Debris/Ice/TPS Assessment and Integrated Photographic Analysis of Shuttle mission STS-108

Armando Oliu

Technical Memorandum – 2005-212556 March 2005

DEBRIS/ICE/TPS ASSESSMENT and
INTEGRATED PHOTOGRAPHIC ANALYSIS
OF SHUTTLE MISSION STS-108

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

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OF
SHUTTLE MISSION STS-108

December 5, 2001

Contributions By:

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

Approved:

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

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

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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-108

1.0 SUMMARY OF SIGNIFICANT EVENTS

STS-108 consisted of OV-105 Endeavour (17th flight), ET-111, and BI-110 SRB's on MLP-1 and Pad 39B. Endeavour was launched at 5:19 pm EDT on 5 December 2001. Landing was at 12:55 p.m. local/eastern time on 17 December 2001.

The GH2 vent line did not latch on the FSS latching mechanism. It appears the vent line impacted the south side of the FSS structure preventing the latch back and caused substantial damage to the saddle structure. The south side bridle cable sheared from the southern tang on the yoke. Pieces of debris (bolts and clevis leg) were found on/in the grating and vent line structure. The GUCP sustained minor damage from the vent line impact with the FSS. The 7-inch QD exhibited no damage and the poppet was observed to be intact. The deceleration cable was in nominal configuration, and the vent line blanket was sooted and torn.

Post landing inspection of Orbiter tiles showed a total of 95 hits, of which 22 had a major dimension of 1-inch or larger. The Orbiter lower surface sustained 81 total hits, of which 17 had a major dimension of 1-inch or larger, both numbers are within family. The majority of the hits (49 total with 12 greater than 1-inch) were located in the area aft of the main landing gear wheel wells. 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 1400 on 3 December 2001. The following personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

A.Oliu	NASA - KSC	Shuttle Ice/Debris Systems
J. Rivera	NASA - KSC	ET Mechanisms/Structures
R. Speece	NASA - KSC	ET Thermal Protection Systems
B. Nguyen	NASA - KSC	SRB Mechanical Systems
M. Payne	NASA - KSC	SRB Mechanical Systems
R. Page	NASA - KSC	SSP Integration
K. Leggett	USA - SFOC	Supervisor, ET/SRB Mechanical Systems
J. Blue	USA - SFOC	ET Mechanical Systems
W. Richards	USA - SFOC	ET Mechanical Systems
M. Wollam	USA - SFOC	ET Mechanical Systems
T. Ford	USA - SFOC	ET Mechanical Systems
R. 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
M. Eastwood	Thiokol-LSS	SRM Processing

2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

The pre-launch inspection of the MLP-1, Pad B FSS and RSS was conducted on 3 December 2001 from 1500 to 1700 hrs EDT. No flight hardware issues/anomalies were detected.

No facility items were documented in Appendix K of S0007VL4. Minor clean-up items were in-work.

Additional Pad work, including preperations for RSS rollback, was in-work at the conclusion of the Debris Inspection.

After the pre-launch inspection, but before start of propellant loading, PR-ET-TS-0018 was initiated during operation OMI T6446 to document damaged ET TPS. The crushed foam was located under the GO2 pressurization line at Xt-852. The area measured 1-1/2 inches in diameter, with a depth of ¼-inch. Since the area where the damaged foam was located has underlying foam of approximately 4-inches thick, the PR was dipositioned to use-as-is, with Material Review Board (MRB) approval.

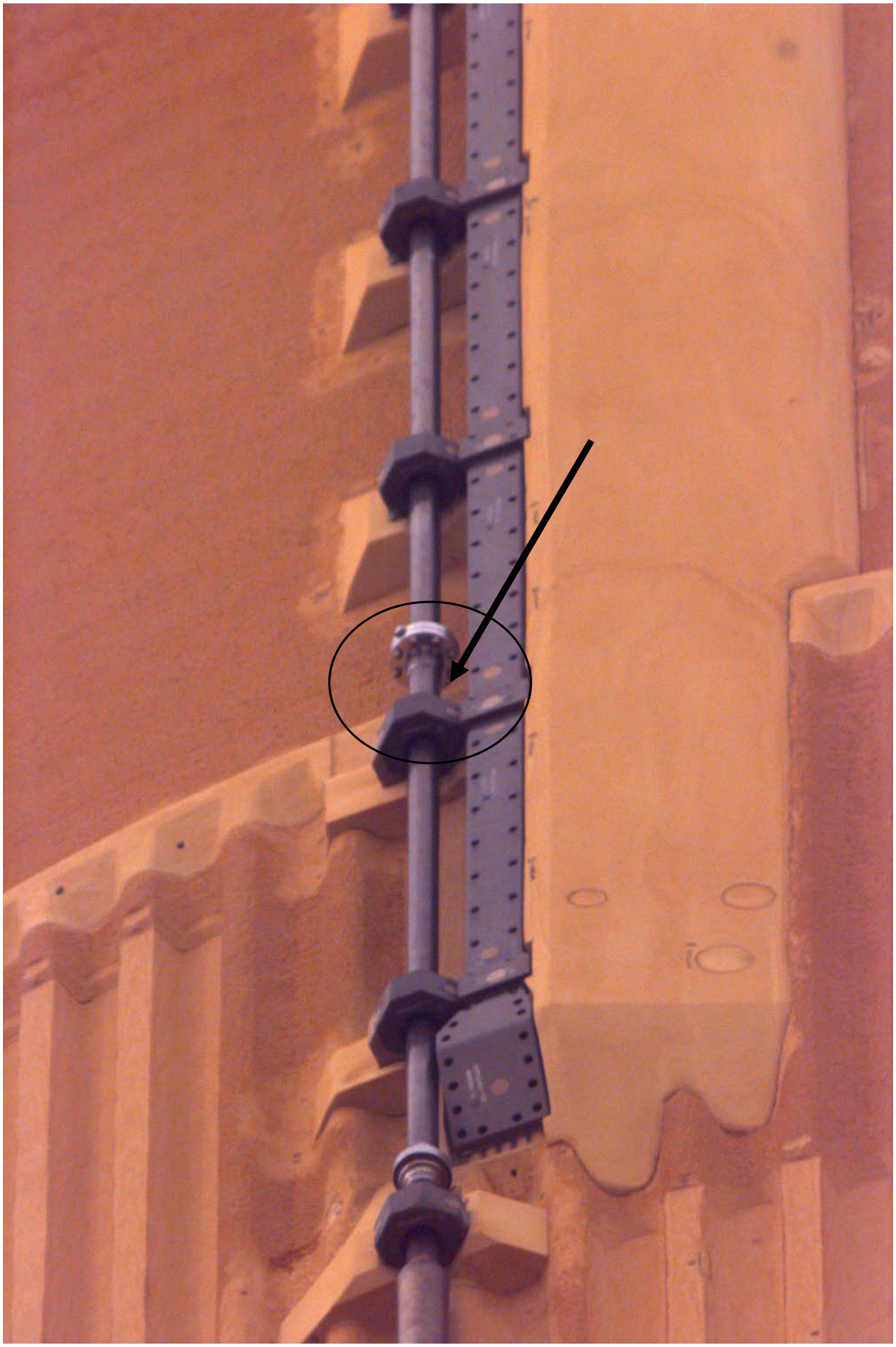


Photo 2: Area of damaged ET TPS under GO2 Pressurization line

PR-ET-TS-0018 was initiated to document crushed foam.

3.0 SCRUB

3.1 FINAL INSPECTION – Weather Scrub

The Final Inspection of the cryoloaded vehicle was performed from 1115 to 1250 hrs on 4 December 2001 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database.

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.

3.1.1 ORBITER

No Orbiter tile or RCC panel anomalies were observed. The RCS thruster paper covers were intact though covers for thrusters F1L, F2D, and R4U were discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface and from the 3 to 9 o'clock position around the SSME #1 heat shield-to-nozzle interface.

3.1.2 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 70 to 76 degrees F. All measured temperatures were above the minimum requirement.

3.1.3 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
74 Degrees F.	LO2 ogive 64 Degrees F	LO2 Tank 56-68 Degrees F
81% RH	LO2 barrel 56 Degrees F	
7 knots	LH2 upper 51 Degrees F	LH2 Tank 51-61 Degrees F
004 degrees	LH2 lower 61 Degrees F	

The Final Inspection Team observed very light condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. The area of crushed ET TPS documented on PR-ET-TS-0018 was free of any ice/frost formations. There were no TPS anomalies on the LO2 tank.

No significant anomalies were present in the intertank TPS. One crack in the intertank stringer valley TPS was observed (-Z of –Y thrust panel). The crack exhibited no ice, frost, nor offset. Therefore, the crack was acceptable for flight per the NSTS-08303 criteria. Ice and frost accumulations on the GUCP were typical.
The LH2 tank was wet with light condensate. There were no acreage TPS anomalies.

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

A 2-1/2 inch long and 1/8 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, inboard 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.

3.1.4 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.

3.2 T-3 HOURS TO SCRUB

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.

This attempt to launch STS-108 was scrubbed due to inclement weather in the launch area.

3.3 POST DRAIN INSPECTION

The post drain inspection of STS-108, MLP-1, and Pad B FSS was conducted on December 4, 2001 from 2300 to 0015 hours under dark conditions. Nevertheless, visibility was adequate for the inspection.

No MLP deck or facility anomalies were detected.

Likewise, no anomalies were observed on the SRBs.

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

The GOX vent arm was in the retracted position. 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 detank Pad inspection also verified no anomalies in this area. No topcoat was missing from the nose cone area under 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 cryogenic stress relief crack in the –Y vertical strut forward facing TPS closed up during vehicle warm up and was no longer visible by the time the post drain inspection team reached that location to visually inspect.

The only ice remaining was located in the LO2/LH2 feedline bellows, the lower EB fittings, and on the ET/ORB umbilical purge vents.

The three ET burst discs were monitored from the LCC Firing Room 2 via OTV and inspected from the MLP Zero Level and no anomaly was observed.

In summary, no IPR conditions and no flight hardware concerns were detected during the post drain inspection. There were no constraints for the next cryoload.

4.0 LAUNCH

4.1 PRE-LAUNCH SSV/PAD INSPECTION

The Post-Drain and additional T-8 hour inspection of the Pad and SSV performed as a result of the weather scrub satisfied the pre-launch inspection requirement. No new issues or concerns were detected.

4.2 FINAL INSPECTION

The Final Inspection of the cryoloaded vehicle was performed from 1130 to 1310 hrs on 5 December 2001 during the two-hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria (LCC) or OMRS criteria violations. There was no acreage icing concerns. There was also no protuberance icing conditions outside of the established database.

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 F1L, F2D, F3D and R4U were discolored. Ice/frost had formed all the way around the SSME #2 heat shield-to-nozzle interface and from the 3 to 9 o'clock position around the SSME #1 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 70 to 75 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 66 Degrees F	LO2 Tank 57-75 Degrees F
84% RH	LO2 barrel 62 Degrees F	
13 knots	LH2 upper 61 Degrees F	LH2 Tank 59-78 Degrees F
069 degrees	LH2 lower 65 Degrees F	

The Final Inspection Team observed very light condensation on the LO2 tank acreage. No acreage ice/frost formations were observed. As in the previous tanking the area of crushed ET TPS documented on PR-ET-TS-0018 was free of any ice/frost formations. There were no TPS anomalies.

No significant anomalies were present in the intertank TPS. One crack in the intertank stringer valley TPS was observed (-Z of –Y thrust panel). This was the same crack identified on the inspection the previous day. The crack exhibited no ice, frost, nor offset. Therefore, the crack was acceptable for flight per the NSTS-08303 criteria. Frost spots were observed above fasteners in the intertank valleys (4th and 5th intertank valleys –Z of the –Y thrust panel and between 16th and 17th stringers +Z of the –Y thrust panel). This condition is acceptable per NSTS-08303. Ice and frost accumulations on the GUCP were typical.

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

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

A 2-1/2 inch long and 1/8 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.

A small frost spot was detected at approximately the 1 o'clock position on the forward edge of the +Y thrust strut knuckle. This frost spot was dissipating as time went on due to all the condensate running off in the area. This frost formation is acceptable per NSTS-08303. 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, inboard 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.

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-108 launched at 22:19:27 UTC (5:19 pm local) on December 5, 2001.

Photo 3: LO2 tank acreage.

Very little condensate was present on the LO2 tank acreage. Surface temperature ranged from 57-75 degrees Fahrenheit. There were no acreage TPS anomalies.

Photo 4: LH2 tank acreage.

The LH2 tank was wet with moderate condensate on the upper portion and significantly more condensation at the aft end. Surface temperature ranged 59 to 78 degrees Fahrenheit. There were no acreage TPS anomalies.

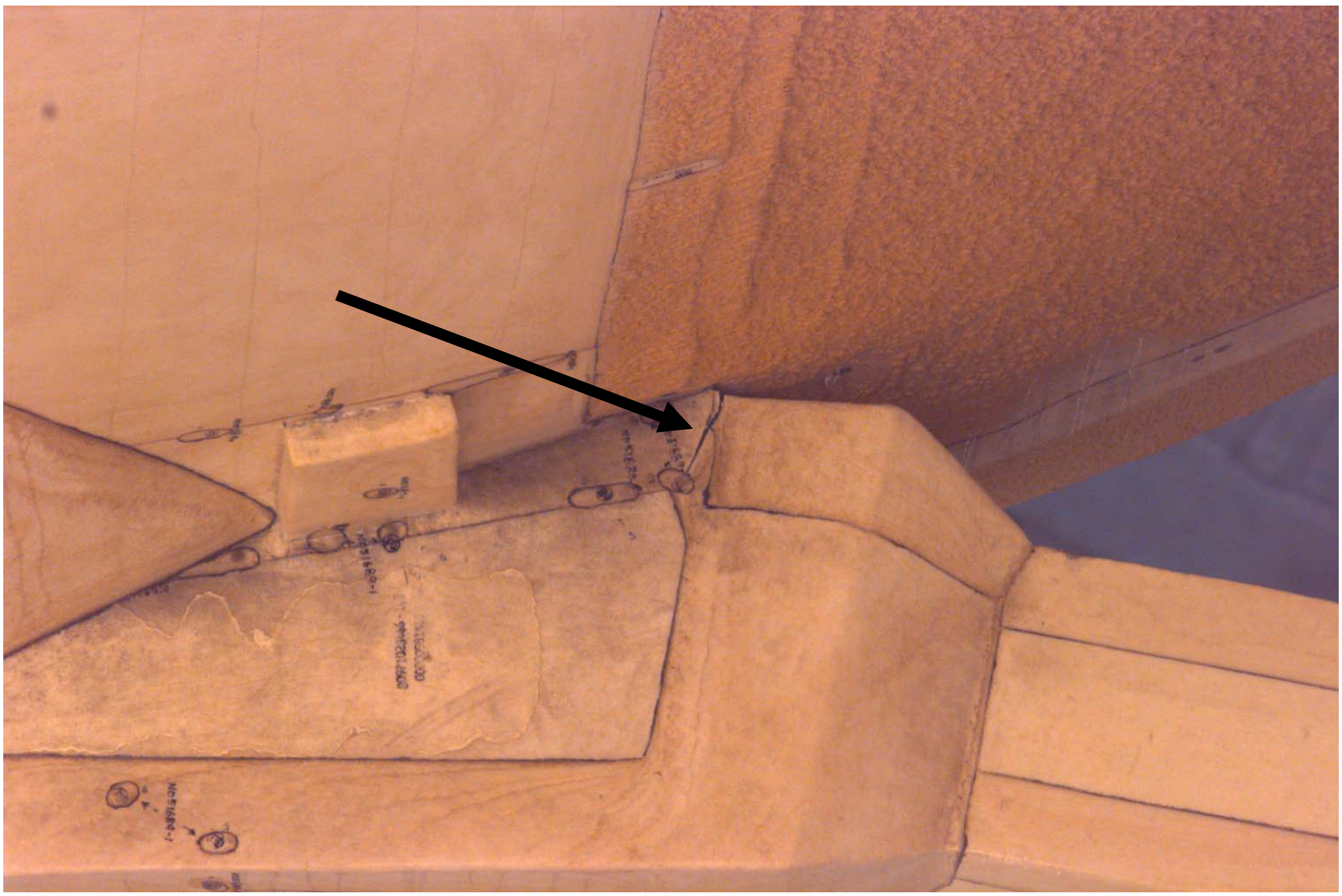


Photo 5: Crack in –Y Vertical Strut TPS

A 2-1/2 inch long and 1/8 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.

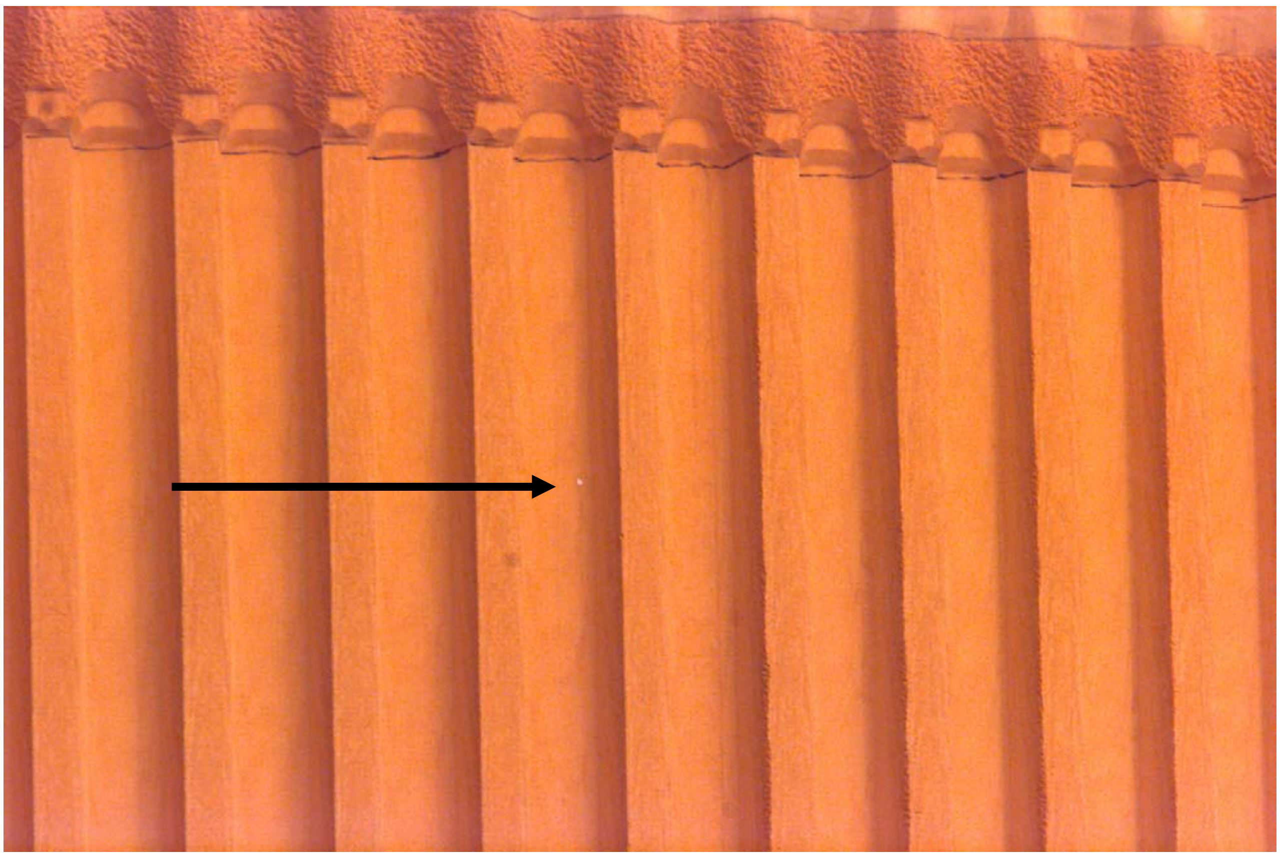


Photo 6: Frost spot over fastener location in intertank valley.
One of four frost spots observed above fasteners.

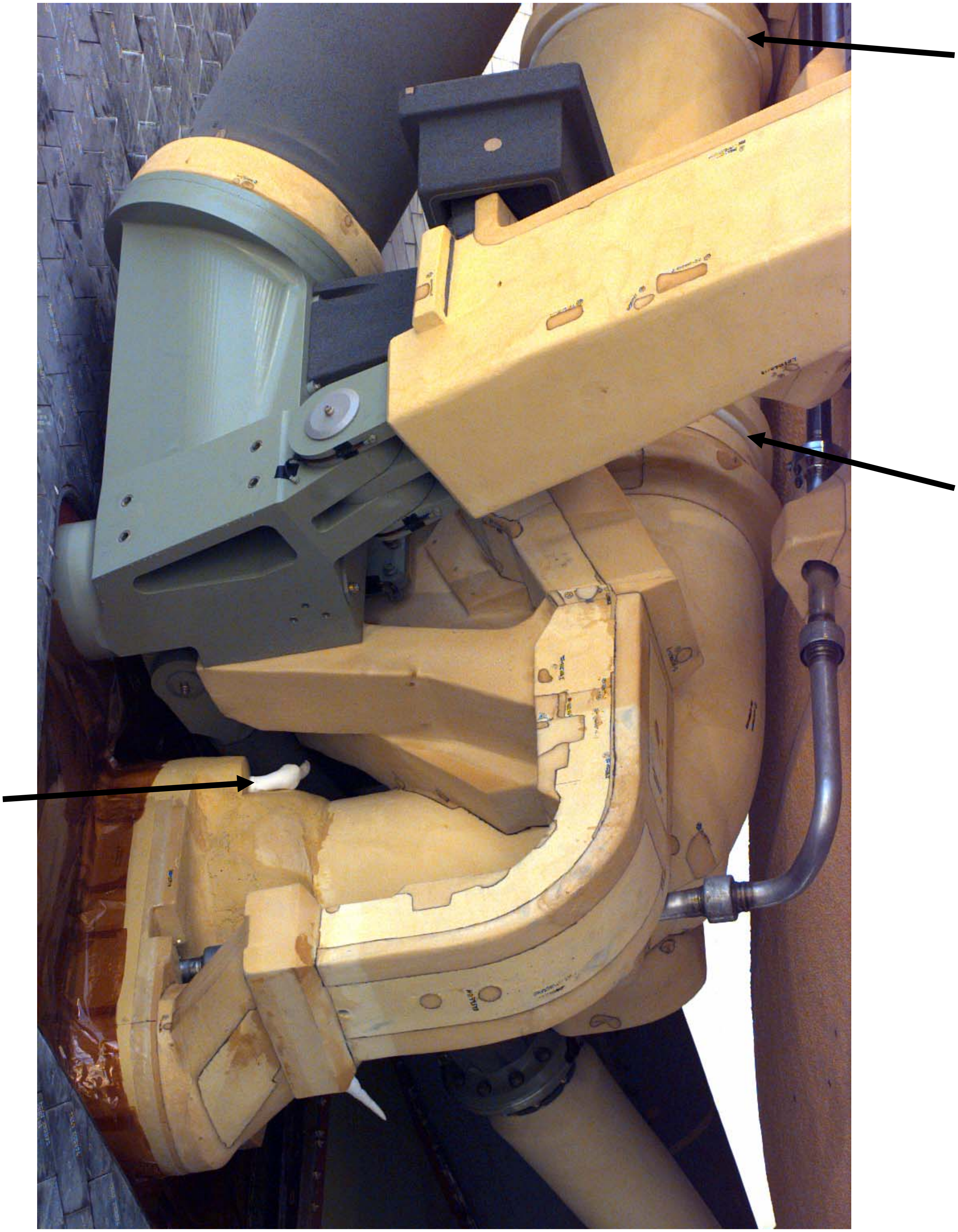


Photo 7: LO2 Umbilical area.

Typical ice/frost finger on pyro canister vent and on LO2 feedline bellows.

5.0 POST LAUNCH PAD DERBIS INSPECTION

The post launch inspection of the MLP-1, Pad B FSS and RSS was conducted on 5 December 2001 from Launch + 2.75 to 4.5 hours (2000 to 2230 EST).

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 0.09G. 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 purge line and the metal braid was partially eroded on the LH purge line.

The LO2 and LH2 Tail Service Masts (TSM) appeared undamaged and the LO2 bonnet was observed to have closed properly. The MLP deck was in generally good shape. All MLP deck communication connector caps were found intact and secured.

The GH2 vent line did not latch on the FSS latching mechanism. It appears the vent line impacted the south side of the FSS structure preventing the latch back and caused substantial damage to the saddle structure. The south side bridle cable sheared from the southern tang on the yoke. Pieces of debris (bolts and clevis leg) were found on/in the grating and vent line structure. The GUCP sustained minor damage from the vent line impact with the FSS. The 7-inch QD exhibited no damage and the poppet was observed to be intact. The deceleration cable was in nominal configuration, and the vent line blanket was sooted and torn. IFA STS-0108-K-001 was generated to document and investigate the anomaly.

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. The access door window on the north side of the hood was broken with loss of material. A major hydraulic leak was observed on the GOX vent arm/FSS structure hinge (255' Level).

Debris findings included:

- FSS 235' level loose cable tray cover latch.
- RSS 215' level broken light fixture.
- FSS 215' level electrical box shorted out burning through the box.
- FSS 175' level pressure gauge cover was found near gauge on grating.
- FSS 155' level pressure gauge cover was noted in cable tray (source not determined).
- MLP deck a piece of steel cable with swedge (kellum grip) was found on the east side.
- Pad surface a 7/8" facility nut was found near the MLP North West pedestal.
- Pad surface numerous pieces of fragmented metal were found (1/16" aluminum)

Overall damage to the pad appeared to be slightly greater than nominal.

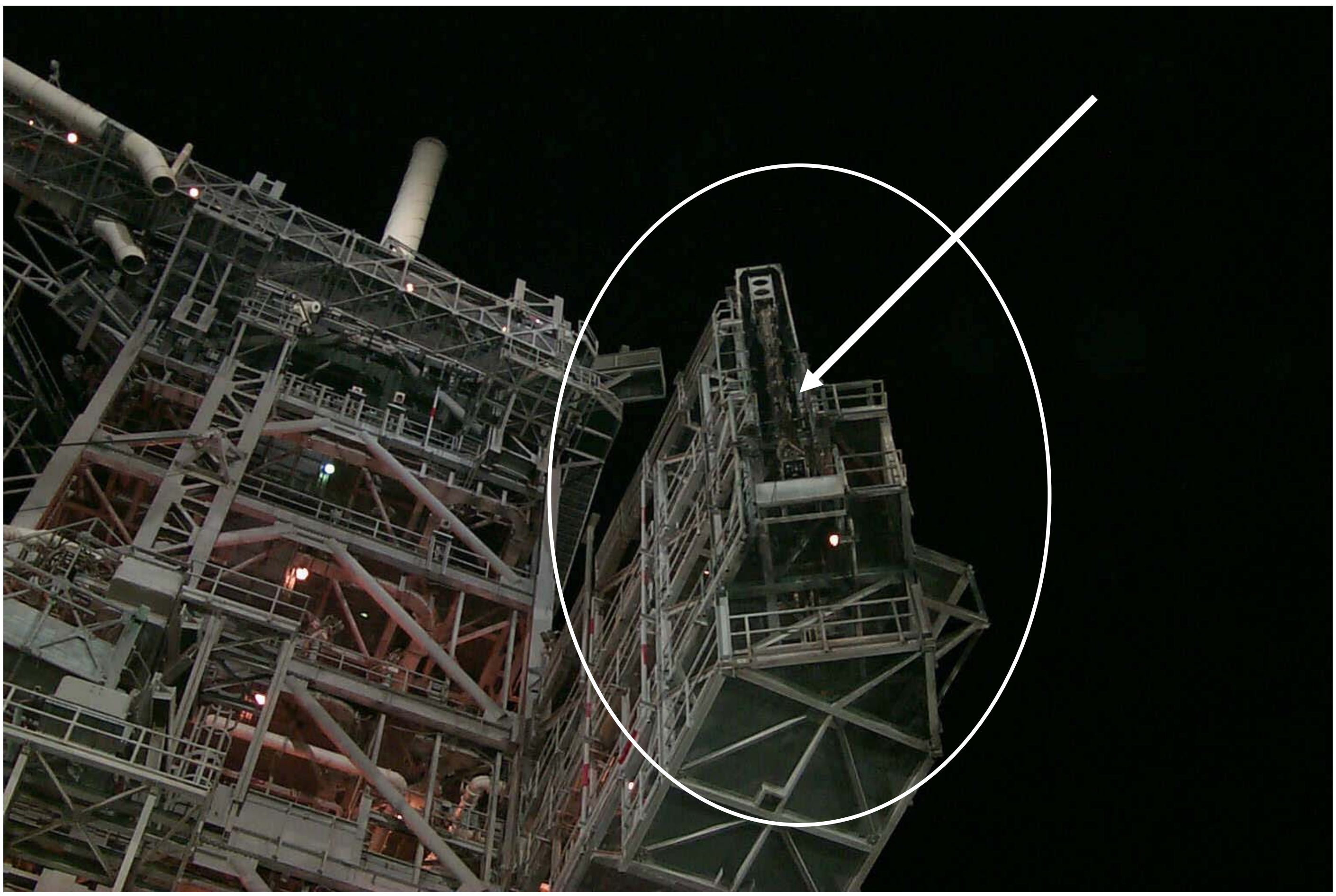


Photo 8: Overall view of GH2 vent line haunch on the FSS post launch.

GH2 vent line struck the FSS and failed to latch back.

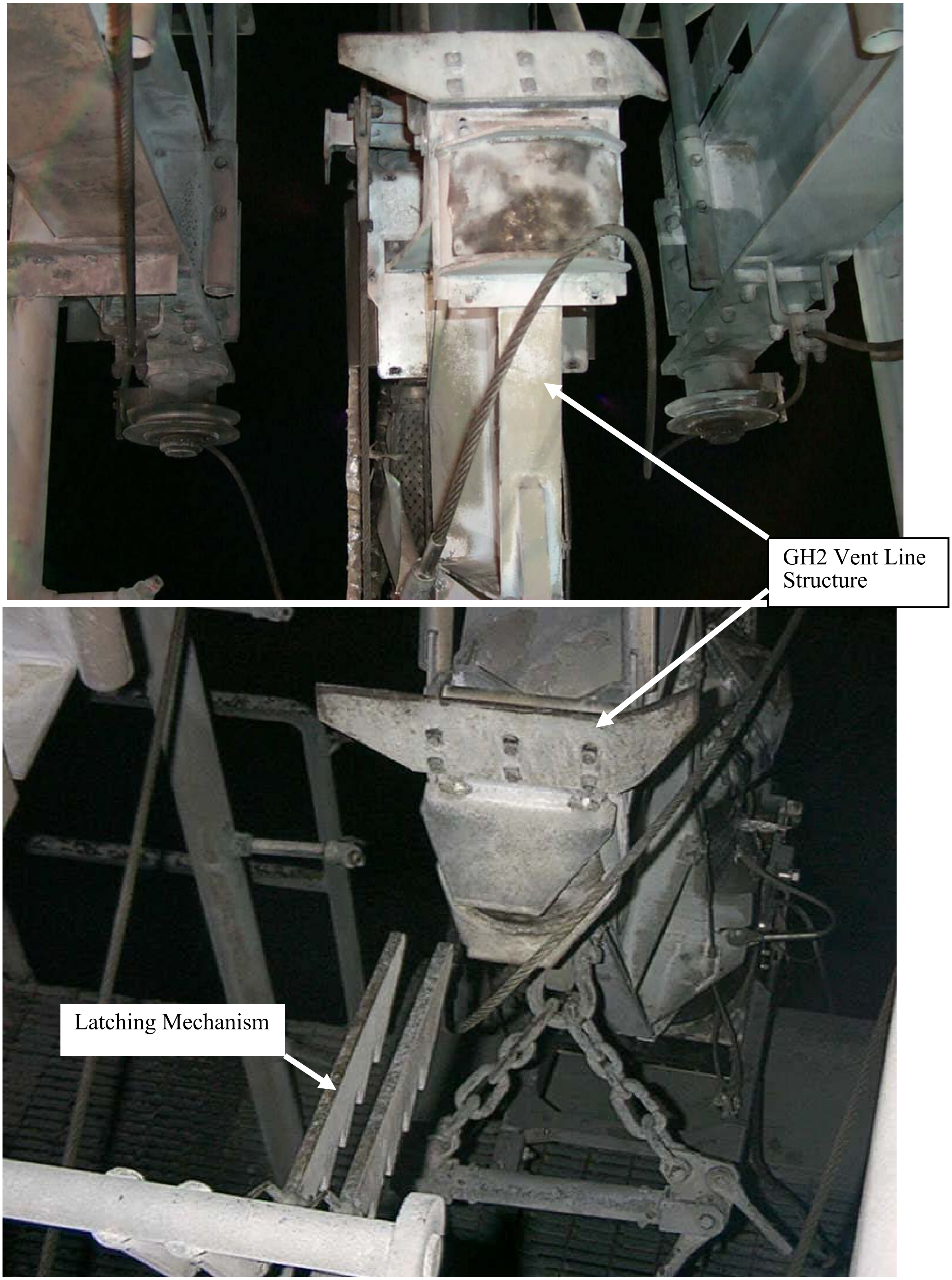


Photo 9: Detail view of some of the damage sustained by the GH2 vent line after impact with FSS.

6.0 FILM REVIEW

Gaseous Hydrogen vent line contacted south side of support structure at two locations; the saddle plate and the bridle cable connection. Contact caused debris, which fell toward SRB exhaust. Vent line did not latch-back and rebounded approximately 3-feet. No contact with flight hardware was observed. (E-41, E-42, E-60) IFA STS-0108-K-001 was generated to investigate the cause.

6.1 LAUNCH FILM AND VIDEO SUMMARY

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

SRB separation appeared normal. (E-207, E-212, E-223)

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

Charring on the ET aft dome was typical. (E-207, E-220, E-223, E-224)

Umbilical purge barrier baggie material fell during roll maneuver. (E-52, E-207, E-212, E-220, E-222)

Forward RCS paper covers were observed falling aft during early ascent. (E-52, E-54, E-207, E-212, E-213, E-220, E-222, E-223, E-224)

Pieces of facility debris entered field of view well after vehicle cleared tower. (E-36, E-40).

Ice from forward LO2 feedline bellows seen falling between ET and Orbiter. No contact with orbiter noted. (E-34, E-40)

GUCP separation from ET nominal. (E-33)

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

After T-0 object seen moving across field of view toward camera E-1 and away from flight hardware. No contact with flight hardware noted. (E-1)

No OMS pod flexing observed. (E-17, E-18)

Debris particle observed emanating from near DCS of HDP #1, moves away from the SRB and aft of orbiter. No contact with flight hardware. (E-9)

Piece of debris noted between HDP 3 and shoe. (E-10)

RTV from base of HDP ejected out of SRB hole and contacted top of HDP #3 blast cover momentarily before being expelled. No contact with flight hardware. (E-10, E-15)

Free-burning GH2 was blown toward vertical stabilizer.

Several ice particles fell from ET/ORB umbilicals during SSME ignition.

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

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

Tile surface coating material was lost from aft face of LH OMS RCS stinger. This is a common occurrence due to SSME ignition acoustics. (E-20)

SRB throat plug material ejected from exhaust hole. No contact with vehicle.

