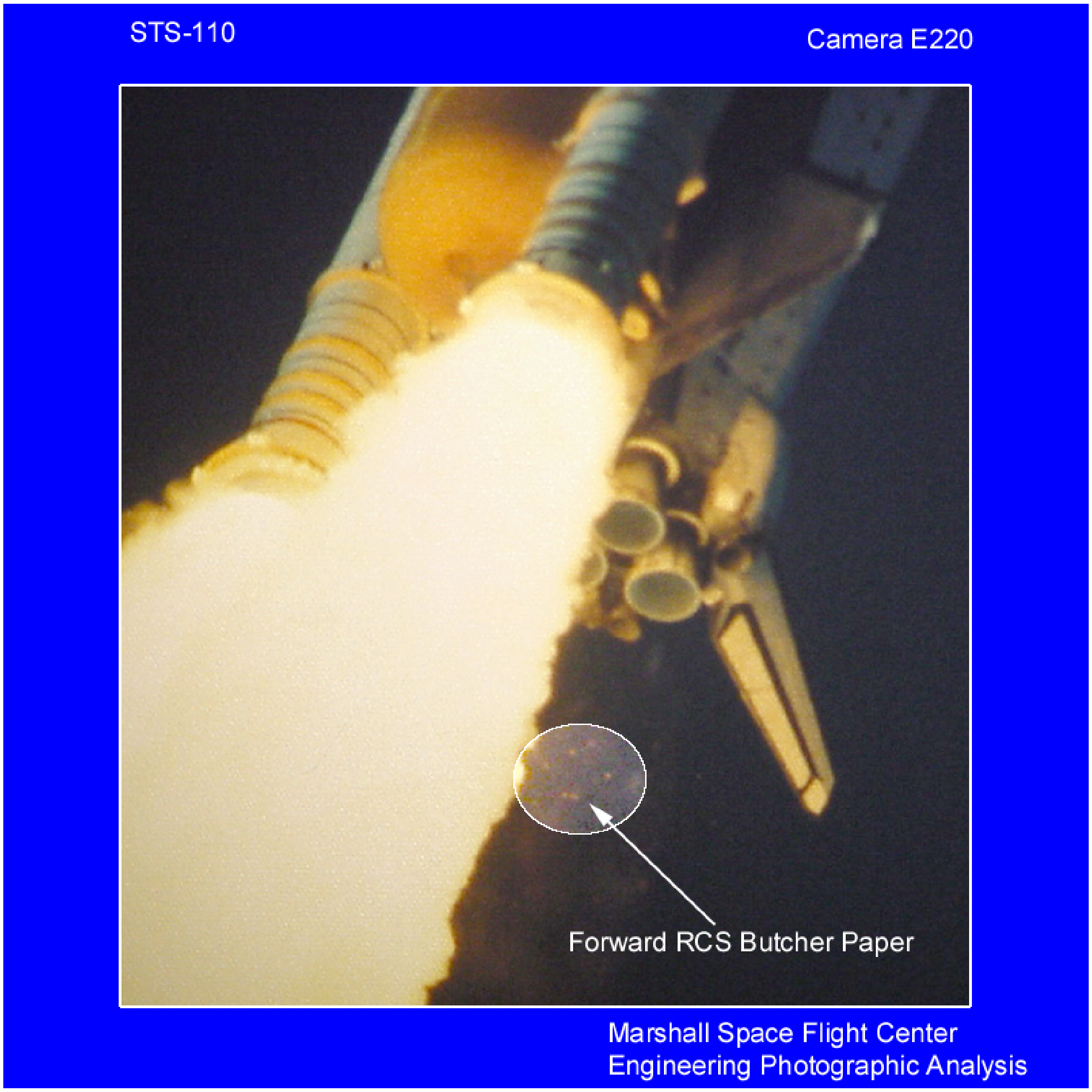

Figure 18. E220: RCS Butcher Paper Debris

Film Camera E223: Debris Induced Streaks in SSME Plumes

Debris-induced streaks were noted in the SSME plumes.

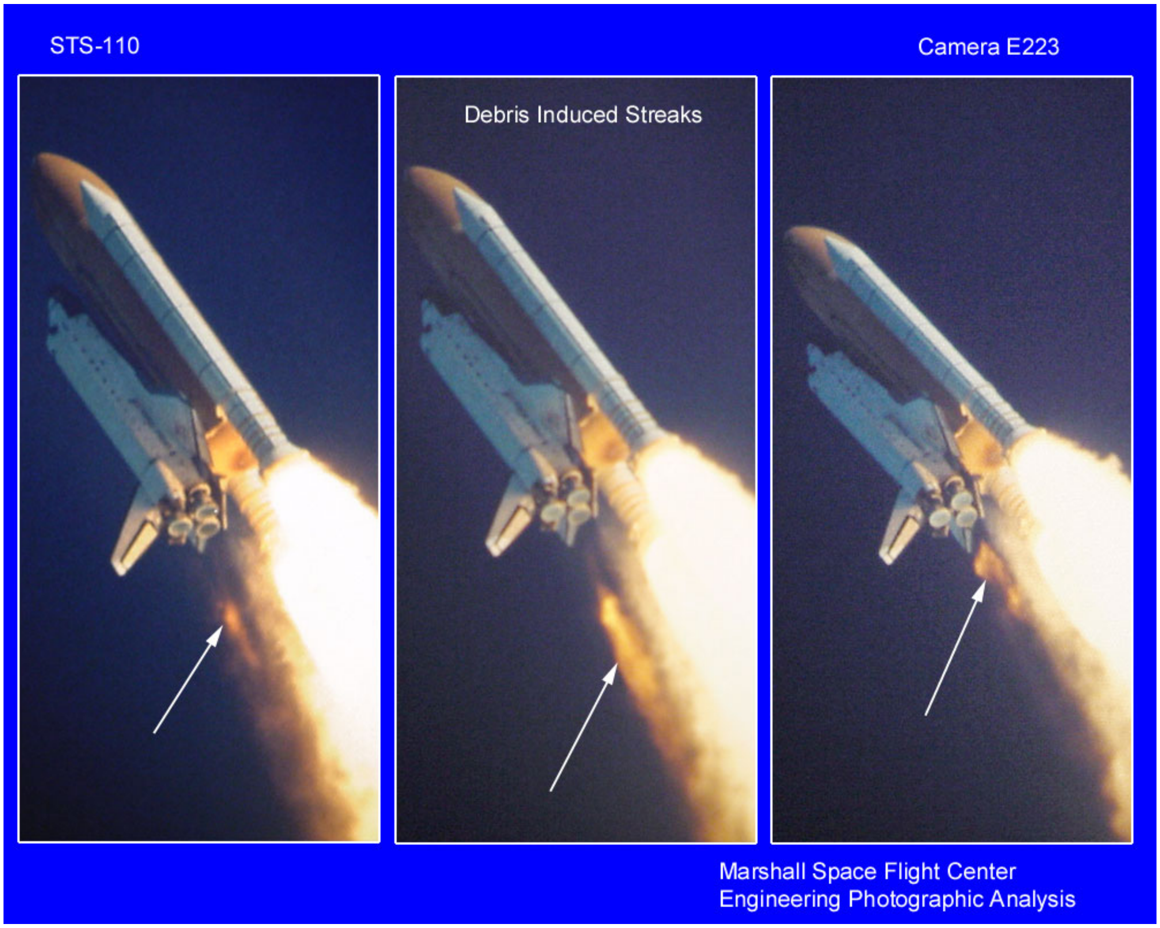

Figure 19. E223: Debris Induced Streaks in SSME Plumes

Film Camera E223: Debris Ejected from SRB Plumes

Debris was ejected from the SRB plumes during ascent.