Deluge water pipe leaking adjacent to HDP 8, water dripping on MLP deck. (E-14)

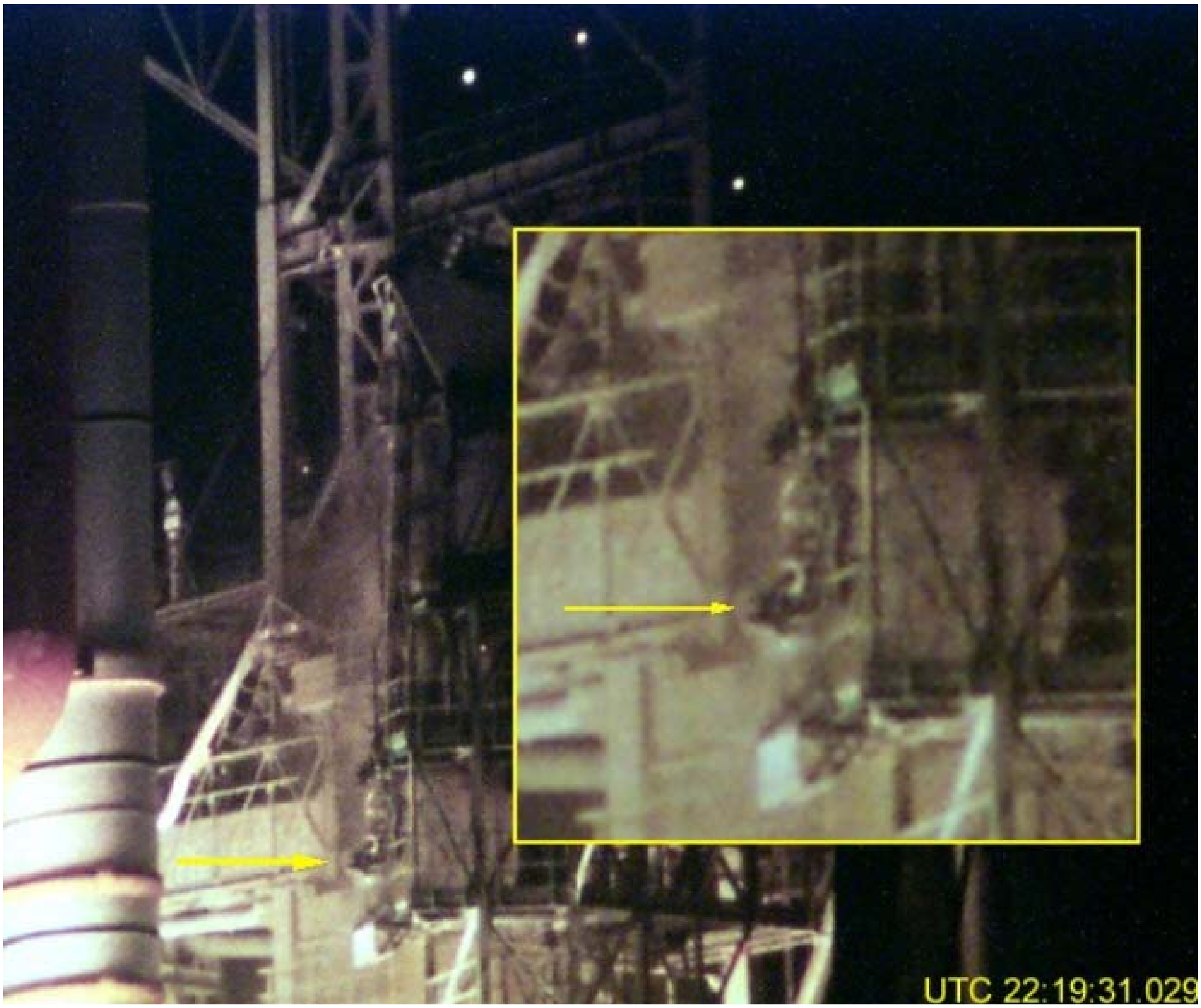


Photo 10: GH2 Vent Line strikes FSS, generating debris, and fails to latch-back.
This view shows the maximum rebound of the vent line.

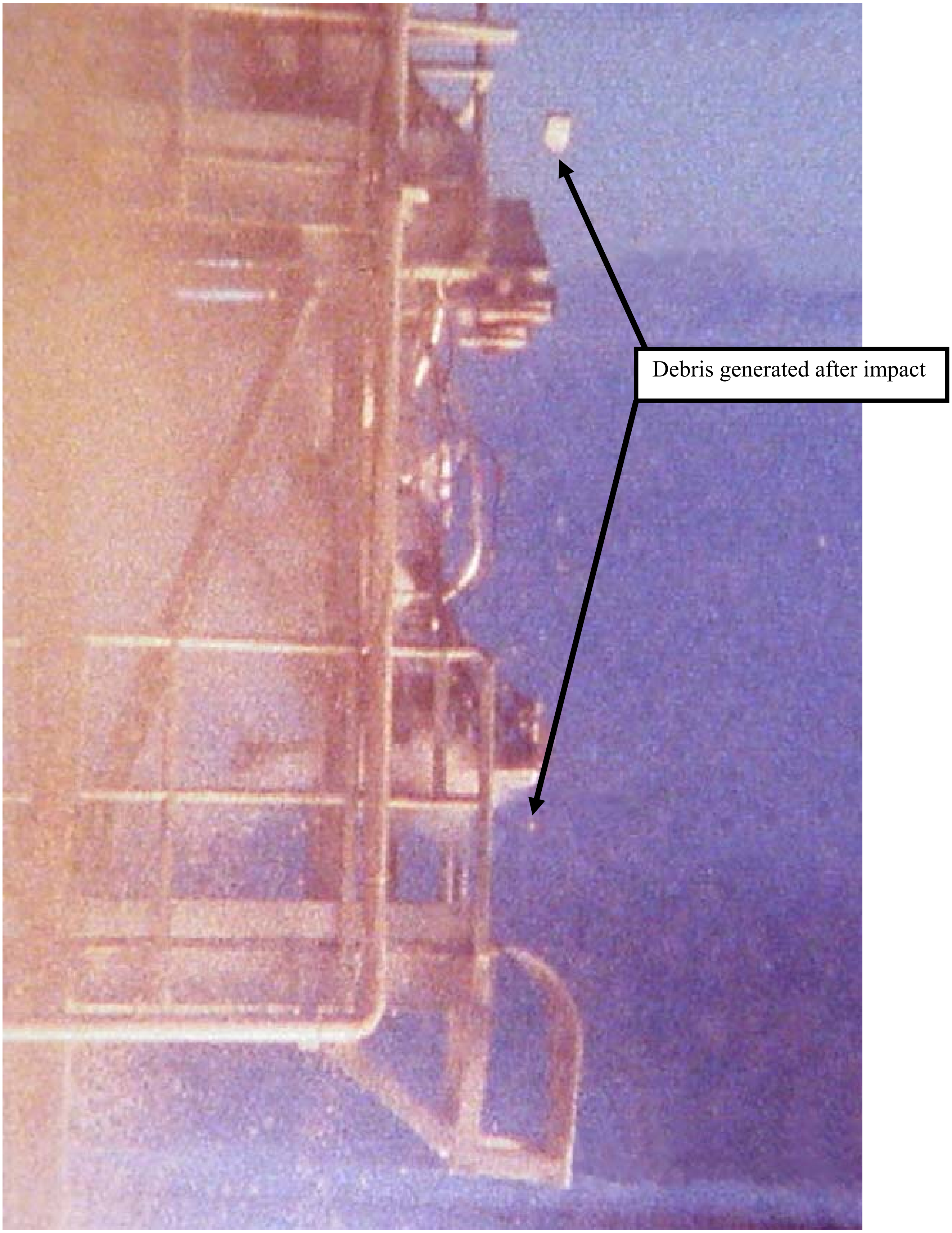


Photo 11: GH2 Vent Line strikes FSS, generating debris, and fails to latch-back.

6.2 ON-ORBIT FILM AND VIDEO SUMMARY

16mm film motion picture films from the LH2 umbilical cameras were reviewed. The 35mm still images from the LO2 ET/ORB umbilical camera and Crew Hand-Held Still Images, of the External Tank were not taken due to darkness.

Left-hand SRB separation appeared to be nominal.

Ablation and charring of the ET/Orbiter LH2 cable tray and the –Y vertical strut thermal protection appeared normal.

The ET separation from the Orbiter was in darkness and could not be analyzed.

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. However, a hole in the drag chute canopy was observed. Post landing evaluation of drag chute revealed that ribbons 34 through 40 on gore 31, as well as a vertical ribbon were broken. No exact cause of the tear could be determined from the evaluation or the films.

No additional anomalies were detected from touchdown through rollout.

7.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

The BI-110 Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 8 December 2001. 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 and locked, but one 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, though one layer of the LH and RH SRB +Z antenna phenolic base plate had delamination at the edge.

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

The holddown post Debris Containment Systems (DCS) appeared to have functioned normally except on HDP No. 1 which was fully obstructed by the frangible nut halves. This condition most likely happened at water impact.

No indication of stud hang up was observed.

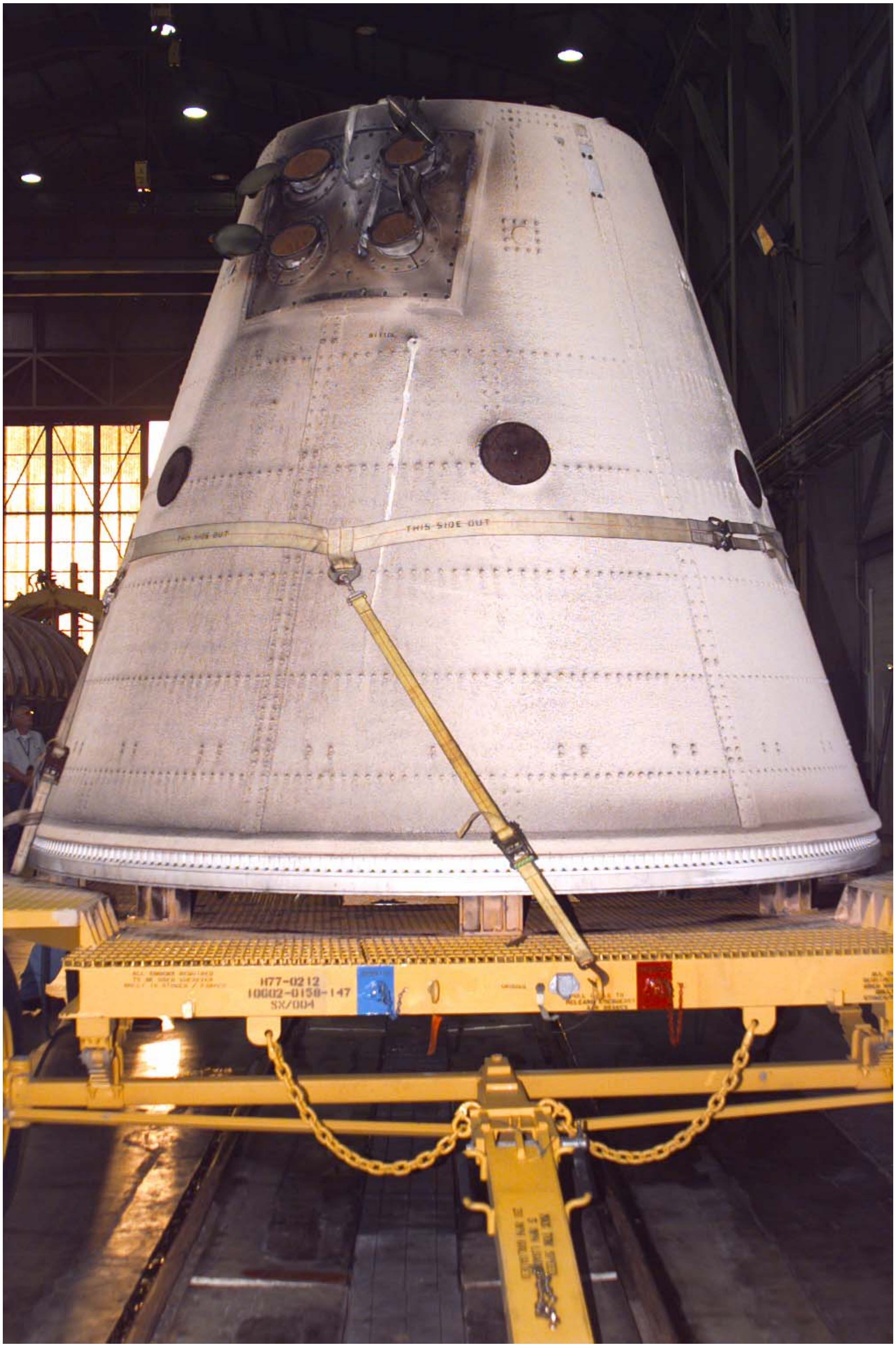


Photo 12: LH Frustum Post Flight Condition

The LH SRB frustum exhibited no debonds/unbonds or missing TPS.

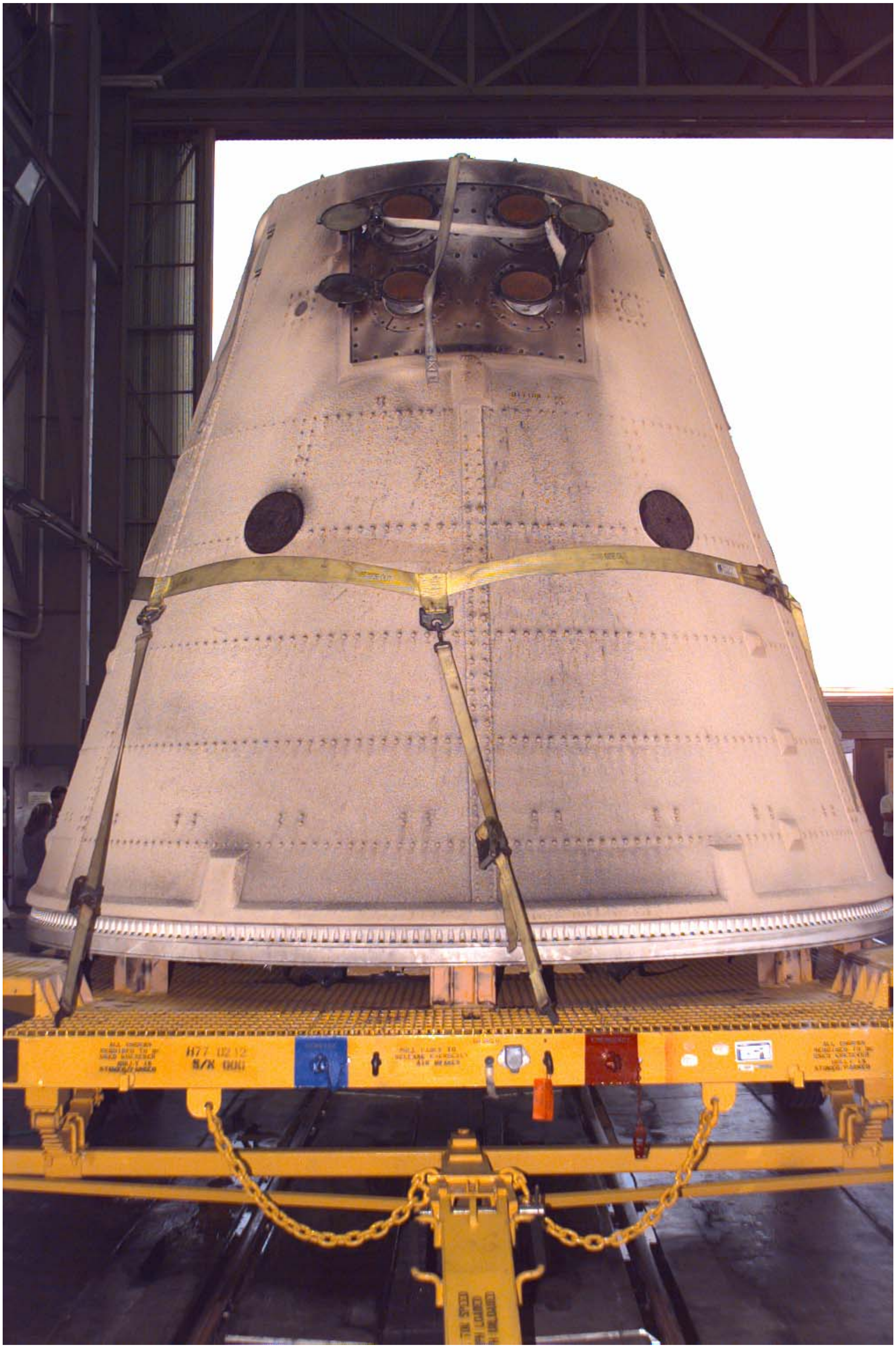
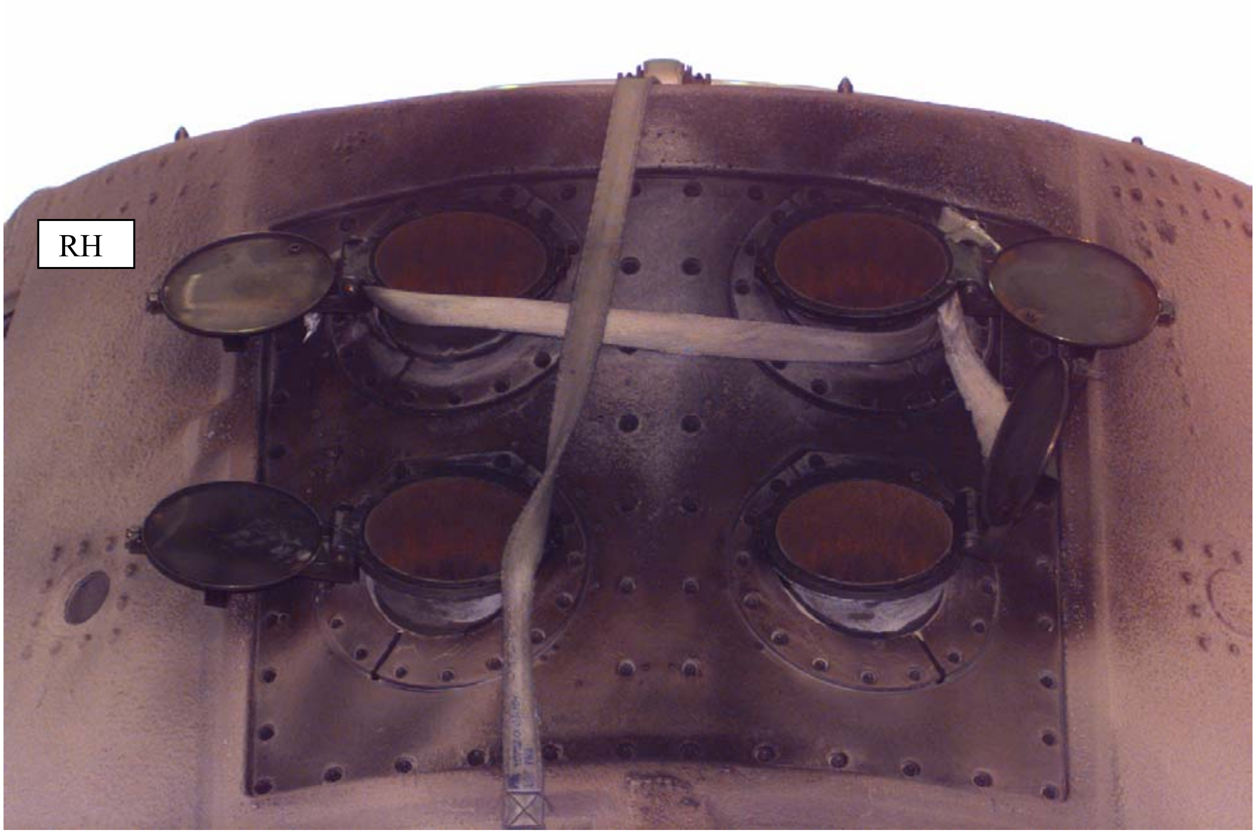


Photo 13: RH Frustum Post Flight Condition

The RH SRB frustum exhibited no debonds/unbonds or missing TPS.



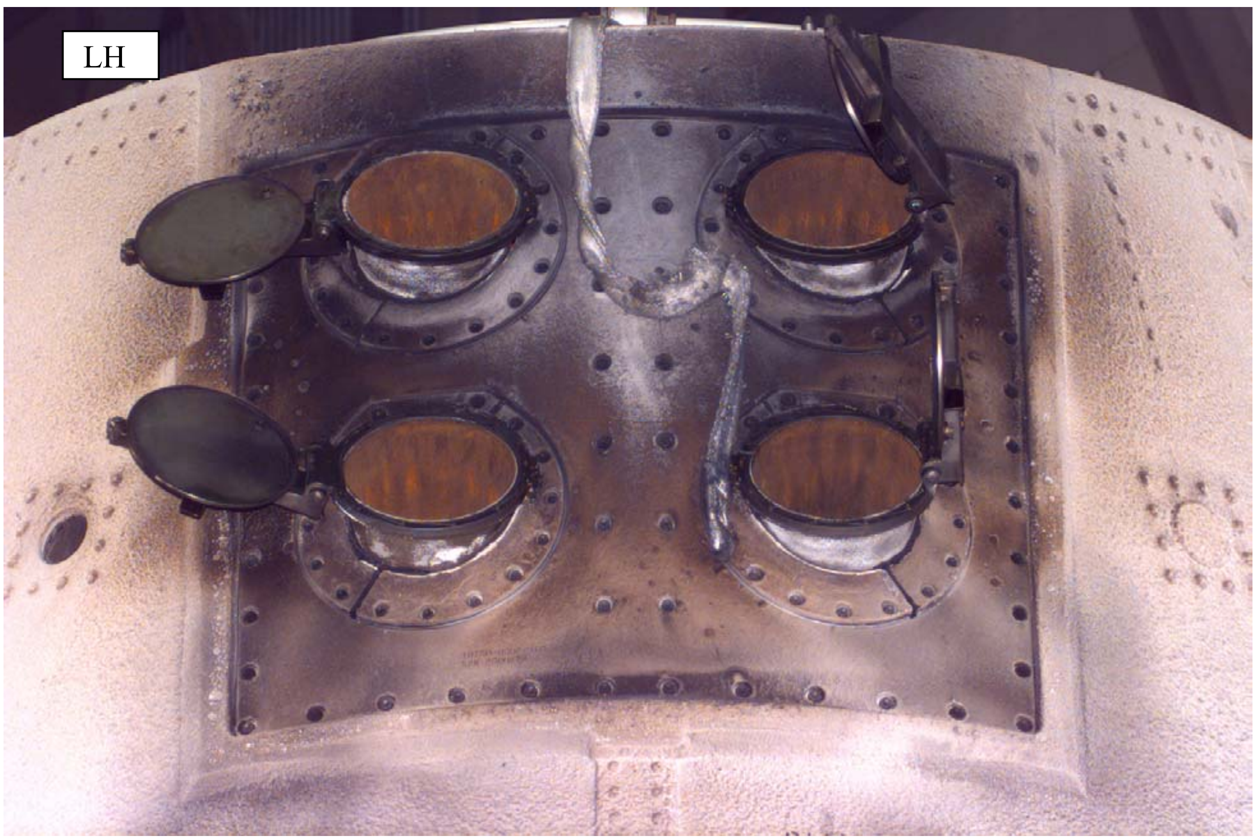


Photo 14: BSM Cover Condition

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

Photo 15: SRB Post Flight Condition
Both SRB's were found in good condition regarding debris assessment

8.0 ORBITER POST LANDING DEBRIS ASSESSMENT

After the 12:56 p.m. local/eastern time landing on 17 December 2001, a post landing inspection of OV-105 Endeavour was conducted at the Kennedy Space Center on SLF runway 15 and in Orbiter Processing Facility bay 1. This inspection was performed to identify debris impact damage and, if possible, debris sources.

The Orbiter TPS sustained a total of 95 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-108 Orbiter damage hits by area:

	HITS > 1-inch	TOTAL HITS
Lower Surface	17	81
Upper Surface	1	1
Window Area	4	13
Right Side	0	0
Left Side	0	0
Right OMS Pod	0	0
Left OMS Pod	0	0
TOTALS	22	95

The Orbiter lower surface sustained 81 total hits, of which 17 had a major dimension of 1-inch or larger, both numbers are well within family. The majority of the hits (49 total with 12 greater than 1-inch) were located in the area aft of the main landing gear wheel wells. Approximately 11 of the total lower surface hits were around the LH2 umbilical area and 24 around the LO2 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 inboard of the RH MLG door, measured 8-1/2 inches long by 1-1/2-inches wide by 3/8-inches deep. The damage spans three separate tiles. The cause of this damage has not been determined yet.

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, though one of the “salad bowl” clips was missing from EO-2 and 6 were missing from EO-3. The EO-2/3 pyro debris shutters were fully closed. A small piece of white RTV (1/2 inch long by 1/8 inch diameter) used for umbilical test-port closeout process was found under the LH2 umbilical. 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 13 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 less than normal.

A 1-1/2 inch diameter by 1/4 inch deep tile damage was noted on the +Z side of the body flap, underneath SSME #3.

The post-landing walkdown of Runway 15 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.

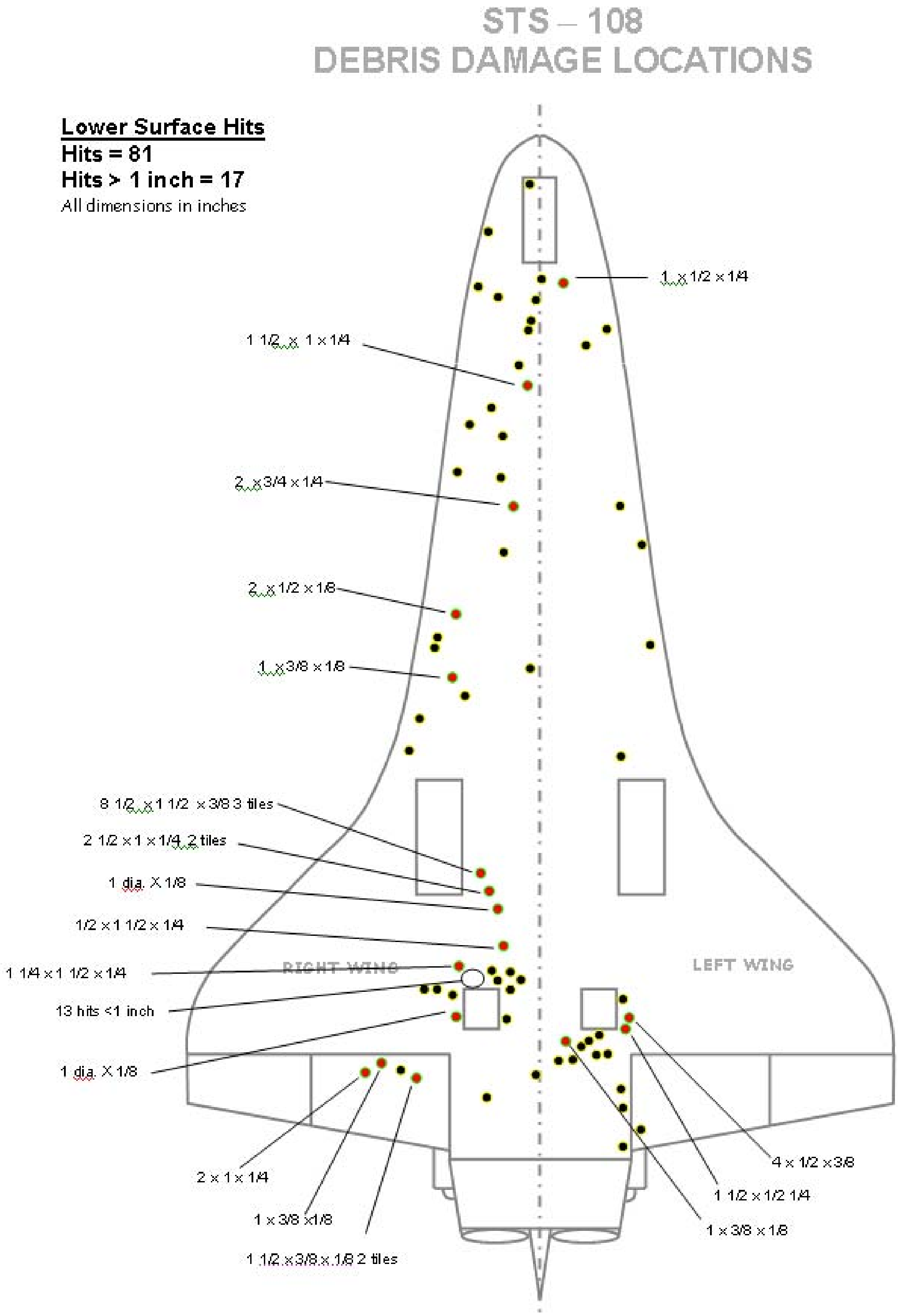


Figure 1: Orbiter Lower Surface Debris Damage Map

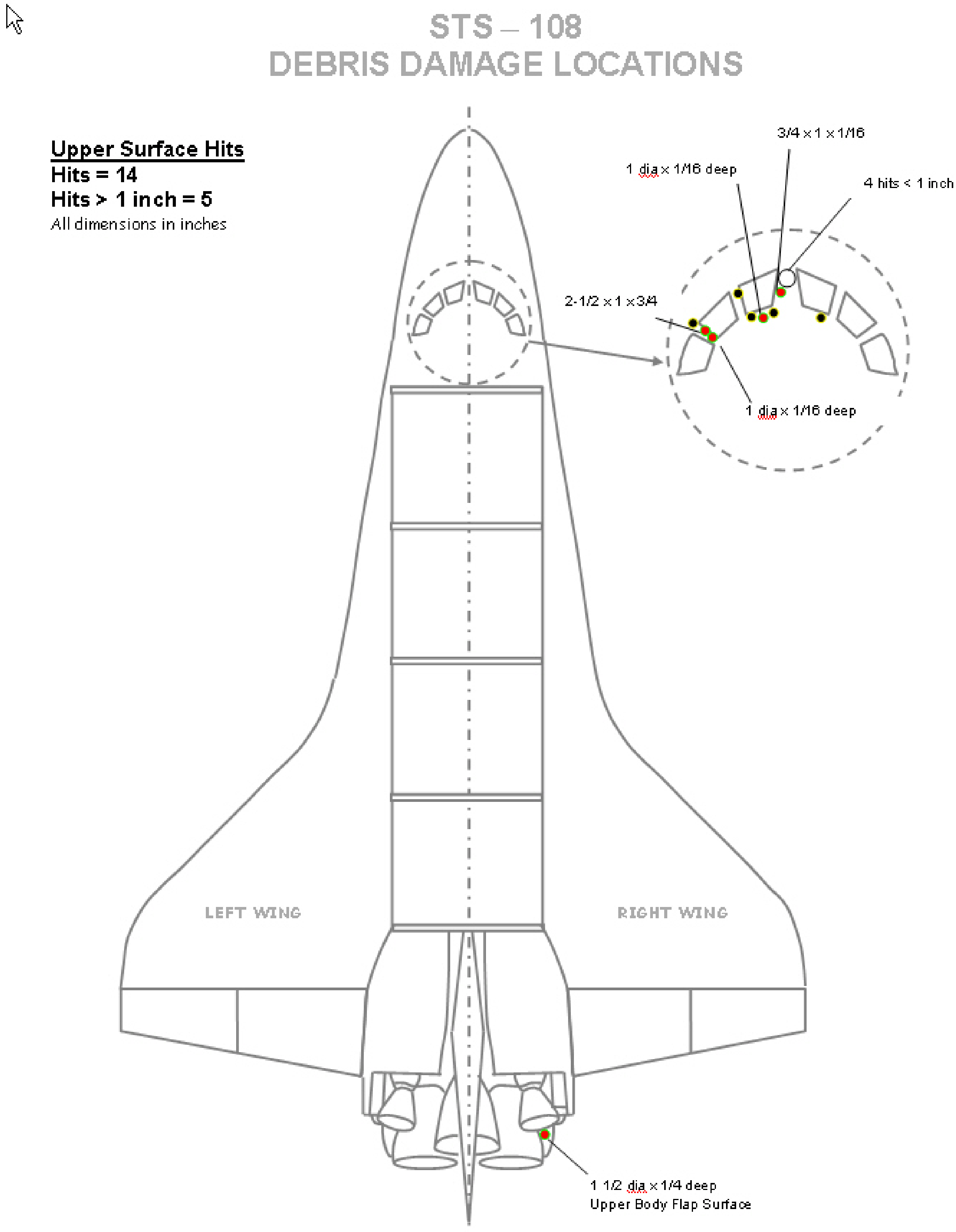


Figure 2: Orbiter Upper Surface Debris Damage Map

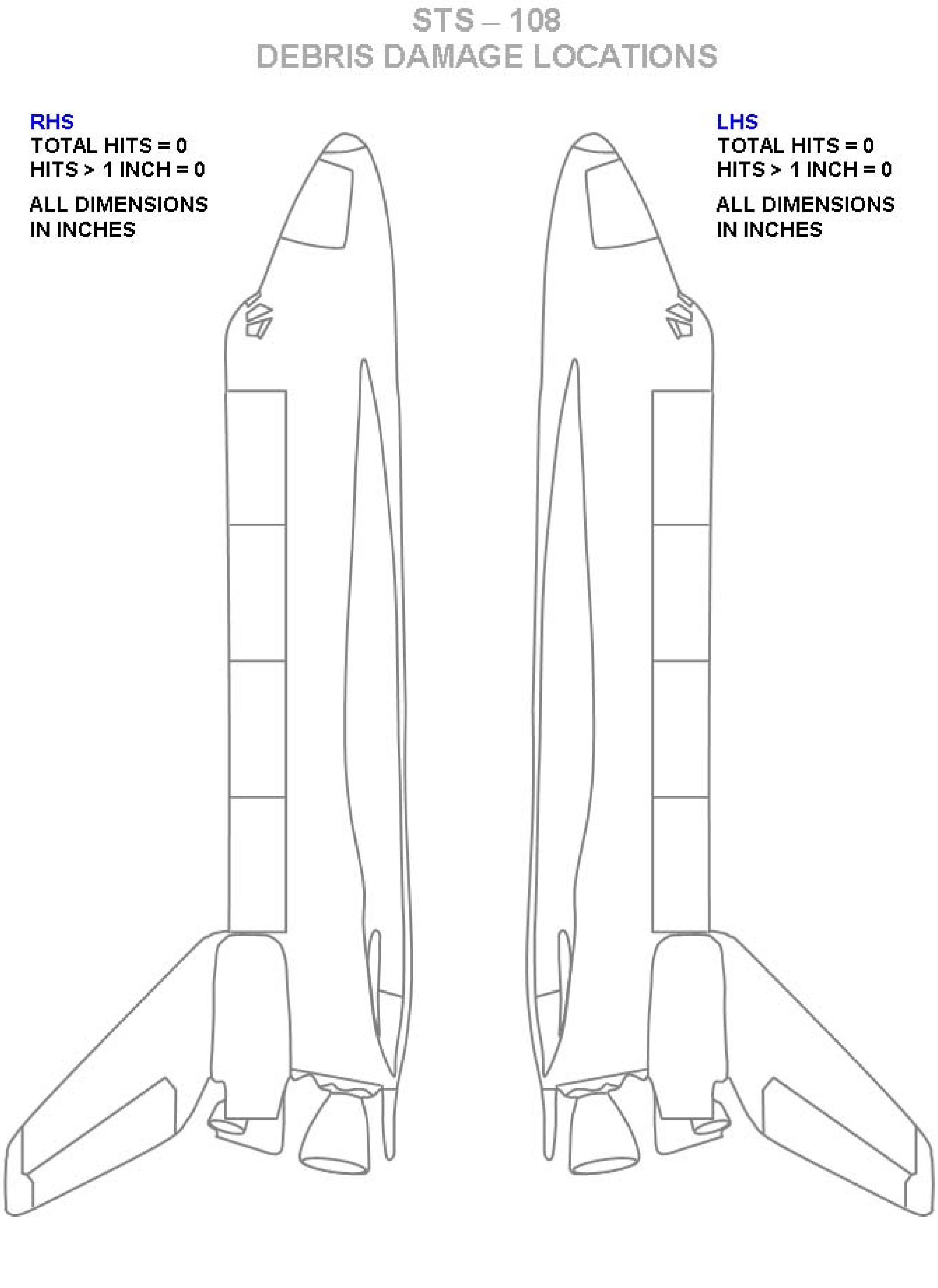
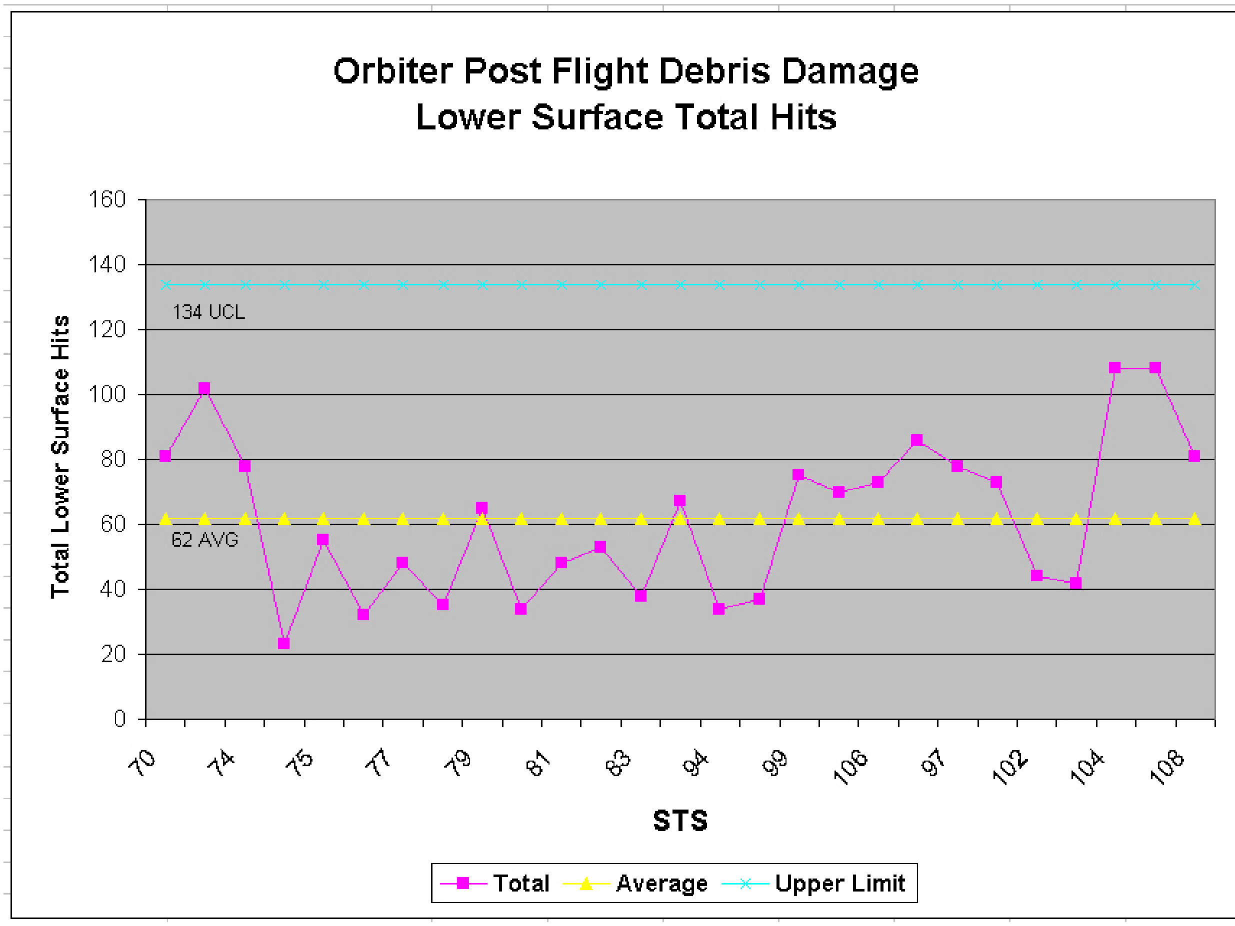


Figure 3: Overall View of Orbiter Sides

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
AVERAGE	11.7	65.3	16.6	104.8
SIGMA	6.0	32.5	6.3	27.9
STS-108	17	81	22	95

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



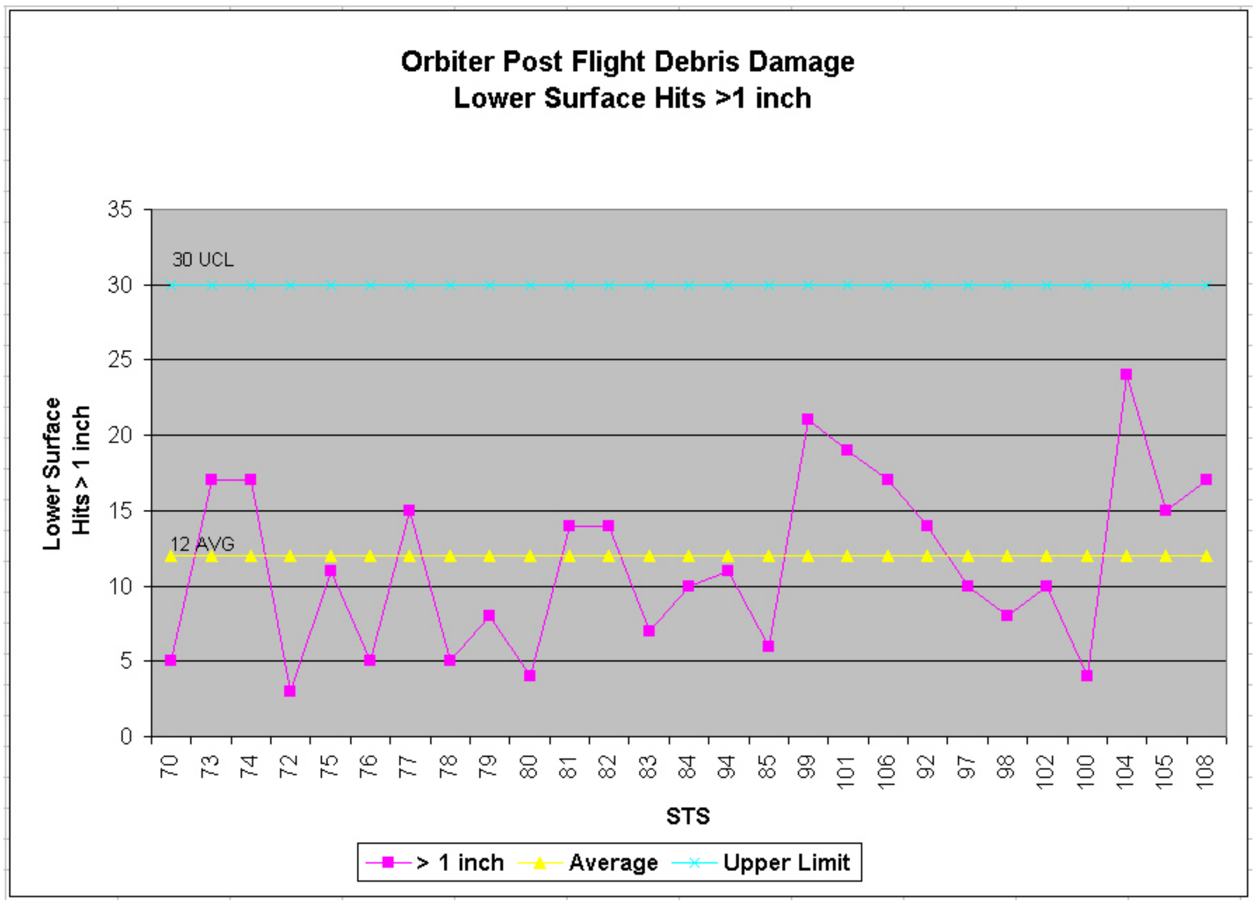
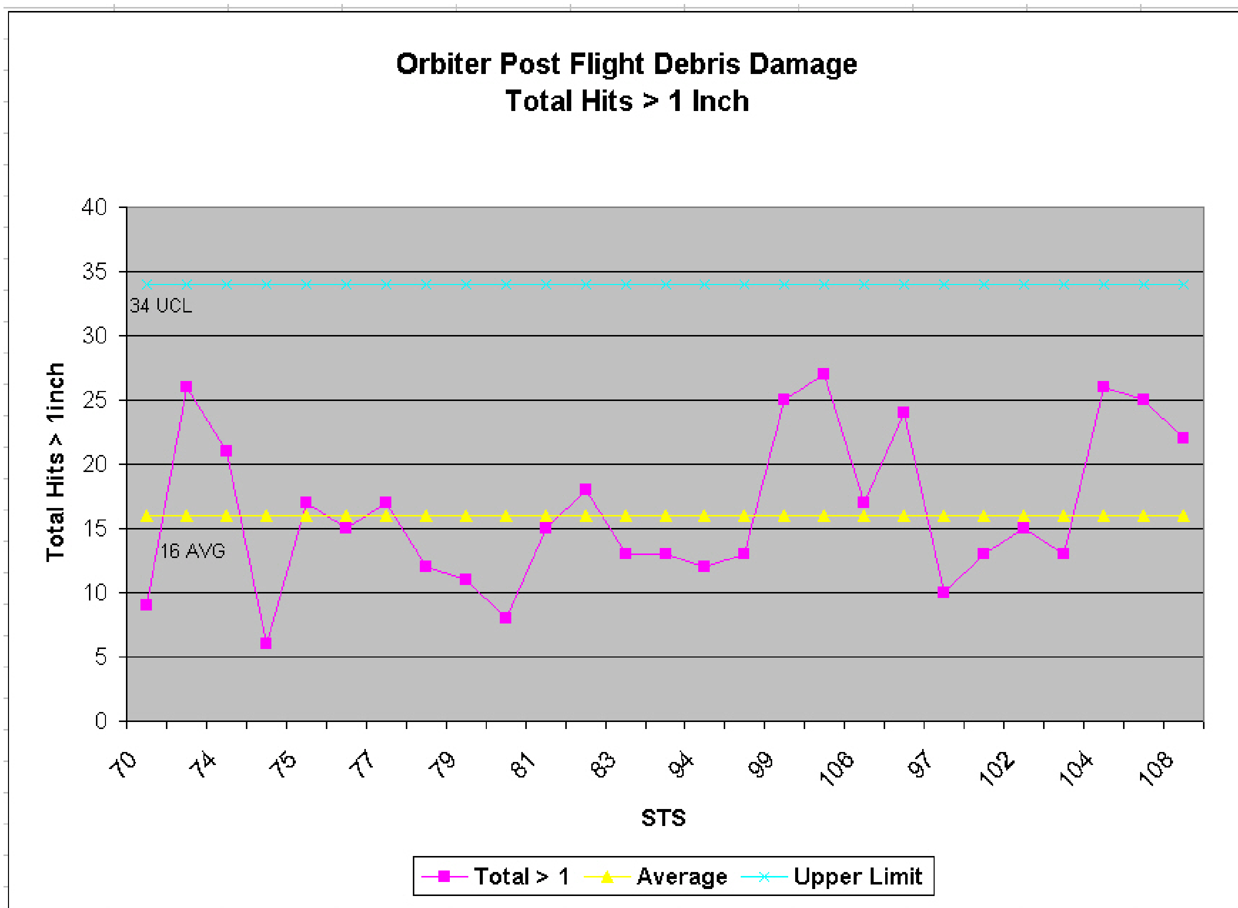


Figure 5: Control Limits for Lower Surface Hits



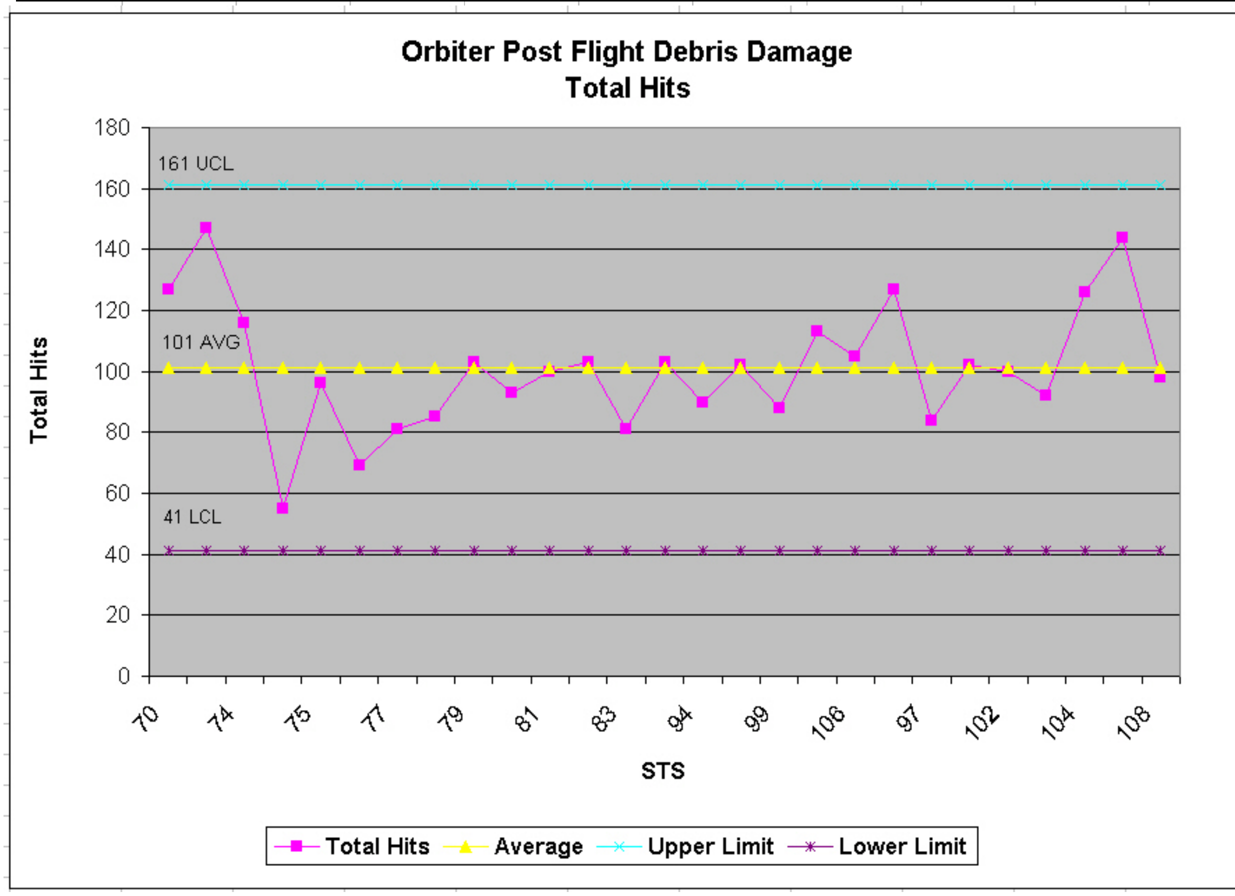


Figure 6: Control Limits for Total Hits

Photo 16: Overall View of Orbiter sides

The Orbiter TPS sustained a total of 95 hits of which 22 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 17: Overall View of Orbiter Windows

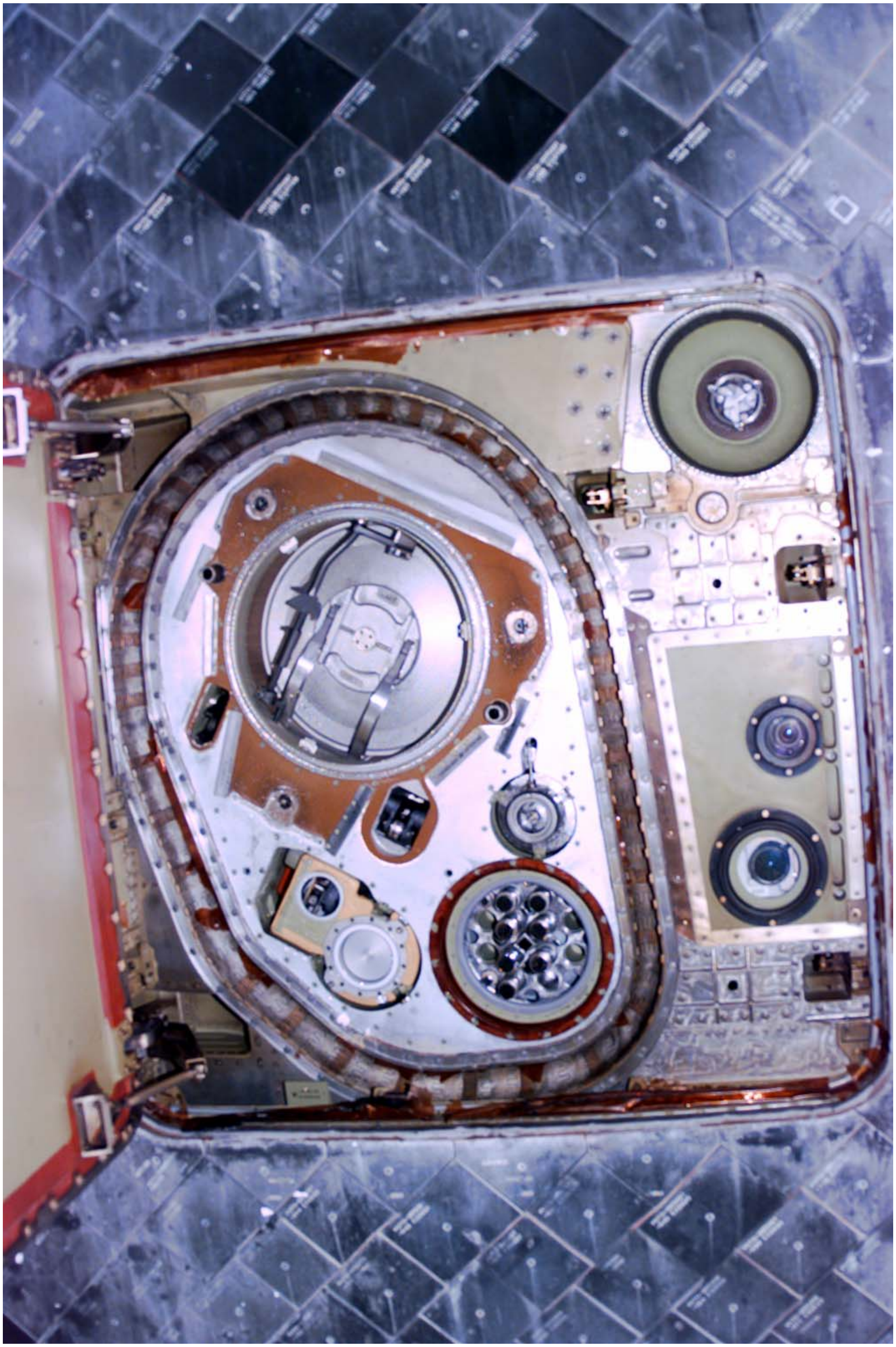


Photo 18: ORB/ET LH2 Umbilical

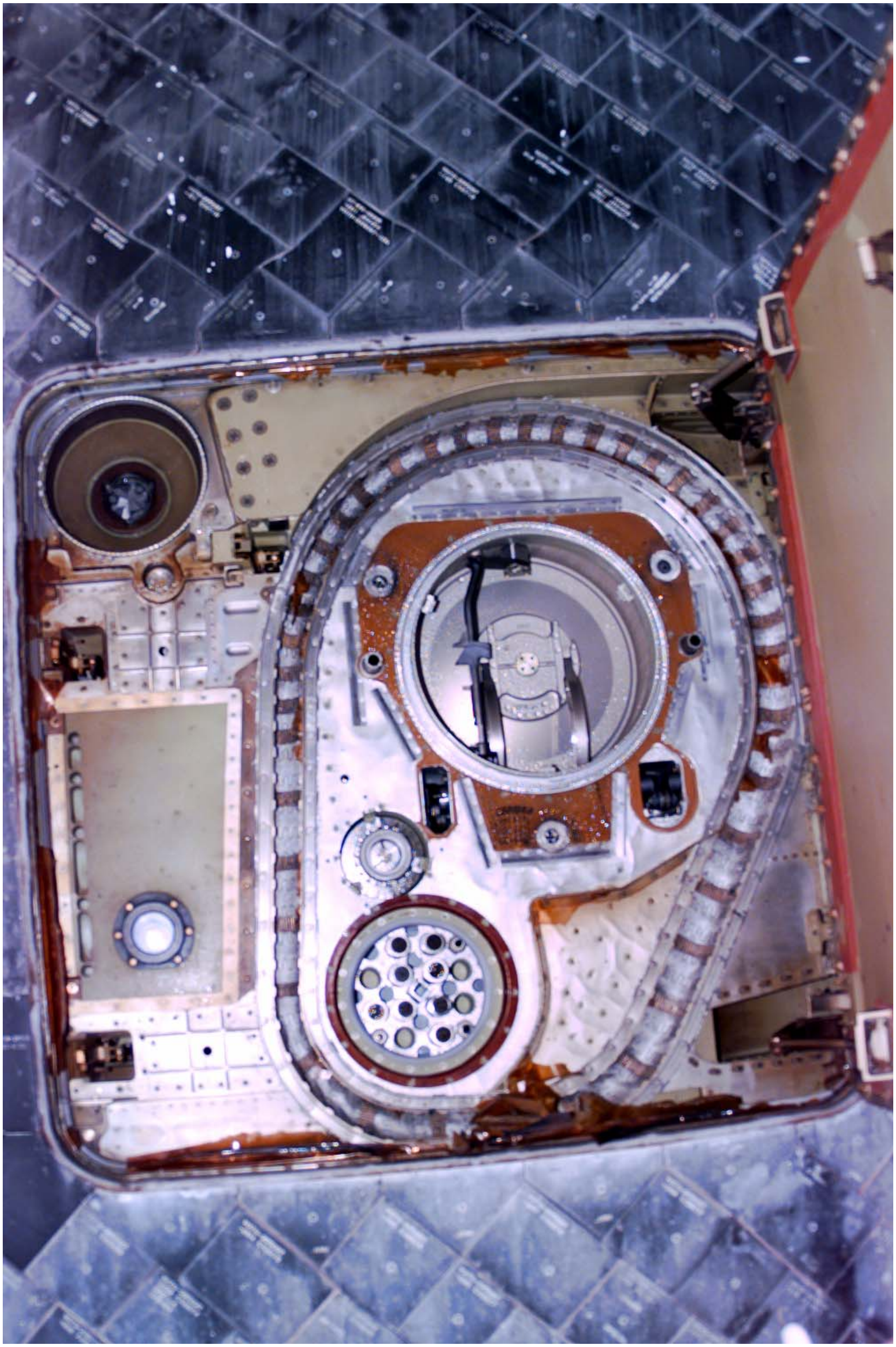


Photo 19: ORB/ET LO2 Umbilical

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.

The organic material analysis provided indication of proteinaceous (as in insect remains), polyurethane (window cover), and silicone (RCS thruster cover/Orbiter TPS) 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, the only post-launch anomalies was the GH2 vent line contact with the FSS and subsequent debris generated from the impact. IFA STS-0108-K-001 was generated to document and investigate the anomaly. The investigation team concluded that there were two major contributors to the anomaly;

- North Haunch Pivot Arm Shock Absorber was very stiff causing the Haunch Pivot Arm to twist when it impacted the shocks. This caused the Vent Line to go further south during retraction.

- Wind was the 2nd strongest recorded at Pad B from the Northeast (15.5 knots) at T-0 (STS-51L to present). This caused the Vent Line to go further south during retraction.

The shock absorbers were removed and refurbished. Modifications are in-work at both launch pads to increase the clearance between vent line and the FSS.

APPENDIX A. JSC PHOTOGRAPHIC ANALYSIS SUMMARY

Table of Contents

Tables and Figures

1 STS-108 (OV-108): Film/Video Screening and Timing Summary

1.1 Screening Activities

1.1.1 Launch

The STS-108 launch of Endeavour (OV-105) from Pad B occurred on December 5, 2001 at 339:22:19:28.055 UTC as seen on camera OTV163. SRB separation occurred at 22:21:31.935 UTC as seen on camera E207.

On launch day, 22 videos were received and screened. Video was not received from cameras OTV154 and ET204. The focus is soft on the long range tracking views (probably due to atmospheric haze).

Twenty-four launch films were screened and a report was sent to the Shuttle Program distribution on December 9, 2001. Eighteen additional films were received for contingency support and anomaly resolution. (Camera film E208 was not provided.)

One anomalous event was seen during the review of the STS-108 launch films and videos that was elevated to the Launch + 4 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report. See Section 2.1. One anomalous event was also seen during the review of the STS-108 landing films that was elevated to the Landing + 3 Day KSC, JSC, MSFC Film/Video Analysis Teams Consolidated Film Review Report. (These reports consolidate the multi-center post flight photo reviews into a single list of observations for engineering review. This integrates the photo review process into the IFA / PRACA process to ensure that the identified observations are assessed and dispositioned prior to the next flight per established problem reporting criteria). No anomalous events were seen on the on-board films that view the (left) Solid Rocket Booster.

Two 16mm umbilical well cameras and the new 35mm umbilical well TPS camera flew on STS-108. See section 2.3. Crew handheld still photography and video of the External Tank was not acquired on STS-108 because of darkness.

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 UF-1 Space Station photographic and television external survey. The Space Station image analysis support will be documented in the UF-1 Imagery Overview Report.

1.1.3 Landing

Endeavour made a daylight landing on runway 15 at the KSC Shuttle Landing Facility on December 17, 2001 (351:17:55:10.884 UTC). Ten videos and ten landing films were received.

The landing touch down appeared normal. The drag chute deploy sequence appeared normal on the landing imagery, however one anomalous event was seen on the drag chute canopy. See Section 2.2.

Post landing, a sink rate analysis of the STS-108 main landing gear was performed for the main gear touchdown. See Section 2.5.

The STS-108 landing films were screened in support of the drag chute deployment investigation.

2 Summary of Significant Events

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

2.1.1 GH2 Vent Impact with FSS

One anomalous event was seen during the review of the STS-108 launch films that was elevated to the Launch +4 day Intercenter Consolidated Film Review Report. An anomalous retraction of the Gaseous Hydrogen (GH2) vent arm occurred during the launch of STS-108. The vent arm traveled outside of its movement envelope, contacted a vertical beam of the Fixed Support Structure (FSS), and partially rebounded from its capture position. Damage occurred to the FSS beam and the GUCP (Gaseous Umbilical Carrier Plate) portion of the vent arm. A two pound piece of debris was generated which may have constituted a risk to the vehicle.

The Shuttle Program considered this event a constraint to the launch of the next Space Shuttle, STS-109. The Space Shuttle Systems Integration Team requested IS&AG (Image Science and Analysis Group) to participate in a multi-center (KSC, MSFC, JSC, Huntington Beach) investigation of the anomaly. JSC and MSFC were tasked to provide film analysis of the External Tank (ET) Hydrogen Vent Line and carrier plate (GUCP) at selected times and locations for previous mission launches. Initial findings were completed in time to support the Space Shuttle Program Requirements Control Board (PRCB) held on January 10, 2002.

Image Screening - The Gaseous Hydrogen (GH2) vent arm was seen to contact the south side of the support structure at, or near, the saddle plate. A large-appearing piece of dark-colored debris was seen falling almost vertically downward toward the left SRB flame trench as a result of the vent arm contact. The vent arm did not latch-back and the Gaseous Umbilical Carrier Plate (GUCP) was seen to rebound beyond the Fixed Service Structure (FSS) a distance equal to approximately one half the length of the GUCP (estimated to be a distance of approximately one foot). See Figure 2.1.1. The left SRB was the closest part of the launch vehicle to the vent arm during the rebound; however, the rebound motion did not bring the GH2 vent arm significantly close to the launch vehicle. Using the left SRB for scaling (the SRB diameter equals 12 feet), it appeared that the distance between the vent arm at the point of maximum rebound and the left SRB was at least thirteen to fifteen feet during liftoff. Neither the rebounded vent arm / carrier plate nor the debris from it’s FSS impact was observed to contact the launch vehicle. The GH2 vent arm retraction appeared normal on the camera views. No excessive slack or other unusual conditions were observed in the GH2 vent arm lanyard during retraction. As typically seen, ice from the ET GUCP vent fell during the GH2 vent arm retraction (camera E33).

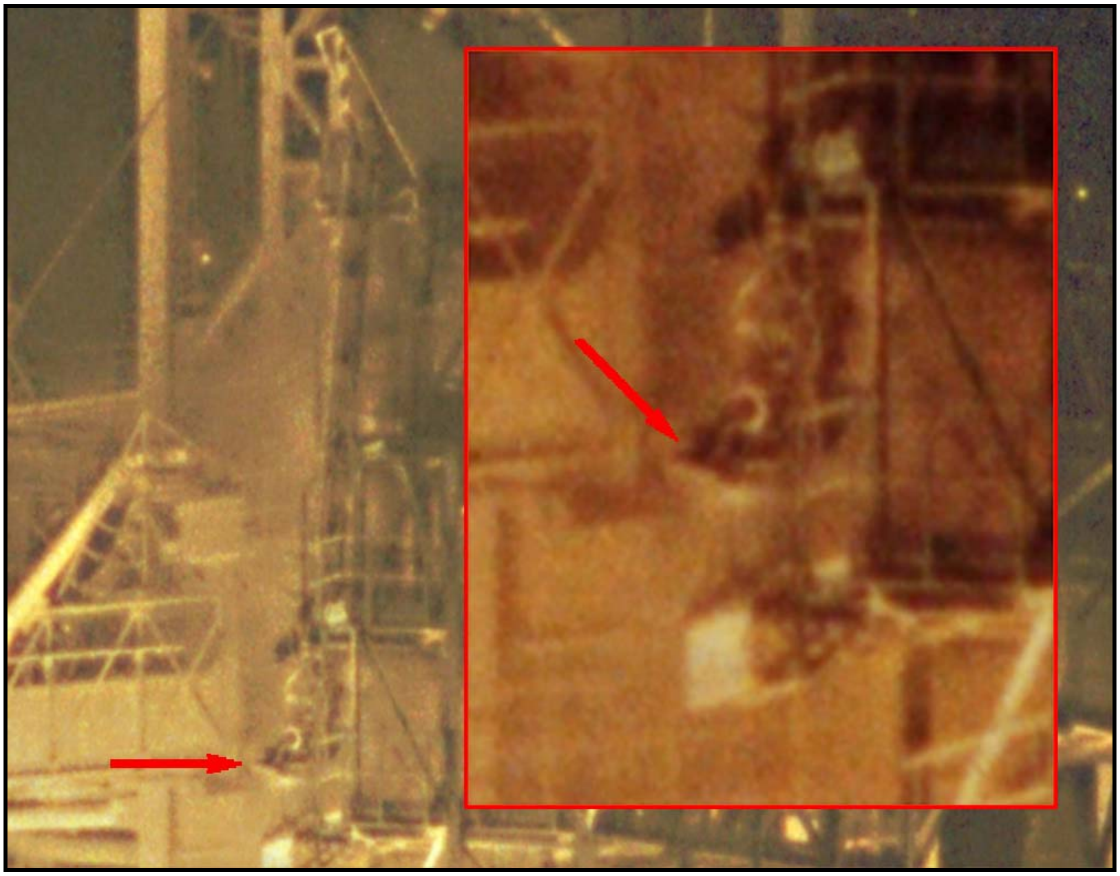


Figure 2.1.1 GH2 Vent Arm at Point of Maximum Rebound (Camera E60, Time 22:19:31.029 UTC)

2.1.2 GH2 Vent Impact Timeline

An event timeline was prepared from the cameras that view the STS-108 GH2 vent line retraction. Table 2.1.2 provides the times as viewed on camera E60 and camera E41.

Time (UTC)	Event	Camera
22:19:28.002	GH2 vent arm at disconnect	E60
22:19:29.335	GH2 vent arm during retraction at mid drop	E60
22:19:29.666	GH2 vent arm impacts FSS and debris first seen	E41
22:19:29.731 – 22:19:31.134	Single piece of dark debris falls toward LSRB flame duct and is obscured by SRB exhaust plume	E41
22:19:29.925	Motion of GH2 vent arm appears to momentarily stop.	E60
22:19:31.029	GH2 vent arm (carrier plate) at point of maximum rebound	E41 and 60
22:19:31.362	SRB aft skirt level with bottom of GH2 vent arm support structure (FSS) during liftoff	E60
22:19:31.657	SRB aft skirt at mid-level of GH2 vent arm support structure (FSS) during liftoff	E60
22:19:31.971	SRB aft skirt level with top of GH2 vent arm support structure (FSS) during liftoff	E60
22:19:59.240	GH2 vent arm after Launch Vehicle clears tower	E60

Table 2.1.2 GH2 Vent Line Retraction Timeline

2.1.3 Analysis of the STS-108 Anomalous GH2 Vent Arm Release

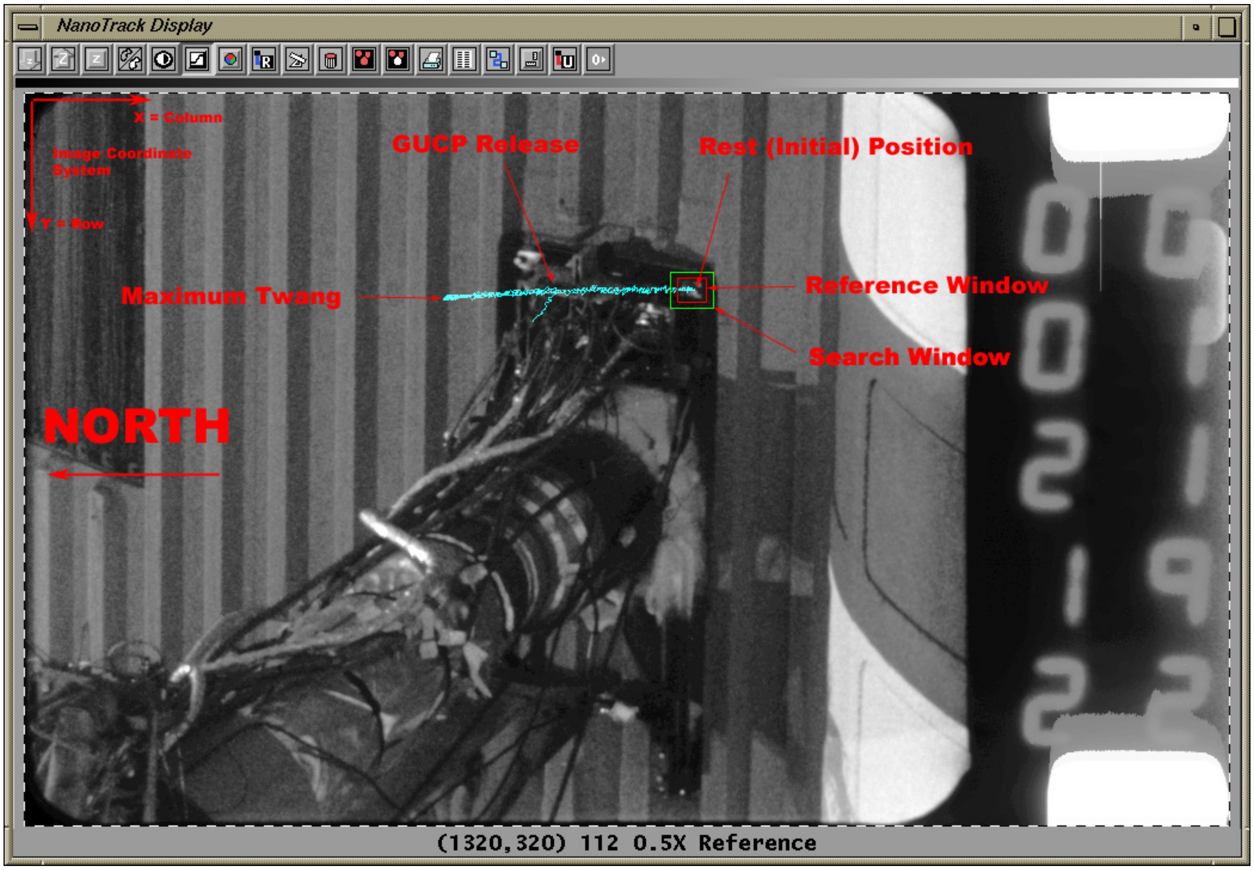


Figure 2.1.3 (A) View of GUCP (Camera E33)

The Space Shuttle Systems Integration Team requested a comparison of the imagery from camera E-33 from STS-108 and selected previous launches. After a review of which additional cameras contained views that might contribute information about the behavior of the vent arm, the imagery from camera E33 for STS-108 and selected previous launches was analyzed. See Figure 2.1.3 (A). Camera E-33 is a 200 frame per second high speed 16mm motion picture camera mounted on the FSS. The camera was positioned about 68 feet from the GUCP, looking slightly down and South of East. The camera had a 100 mm focal length lens and provided an excellent view of the GUCP at launch. During main engine start, the forces from the engines force the vehicle stack to sway (the Twang maneuver). At the level of the GUCP, the stack sways about 20 inches to the North and rebounds about 9 inches before the SRB's (Shuttle Rocket Booster) ignite. At SRB ignition the GH2 vent arm disconnects from the External Tank and swings down away from the vehicle (pivoting around a shoulder joint where it attaches to the FSS) to its capture position within the FSS while the vehicle accelerates upward. The entire horizontal motion of the GUCP during the Twang is within the field of view of the camera. During the disconnect the GUCP first released at the top, pivoted out around its feet which were standing on two small shelves projecting from the ET, and then fell vertically once the feet had been dragged off their shelves. Soon after the GUCP disconnects from the ET, it exited the bottom of the field of view.