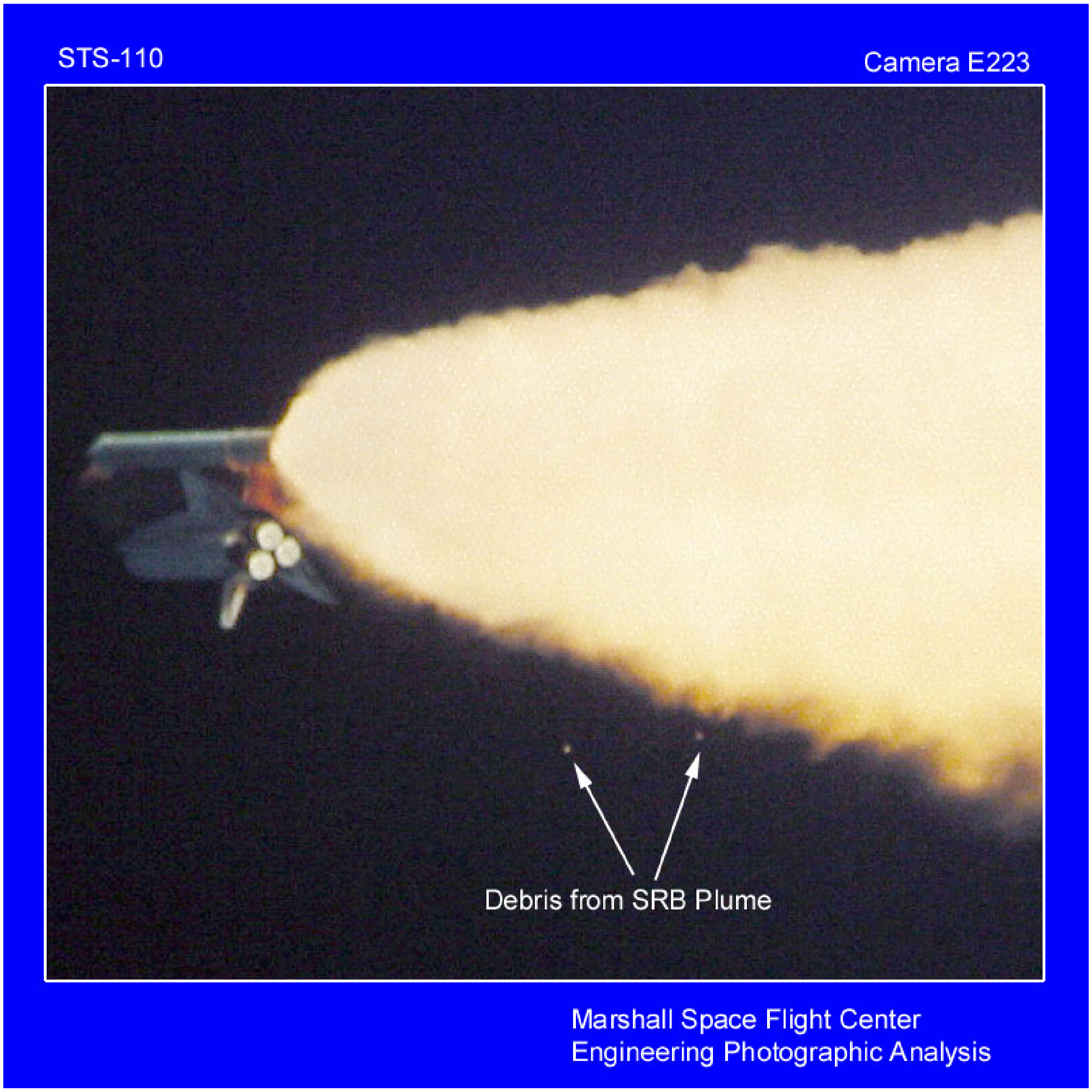

Figure 20. E223: Debris Ejected from SRB Plumes

Film Camera E54: RCS Butcher Paper Debris

Several pieces of Forward RCS Butcher Paper were observed falling over the +Y wing during ascent.

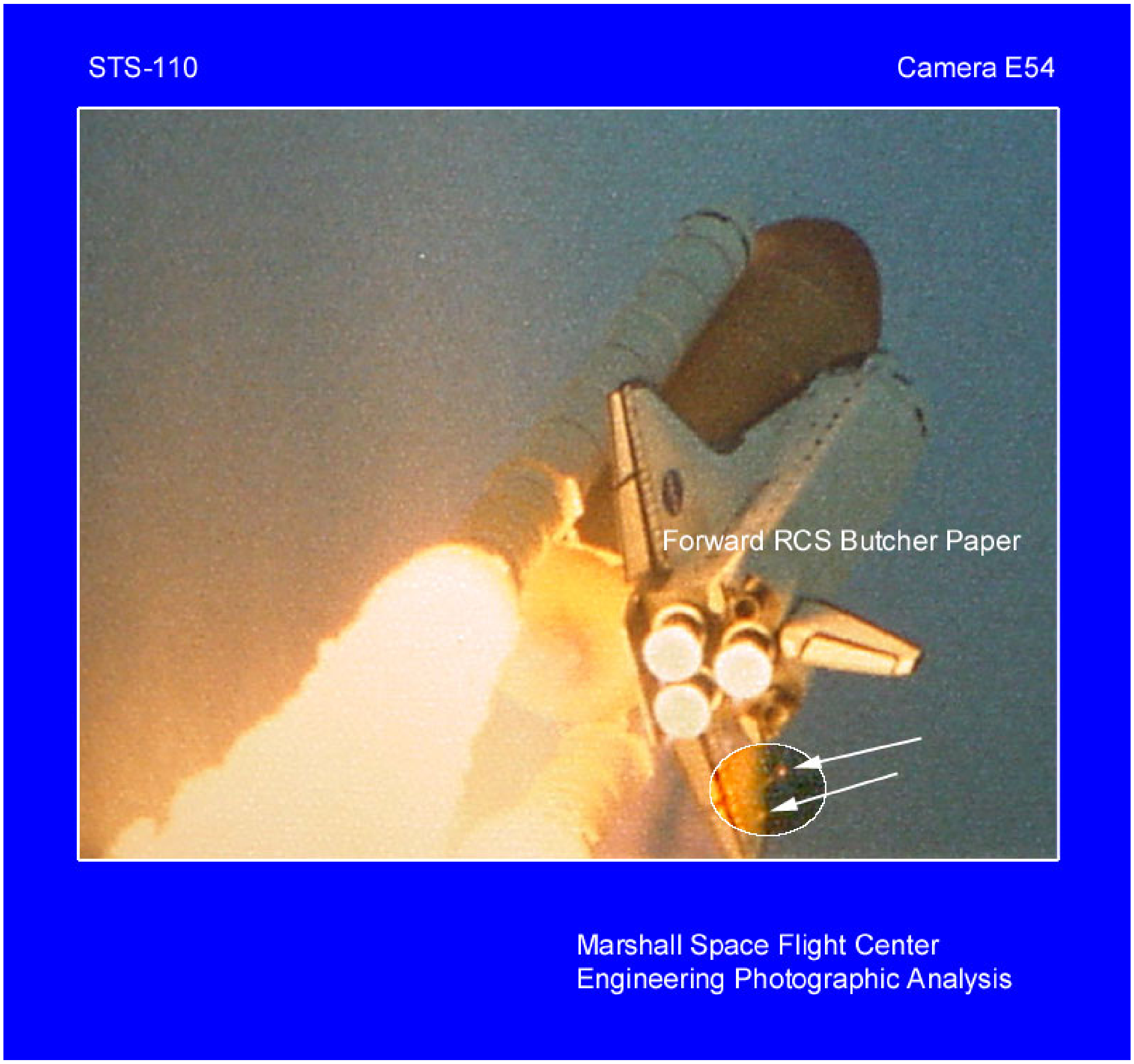

Figure 21. E54: RCS Butcher Paper Debris

Film Camera E207: Debris Falling Aft

Debris was observed falling aft of the vehicle during ascent.