The Engineering Photographic Analysis team at Marshall Space Flight Center (MSFC) digitized the film from STS-108, and STS-104, -102, -97, -106, -95, -61, -58, -52 and provided the digitized movies to IS&AG for concurrent analyses. This analysis focused on whether there was anything anomalous in the vehicle motion parallel to the ET's Z axis prior to GUCP disconnect from the ET. It was decided that a comparison of the GUCP motion during the time just before SSME ignition to liftoff from the various missions would be sufficient to indicate whether the STS-108 pre-launch motion was abnormal. The analysis used a single camera view (E-33) and assumed that the camera was aligned with the ET coordinate system such that all motion in the horizontal dimension on the camera's image plane was directly related to motion along the ET's Z axis. A scale factor was determined that related the measurement of the GUCP motion in the image plane to actual motion in inches along the ET Z axis. All measurements of GUCP position from just before SSME startup to liftoff were therefore measured in the image plane (in pixels) and then scaled to motion in inches along the ET's Z axis.

The interval of the movies that was digitized began about 600 frames prior to main engine ignition and ended 1600 frames later, after the GUCP was no longer within the field of view. In all movies except from STS-108, -106, and –104, 600 frames showing the initial twang motion were excluded. The portions of the movies that were included were sufficient to show the initial vehicle position, the position of maximum twang, and the position of GUCP release. By measuring these positions it would be possible to determine the magnitude of the twang for each mission, the magnitude of the rebound prior to GUCP disconnect, and the time interval between max twang and GUCP disconnect.

The camera exhibited significant vibration, making it difficult to unambiguously determine the frame showing maximum twang and thus directly make the measurements. A distinctive point was selected on the GUCP in the first frame and its position was tracked through all successive frames. The tracking was done automatically by special purpose software using area-based correlation. The result was a trajectory of the point in image coordinates showing the large scale motion with a superimposed oscillatory noise signal that varied in magnitude. A sub-interval of the trajectory around maximum twang was selected and a quadratic polynomial was fit to the trajectory by least-squares approximation. The minimum of the quadratic was taken to show the frame and coordinate of maximum twang.

The frame of GUCP release was determined by visual inspection. The position of the GUCP in this frame as measured by the tracking software was used in computing the magnitude of the rebound. This method neglects the noise contribution to the apparent position of the GUCP.

A comparison of the maximum twang, rebound, and duration or rebound from all nine missions examined found no significant differences between STS-108 and the eight reference missions. Minor variations that were deemed to be insignificant were observed. The three earliest missions all showed GUCP release positions closer to the initial position (further South) than all of the later missions. The STS-108 trajectory showed a very small (0.1 inch) excursion to the South immediately prior to beginning the Twang. None of the variations were judged to be large enough to have carried the vent arm outside of its design permitted position envelope. As long as the vent arm (and GUCP) remain within their design permitted position volumes at all times prior to disconnect, it should not be possible for the vehicle to impart anomalous motion on the vent arm. This statement appears to neglect the possibility of the vehicle to have thrown the vent arm by some sudden acceleration while remaining within the excursion limits. This possibility is excluded by the fact that the STS-108 trajectory does not differ from the reference trajectories at any point by enough to indicate that any such mission unique acceleration could have occurred.

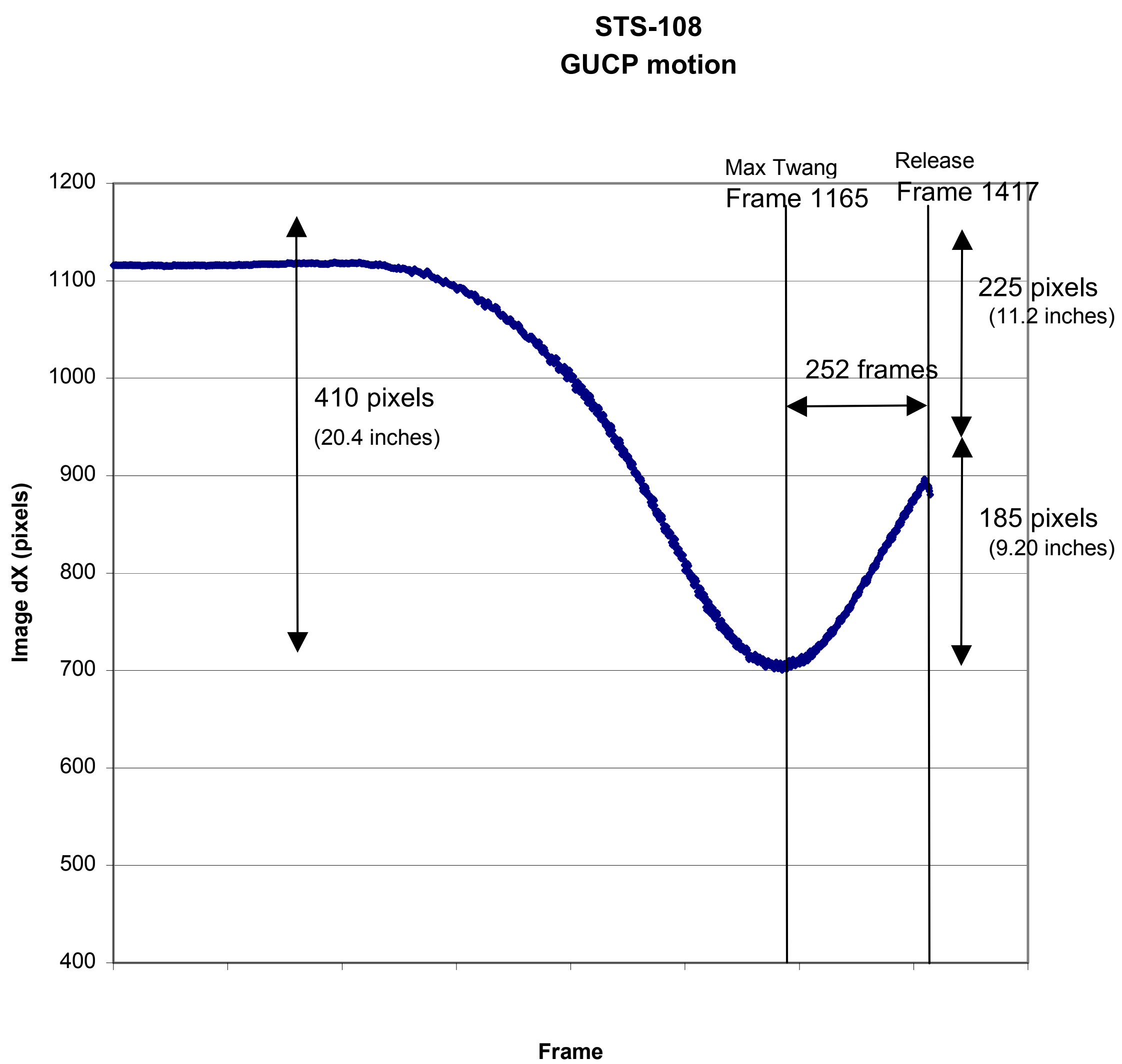


Figure 2.1.3 (B) STS-108 GUCP Motion

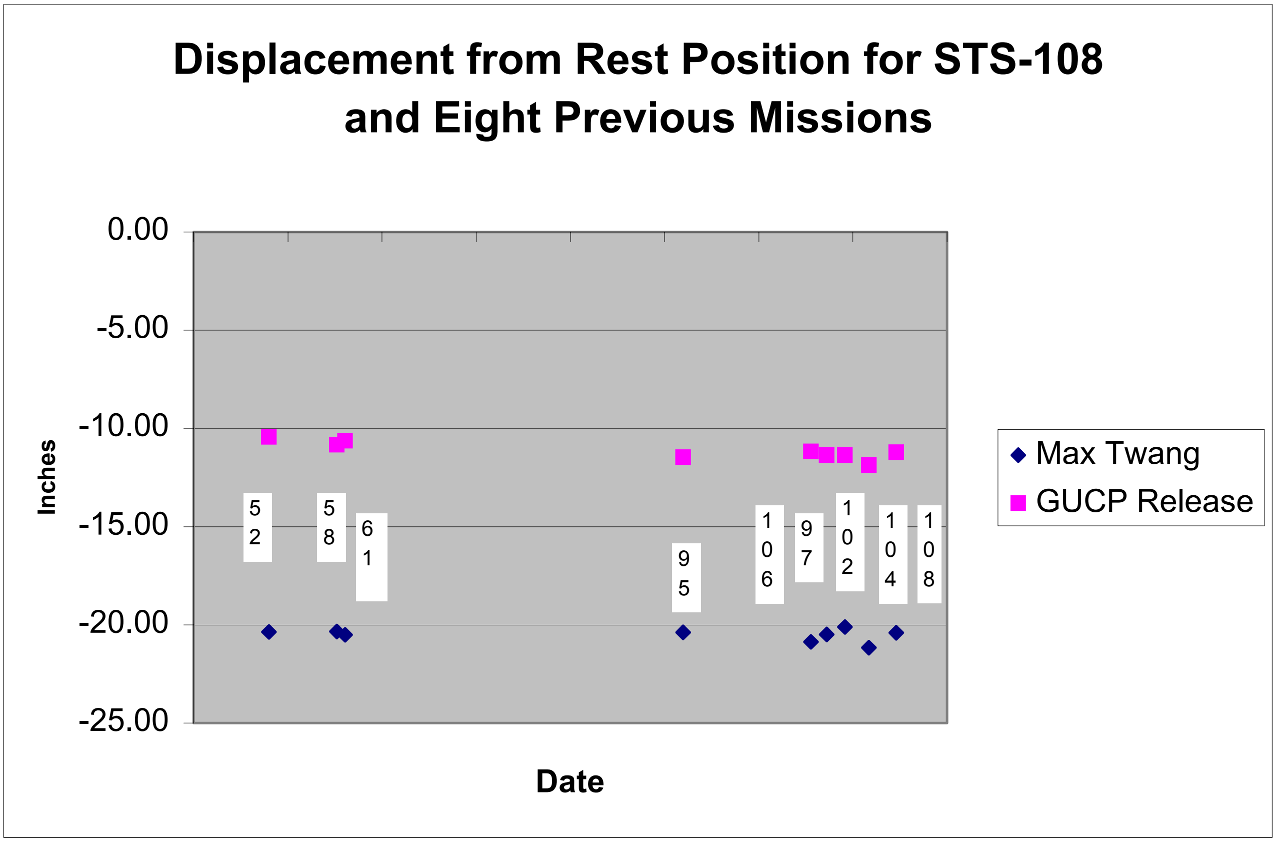


Figure 2.1.3 (C) Launch Vehicle Displacement from Rest Position

2.1.4 Analysis of Time between Mach Diamond Formation and Liftoff

Post-SSME start excursions for the ET GUCP derived for STS-108 and several previous missions were examined from the launch imagery. The results indicate STS-108 was within flight experience base. See Table 2.1.4. Times were derived from films for Mach diamond formation to maximum twang and GUCP release for STS-108, STS-104, STS-102, STS-97, STS-106, and STS-95. The data indicated that the STS-108 time was slightly greater than the other missions, but did not appear to be out of family. (The timing was not correlated to engine start command, thrust build-up or T-0 command.)

Mission	Average Times between Mach Diamond formation and PIC Firing (seconds)	Maximum Twang along ET Z axis (inches)	Distance in inches along ET Z axis from Rest to Release (inches)
STS-108	3.202	-20.41	-11.21
STS-104	3.131	-21.16	-11.87
STS-102	3.045	-20.12	-11.36
STS-97	3.079	-20.49	-11.37
STS-106	3.016	-20.88	-11.17
STS-95	3.136	-20.38	-11.47

Table 2.1.4 Times between Mach Diamond Formation and Liftoff

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

2.2.1 Defect on Drag Chute Canopy

One anomalous event was seen on the STS-108 landing imagery that was elevated to the Landing +3 day Intercenter Consolidated Film Review Report.

Figure 2.2.1 (A) Defect on Drag Chute Canopy

A defect (hole or tear) was visible on the drag chute canopy during the chute dis-reef until drag chute release during the landing roll-out of the Orbiter on KSC Runway 15. See Figure 2.2.1 (A). JSC engineers stated that it appeared that two of the drag chute ribbons had failed. No effect on the dynamics from the hole in the drag chute was seen on the landing imagery. A report of this finding on the drag chute canopy was sent to the Shuttle Program distribution. The anomalous drag chute event was taken to the January 10, 2002 Shuttle Program Control Board (PRCB) post-flight review.

A post-landing evaluation of the STS-108 drag chute was conducted at KSC. Ribbons 34 thru 40 on gore 31 were found to be broken. The vertical ribbon was also found to be broken. The ribbons did not have any indications of friction burning from contact with other nylon elements. KSC engineers reported that they suspect that the hole was caused by contact with the cotton line ties or the deployment bag flaps. (The deployment bag shows no damage but the bag is made of teflon and Kevlar and is tough compared to the canopy ribbons.)

It was also noted during the KSC post-landing evaluation that one of the Kevlar ties that secure the pilot parachute deployment bag to the sabot was loose and that one of the deployment bag beckets/loops had been completely torn from the bag (the remaining two beckets had broken stitchings). Table 2.2.1 (A) contains a timeline of the STS-108 landing and drag chute deploy events.

Event Description	Time (UTC)	Camera
Left main gear door opening	351:17:54:50.140	KTV15L
Right main gear door opening	351:17:54:50.306	KTV15L
Right main gear tire touchdown	351:17:55:10.884	EL17 IR
Left main gear tire touchdown	351:17:55:11.050	EL17 IR
Drag chute initiation	~351:17:55:16.055	EL17 IR
Pilot chute bag release	~351:17:55:16.566	EL10
Pilot chute at full inflation	351:17:55:16.885	KTV33L
Drag chute bag release	351:17:55:17.386	KTV33L
Dark object visible on drag chute	351:17:55:17.836	EL10
Hole first seen on drag chute	351:17:55:18.241	EL10
Drag chute inflation in reefed configuration	351:17:55:18.821	KTV33L
Black object seen on drag chute	351:17:55:21.391	EL10
Drag chute inflation in disreefed configuration	351:17:55:21.957	KTV33L
Nose gear tire touchdown	351:17:55:23.926	KTV33L
Hole visible	351:17:55:26.089 – 351:17:55:32.701	EL2
Hole visible	351:17:55:37.558 – 351:17:55:43.512	EL2
Ribbon like material above drag chute	351:17:55:43.761	EL2
Ribbon like material above drag chute lost from view	351:17:55:45.746	EL2
Two black objects visible on drag chute	351:17:55:47.046	EL15
Drag chute release	351:17:55:48.317	KTV33L
Wheel Stop	~351:17:56:16.971	KTV11L

Note: ~ Denotes that the time shown is approximate.

Table 2.2.1 (A) Timeline of Landing and Drag Chute Deploy Events

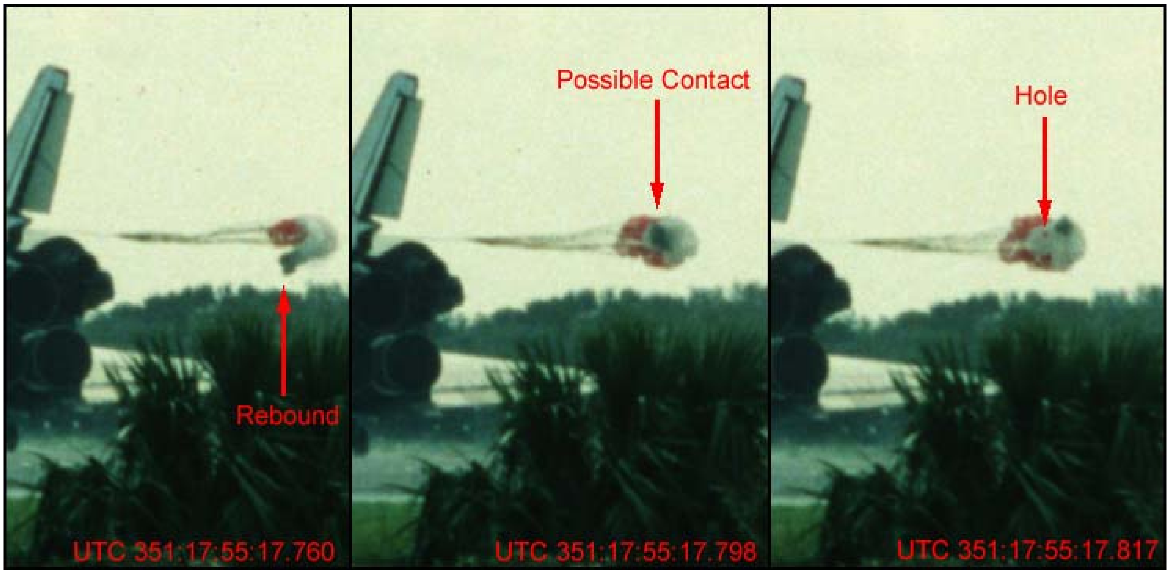


Figure 2.2.1 (B) STS-108 Drag Chute Deploy Sequence Showing Possible Hole Formation (Camera EL10)

On the STS-108 landing imagery, the tip of the drag chute was seen to rebound and contact the drag chute during the initial deploy. See Figure 2.2.1 (B). The hole in the drag chute was visible immediately after the rebound and contact.

At the request of the Space Shuttle Program management, imagery from previous daylight Space Shuttle landings were reviewed for indications of the drag chute folding back on itself similar to that seen on STS-108.

Table 2.2.1 (B) is a summary of the results from the film screening of fourteen daylight landings prior to STS-108 for indications of the drag chute rebounding during deployment. Table 2.2.1 (B) contains the times for the drag chute bag release, and the times for the drag chute in the reefed configuration for twenty-two previous daylight landings.

Mission	Runway	Rebounding or Folding Back of Drag Chute during Deploy	* Pitch Angle at Deploy	Time between Bag Release & Reefed Configuration (seconds)	*Winds (kts) Cross (+=L)	*Winds (kts) Head	**Bag Height (Feet)
STS-108	**KSC 15**	**Rebound**	**8.97**	**1.44**	**1**	**5.9**	**23 ± 2**
STS-105	KSC 15	Normal	9.23	1.41	6	0	**23 ± 2**
STS-100	**EAFB 22**	**Rebound**	**10.16**	**0.93**	**-5.5**	**4.3**	
STS-98	**EAFB 22**	**Slight Rebound**	**6.37**	**0.83**	**1.5**	**19.9**	
STS-92	EAFB 22	Normal	8.45	0.7	3.3	8.4	
STS-99	KSC 33	Normal	-3.91	2.0	-6.9	1.2	
STS-91	KSC 15	Normal	-3.8	2.4	6.6	-2.4	**51 ± 4**
STS-90	**KSC 33**	**Rebound**	**7.1**	**1.09**	**3.9**	**-0.7**	**33 ± 3**
STS-89	KSC 15	Normal	8.32	1.14	3.8	-3.2	**22 ± 2**
STS-87	**KSC 33**	**Rebound**	**9.36**	**1.06**	**0**	**6**	**23 ± 2**
STS-86	KSC 15	Normal	-3.67	1.97	8.7	2.3	
STS-75	**KSC 33**	**Slight Rebound**	**6.74**	**0.86**	**0.9**	**13**	**23 ± 2**
STS-74	KSC 33	Normal	7.19	0.8	-4.5	5.4	
STS-70	KSC 33	Normal	7.18	.07	3.8	-3.2	
STS-71	KSC 15	Normal	8.26	1.09	6.1	-3.5	

Note: *Pitch angle and wind data provided by Boeing.
**Heights are crude approximations of the height of the drag chute bag above the runway.

Table 2.2.1 (B) Previous Mission Film Screening for Rebound of the Drag Chute during Deploy

Measurements were made from film of the height of the main chute bag above the runway at bag release. The height of the drag chute bag above the runway for each landing analyzed is also provided in Table 2.2.1 (B). The bag release heights are estimates and do not indicate exact heights of the drag chute bag above the runway. The values approximate the various heights that the drag chute may deploy at depending on the variables such as the Orbiter pitch, drag chute initiation time and wind velocities. The bag height data will be used to characterize the behavior of the drag chute at these different deploy heights.

2.3 Other Launch Observations

2.3.1 Debris from SSME Ignition through Liftoff

Figure 2.3.1 (A) Rectangular-shaped Debris during SSME Ignition (Camera E5)

Two unidentified pieces of red-colored debris were seen between SSME #2 / SSME #3 and the +Z side of the body flap before falling aft during SSME ignition (22:19:23.898 and 22:19:24.280 UTC). These debris pieces appeared rectangular in shape and somewhat stiff, resembling possible tags or tile shims. It is possible that this debris was RCS paper, however, they did not appear flexible and did not "float" as RCS paper debris typically does. These objects were not identified from the other camera views. (Camera E5)

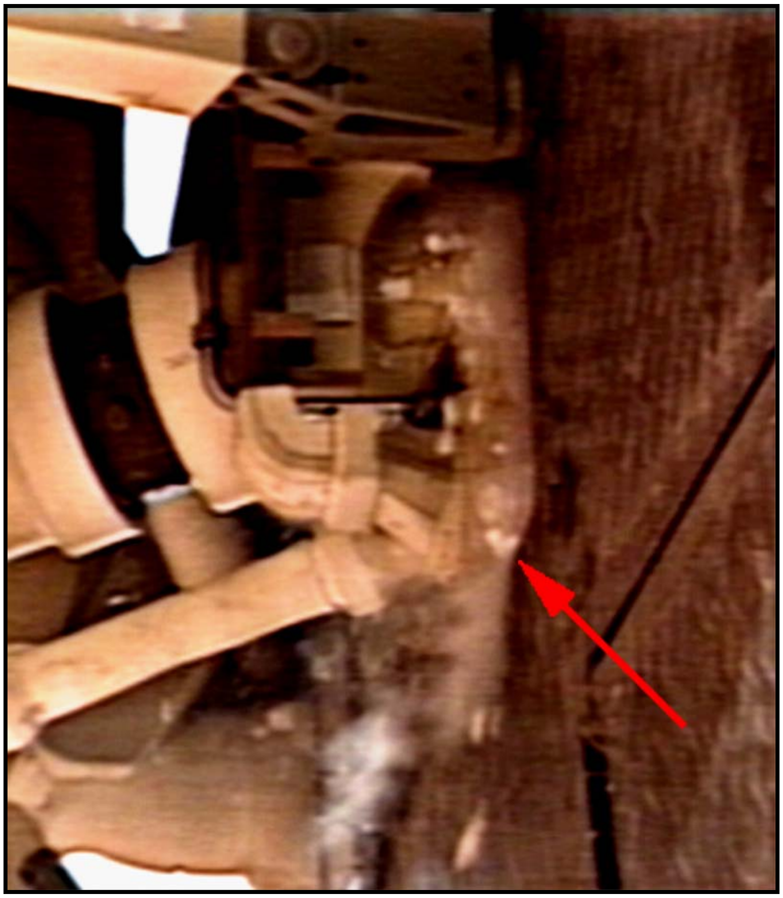


Figure 2.3.1 (B) Ice Contacts LH2 Umbilical Well Door Sill (Camera OTV109)

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. Six pieces of umbilical ice debris were seen to contact the LH2 umbilical well door sill during SSME ignition (22:19:23.584, 22:19:23.750, 22:19:24.151, 22:19:24.818, 22:19:25.185, 22:19:26.120 UTC). No damage to the launch vehicle was detected. See Figure 2.3.1 (B). Umbilical ice debris contacting the Orbiter surfaces has been seen on previous missions. (Cameras OTV163, OTV109, E4, E5, E18, E19, E20, E34, E36, E52, E63)

A light-colored piece of debris was seen between SSME #2 and SSME #3 near the base heat shield falling aft along the + Z side of the body flap during SSME ignition. This debris appeared to be RCS paper (22:19:25.197 UTC). An unidentified dark-colored piece of debris (possibly a paint chip) fell aft along the LO2 TSM (22:19:25.197 UTC). (Camera E5)

A single piece of light-colored debris (probably SRB flame duct material) was seen north of the MLP during liftoff (22:19:29.10 UTC). (Cameras KTV4B, KTV7B, KTV21B). On camera E222, several pieces of debris were seen north of the MLP.

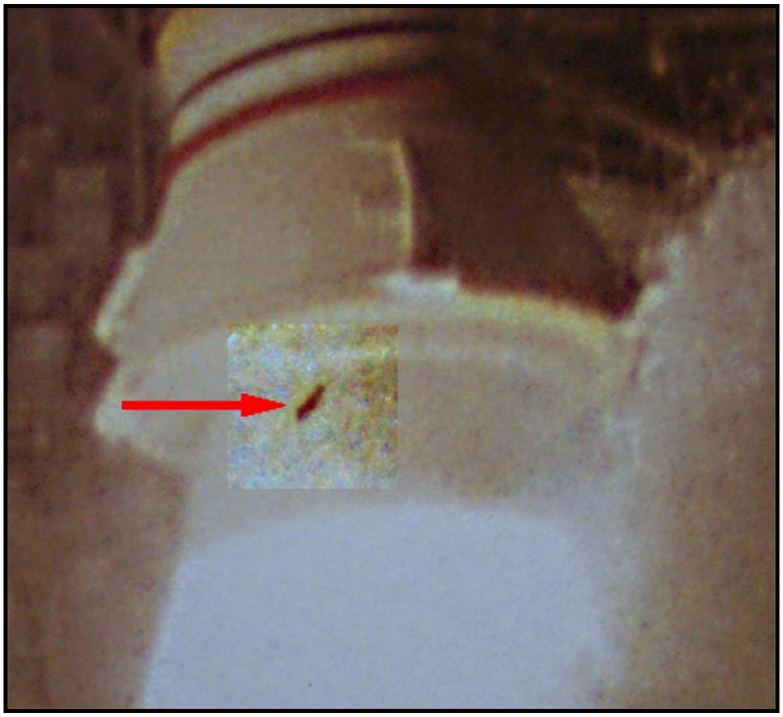


Figure 2.3.1 (C) Debris Near RSRB Aft Skirt During Liftoff (Camera E1)

Multiple pieces of SRB throat plug and/or SRB flame duct debris were seen near the right and left SRBs during liftoff. On camera E5, a light-colored piece of debris first seen on the east side of the RSRB traveled toward the –Z side of the body flap before falling aft. An unidentified, light-colored piece of debris was seen near the RSRB and the ET aft dome falling aft towards the –Z side of the Orbiter body flap during liftoff (22:19:28.55 UTC). (Camera OTV160) A light-colored piece of unidentified debris was seen near the RSRB aft stiffener ring moving in a –Y direction beneath the ET aft dome during liftoff (22:19:28.749 UTC). Several pieces of unidentified light-colored debris (possibly SRB flame duct material) were seen moving from the vicinity of the ET toward the Orbiter near the time of liftoff (22:19:26.386, 22:19:27.788 UTC). (Camera OTV109) An unidentified, dark-colored piece of debris was first seen on the east side of the MLP near the RSRB aft skirt and moved in a northwest direction during liftoff (22:19:29.324 UTC). Also, a large, dark-appearing piece of debris was seen near the RSRB aft skirt moving in a –Y direction and traveled to the north side of the LSRB aft skirt. (Camera E1) See Figure 2.3.1 (C). On camera E222, several pieces of probable SRB throat plug or SRB flame duct debris were seen near the RSRB aft skirt and moved upwards toward the trailing edge of the right wing (22:19:30.061 UTC). (Cameras E2, E222) None of this debris was seen to contact the launch vehicle.

On camera E63, a single piece of debris was seen near the LSRB aft skirt moving in a +Y direction and then fell aft of the SSMEs (22:19:30.356 UTC). (Cameras OTV160, E4, E5, E17, E63, E222)

A small, white-colored piece of debris was seen falling from near the ET/Orbiter forward attach bipod between the ET and the Orbiter fuselage tiles during liftoff (22:19:30.858 UTC). This debris was probably frost / ice from the forward LO2 feedline bellows. The debris did not appear to contact the Orbiter tiles. (Camera OTV161)

A light-colored object that appeared to be flashing as it tumbled was first seen near the MLP and appeared to move upward at the same rate as the launch vehicle during liftoff (22:19:29.900 UTC). (Camera E34)

2.3.2 Debris During Ascent

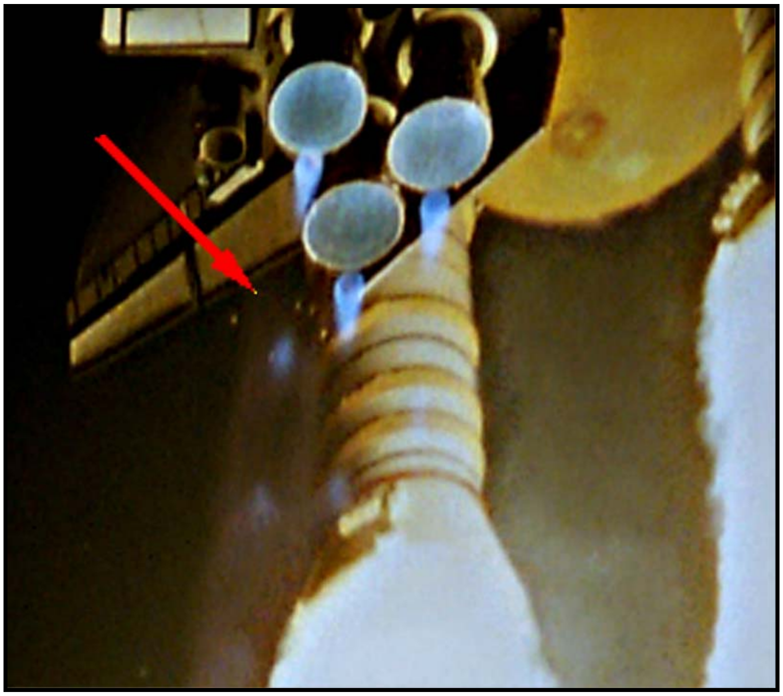


Figure 2.3.2 (A) Spray of RCS Paper Debris Seen Aft of Left Wing During Ascent (Camera E52)

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
22:19:39.213 UTC	RCS paper debris seen near the aft end of the launch vehicle (Camera ET207, E54) Multiple pieces of RCS paper debris were seen forward of the vertical stabilizer along the Orbiter fuselage and falling aft along the left wing (E54).
22:19:39.549 and 22:19:40.344 UTC	Multiple pieces of RCS paper debris seen near left wing (E52) **See Figure 2.3.2 (A).**
22:19:43.45 UTC	RCS paper debris seen near the aft end of the launch vehicle (Camera ET207)
22:19:48.680 UTC	ET / Orbiter umbilical ice fell aft along body flap (E224)
22:19:52.983 UTC	Umbilical ice debris fell along body flap (E222)
22:19:54.553 UTC	RCS paper debris seen at base of the SSMEs (207, E222)
22:19:56.509 UTC	Multiple pieces of forward RCS paper debris seen near the base of the vertical stabilizer (E222)
22:20:06.309 UTC	Forward RCS paper seen falling past vertical stabilizer (E220)
22:20:13.371 UTC	Large piece of probable RCS paper seen at base of vertical stabilizer (E220)

Table 2.3.2 (A) RCS Paper and Umbilical Ice Debris During Ascent

Several pieces of ET / Orbiter umbilical purge barrier material were seen to detach from the ET / Orbiter umbilical and fall aft along the body flap during the roll maneuver (22:19:43.416 UTC). ET/Orbiter purge material debris during ascent has been seen on previous mission imagery. (Cameras E207, E212, E220)

Light-colored debris (possibly instafoam from the RSRB aft skirt) moved inboard toward the SSMEs and fell aft into SSME exhaust plume during ascent (22:19:52.853 through 22:19:52.997, 22:20:00.800 through 22:20:00.886 UTC). (Cameras E207, E222)

A single piece of debris seen near the LSRB traveled in a +Z direction toward the Orbiter and fell aft into the SSME exhaust plume (22:20:00.806 UTC). This debris was not seen to contact the launch vehicle. (Camera E223)

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	Camera
22:19:36.672 UTC	E52
22:19:53.900 UTC	E54
22:19:55.735 UTC	E54
22:19:56.800 UTC	E54
22:20:03.441 UTC	E222
22:20:24.734 UTC	E223, E224
22:20:31.336 UTC	E220
22:20:38.16 UTC	KTV4B
22:20:39.00 UTC	KTV4B
22:20:40.03 UTC	KTV4B
22:20:44.55 UTC	ET212
22:20:45.10 UTC	KTV4B
22:20:46.44 UTC	KTV4B
22:20:48.01 UTC	KTV4B
22:21:27.556 UTC	KTV4B, KTV13, ET207, ET208, E207
22:21:28.65 UTC	KTV4B
22:21:29.57 UTC	KTV13
22:21:31.94 UTC	ET208

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 2.2.3 are from film E19:

SSME	TIME (UTC)
SSME #3	22:19:24.701
SSME #2	22:19:24.758
SSME #1	22:19:24.923

Table 2.3.3 SSME Mach Diamond Formation Times

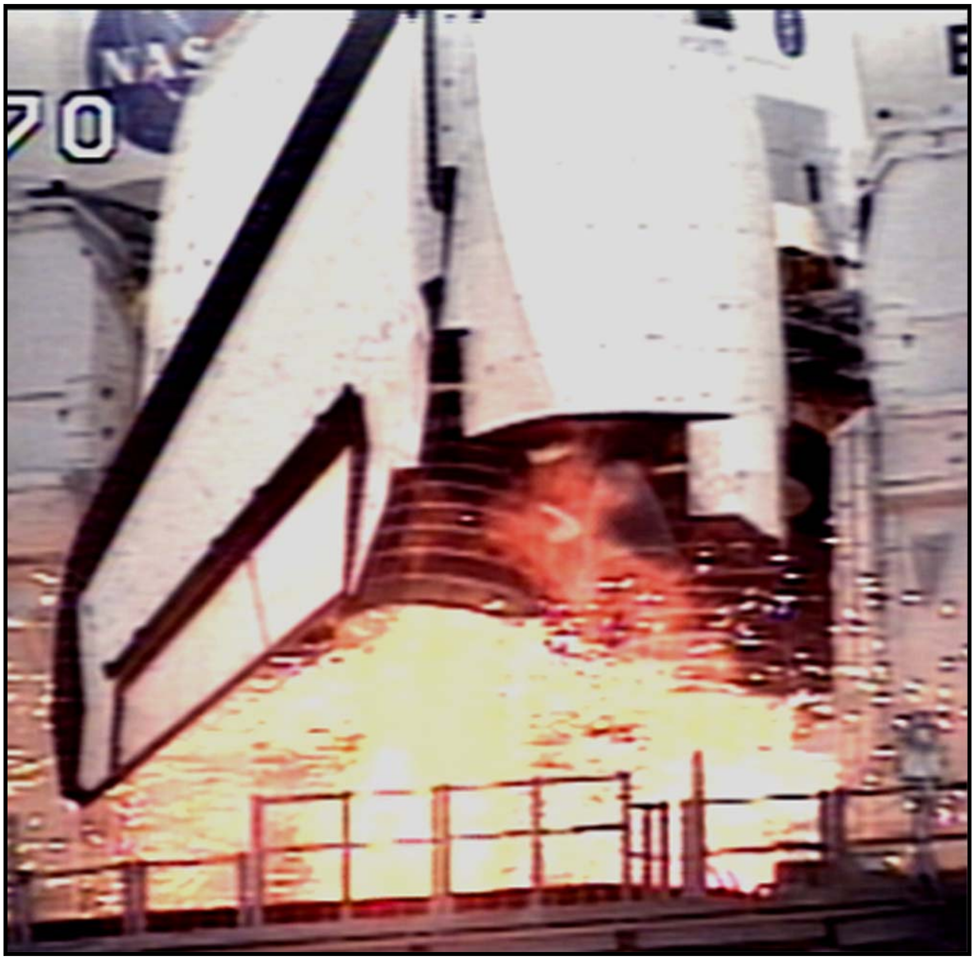


Figure 2.3.3 (A) Orange Vapor Seen Above SSME Rims Prior to Liftoff (Camera OTV170)

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. Orange vapor forward of the aft end of the Orbiter during SSME ignition has been seen on previous mission films and videos. (Cameras OTV170, E1, E2, E4, E17, E19, E20, E36, E52, E63, E76)

A slight flexing of the base heat shield between the SSME cluster was seen during SSME ignition (22:19:24.360 UTC). Flexing of the base heat shield, although not common, has been seen on previous mission films. (Camera E76)

Flickering of the LH2 TSM T-0 barrier material was seen during SSME ignition. This event has been seen on previous mission imagery. (Camera OTV170)

Frost was seen on the –Y ET nose cone vent louver during liftoff. Frost on the ET vent louvers has been seen on previous mission imagery. (Camera 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 (Cameras E1, E2, E18, E19):

SSME #1 - 22:19:26.672, 22:19:27.194, 22:19:30.048, 22:19:30.086 UTC
SSME #2 - 22:19:26.762 UTC
SSME #3 - 22:19:25.616, 22:19:26.190, 22:19:27.993 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, on the base of the left RCS stinger near the L1U RCS (22:19:23.3 UTC), on the base heat shield outboard of SSME #2 (22:19:23.323 UTC), and near the base of the right OMS nozzle during SSME ignition (22:19:24.5 UTC). (Cameras E17, E18, E19, E20)

No significant movement of the OMS pod tiles during SSME ignition was detected on the STS-108 camera films. (Cameras E17, E18)

A small piece of LO2 TSM T-0 umbilical ice contacted the +Y side of SSME #3 just above the rim (22:19:27.585 UTC). Also, a small piece of LH2 TSM T-0 umbilical ice contacted the -Y side of SSME #2 just above the rim (22:19:25.303 UTC). No damage to the SSME surfaces was noted. (Cameras E17, E18)

Both of the TSM doors appeared to rebound slightly before closing during liftoff. Slight rebounds of the TSM doors have been seen on previous mission films. (Cameras E19, E20, E76)

SRB ignition was at 22:19:27.996 UTC based on the observation of the PIC firing at LSRB holddown post M-8. (Camera E14)

A small, dark-colored piece of debris was seen exiting the Hydraulic Power Unit (HPU) exhaust port near LSRB holddown post M-6 and fell into the SRB flame duct during liftoff (22:19:28.621 UTC). (Camera E13)

The left and right SRB GN2 purge lines appeared wrapped, upright, and intact until they were obscured by exhaust plumes at 22:19:30.076 UTC (right purge line) and 22:19:27.702 UTC (left purge line). (Cameras E8, E13)

2.3.4 Ascent Events

Figure 2.3.4 Flare Seen in SSME Exhaust Plume (Camera E222)

Multiple light-orange-colored flares (possibly debris induced) were noted in the SSME exhaust plume during ascent on the long range tracking camera films. Often on previous mission imagery, debris has been seen contacting the SSME exhaust plume resulting in visible flares. Usually this debris 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-108 can be seen in Table 2.3.4:

Time	Event	Camera
22:19:36.011 UTC	Flare seen in SSME exhaust plume	E52
22:19:38.508 UTC	Flare seen in SSME exhaust plume	E52
22:19:41.988 UTC	White-colored flash in SSME exhaust plume	KTV41B
22:19:46.843 UTC	Flare in SSME #1 exhaust plume	E222
22:19:48.676 UTC	Flare in SSME #1 exhaust plume	E207, E222
22:19:52.940 UTC	Flare in SSME #1 exhaust plume	E207
22:19:53.200 UTC	Flare in SSME #1 exhaust plume	ET207
22:19:54.666 UTC	RCS paper induced flare in SSME #1 exhaust plume	E222, E223
22:19:55.086 UTC	Flare in SSME #1 exhaust plume	E207
22:19:55.530 UTC	Flare in SSME #1 exhaust plume	ET207
22:19:55.608 UTC	Flare in SSME #1 exhaust plume	E222, E223
22:19:57.170 UTC	Flare in SSME #3 exhaust plume	ET207
22:19:59.721 UTC	Flare in SSME exhaust plume	E207
22:20:00.840 UTC	Debris first seen near aft end of LSRB induced flare in SSME exhaust plume	ET207
22:20:01.137 UTC	Flare in SSME #2/3 exhaust plume	E222
22:20:02.151 UTC	Flare in SSME #1 exhaust plume	E223
22:20:02.700 UTC	Flare in SSME #1 exhaust plume	E222, E223
22:20:02.770 UTC	Flare in SSME #1 exhaust plume	E222
22:20:13.000 UTC	Flare in SSME #1 exhaust plume	E207
22:20:13.344 UTC	Flare	KTV4
22:20:13.447 UTC	Flare in SSME #1 exhaust plume	E222
22:20:13.480 UTC	Flare in SSME #1 exhaust plume	ET207

Table 2.3.4 Flares Seen in SSME Exhaust Plumes During Ascent

A white-colored streak was seen near the base of the vertical stabilizer (possibly RCS paper debris) during ascent (22:20:06.237 UTC). (KTV4B)

Bright spots (or flickering) were seen on the +Z side of the left RCS stinger which was probably a piece of partially detached RCS paper during ascent (22:19:43.683 UTC). (Partially detached RCS paper on the left RCS stinger was seen at lift off on the camera E20 view.) The RCS paper was seen to detach from the left RCS stinger during ascent at 22:20:03.725 UTC. (Camera E220)

Body flap motion typical of that seen on previous missions was seen during ascent (22:19:52 through 22:20:18.4 UTC). (Camera ET207, E207, E212, E223)

An orange-colored flash from the early OMS-2 assist burn was seen approximately ten seconds after SRB separation (22:21:42.321 UTC). (Cameras KTV13, ET208, E212)

2.4 Onboard Photography of the External Tank (ET-111)

2.4.1 16mm Umbilical Well Camera Films

The LSRB separation appeared normal on the two 16mm umbilical well camera films. Similar to previous missions, 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. Pieces of TPS were seen detaching from the aft surface of the horizontal section of the -Y ET vertical strut. The amount of ablation of the TPS on the aft dome was typical of previous flights. The left SRB nose cap was visible during SRB separation.

The ET separation from the Orbiter was too dark for analysis on the 16 mm umbilical well camera films due to the nighttime conditions. However, for short periods, portions of the aft end of the ET could be seen from the light coming from the RCS thruster firings. No anomalous conditions were noted.

The film quality of both of the 16 mm umbilical well camera films was good during the SRB separation sequence. Timing data was present on the 16mm umbilical well camera films.

2.4.2 35mm Umbilical Well Camera Film (Roll 384)

The ET separation from the Orbiter was not imaged on the 35 mm umbilical well camera films due to darkness.

2.4.3 ET Handheld Imagery

The 35mm handheld film and the Camcorder video of the ET were not acquired on STS-108 because of darkness.

2.5 Landing Events Timing

The time codes from videos were used to identify specific events during the screening process. The STS-108 landing event times are provided in Table 2.2.1 (A).

2.6 Landing Sink Rate Analysis

Image data from the SLF North centerline video camera at the approach end of runway 15 was used to determine the landing sink rate of the main gear. In the analysis, data from approximately one second of imagery immediately prior to touch down for each of the landing gear was considered. Data points defining the main gear struts were collected on every frame (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-108 landing at one second, at half a second, and at a one quarter of a second are provided in Table 2.6 (A).

Time Prior to Touchdown	Main Gear Midpoint Sink Rate	Estimated Error (1σ)
1.00 Sec.	1.6 ft/sec	± 0.2 ft/sec
0.50 Sec.	2.3 ft/sec	± 0.3 ft/sec
0.25 Sec.	2.8 ft/sec	± 0.8 ft/sec

Table 2.6 (A) Main Gear Midpoint Landing Sink Rate

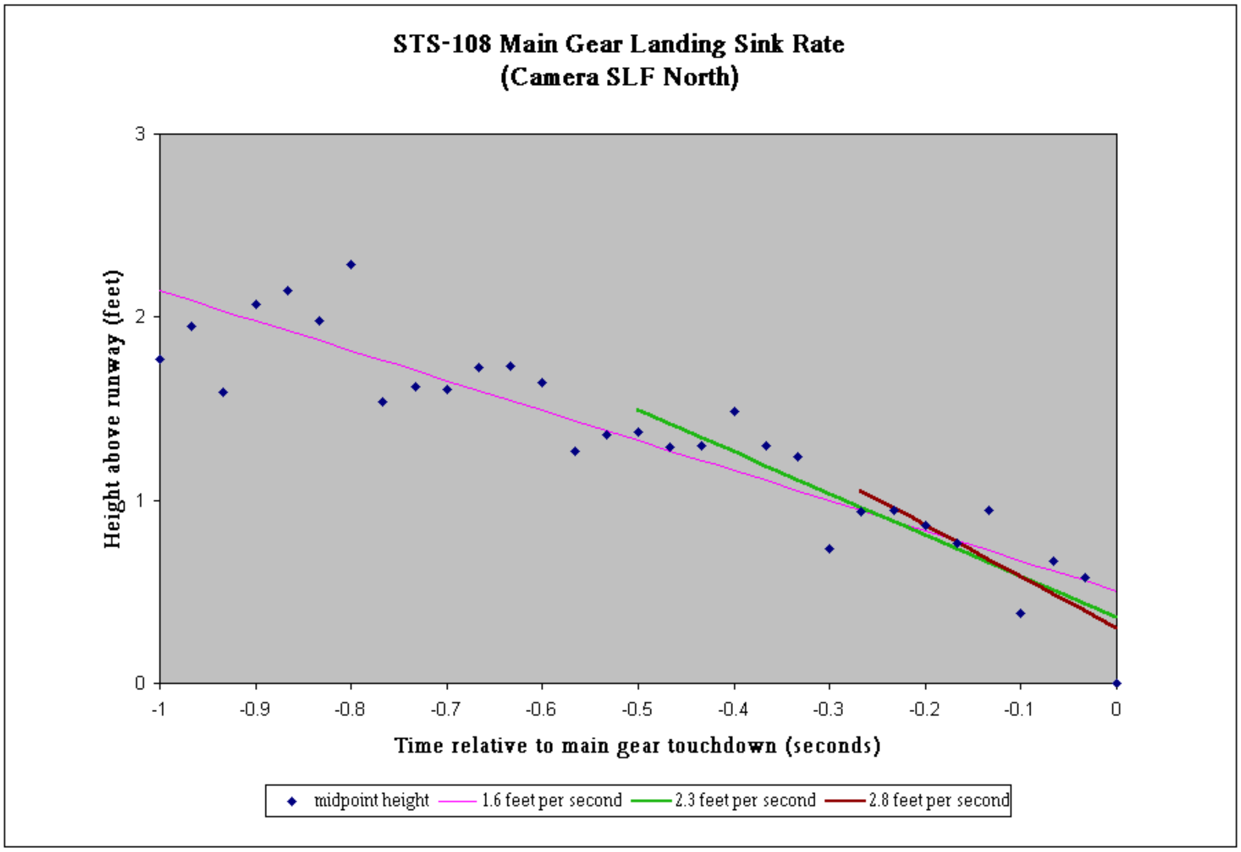


Figure 2.6 (B) Main Gear Midpoint Landing Sink Rate

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-108 vehicle was reported to be 226,442 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
- 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 LOS2 TSM door closure

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-108

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)

February 22, 2002
Marshall Space Flight Center,
Huntsville, AL 35812

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Engineering Photographic Analysis Report for STS-108

Launch of the one-hundred-seventh Space Shuttle mission, STS-108, seventeenth flight of the Orbiter Endeavour (OV-105), occurred December 5, 2001at 4:19 PM CST from launch complex 39-B, Kennedy Space Center (KSC), Florida. Launch time is reported as 01:339:22:19:27.987 Universal Coordinated Time (UTC) by the MSFC Flight Evaluation Team.

STS-108 Photographic Analysis Summary:

One anomalous event was observed on launch film cameras E33, E34, E36, E41, E42, E52, and E60 covering Space Shuttle mission, STS-108. This item was included in the Launch+4 Day "CONSOLIDATED FILM REVIEW REPORT", 12 December 2001- CFVR-108-01, as noted below.

At GMT 22:19:28.002 the Gaseous Hydrogen (GH2) vent arm contacted the side of the support structure at, or near, the saddle plate. A large-appearing piece of dark-colored debris was seen falling almost vertically downward toward the left SRB flame trench as a result of the vent arm contact. The vent arm did not latch-back and the Ground Umbilical Carrier Plate (GUCP) was seen to rebound beyond the Fixed Service Structure (FSS) a distance equal to approximately one half the length of the GUCP (estimated to be a distance of approximately one foot). The left SRB was the closest part of the launch vehicle to the vent arm during the rebound; however, the rebound motion did not bring the GH2 vent arm significantly close to the launch vehicle. Using the left SRB for scaling (the SRB diameter equals 12 feet), it appeared that the distance between the vent arm at the point of maximum rebound and the left SRB was at least thirteen to fifteen feet during liftoff. Neither the rebounded vent arm/carrier plate nor the debris from the FSS impact was observed to contact the launch vehicle. The GUCP/ET separation appeared normal on the camera views. No excessive slack or other unusual conditions were observed during the GH2 vent arm lanyard retraction.

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/sts108/sts108.html

Information available on the MSFC Engineering Photographic Analysis website includes:

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

Photographic Coverage:

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

Sixty-three 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-108 is illustrated in the following table.

	16mm	35mm	Video
MLP	19	0	3
FSS	5	0	3
Perimeter	0	7	4
Tracking	0	9	11
Onboard	2	0	0
Other	0	0	0
Totals	24	16	21

Table 1. STS-108 Camera Coverage

No video was received from video cameras OTV154 and OTV171. Camera OTV109 loses focus as the vehicle lifts off. Cameras OTV141 and OTV160 were overexposed at or after liftoff. Camera OTV148 loses track of the vehicle at liftoff.

Film cameras E57 and E59 lost track of the vehicle after liftoff. Film from camera E31 was of little engineering value due to poor focus.

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	339:22:19:27.996
M-2	E8	339:22:19:27.996
M-5	E12	339:22:19:27.995
M-6	E13	339:22:19:27.994

Table 2. STS-108 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 339:22:21:31.921 UTC.

Anomalous Events:

One anomalous event was noted during the screening of the STS-108 launch films. The Gaseous Hydrogen (GH2) vent arm contacted the south side of the support structure at, or near, the saddle plate. The left SRB was the closest part of the launch vehicle to the vent arm during the rebound; however, the rebound motion did not bring the GH2 vent arm significantly close to the launch vehicle. The GH2 vent arm retraction appeared normal on the camera views. No excessive slack or other unusual conditions were observed in the GH2 vent arm lanyard during retraction.

A more thorough investigation of this incident was initiated. MSFC was asked to digitize film from camera E33 from several missions (STS-108, STS-104, STS-106, STS102, STS-97, STS-95, STS-61, STS-58, and STS-52) for the teams to analyze and also perform an independent investigation of the digitized films. Analysis of the film included an analysis of the motion of the GUCP during ET tip deflection and GH2 Vent Arm retraction. The analyses are included in the Special Investigations section of this report.

Movies of the digitized film from Camera E33 and results of the analyses are available on the website.

Film Camera E36: GH2 Vent Arm Retraction

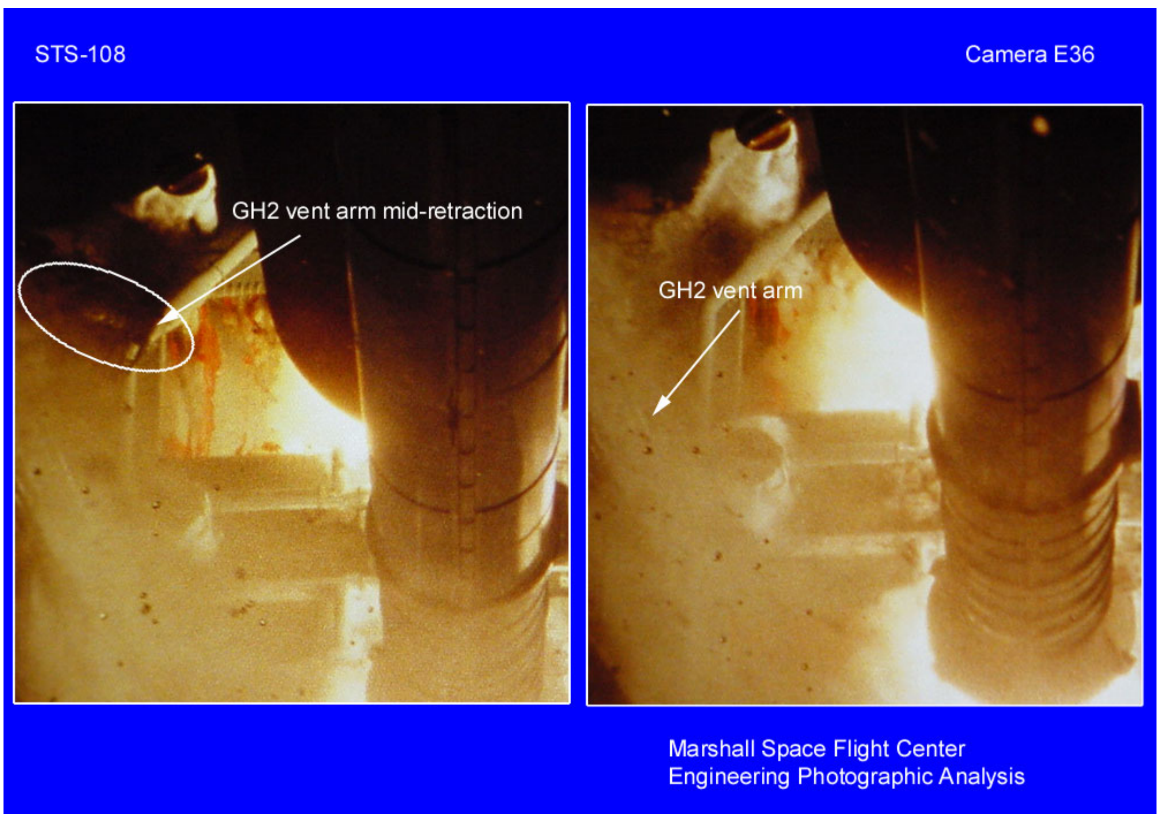


Figure 1. Film Camera E36: GH2 Vent Arm Retraction

Film Camera E60: GH2 Vent Arm Rebound

The GH2 Vent Arm did not latch-back and the Ground Umbilical Carrier Plate (GUCP) was seen to rebound beyond the Fixed Service Structure (FSS).

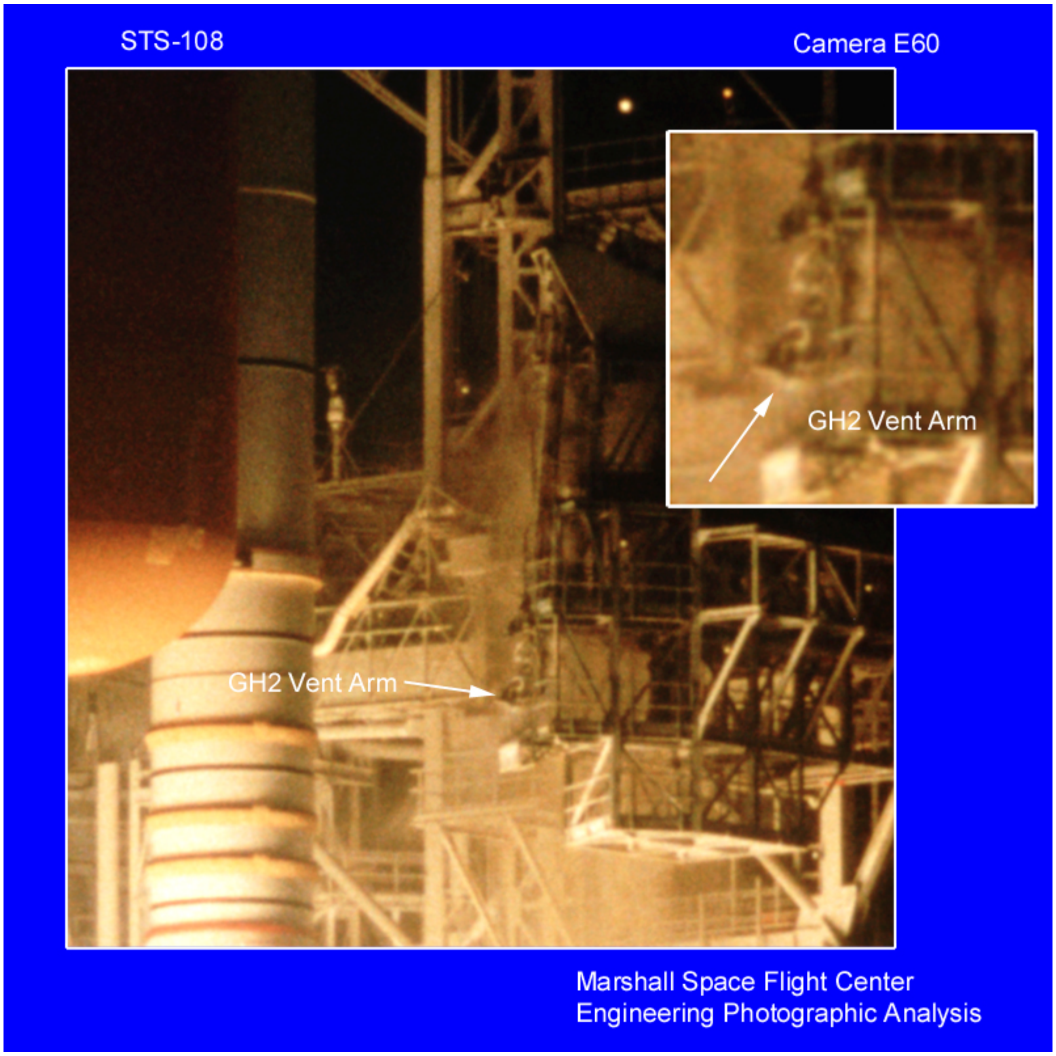


Figure 2. Film Camera E60: GH2 Vent Arm Rebound

Film Camera E42: Debris from GH2 Vent Arm Impact

A large piece of light-colored debris (falling almost vertically downward toward the left SRB flame trench) resulting from the GH2 Vent Arm impact with the Fixed Service Structure (FSS) was observed. The debris did not impact the vehicle.

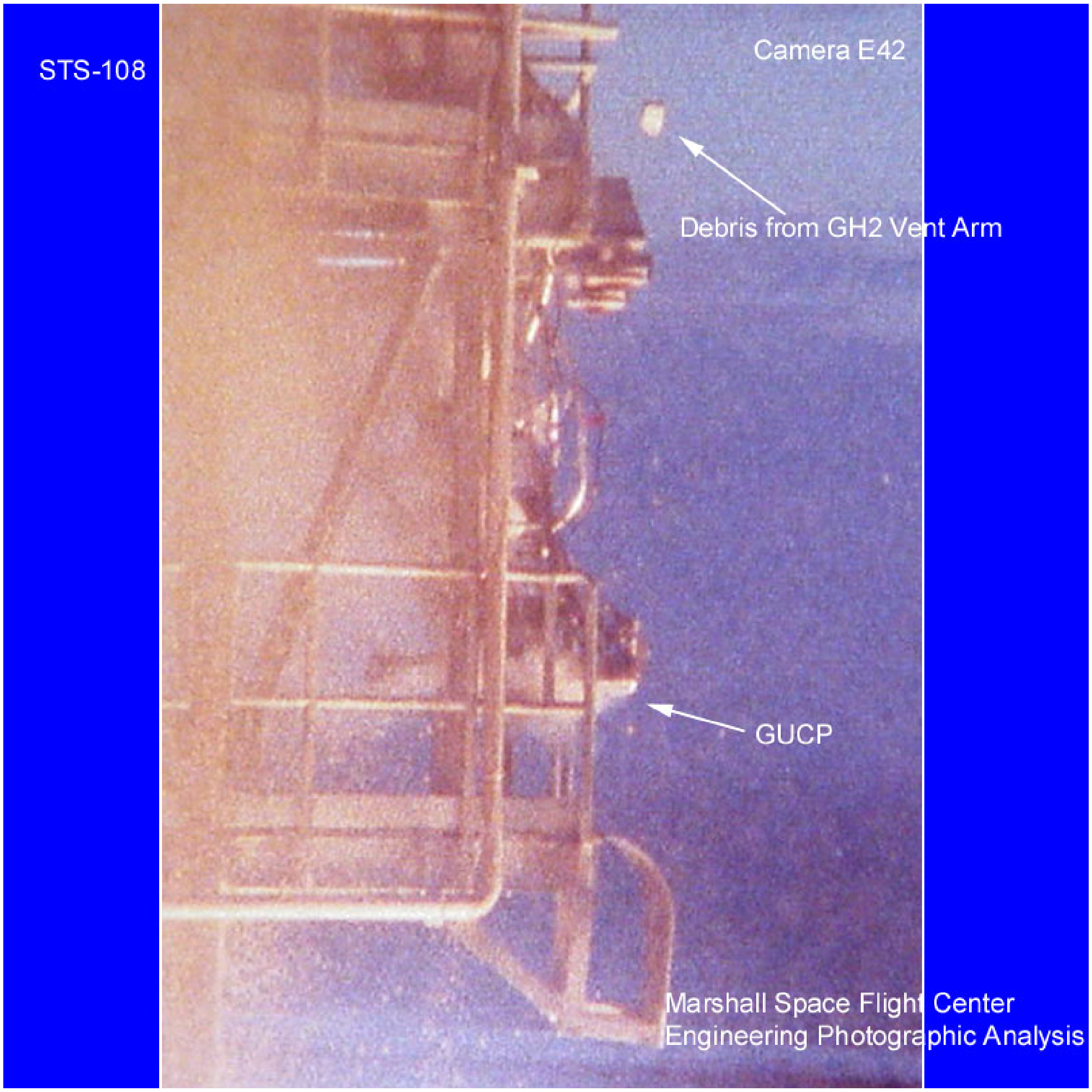


Figure 3. Film Camera E42: Debris from GH2 Vent Arm Impact

__Film Camera E42: GH2 Vent Arm Rebound__

The extent of the GH2 Vent Arm rebound is noted.

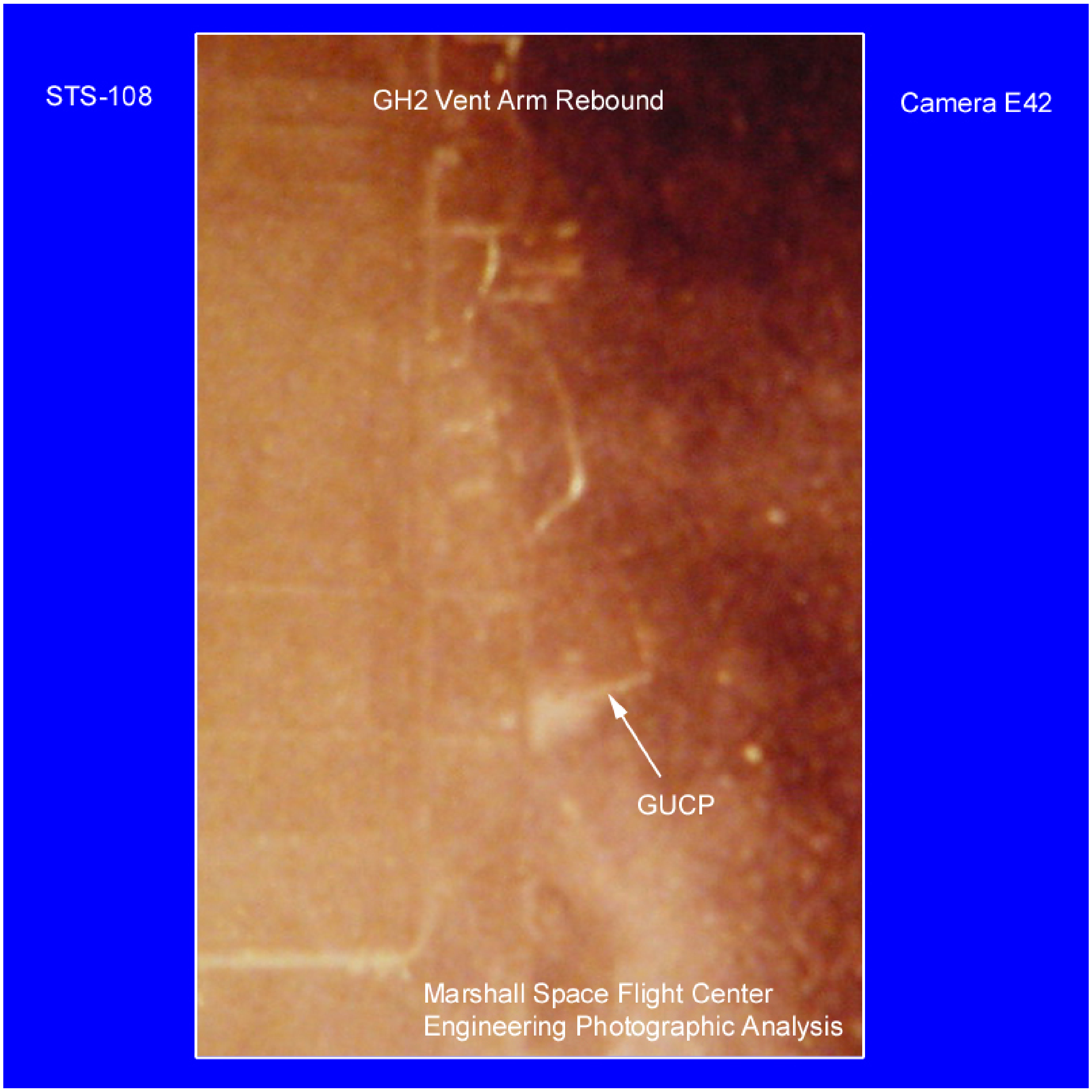


Figure 4. Film Camera E42: GH2 Vent Arm Rebound

Film Camera E60: GH2 Vent Arm Drop Sequence Comparison

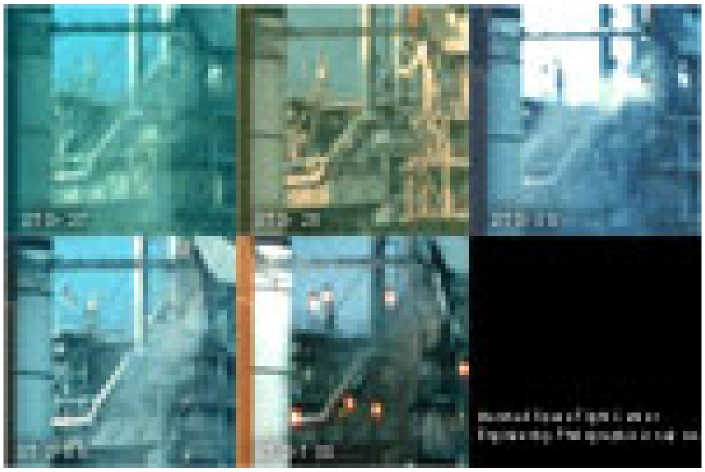


Figure 5. Film Camera E60: Vent Arm Drop Comparison Movie

A movie of the vent arm drop sequence from missions STS-108, STS-85, STS-27, STS-28R, and STS-30 was made. Comparison of the vent arm drop sequences detected little variation between missions. The movie may be observed on the engineering photographic analysis website.

Film Camera E33: GH2 Vent Arm Separation Sequence Comparison

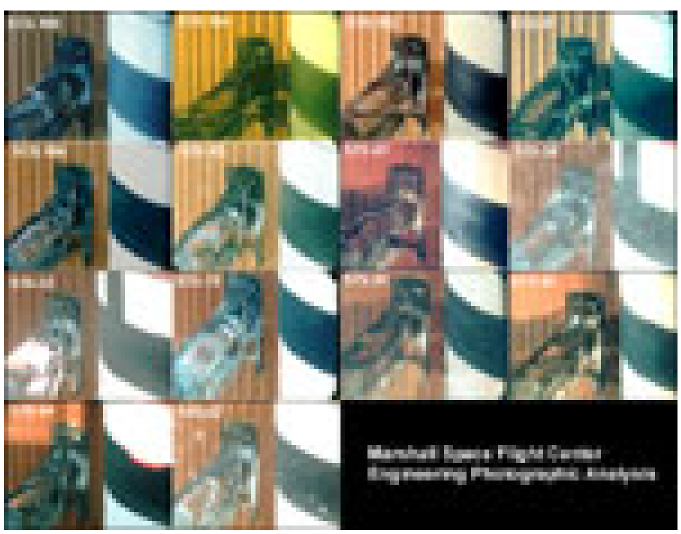


Figure 6. Film Camera E33: Vent Arm Drop Separation Comparison Movie

A movie of the vent arm separation sequence from missions STS-108, STS-104, STS-102, STS-97, STS-106, STS-95, STS-61, STS-58, STS-52, STS-62, STS-63, STS-64, STS-78, and STS-81 was made. Comparison of the vent arm separation sequences detected little variation between missions. The movie may be observed on the engineering photographic analysis website.