Figure 22. E207: Debris Falling Aft

Film Camera E207: Debris Induced Streak in SSME Plumes

A debris-induced streak was noted in the SSME plumes.

Figure 23. E207: Debris Induced Streak in SSME Plumes

Film Camera E212: Debris Induced Streak in SSME Plumes

A large debris-induced streak was noted in the SSME plumes.

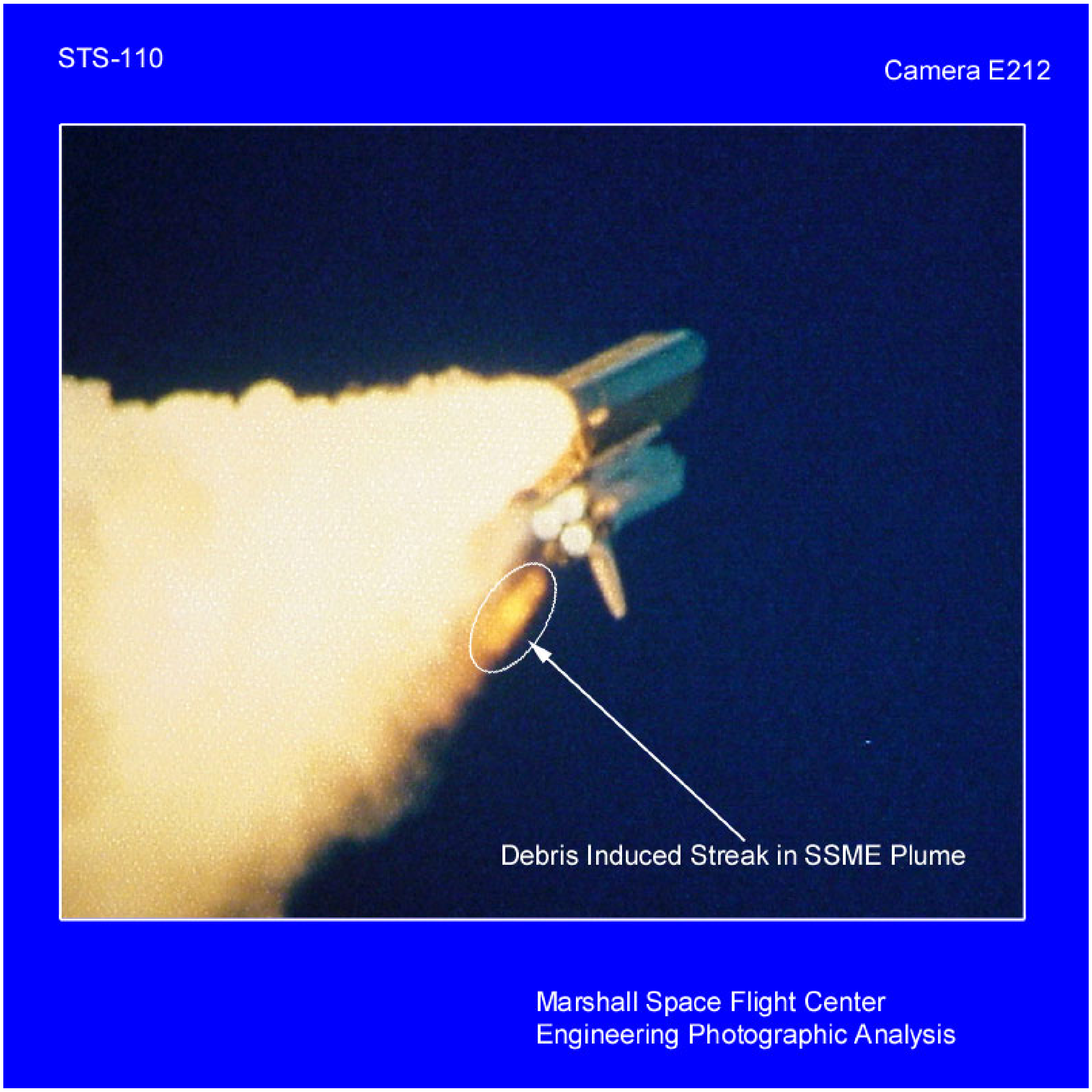

Figure 24. E212: Debris Induced Streak in SSME Plumes

Film Camera E212: Debris Ejected from SRB Plumes

Debris was ejected from the SRB plumes during ascent.

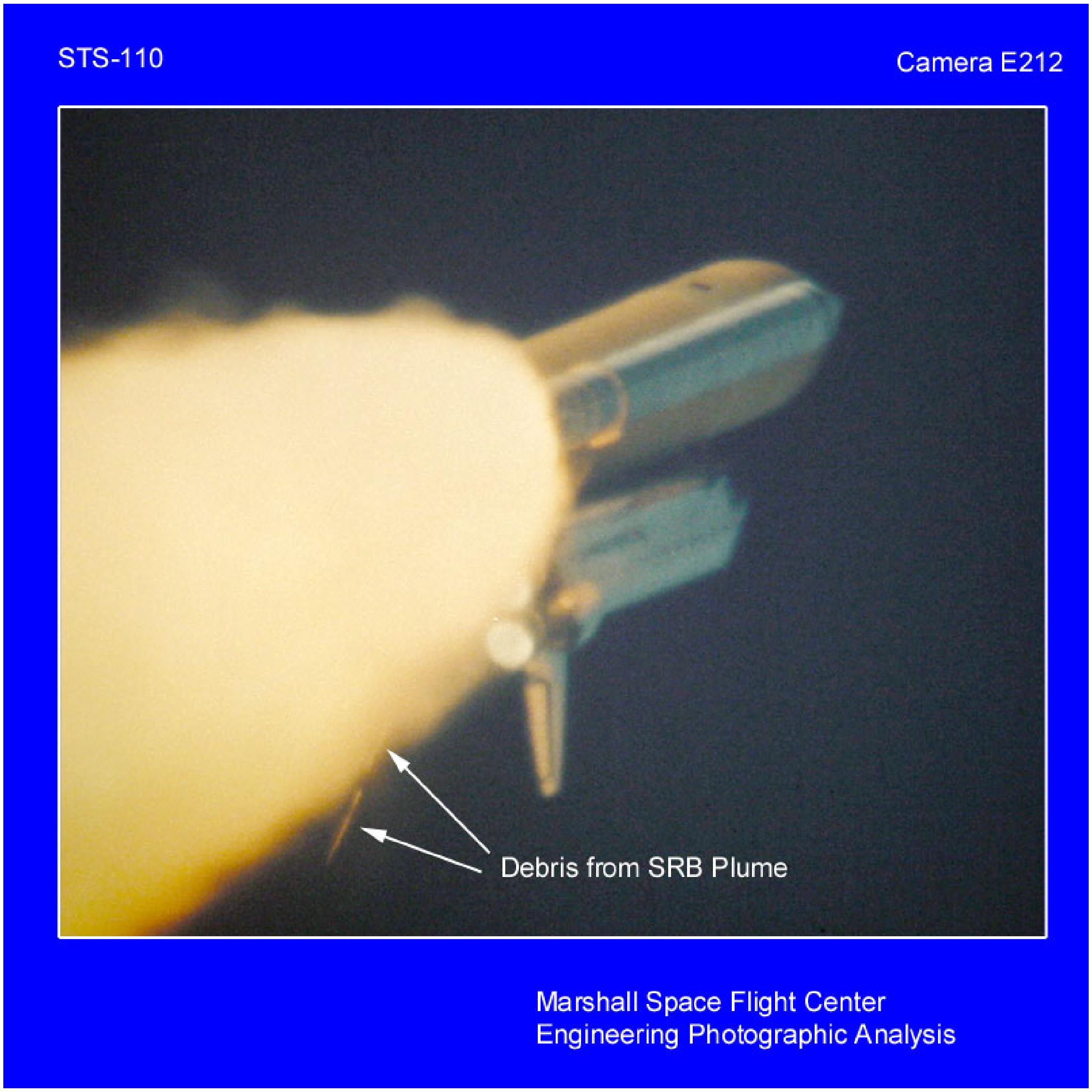

Figure 25. E212: Debris Ejected from SRB Plumes

Film Camera E224: Butch Paper Falling Aft

Numerous pieces of Butcher Paper were observed falling aft of the vehicle.

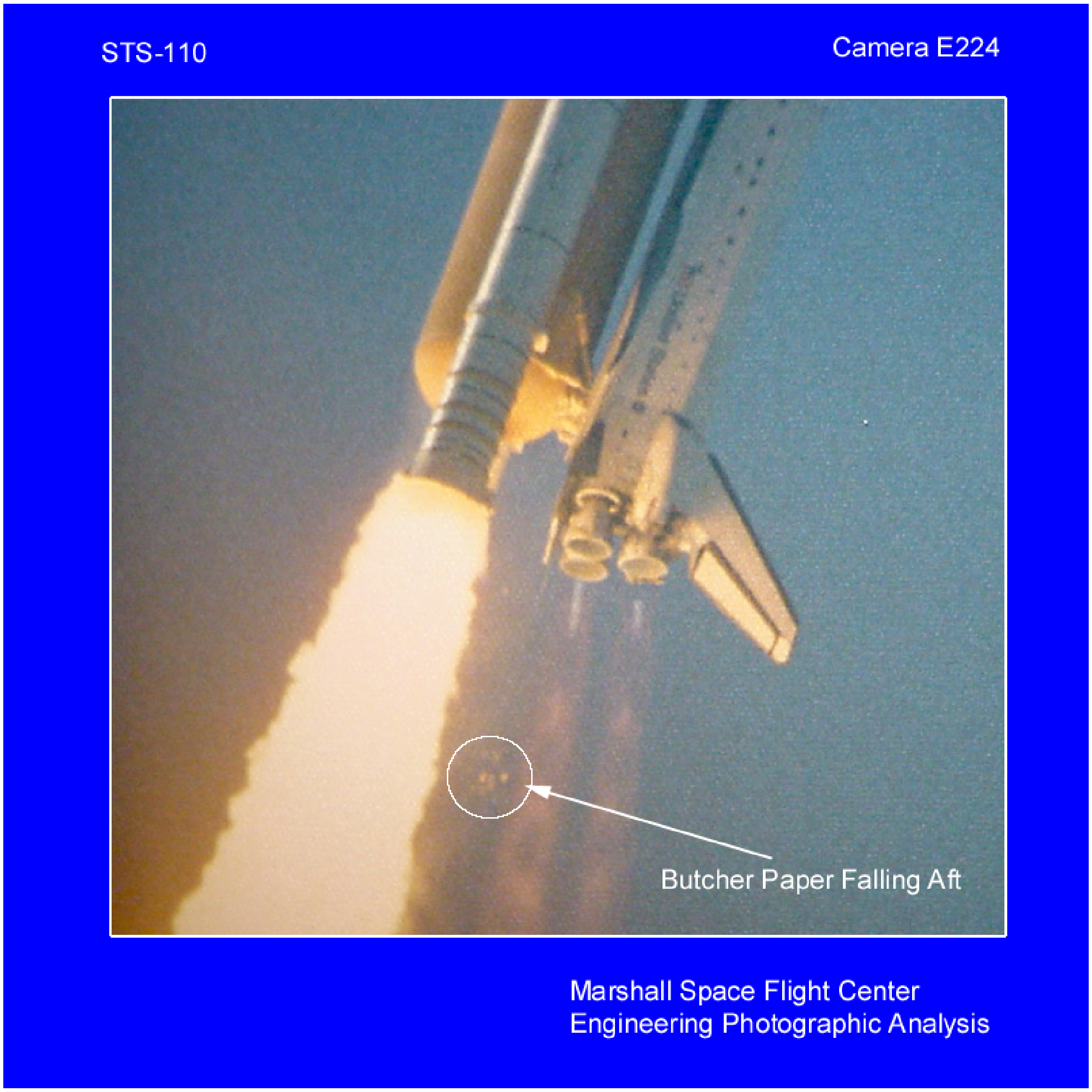

Figure 26. E224: Butch Paper Falling Aft

Film Camera E205: Flow Recirculation

Flow recirculation was observed.