Observations:

Film Camera E52: Free Burning Hydrogen

Free burning Hydrogen was observed at SSME ignition.

Figure 7. Film Camera E52: Free Burning Hydrogen

Video Camera OTV170: Free Burning Hydrogen

Free burning Hydrogen was observed at SSME ignition.

Figure 8. Video Camera OTV170: Free Burning Hydrogen

Video Camera TV4B: Free Burning Hydrogen

Free burning Hydrogen was observed at SSME ignition.

Figure 9. Video Camera TV4B: Free Burning Hydrogen

Video Camera OTV109: Frost/Ice near Umbilical Well Doorsill

Ice/frost impacted the umbilical well doorsill. No damage was observed.

Figure 10. Video Camera OTV109: Frost/Ice near Umbilical Well Door Sill

Film Camera E2: Engine Streak in SSME#1 Plume

An engine streak was noted in SSME #1 plume.

Figure 11. Film Camera E2: Engine Streak in SSME#1 Plume

Film Camera E33: Frost/Ice from GUCP

Frost was noted around the periphery of the GUCA after GH2 Vent arm retraction.

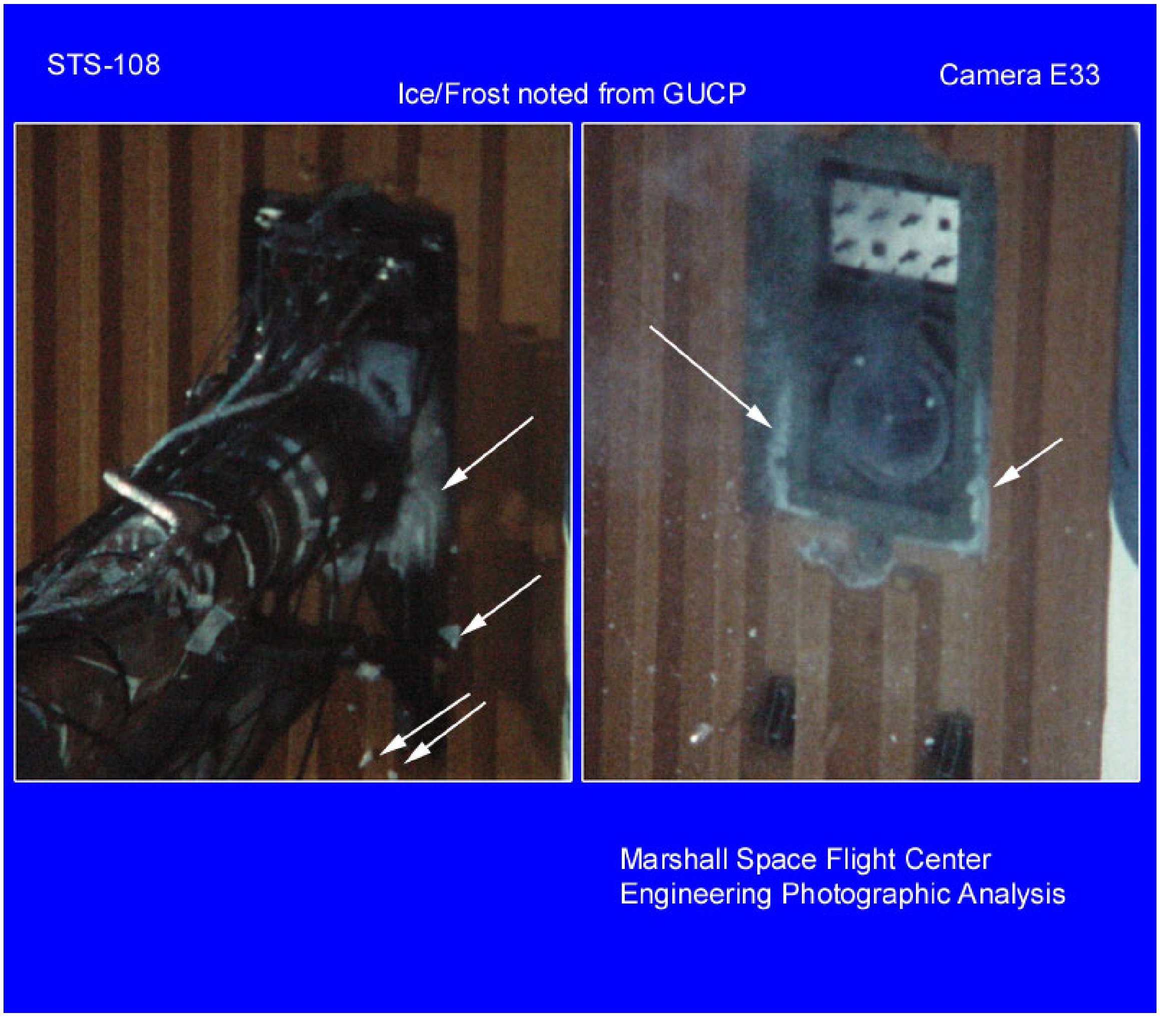


Figure 12. Film Camera E33: Frost/Ice from GUCP

Film Camera E9: Debris near Holddown Post M1

Debris was observed emanating from Debris Containment System of HDP M1 just after PIC firing.

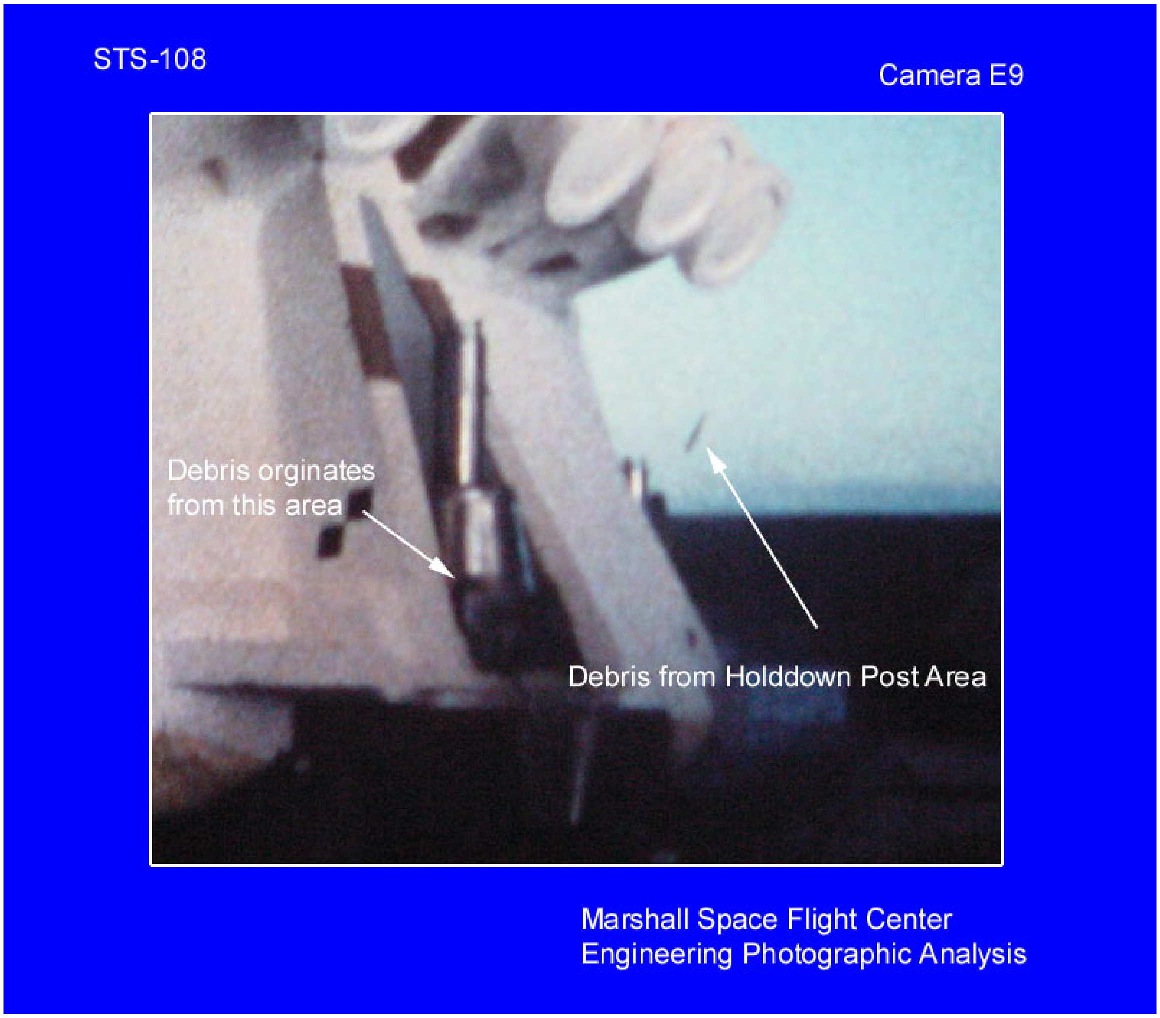


Figure 13. Film Camera E9: Debris near Holddown Post M1

Film Camera E2: Engine Streaks in SSME#1 Plume

Other engine streaks noted in SSME #1 plumes.

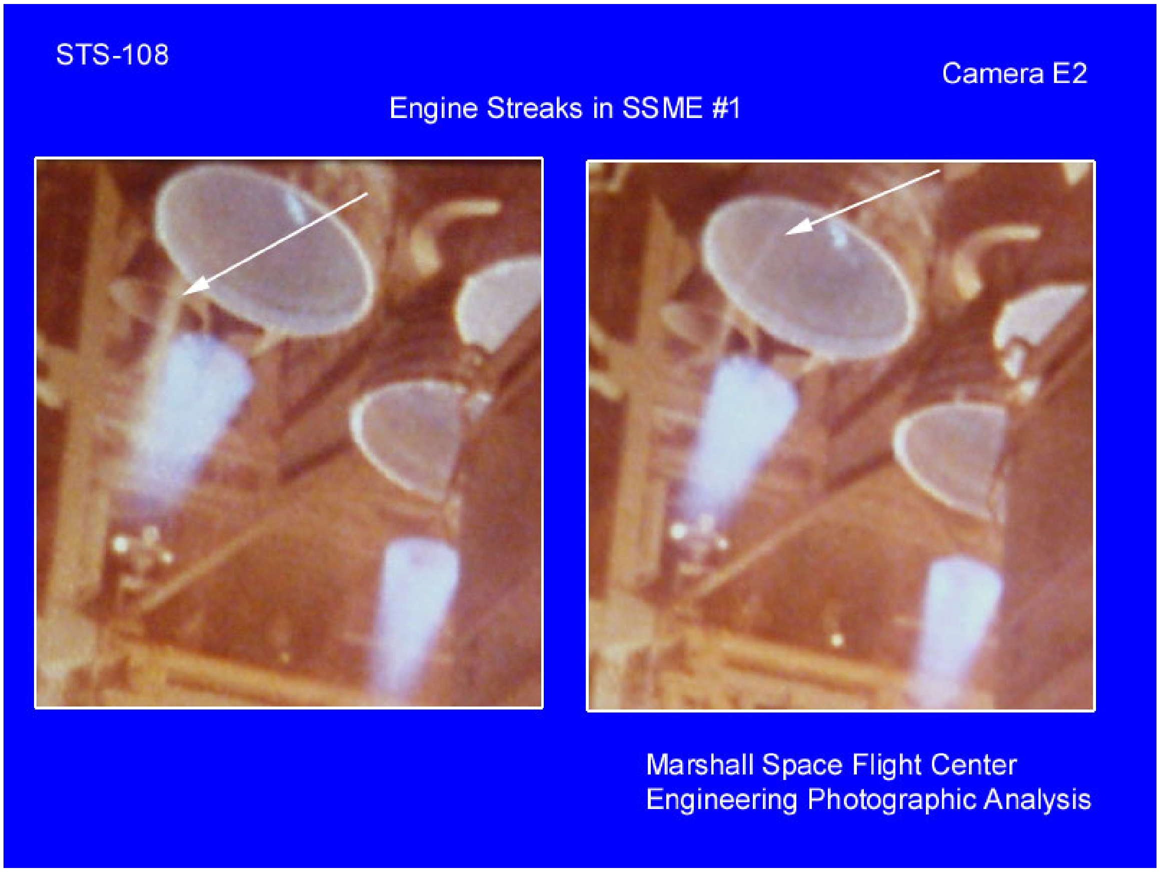


Figure 14. Film Camera E2: Engine Streaks in SSME#1 Plume

Film Camera E3: Engine Streak in SSME#1 Plume

An engine streak was noted in SSME #1 plume after vehicle lift-off.

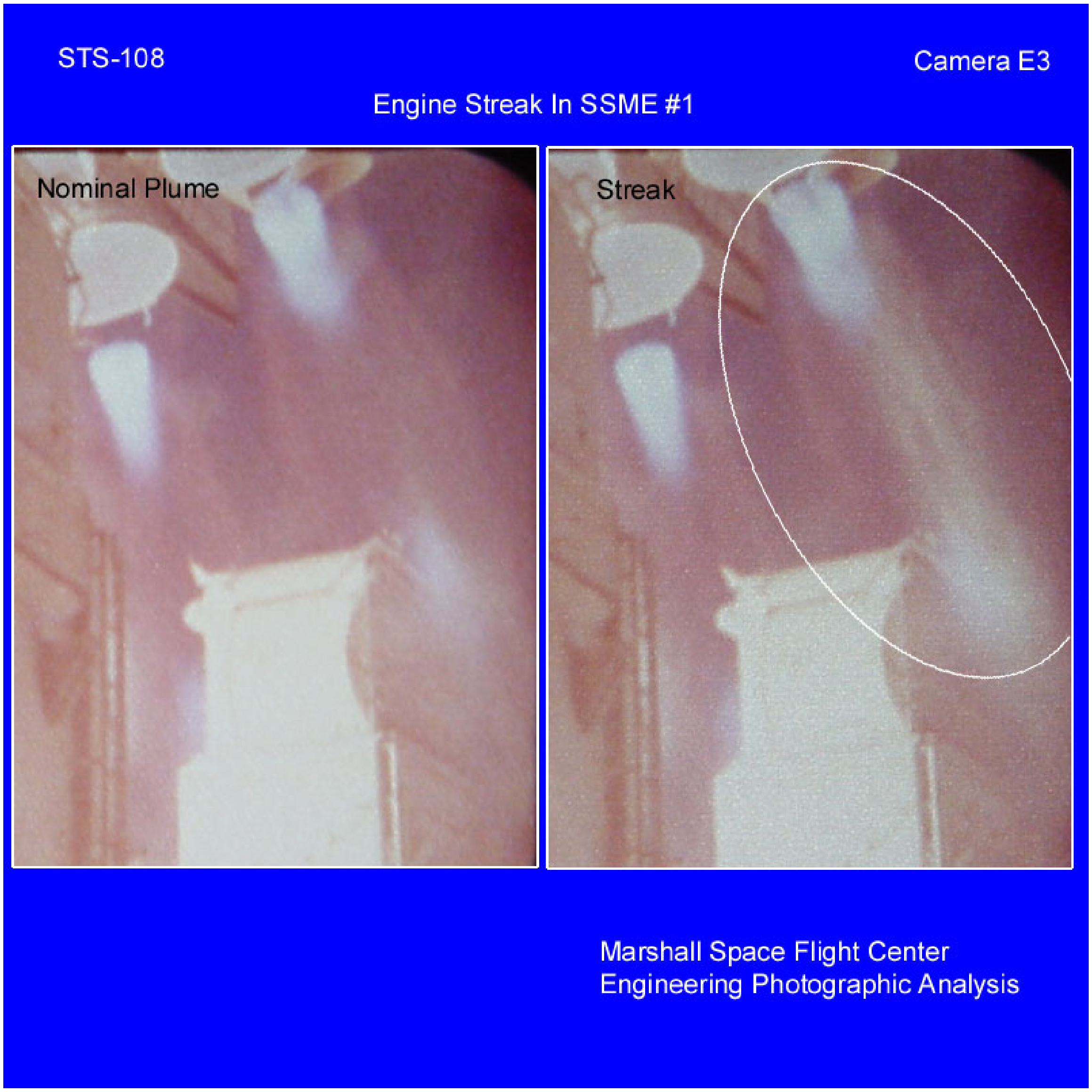


Figure 15. Film Camera E3: Engine Streak in SSME#1 Plume

Film Camera E207: Debris Falling Aft

Debris was noted falling aft of the vehicle. This debris is thought to be butcher paper from the forward RCS motors.

Figure 16. Film Camera E207: Debris Falling Aft

Film Camera E207: Umbilical Well Purge Barrier Debris

Debris was observed falling aft of the vehicle. This debris is thought to be umbilical well purge barrier material.

Figure 17. Film Camera E207: Umbilical Well Purge Barrier Debris

Film Camera E220: Debris Falling Aft

Debris was noted falling aft of the vehicle on the –Z side of the External Tank. The debris appeared to emanate from forward of the SRB-ET aft attach point.

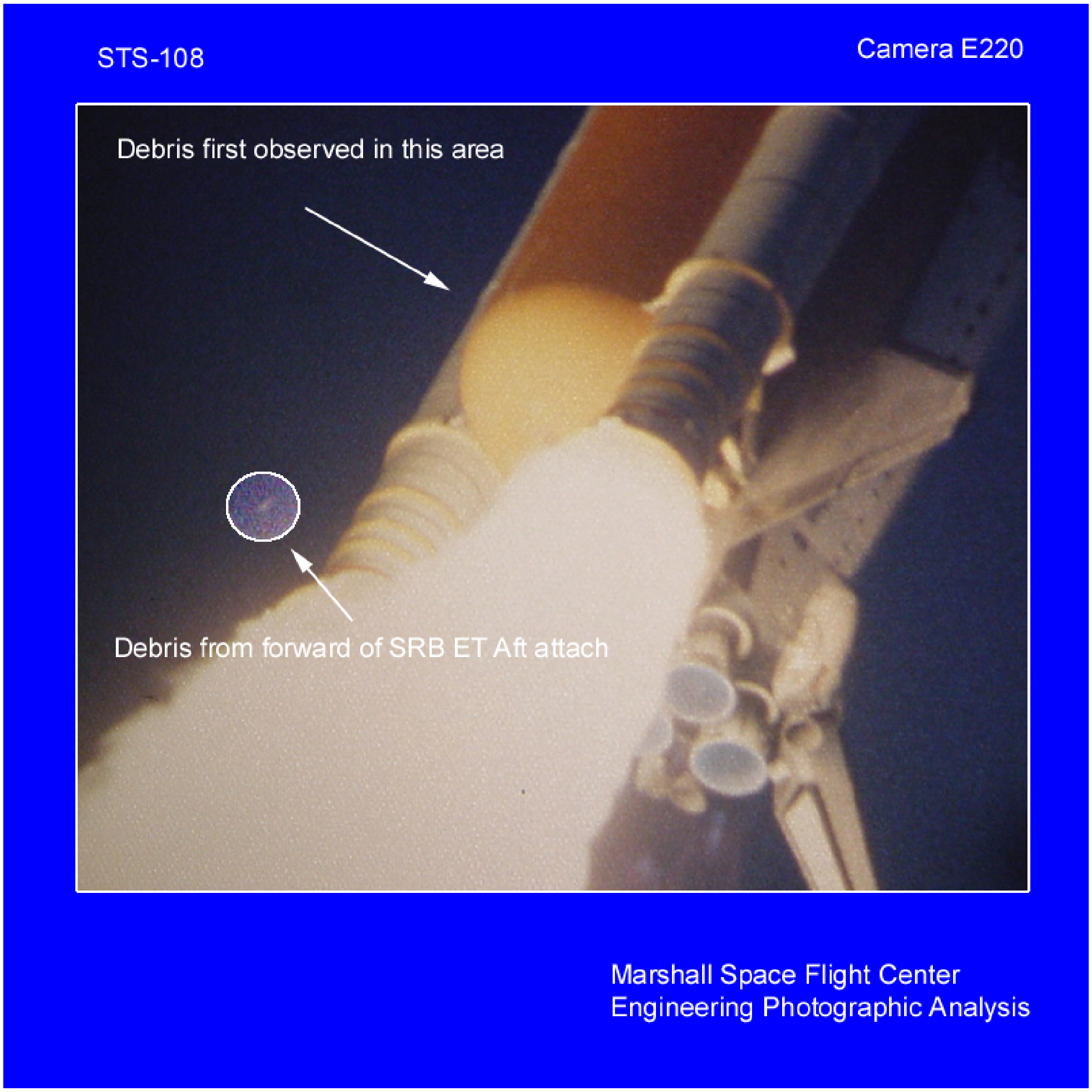


Figure 18. Film Camera E220: Debris Falling Aft

Video Camera TV4B: RCS Butcher Paper Debris

Debris flows aft of the vehicle. The debris is thought to be butcher paper from the forward RCS motors.

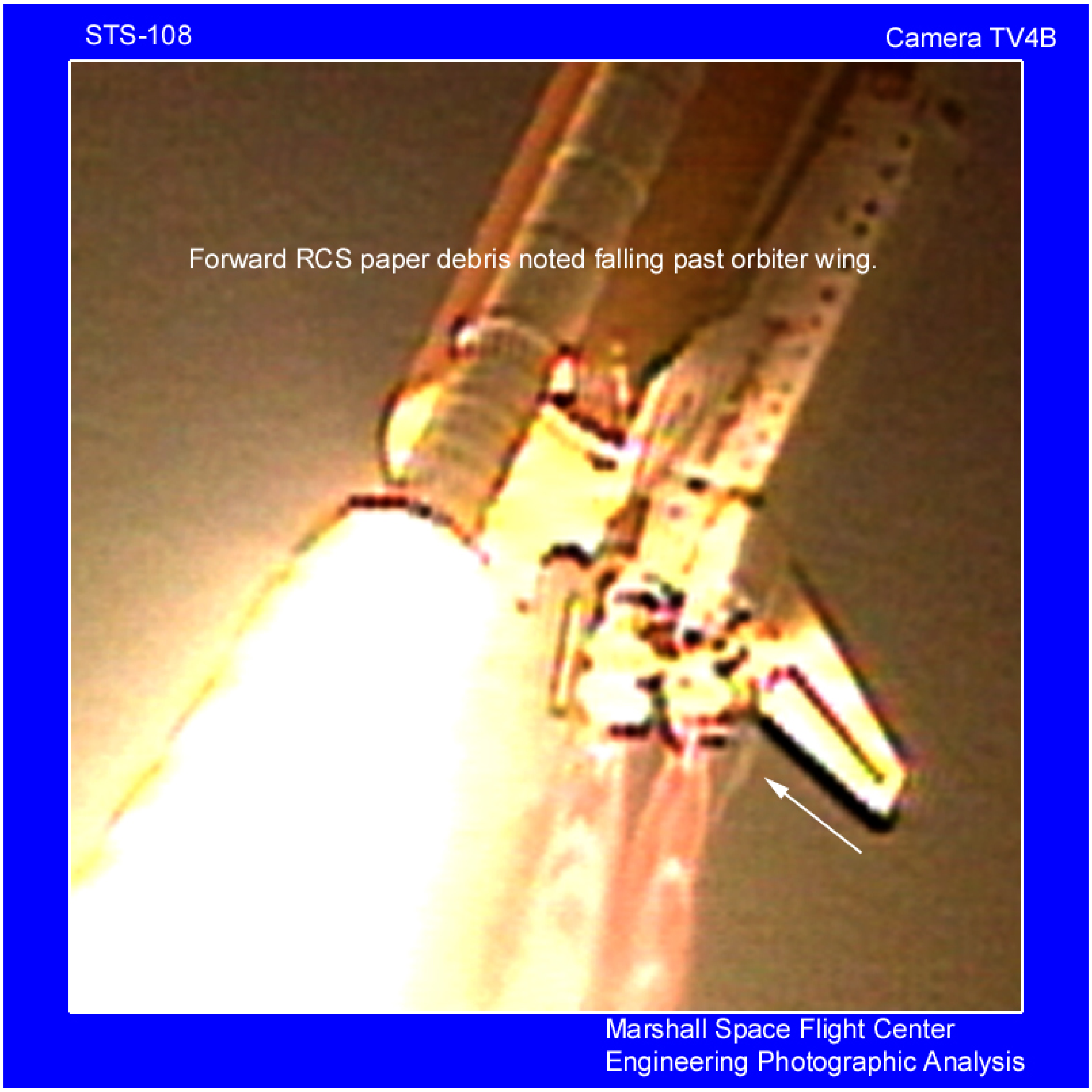


Figure 19. Video Camera TV4B: RCS Butcher Paper Debris

Film Camera E222: RCS Butcher Paper Debris

Debris was observed falling aft of the vehicle. This debris appears to be butcher paper from forward RCS motors.

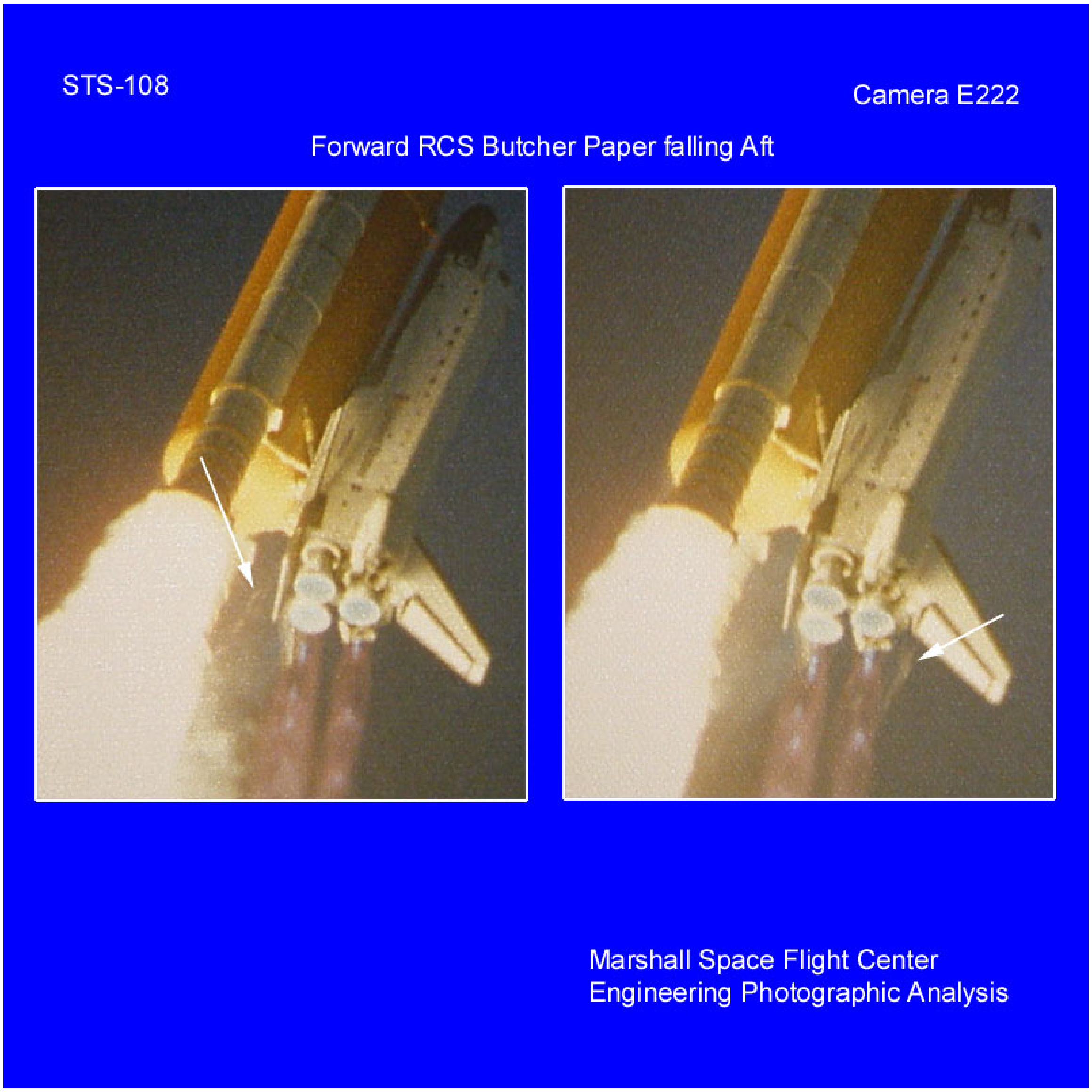


Figure 20. Film Camera E222: RCS Butcher Paper Debris

Film Camera E223: Debris Induced Streak

Typical debris induced streaks were noted in the SSME plumes.

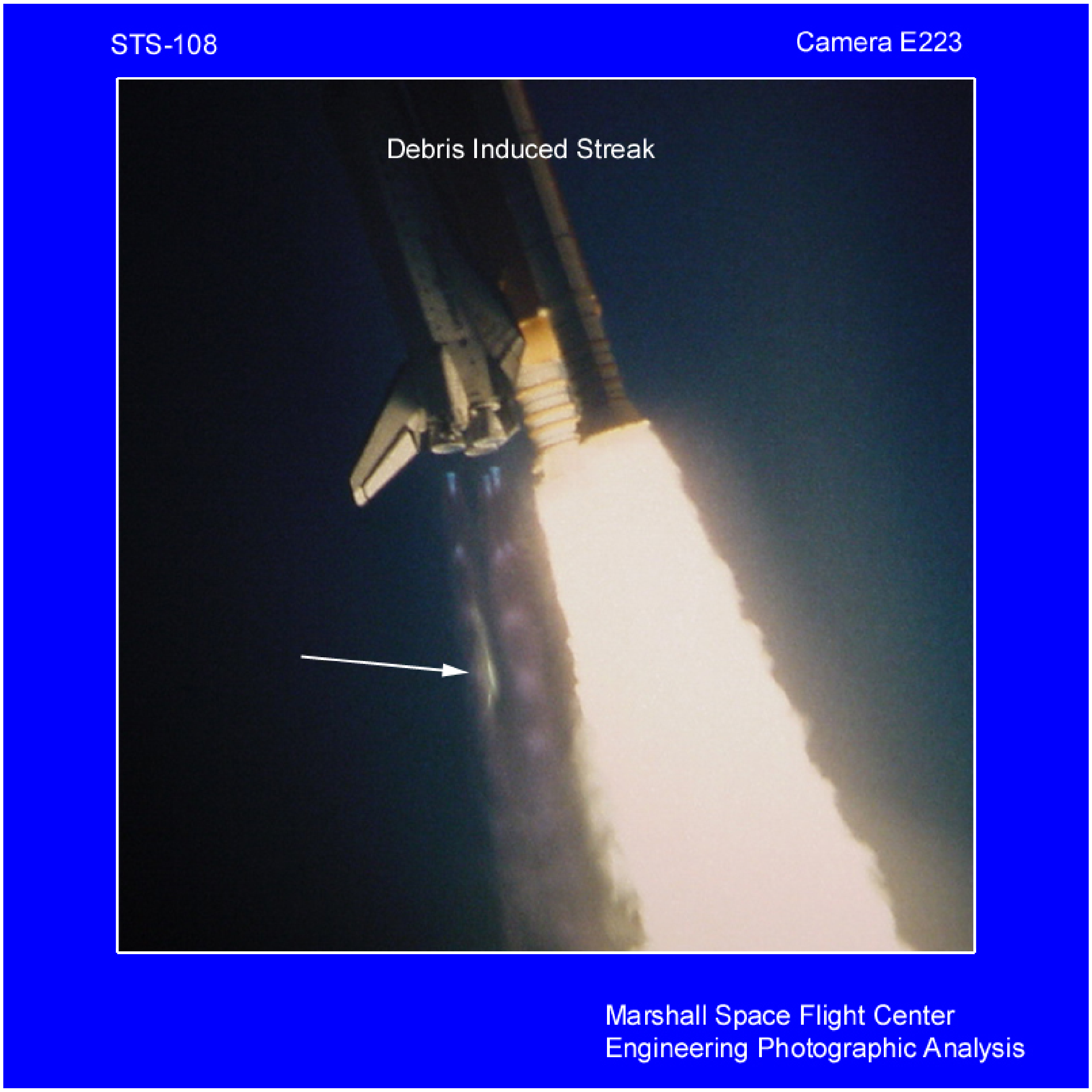


Figure 21. Film Camera E223: Debris Induced Streak

Video Camera ET213: Debris Induced Streak in SSME Plume

Debris induced streaks were noted in SSME plumes.

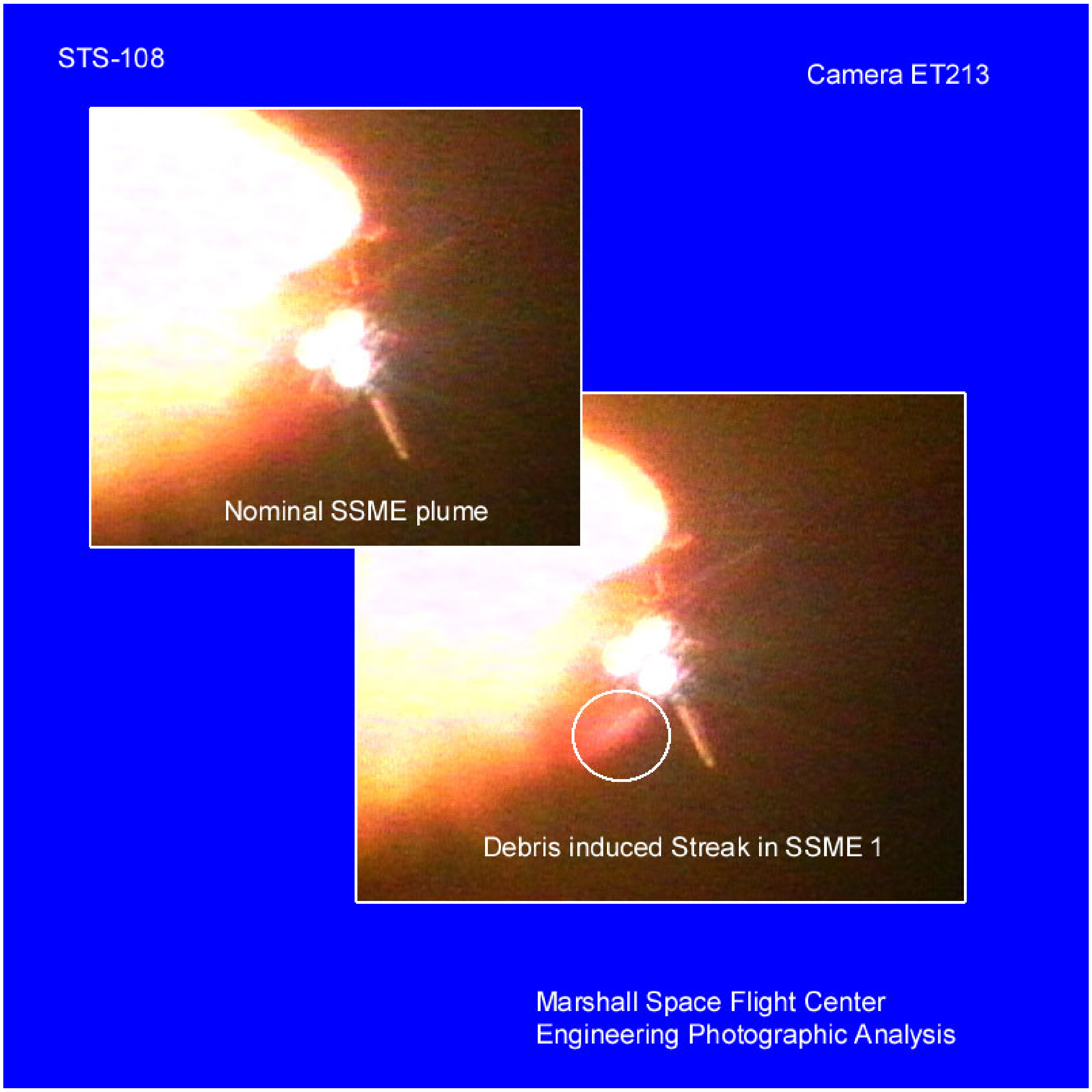


Figure 22. Video Camera ET213: Debris Induced Streak in SSME Plume

Video Camera ET212: Debris Induced Streak in SSME Plumes

Debris induced streaks were observed in the SSME #1 plume.