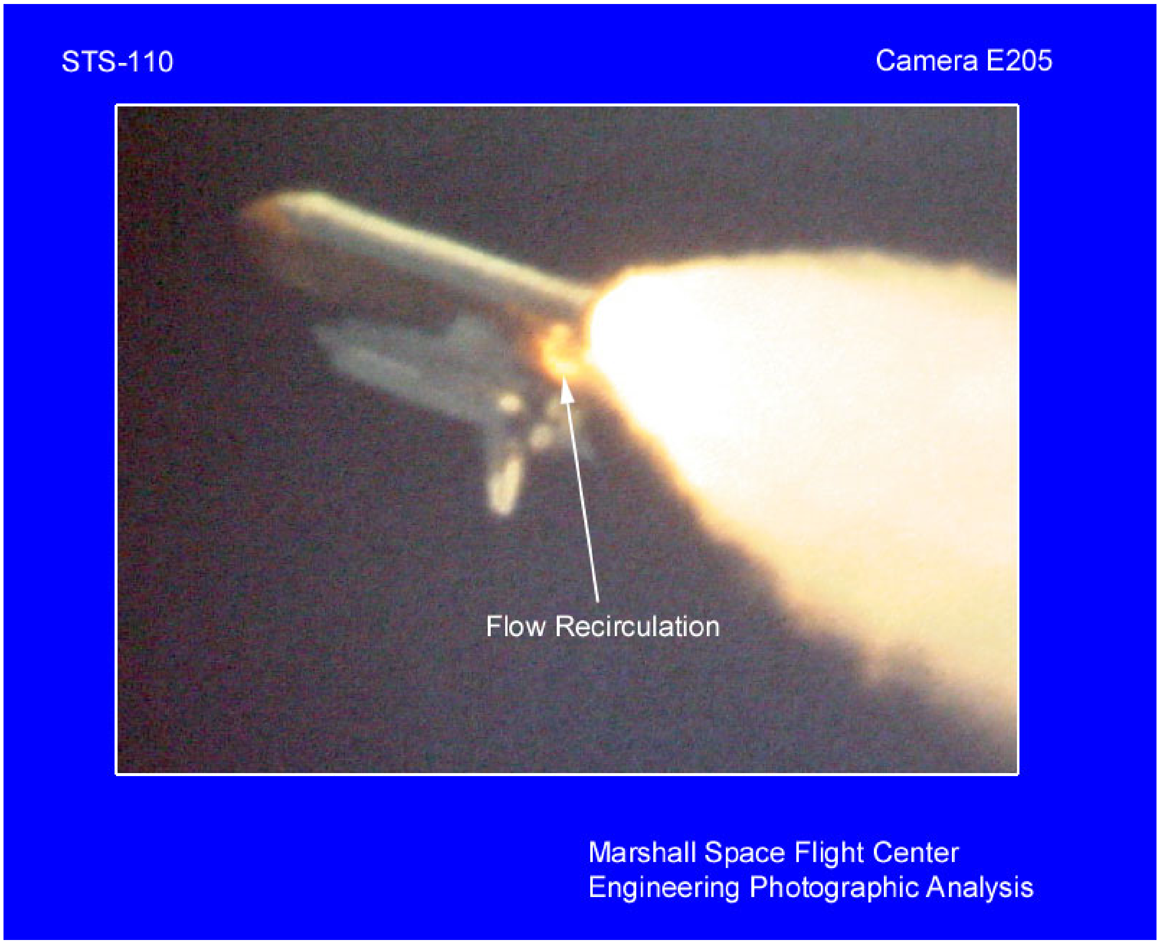

Figure 27. E205: Flow Recirculation

Film Camera E207: Debris at SRB Separation

Debris material falling aft, over the –Y side of the vehicle wing, was observed during SRB separation.

Figure 28. E207: Debris at SRB Separation

Film Camera E207: OMS Assist Burn

The OMS Assist burn after SRB separation was observed.

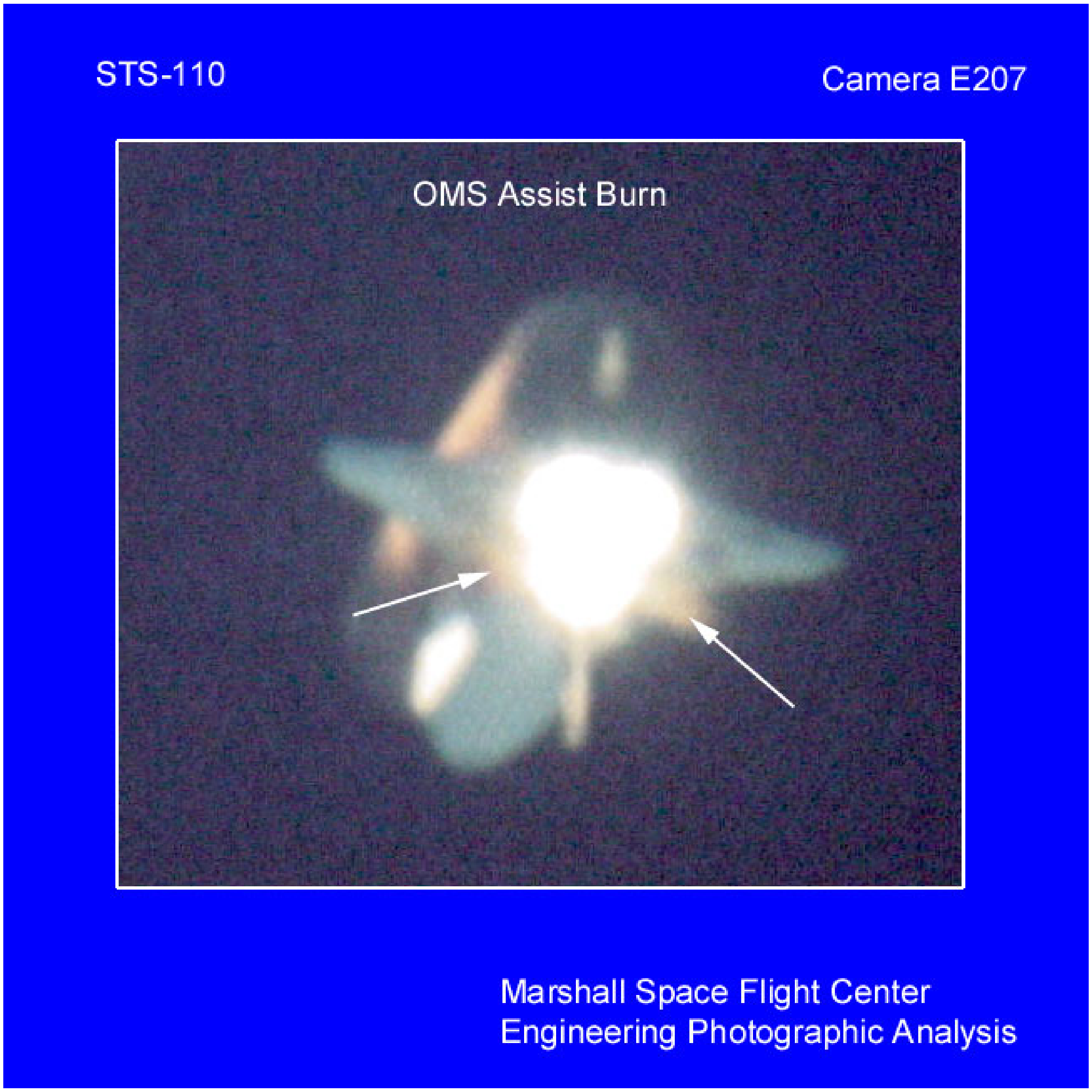

Figure 29. E207: OMS Assist Burn

35mm Umbilical Well Still Camera: ET/Orbiter Yaw Separation

An unexpected –Y yaw angle between the ET and Orbiter was observed after ET/Orbiter separation. A –Y yaw angle has not been observed on prior missions.

Mr. Gregory Manich, Boeing, attributed this post-separation relative yaw as due to residual angular velocity from the OI-29 alpha-beta management maneuver. Mr. Manich notes that this is to be considered a nominal sequence of events and the same can be expected on any future flight and is within the scope of certification.