Figure 23. Video Camera ET212: Debris Induced Streak in SSME Plumes

Video Camera TV4B: Debris Ejected from SRB Plumes

Debris was observed emanating from the SRB plumes prior to SRB separation.

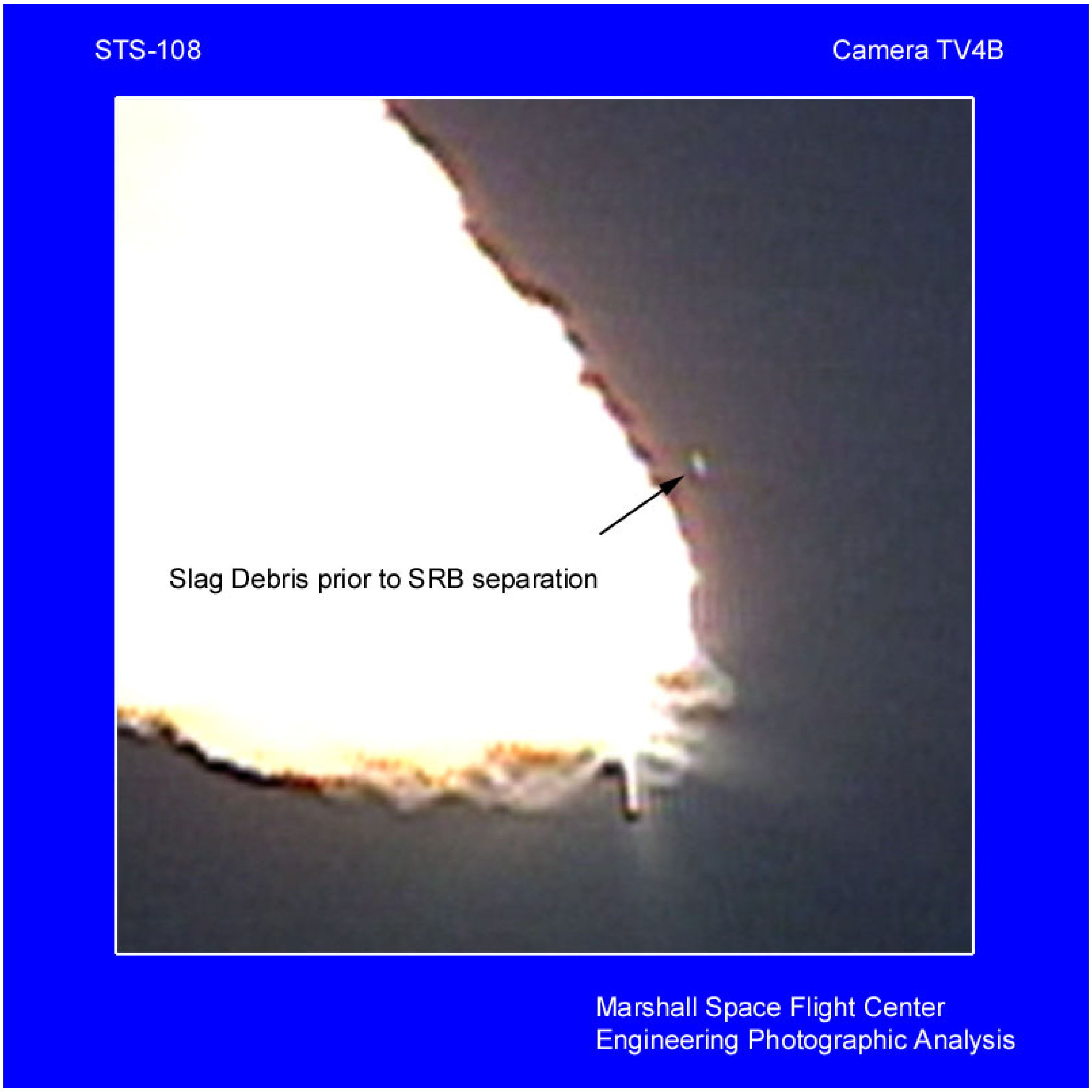


Figure 24. Video Camera TV4B: Debris Ejected from SRB Plumes

Film Camera E224: Debris Ejected From SRB Plumes

Slag ejected from the SRB plumes was observed.

Figure 25. Film Camera 224: Debris Ejected from SRB Plumes

Film Camera E205: Flow Recirculation

Flow recirculation was noted at the aft of the external tank.

Figure 26. Film Camera E205: Flow Recirculation

Film Camera E207: Debris at SRB Separation

Slag debris was observed emanating from the SRB plumes at SRB separation.

Figure 27. Film Camera E207: Debris at SRB Separation

Film Camera E205: Slag Debris

Slag debris from SRB plumes was observed at SRB separation.

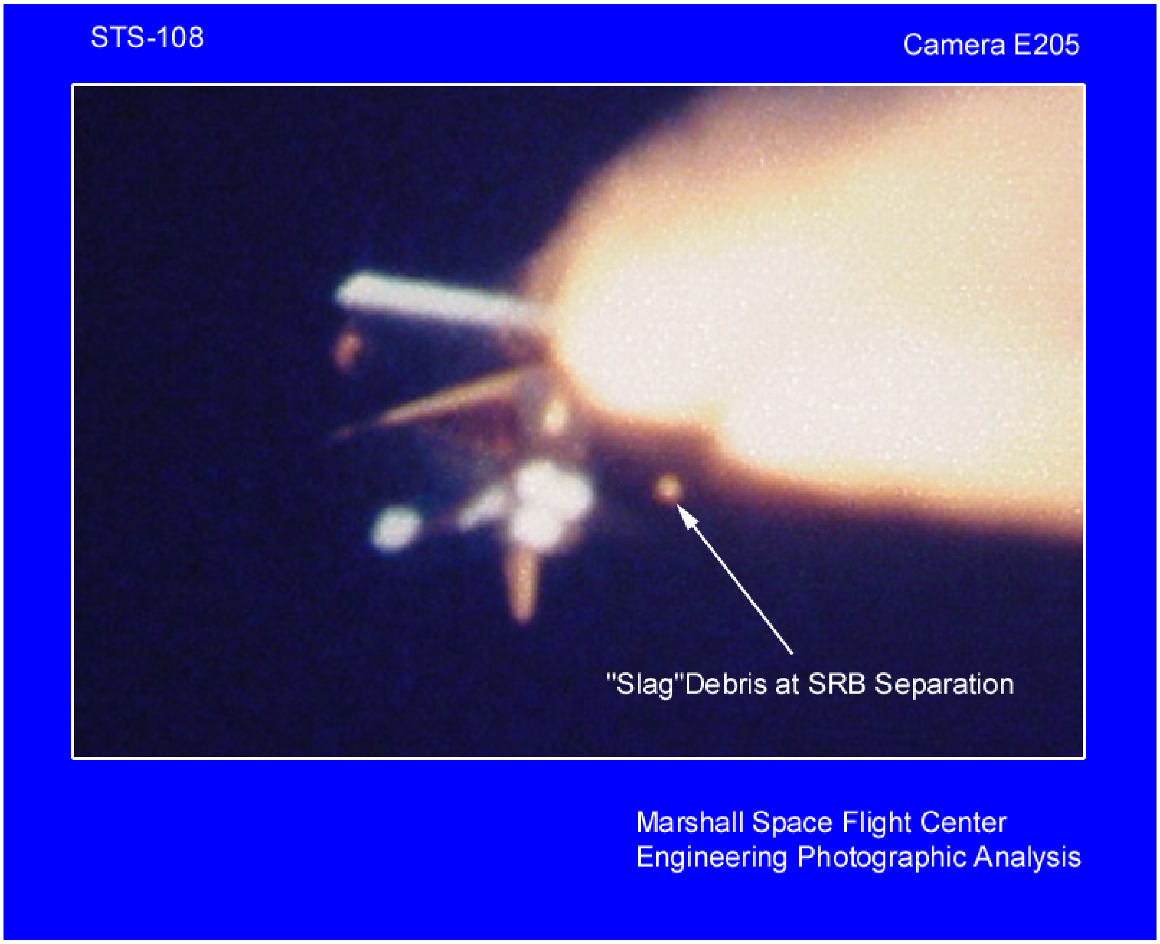


Figure 28. Film Camera E205: Slag debris at SRB Separation

Film Camera FL101: ET/SRB Separation

A slight twang at the EB-9 electrical connector interface of the ET/SRB upper attach was observed at ET/SRB separation. This motion has been observed on previous missions.

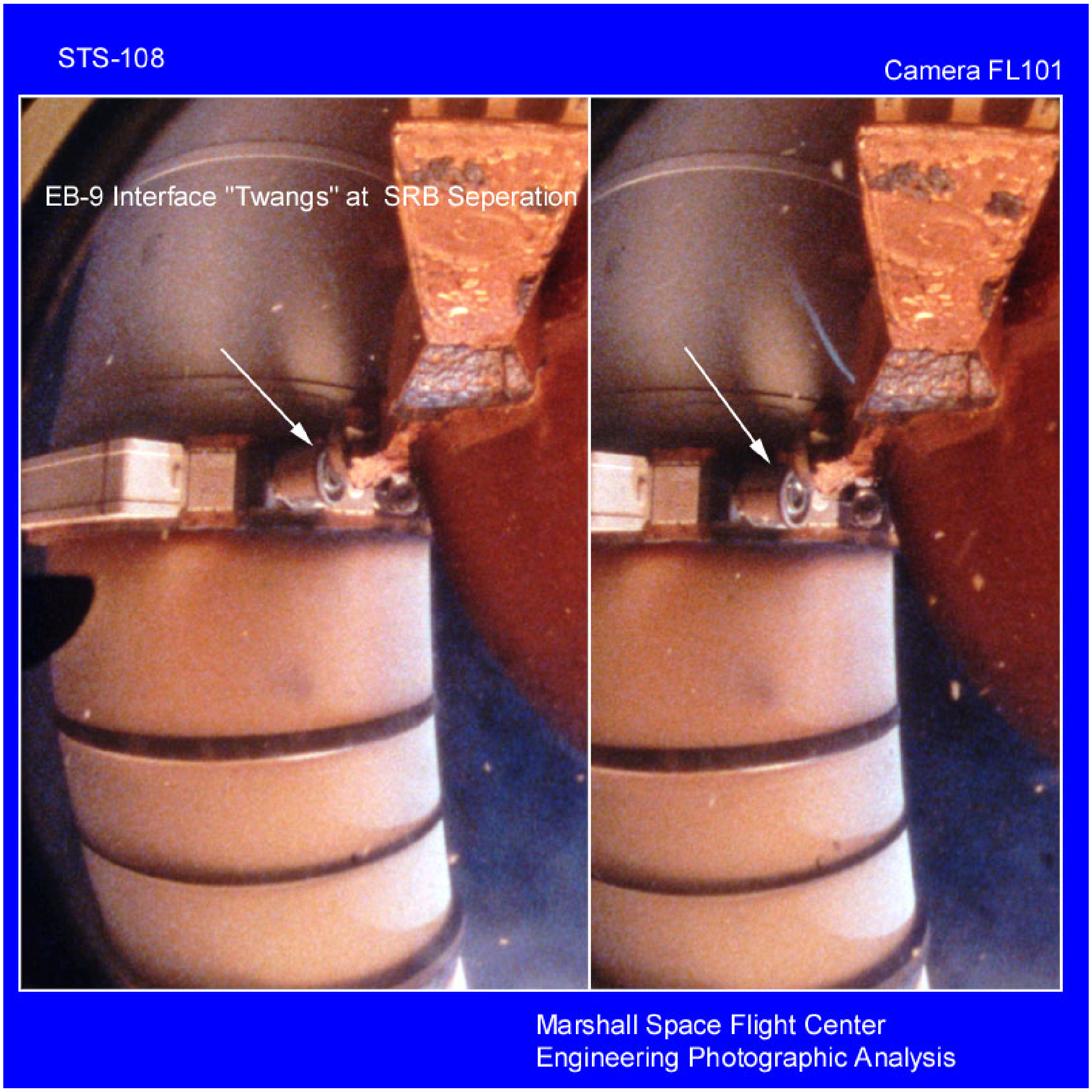


Figure 29. Film Camera FL101: ET/SRB Separation

Video Camera TV13: OMS Motor Burn after SRB Separation

The scheduled OMS motor burn was observed after SRB separation.

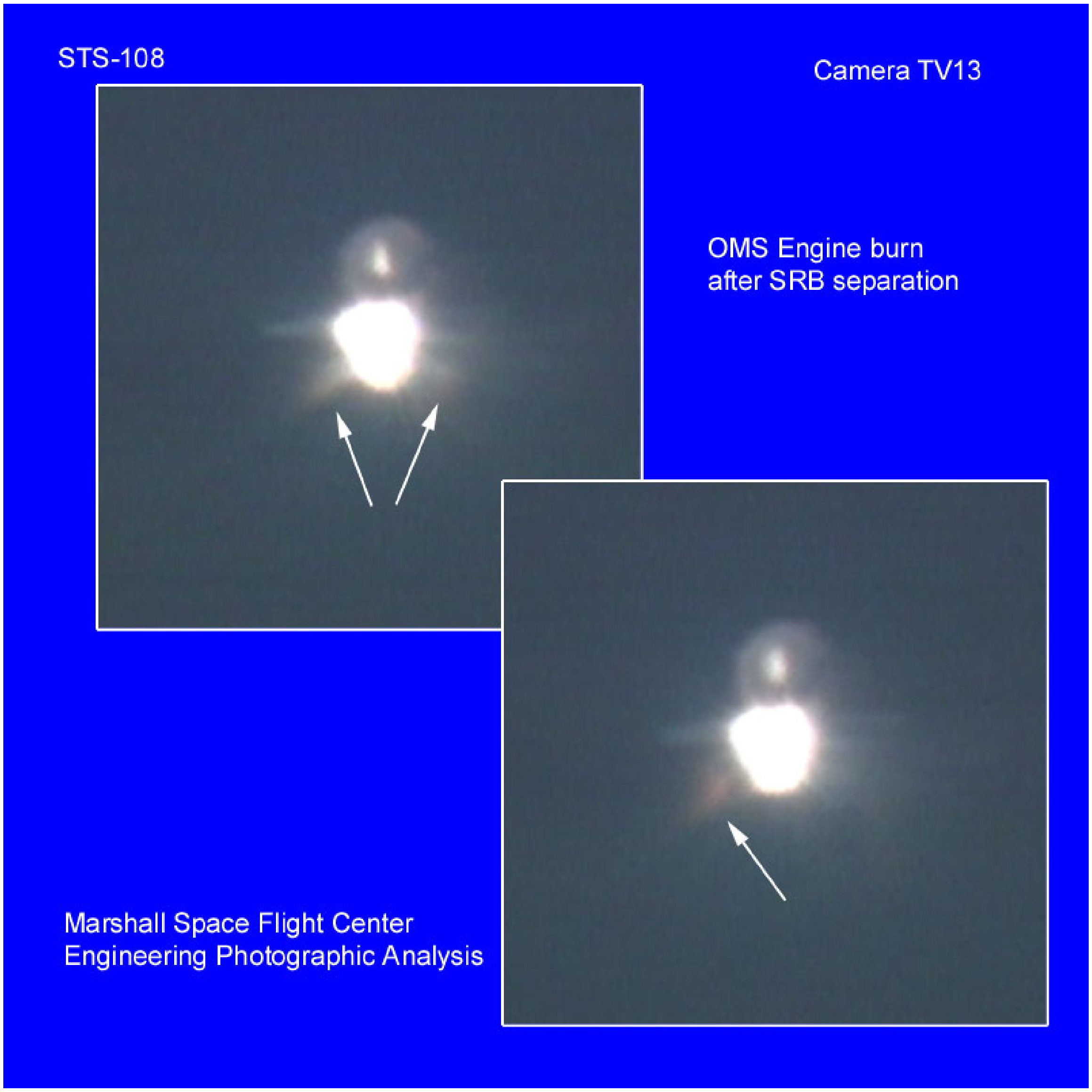


Figure 30. Video Camera TV13: OMS Motor Burn after SRB Separation

Special Investigations:

GH2 Vent Arm Retraction Investigation: Film Digitization

Since high-resolution digital images were necessary for the required GUCP motion accuracy, MSFC was initially tasked to digitize film from camera E-33 for missions STS-108, STS-104, STS-106, STS102, STS-97, STS-95, STS-61, STS-58, and STS-52 on our Oxberry Film-to-Digital Image Transfer equipment and provide those digitized images to JSC Image Science and Analysis Group. Digitization of camera E33 images from other missions was later requested as well as images from other cameras. Mission and camera information for the digitized films are provided in Table 3.

Each mission film was digitized into a sequence of 700 frames. The frame rate for film camera E-33 is 200 frames/second (fps). One second of film, 200 frames, was digitized from a period before SSME ignition and 2.50 seconds of film, 500 frames, beginning at approximately 0.5 seconds before T-0.

Mission	PAD	T-0 (GMT)	E33	E39	E60	E42
STS-108	B	339:22:19:27.987	D,M,A		D,M	D,M
STS-104	B	193:09:03:58.991	D,M,A			
STS-102	B	067:11:42:09.004	D,M,A			
STS-097	B	336:03:06:00.986	D,M,A			
STS-106	B	252:12:45:47.008	D,M,A			
STS-95	B	302:19:19:33.984	D,M,A			
STS-61	B	336:09:26:59.983	D,M,A			
STS-58	B	291:14:53:10.009	D,M,A			
STS-52	B	296:17:09:39.007	D,M,A			
STS-62	B	063:13:53:00.009	D,M,A			
STS-63	B	034:05:22:03.994	D,M,A			
STS-64	B	252:22:22:54.982	D,M,A			
STS-78	B	172:14:49:00.019	D,M,A			
STS-81	B	012:09:27:22.984	D,M,A			
STS-85	A	219:14:41:00.013			D,M	
STS-27	B	337:14:30:33.987			D,M	
STS-28R	B	220:12:37:00.012		D,M	D,M	
STS-30	B	124:18:46:59.011			D,M	

D: Digitization M: Movie A: Analysis

Table 3. Film Digitization List

A movie was created for each mission and a movie comparing all missions and frame synchronized to T-0 are available for viewing on the website. Also, selected frames of the event are available. Additionally, movies of camera views from Camera E60, E42, and E33 for this STS-108 anomalous event are available on the website.

GH2 Vent Arm Retraction Investigation: Analysis of Film Camera E33 Imagery

MSFC was tasked to also perform an independent investigation of the digitized films. Analysis of the film included an analysis of the motion of the GUCP during ET tip deflection and GH2 Vent Arm retraction. Specifically, results from the analysis included: the time and maximum deflection of the GUCP in the Z-direction, the time and rebound distance of the GUCP, the time of GUCP release, and the angle between the GUCP and ET surface as the GUCP pivots away from the ET.

Data:

Values for locations are in External Tank (X_T) coordinates (x,y,z). Two points on the GUCP were tracked frame-to-frame in each set of digitized images to estimate the motion of the GUCP in the XZ-plane during ET tip deflection. These points were the exposed top of bolts (UNJF-3B) (as depicted in IRN No. TC-1603 pg. 136) located on the forward right and left sides of the GUCP. The distance between these two points was reported as 16.375 inches.

GUCP separation point	(1012.918, -143.327, 317.250)
Camera E33 location	(745.000, -911.000, 262.000)

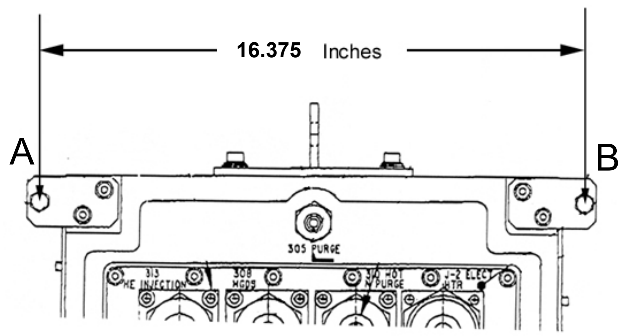


Figure 31. Drawing of Tracked Points

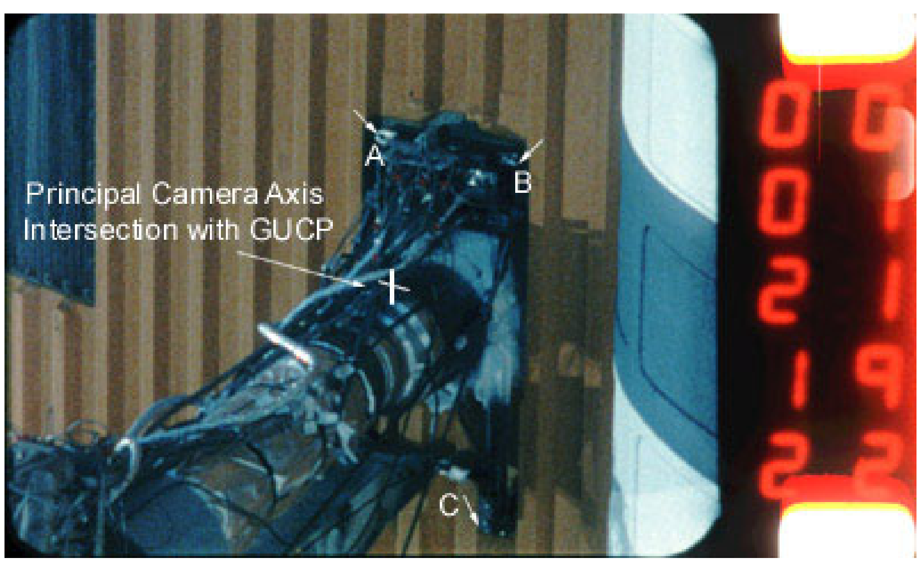


Figure 32. Image of Tracked Points

The principal camera axis did not appear to coincide with the separation point on the GUCP and a small correction where the principal camera axis intersects the plane of the GUCP was made.

GUCP/Principal camera axis intersection point (1019.518, -140.124, 311.702)

An additional point was tracked in each set of images to estimate the angle of separation between the GUCP and ET surface as the GUCP pivots away from the ET. This point was a located near the GUCP pivot point. These locations were estimated from drawings.

GUCP pivot point (Point C) (1045.380, -150.093, 312.432)
GUCP top "right" point (Point B) (1003.170, -144.626, 316.500)

The digitized sequences were comprised of two segments. The first segment included two hundred frames with approximately one hundred of those frames before SSME ignition and the second segment was composed of approximately five hundred frames beginning just before maximum ET tip deflection until just after the vehicle leaves the pad.

The initial two hundred frames from each sequence were used to obtain a reference position and a scaling factor relating distance in the image to distance in pixels in the image plane. The projection of the vector from Point A to Point B, L_G , into a plane parallel to the film plane results in a vector, L_{GF} , which scales the actual distance of 16.375 inches between the Points A and B into the distance as seen in a plane parallel to the film plane. Since we need the motion in the z-direction, we project the vector, L_{GF} , into the xz-plane to obtain the vector, L_{GFZ} . An overall scale factor for motion in the z direction was determined separately for each mission by dividing the magnitude of the L_{GFZ} vector by the average pixel distance between the Points A and Points B over the first two hundred frames.

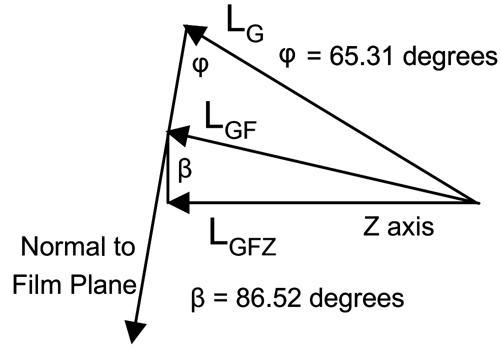


Figure 33. Z-Component Determination of Projection into Image Plane

The above scaled orthographic projection method introduces a small error in calculation of travel distance. The error was estimated to be about 0.01 -0.03 inches and was neglected since that amount of deviation was not significant compared to the deviation in travel distance due to measurement error. This deviation was calculated by determining the angle λ, Figure 34 , the angle of the line of sight vector with the focal plane, the angle ε (90-β from the projection method diagram), and using the estimated lengths calculated by the projection method.

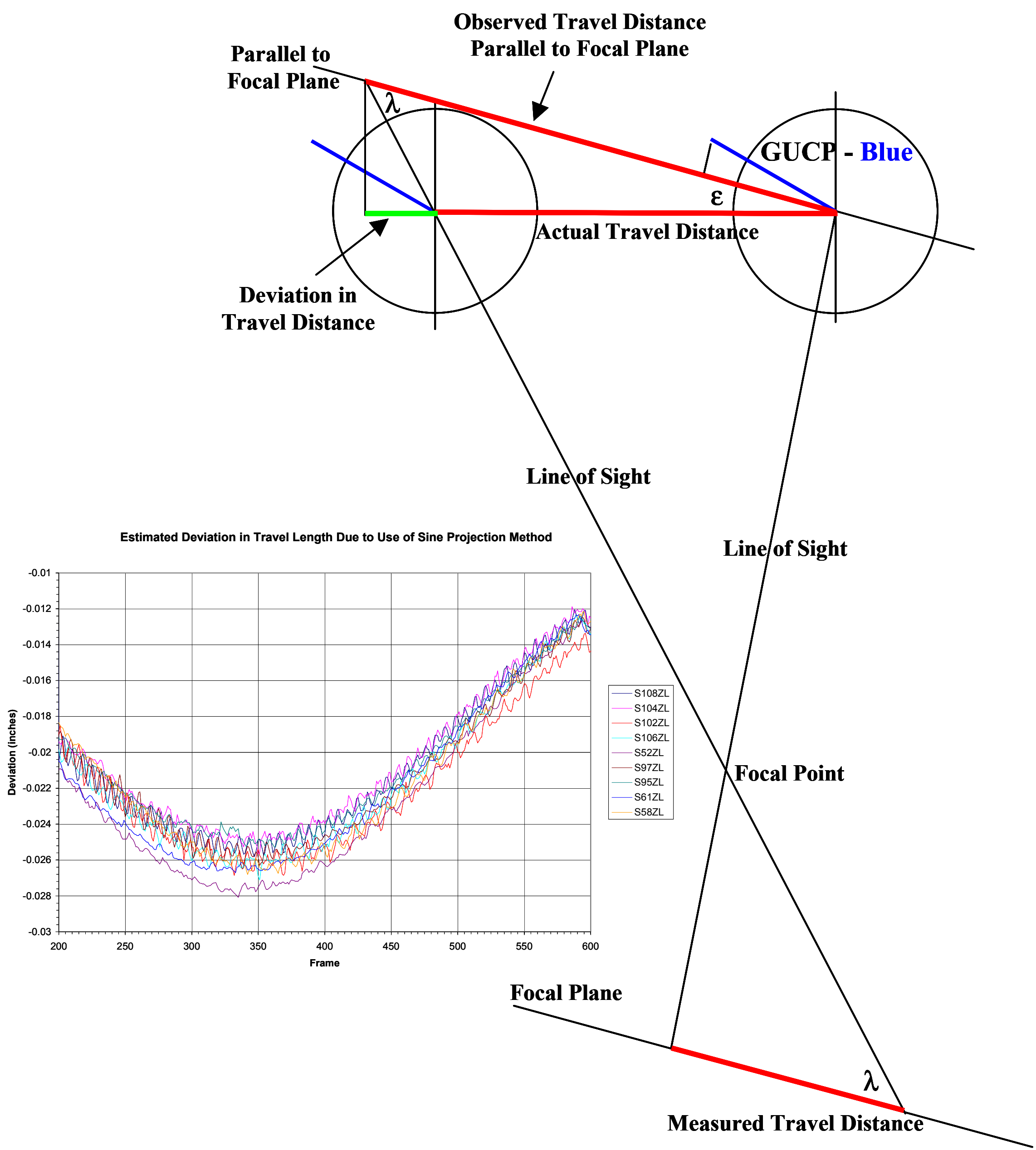


Figure 34. Calculation of Estimated Deviation to Actual Travel Distance

GUCP Deflection in the X- and Z-Directions:

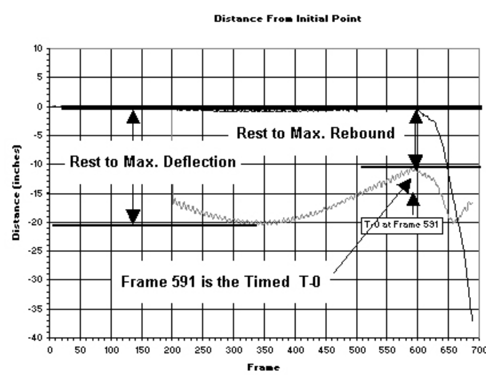
Point A, Figure 32, was selected as a reference for the rest position for the GUCP. The distance, measured in pixels, from the rest position to the location of the tracked Point A , multiplied by the scale factor, (select scale factors illustrated in Table 4), yields the approximation to the distance, in inches, traveled from the rest position.

STS-108	**0.04930**
STS-104	**0.04900**
STS-102	**0.05088**
STS-106	**0.04932**
STS-52	**0.05047**
STS-97	**0.04956**
STS-95	**0.04937**
STS-61	**0.04988**
STS-58	**0.05042**
Mean XZ-Plane Scale Factor =	**0.04980**

Table 4. Scale Factors

Separate X and Z deflection charts are shown in Figure 35 through Figure 43. Also contained in these charts is the smoothed curve for the Z excursion.