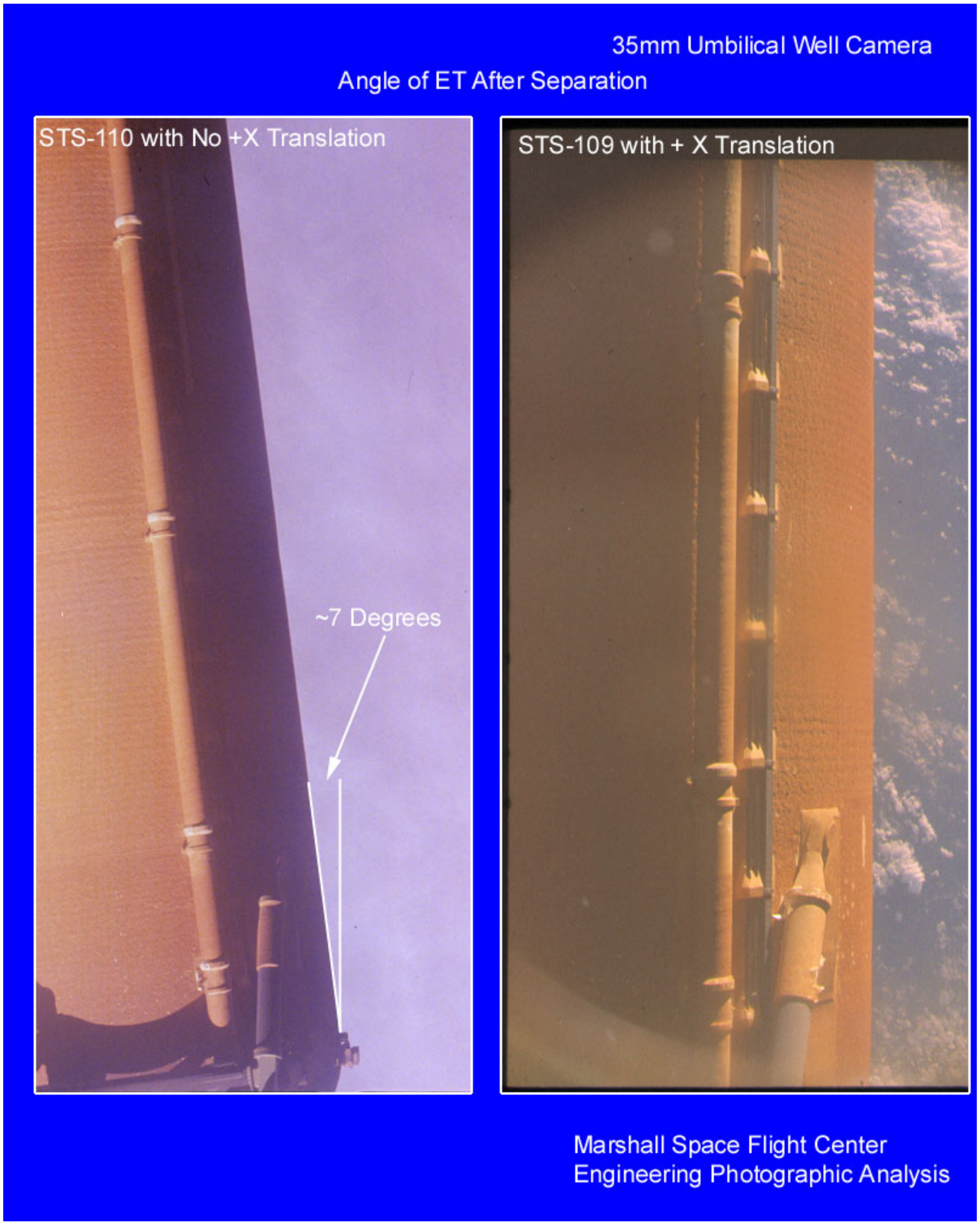

Figure 30. 35mm Umbilical Well Still Camera: ET/Orbiter Yaw Separation

Film Camera FL101: TPS "Popcorning" Line

"Popcorning" on the aft dome was noted to be most dense along a band. Typical "popcorning" is more randomly distributed on the aft dome of the ET.

An orange-brown colored, flapping material was observed attached to the Orbiter near the FL101 viewport prior to ET separation. This material was not observed after ET separation.

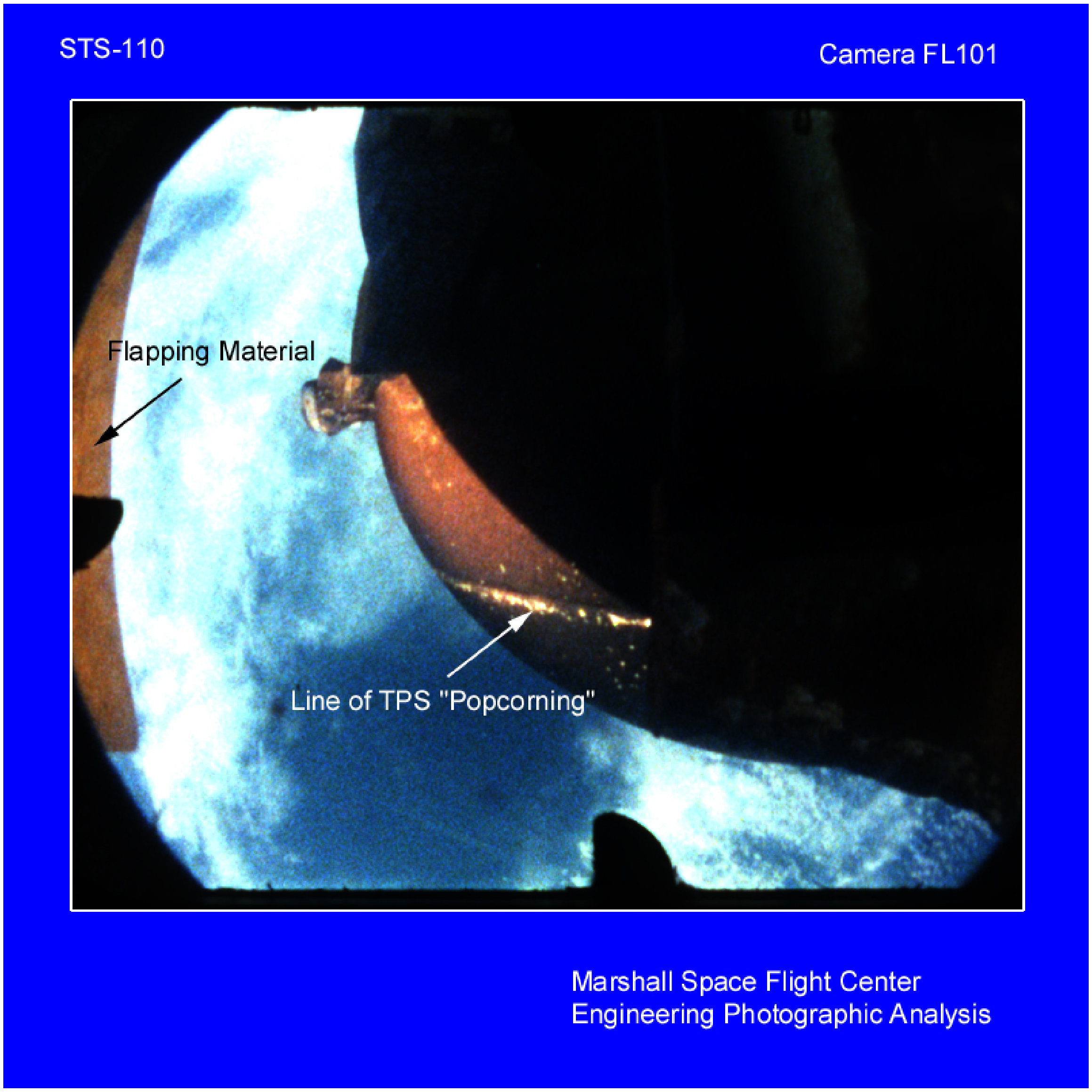

Figure 31. FL101: TPS "Popcorning" Line and Flapping Material on FL101 Port

Video Movies Available on Website:

Movies illustrating the yaw separation between the External Tank and the Orbiter were created and made available on the website.

Figure 32. 35mmUmbilical Well Still Camera Movie

Figure 33. FL101 and FL102 ET/Orbiter Yaw Separation Movies

Special Investigation: External Tank Yaw Angle

Images of the External Tank from film camera FL102 and the 35mm Umbilical Still camera were digitized and selected points were tracked. An orientation for the External Tank was calculated using displacement of the LOX Feedline from vertical. Charts of the yaw angle from both data sets indicate an increasing yaw angle.

Points from a sequence of thirty-nine images from 35mm Umbilical Still Camera, spaced approximately 0.5 seconds apart, were tracked. The 17-inch pressure disconnect event was not imaged by this camera. Using a linear approximation to the ET orientation, a yaw rate of 0.42 degrees per second was obtained, shown on associated Umbilical Still Camera chart.

Points from a sequence of nine hundred images from film camera FL102, spaced at 1/24 of a second (0.0417 sec) apart, were tracked. The 17-inch pressure disconnect event was determined to be about 298 frames prior to the frame where tracking points began. Using a linear approximation to the ET orientation, a yaw rate of 0.44 degrees/second was obtained, which agreed with the yaw rate from the 35mm Umbilical Still Camera images. A more physically appropriate second order curve fit for ET orientation was also performed with the FL102 data. The angular acceleration was calculated to be 0.0026 degrees/sec^2 and the angular velocity was calculated to be 0.279 degrees/sec, shown on associated FL102 camera chart.

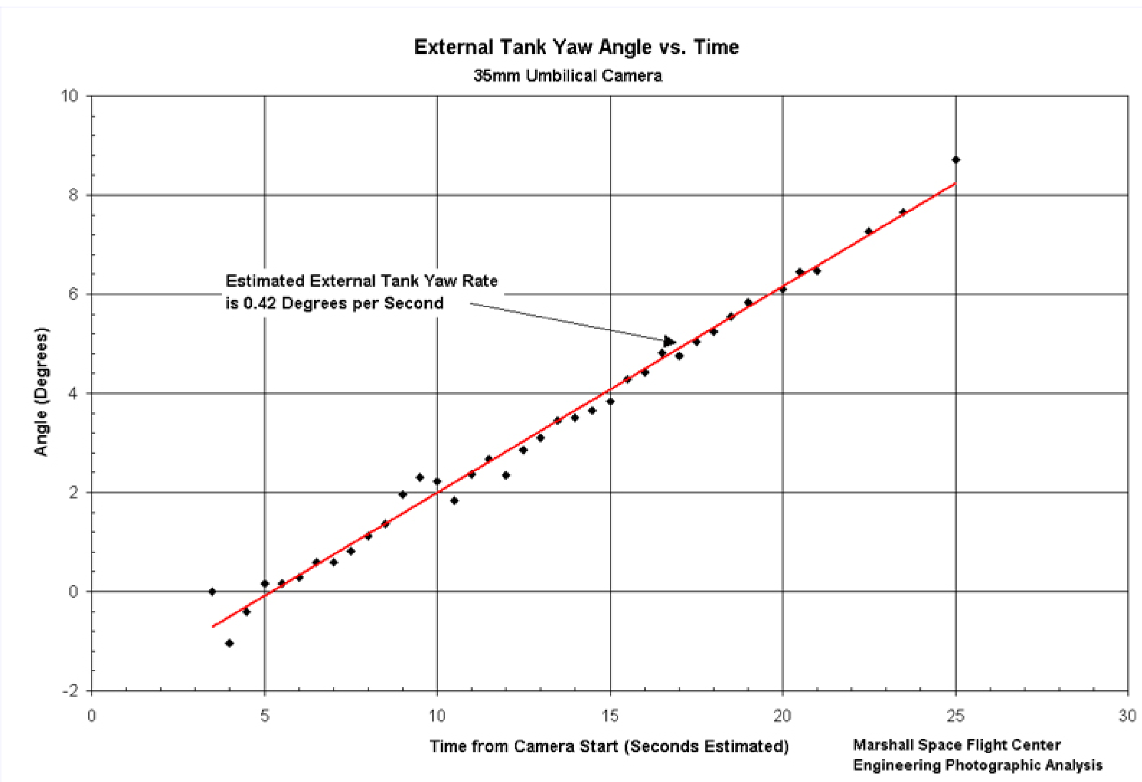

Figure 34. 35mm Umbilical Well Still Camera ET/Orbiter Yaw Separation Chart

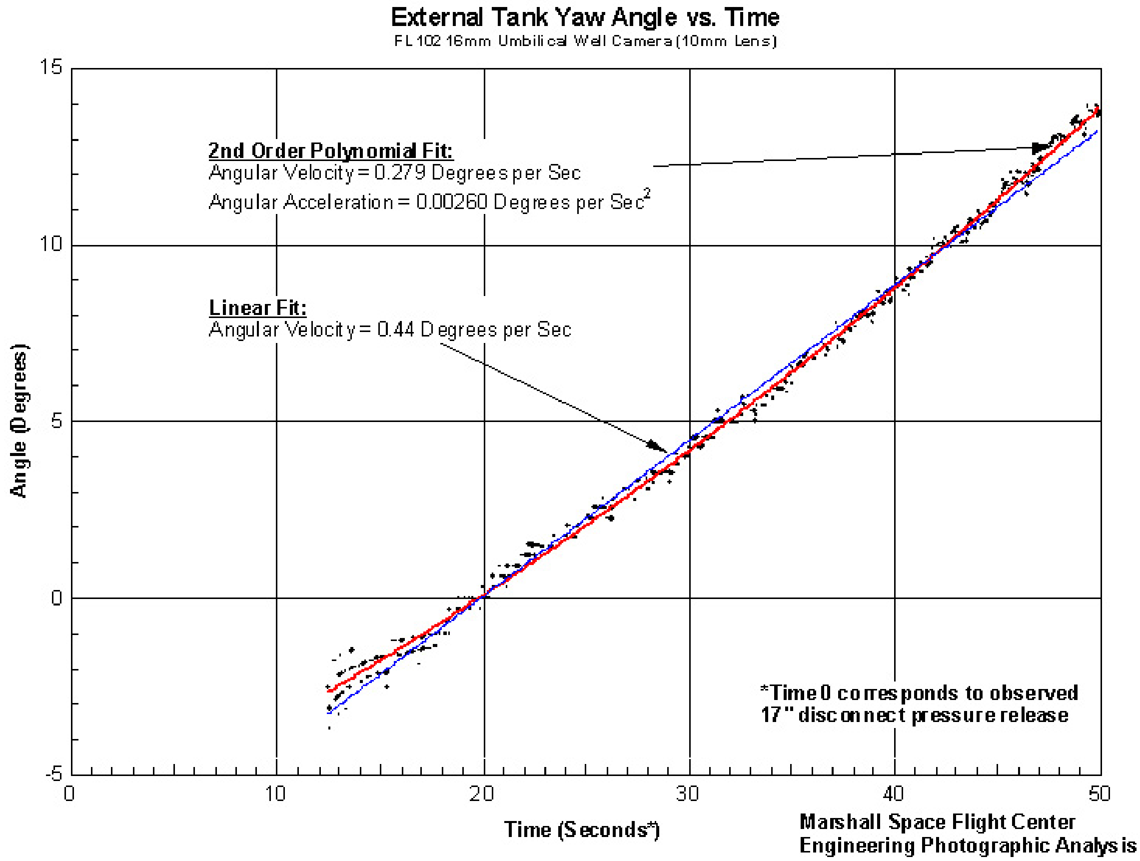

Figure 35. FL102 ET/Orbiter Yaw Separation Chart

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-110 may also be found on the website.

Video Camera Assessments

TV13 — Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. OMS burn noted after SRB separation.

TV4B — Typical debris observed falling aft of vehicle. Debris-induced streaks observed in SSME plume. Condensation collar observed. Debris ejected from SRB plumes during ascent.

ET204 — Linear optical distortions noted.

ET207 — Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume after separation. Debris-induced streaks observed in SSME plume. Linear optical distortions noted. Flow recirculation noted. Body flap motion noted. OMS motor burn noted approximately ten seconds after SRB separation.

ET208 — Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. SRB separation: 98:20:46:22.3 UTC.

ET212 — Debris-induced streaks observed in SSME plume.

OTV109 — Typical ice/frost from 17-inch disconnects. Yellowish colored debris appears to impact body flap tiles. No damage noted.

OTV141 — Sun glare degrades quality of image early in ascent.

OTV148 — Does not track vehicle.

OTV154 — Typical ice/frost from 17-inch disconnects.

OTV161 — Typical debris observed falling aft of vehicle. Ice/frost falling between ET and Orbiter observed. Doesn't appear to strike Orbiter.

OTV163 — Typical ice/frost from 17-inch disconnects. Free burning hydrogen observed on -Z side of body flap.

OTV170 — Typical debris observed falling aft of vehicle. Ice/frost noted striking SSME#3 nozzle bell. No damage noted.

Film Camera Assessments

E1 — Pad debris noted rising and falling. Free burning hydrogen observed near body flap.

E2 — Engine produced streaks noted, one streak imaged at 20:44:17.085 UTC.

E3 — Free burning hydrogen observed. Engine produced streaks noted, one streak imaged at 20:44:16.672 UTC. Rope-like debris item noted moving across MLP deck away from vehicle, imaged at 20:44:22.120 UTC.

E4 — Typical ice/frost from 17-inch disconnects.

E6 — Typical debris observed falling aft of vehicle. Typical ice/frost from LO2 disconnect. Ice/frost impacts cable tray. No damage observed.

E7 — Leaking water pipe noted. Typical debris rising from SRB blast hole observed.

E8 — Holddown Post M2 PIC firing time at 20:44:18.991 UTC. Shoe rotation noted.

E9 — SRB Holddown Post M1 PIC firing time 20:44:18.992 UTC. Ice/frost from 17 inch disconnects observed.

E10 — Pad debris noted rising and falling.

E11 — Pad debris noted rising and falling.

E12 — Pad debris noted rising and falling. Free burning Hydrogen in field of view, imaged at 20:44:13.676 UTC. SRB Holddown Post M5 PIC firing time at 20:44:18.991 UTC.

E13 — Holddown Post M6 PIC firing time at 20:44:18.992 UTC. Shoe rotation noted.

E14	Pad debris noted rising and falling. Rectangular debris item coming from SRB blast hole, imaged at 20:44:20.203 UTC.
E15	Pad debris noted rising and falling.
E16	Pad debris noted rising and falling. Free burning Hydrogen noted near body flap.
E17	Typical debris observed falling aft of vehicle. Typical ice/frost from LO2 T-0 umbilical observed.
E18	Typical debris observed falling aft of vehicle. Free burning Hydrogen noted. SSME#2 Eyelid blanket motion noted.
E19	Free burning hydrogen observed. Mach diamond formation in 2-3-1 order.
E20	Typical debris observed falling aft of vehicle. Free burning hydrogen observed. Engine streak noted in SSME#1 plume, imaged at 20:44:17.013 UTC.
E31	Typical debris observed falling aft of vehicle. Typical ice/frost from 17-inch disconnects. Typical wing motion observed.
E33	Heavy frost was noted on GUCP.
E34	Typical debris observed falling aft of vehicle.
E39	GH2 vent arm latches successfully.
E43	Deceleration system appears to function correctly.
E52	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Debris-induced streaks observed in SSME plume.
E54	Debris falling aft of vehicle noted, imaged at 20:44:38.061 UTC.
E57	Camera moves horizontally instead of vertically and loses track of vehicle at liftoff.
E59	Camera moves horizontally instead of vertically and loses track of vehicle at lift-off.
E62	Typical debris observed falling aft of vehicle. Mach diamond formation in 2-3-1 order. GOX Beanie cap noted moving in SRB exhaust plume.
E63	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle.
D64	Ice/frost noted falling from GUCP just prior to impact. APU exhaust on SRB noted.
E205	Debris-induced streak noted in SSME plume. SRB separation: 20:46:22.315 UTC. Flow recirculation noted and imaged at 20:45.51.228 UTC. OMS assist burn after SRB separation observed. Glowing debris particles ejected prior to and after SRB separation.
E207	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. Flow recirculation noted. SRB separation: 20:46:22.308 UTC. Body flap motion noted. Numerous debris induced streaks noted in SSME plumes. Streaks imaged at 20:45:11.200 UTC and 20:45:10.062 UTC. Debris observed over left side of vehicle at SRB separation. RCS motor firing during SRB separation noted. OMS assist burn after SRB separation noted at 20:46:32.773 UTC
E208	Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. RCS motor plumes noted at SRB separation.
E212	Linear optical distortions noted. Localized condensation observed. Debris ejected from SRB plumes during ascent. Glowing debris particles ejected from SRB plumes prior to and after SRB separation. RCS motor plumes visible during SRB separation.
E213	Typical debris observed falling aft of vehicle. Debris-induced streaks in SSME plume observed.
E220	Typical debris observed falling aft of vehicle. SRB separation: 20:46:22.319 UTC. Debris noted on -Z side of right SRB at 20:45:04.356 UTC. Flashes in SSME plumes observed at 20:45:09.888 UTC and 20:45:10.064 UTC. Debris ejected from SRB plumes during ascent. Condensation vapors noted around forward SRBs.
E222	Typical debris observed falling aft of vehicle. Numerous debris-induced streaks noted in SSME plumes. SSME plume streak imaged at 20:45:08.890 UTC. Debris falling aft imaged at 20:44:41.276 UTC. Vapor-like streak noted emanating from under body flap at 20:44:41.556 UTC.
E223	Typical debris observed falling aft of vehicle. Linear optical distortions noted. Numerous debris induced streaks in SSME plumes were noted, three conspicuous streaks were imaged at 20:45:06.263 UTC, 20:45:08.887 UTC, and 20:45:13.268 UTC. Debris ejected from SRB plumes observed at 20:45:30.246 UTC.
E224	Debris induced streaks in SSME plumes noted early in ascent. Outgassing from ET aft dome clearly visible.

FL101 Band of divots noted on ET aft dome. Orange-brown flapping material observed near camera viewport.

FL102 Yaw angle between ET and Orbiter noted. Divots were noted under the bipod. The camera focus was soft.

35mm Umbilical Well Still Camera Yaw angle between ET and Orbiter noted. Forward portion of the ET not imaged due to yaw condition.

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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