Mission	Curve Fitted Scaled Data					
	Distance Rest to Max Deflection		Distance At T-0		Distance Rest to Max Rebound	
	Inches	Time	Inches	Time	Inches	Time
STS108	-20.15	-1.22	-11.25	0.00	-11.24	0.04
STS104	-20.99	-1.21	-11.65	0.00	-11.64	-0.03
STS102	-20.65	-1.11	-12.21	0.00	-12.16	0.02
STS97	-20.41	-1.27	-11.36	0.00	-11.31	0.02
STS106	-20.15	-1.20	-11.40	0.00	-11.40	-0.01
STS95	-20.06	-1.25	-11.57	0.00	-11.57	0.01
STS61	-20.60	-1.29	-11.15	0.00	-11.14	-0.01
STS58	-20.79	-1.25	-11.27	0.00	-11.27	0.02
STS52	-20.76	-1.28	-10.98	0.00	-10.98	0.01
STS78	-21.14	-1.21	-11.68	0.00	-11.67	0.01
STS81	-20.57	-1.20	-11.73	0.00	-11.72	-0.16
STS63	-20.28	-1.21	-10.95	0.00	-10.95	0.01
STS64	-20.18	-1.26	-11.24	0.00	-11.2	-0.04
STS62	-20.44	-1.22	-11.34	0.00	-11.34	0.01



Time: Seconds Relative to T-0
Distance: Inches Relative to Initial Starting Point

Table 5. Z-Excursion Results

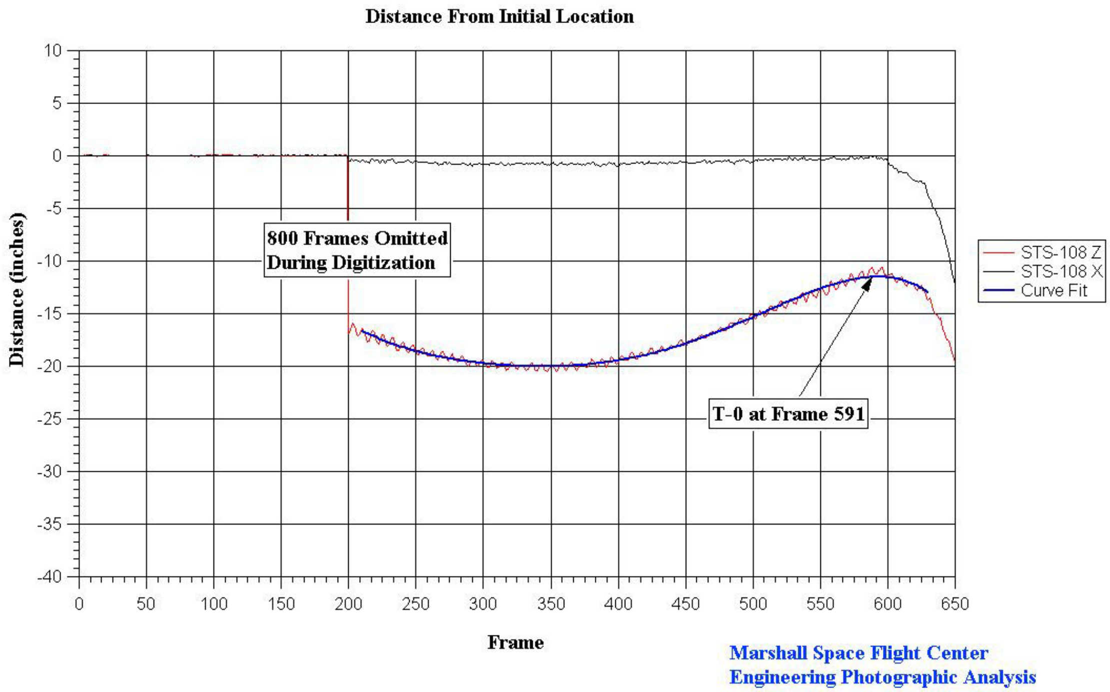


Figure 35. X- and Z-Excursion of GUCP on STS-108

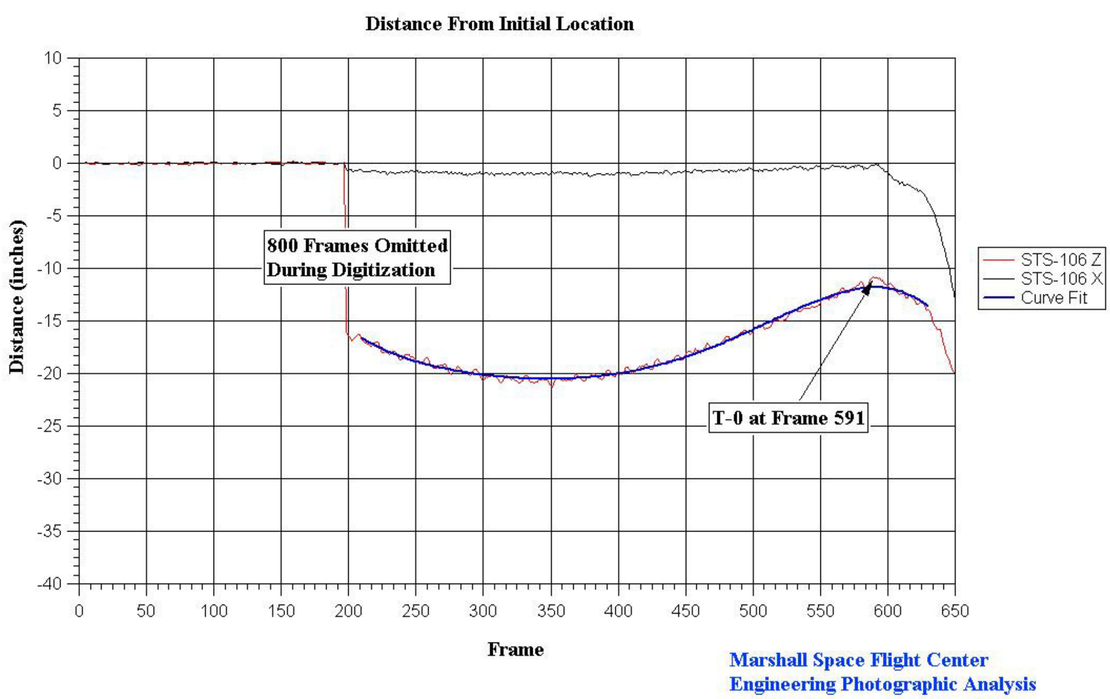


Figure 36. X- and Z-Excursion of GUCP on STS-106

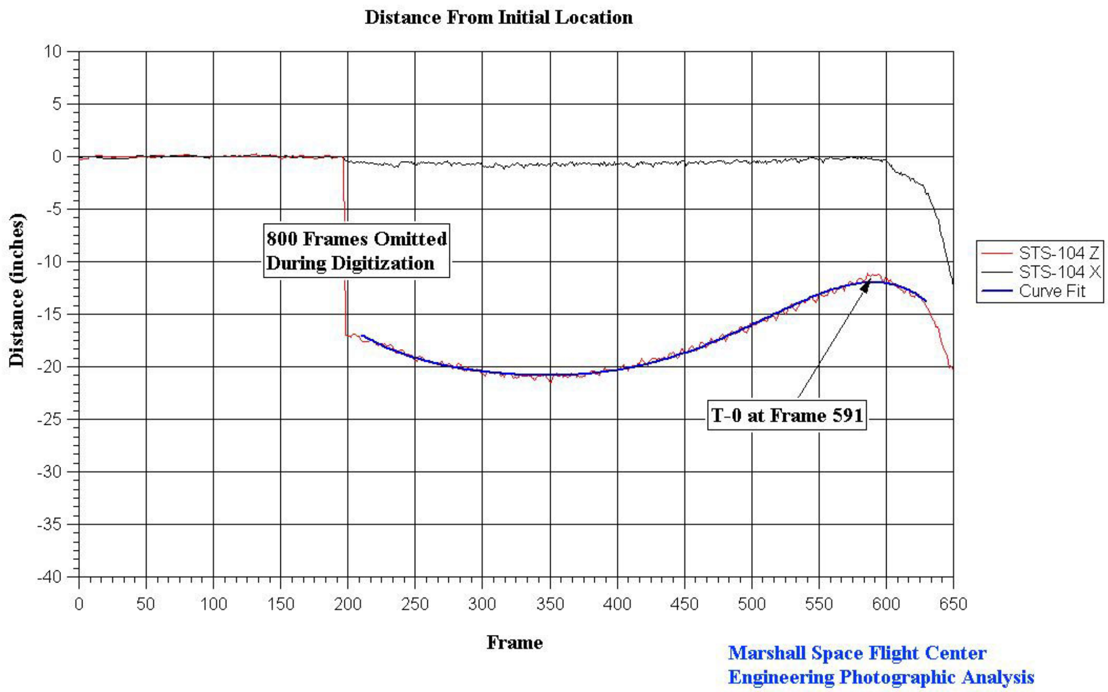


Figure 37. X- and Z-Excursion of GUCP on STS-104

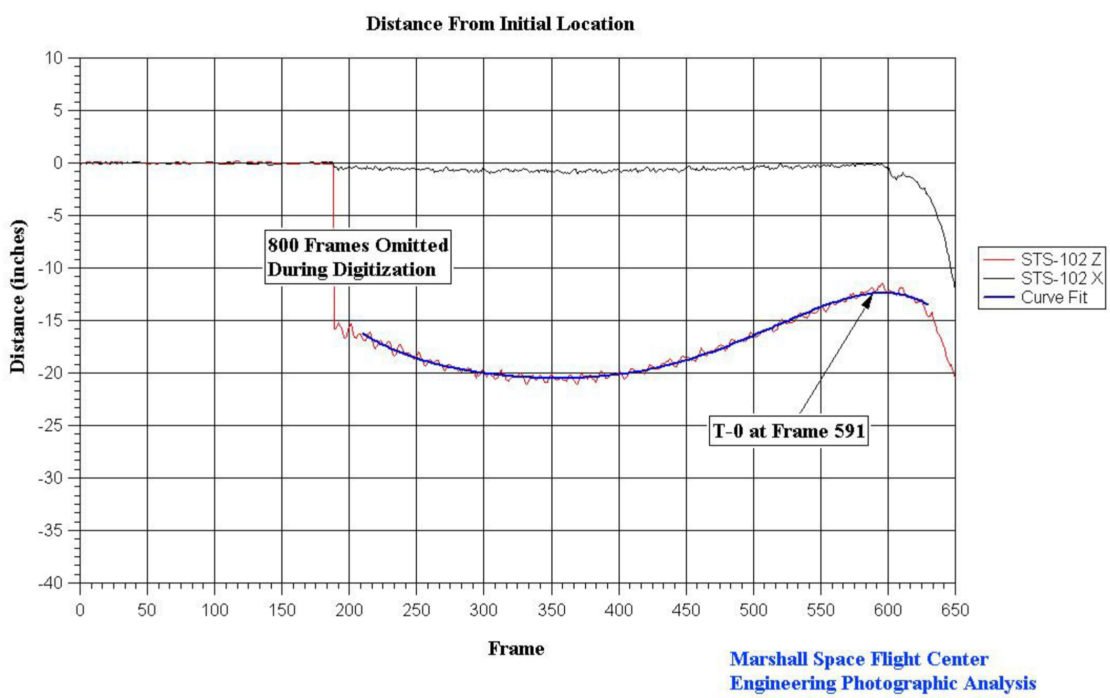


Figure 38. X- and Z-Excursion of GUCP on STS-102

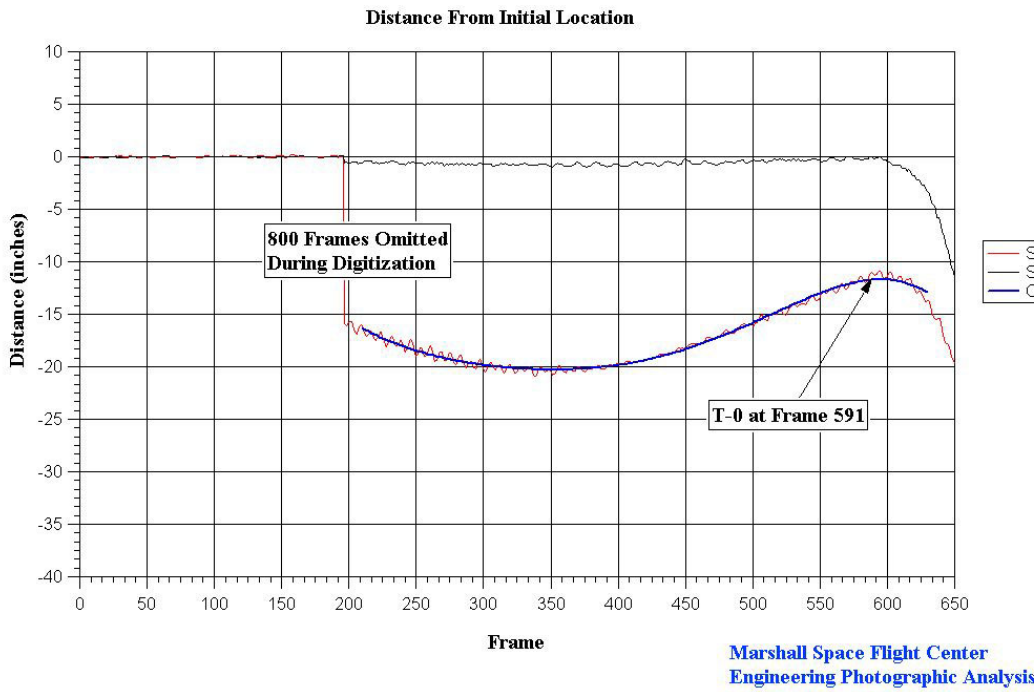


Figure 39. X- and Z-Excursion of GUCP on STS-97

Figure 40. X- and Z-Excursion of GUCP on STS-95

Figure 41. X- and Z-Excursion of GUCP on STS-61

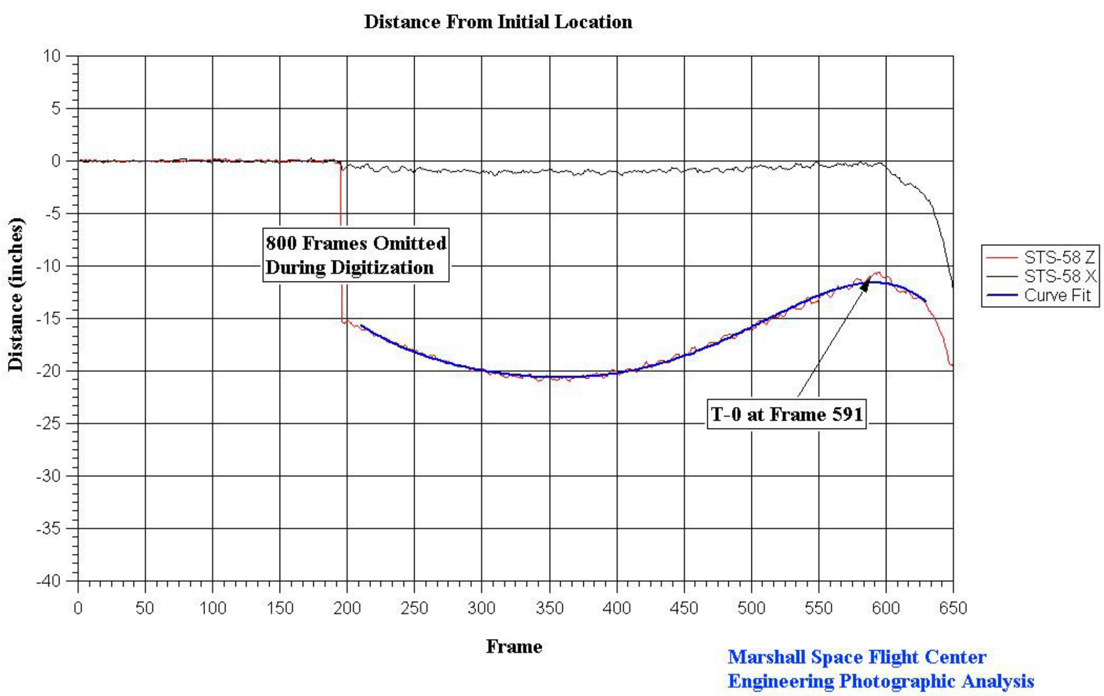


Figure 42. X- and Z-Excursion of GUCP on STS-58

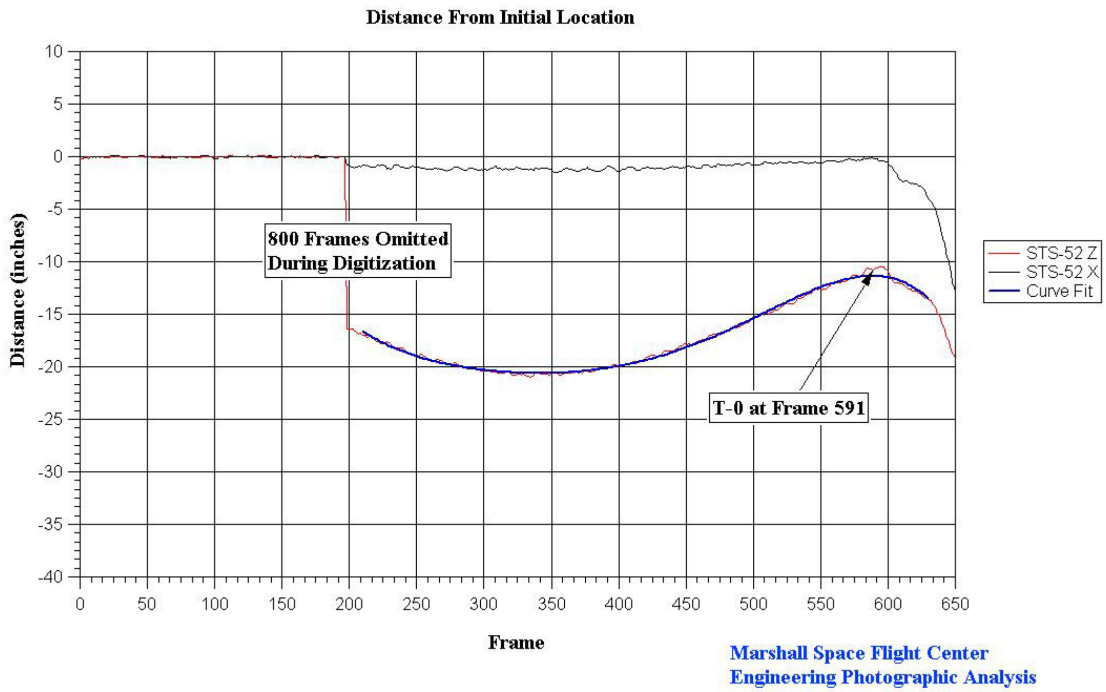


Figure 43. X- and Z-Excursion of GUCP on STS-52

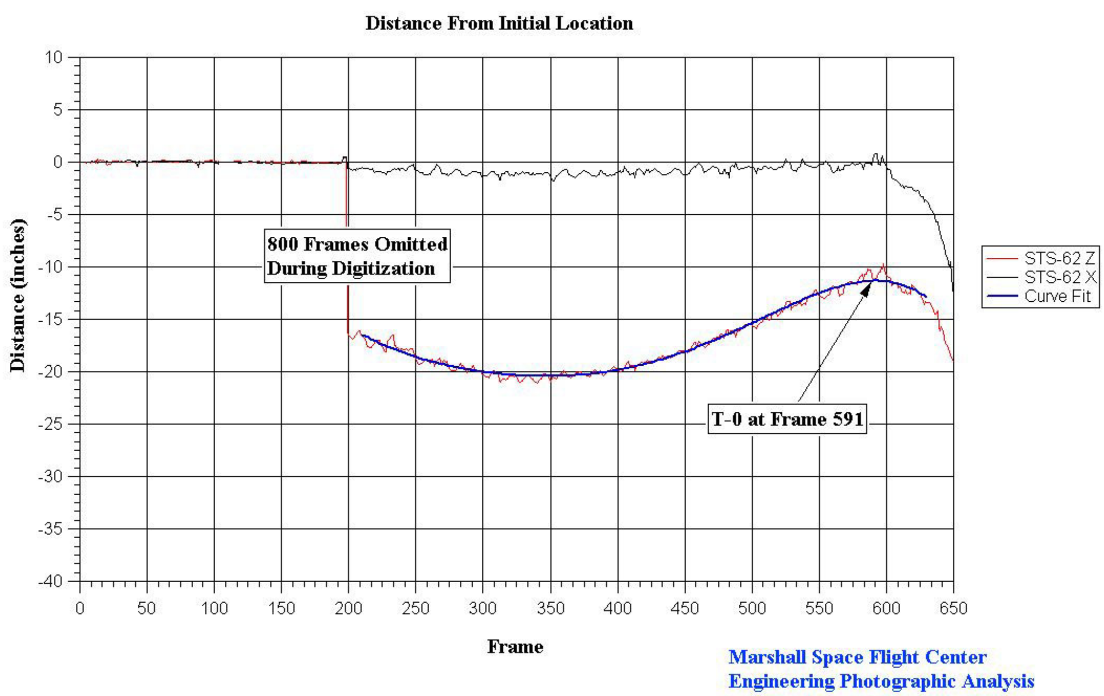


Figure 44. X- and Z-Excursion of GUCP on STS-62

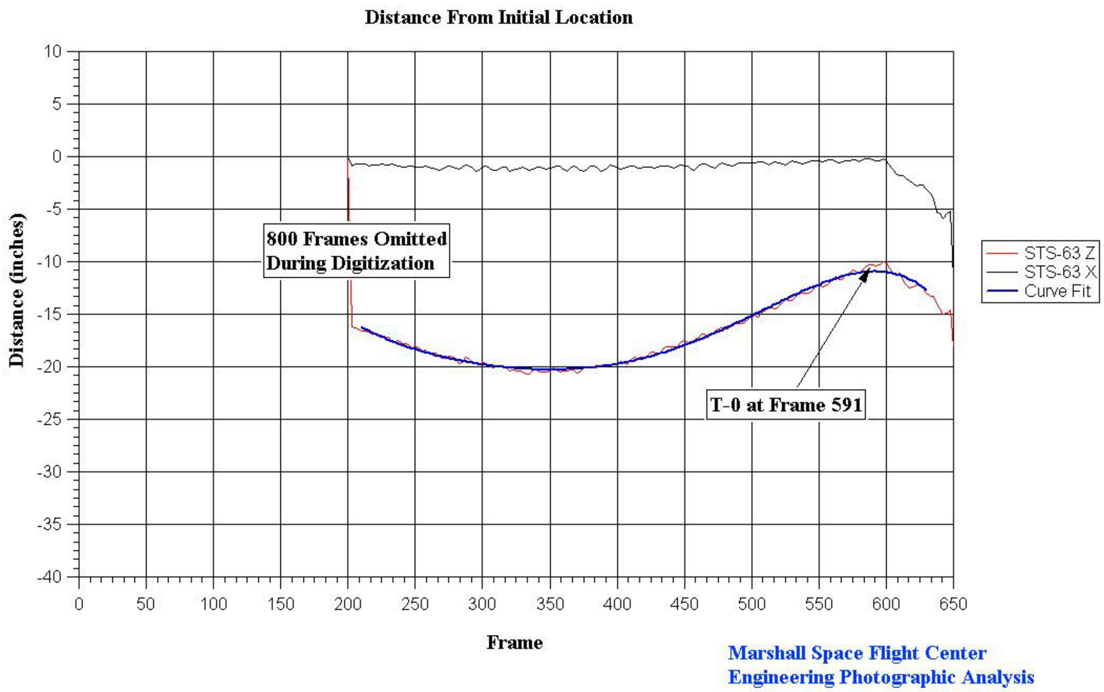


Figure 45. X- and Z-Excursion of GUCP on STS-63

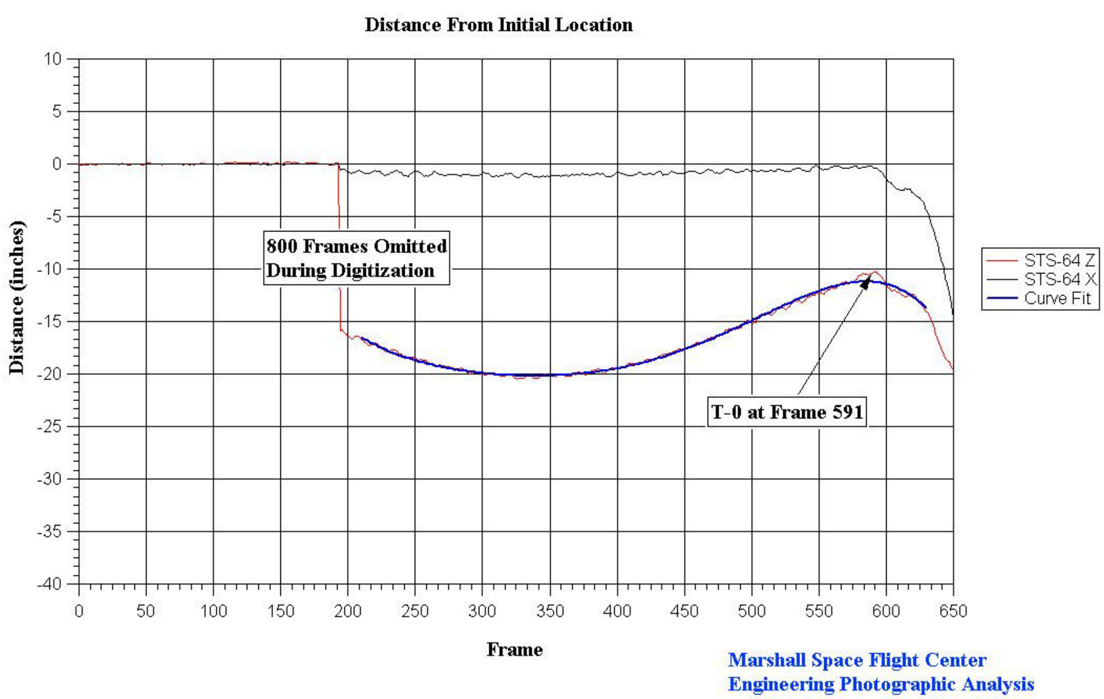


Figure 46. X- and Z-Excursion of GUCP on STS-64

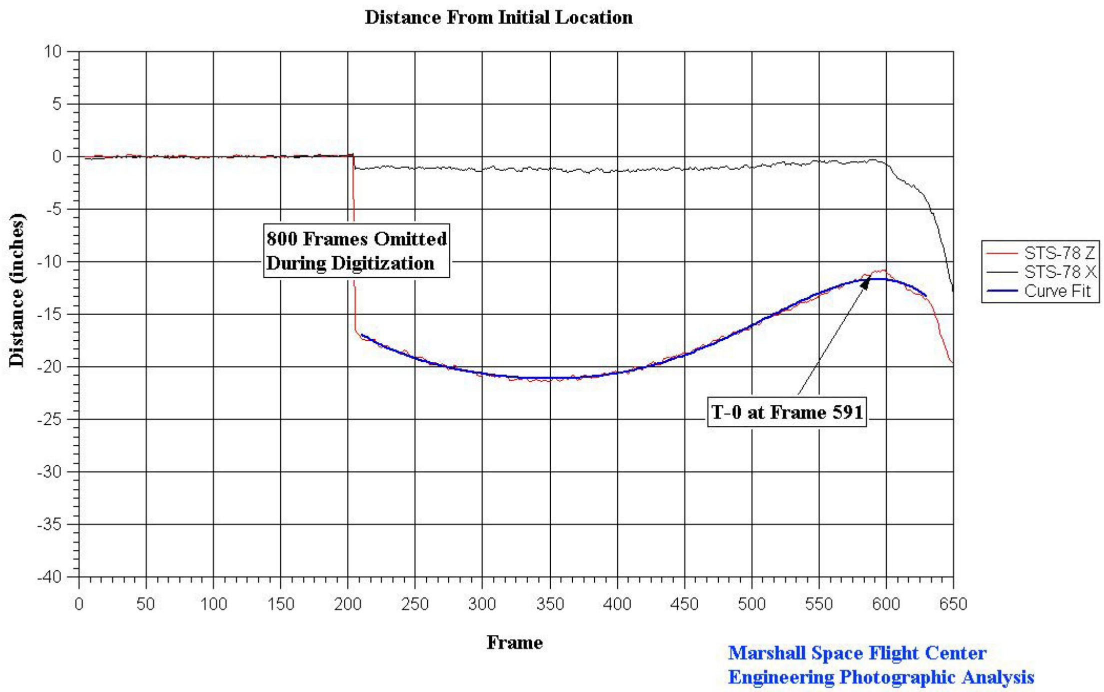


Figure 47. X- and Z-Excursion of GUCP on STS-78

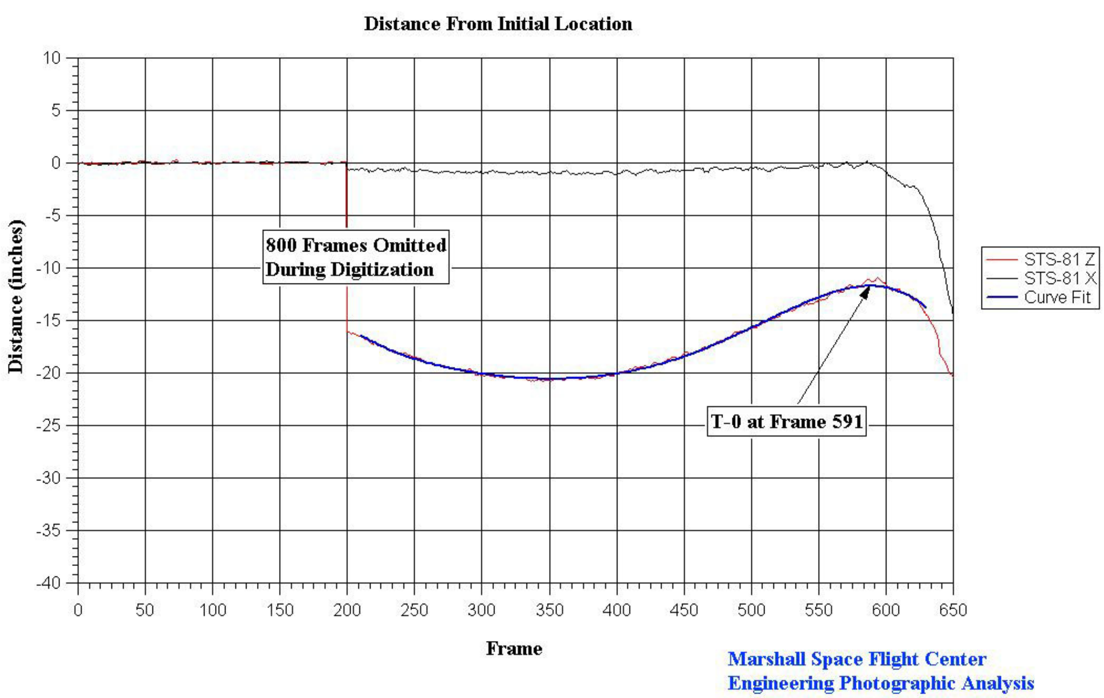


Figure 48. X- and Z-Excursion of GUCP on STS-81

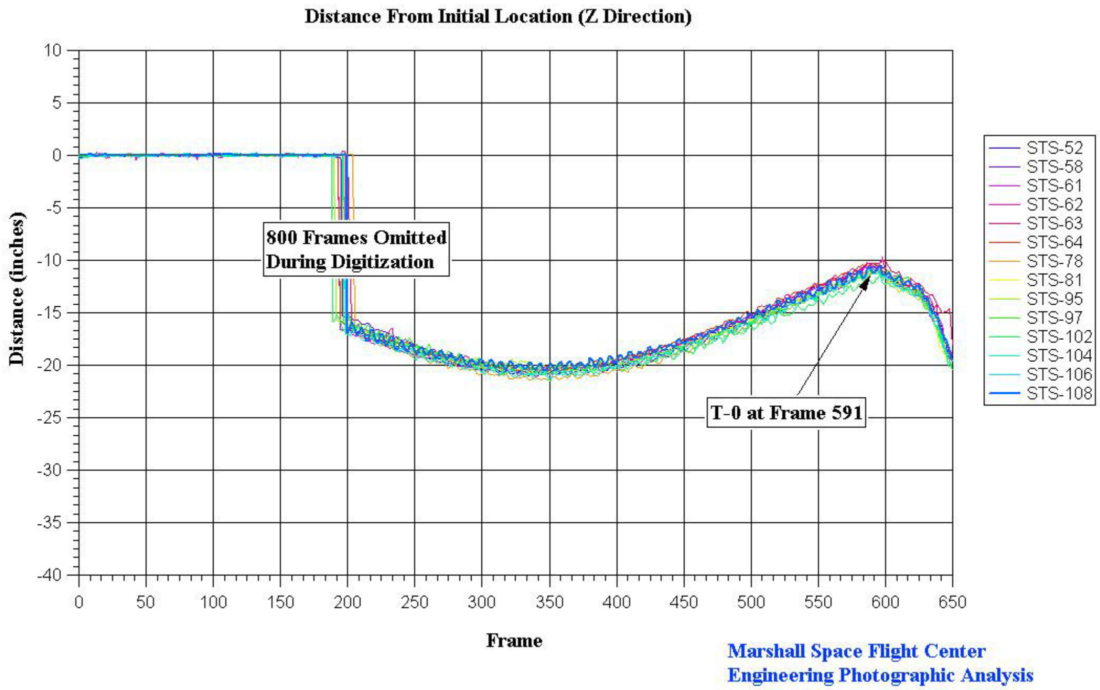


Figure 49. Z-Excursion for All Missions

Figure 50. X-Excursion for All Missions

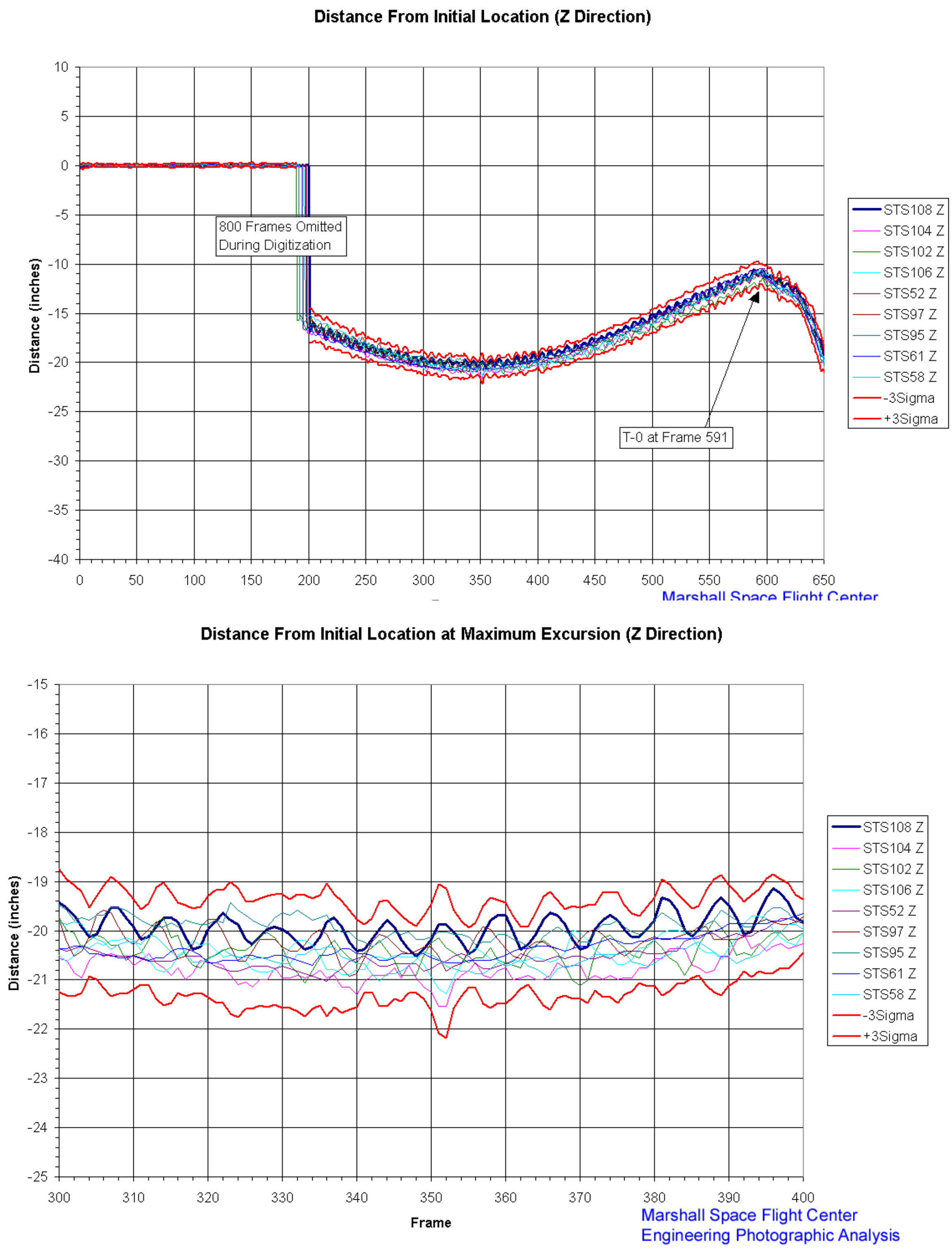


Figure 52. Three Sigma Bounds and Z-Excursion Data at Maximum Deflection

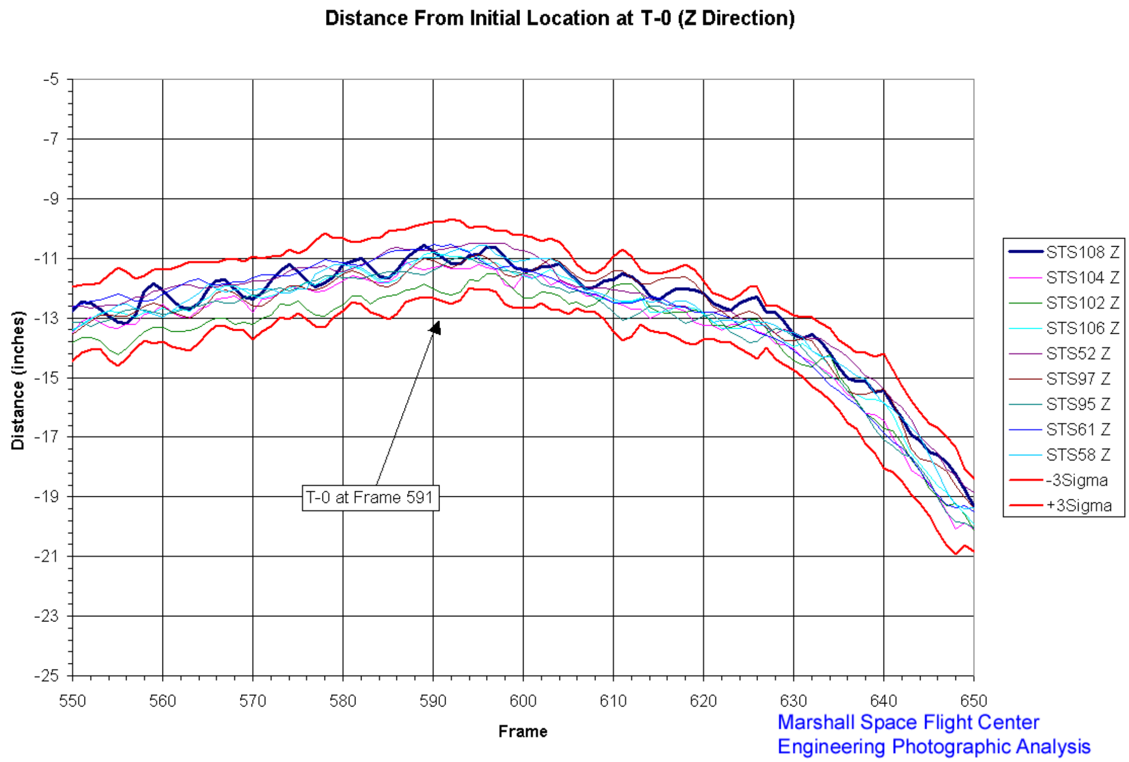


Figure 53. Three Sigma Bounds and Z-Excursion Data at T-0

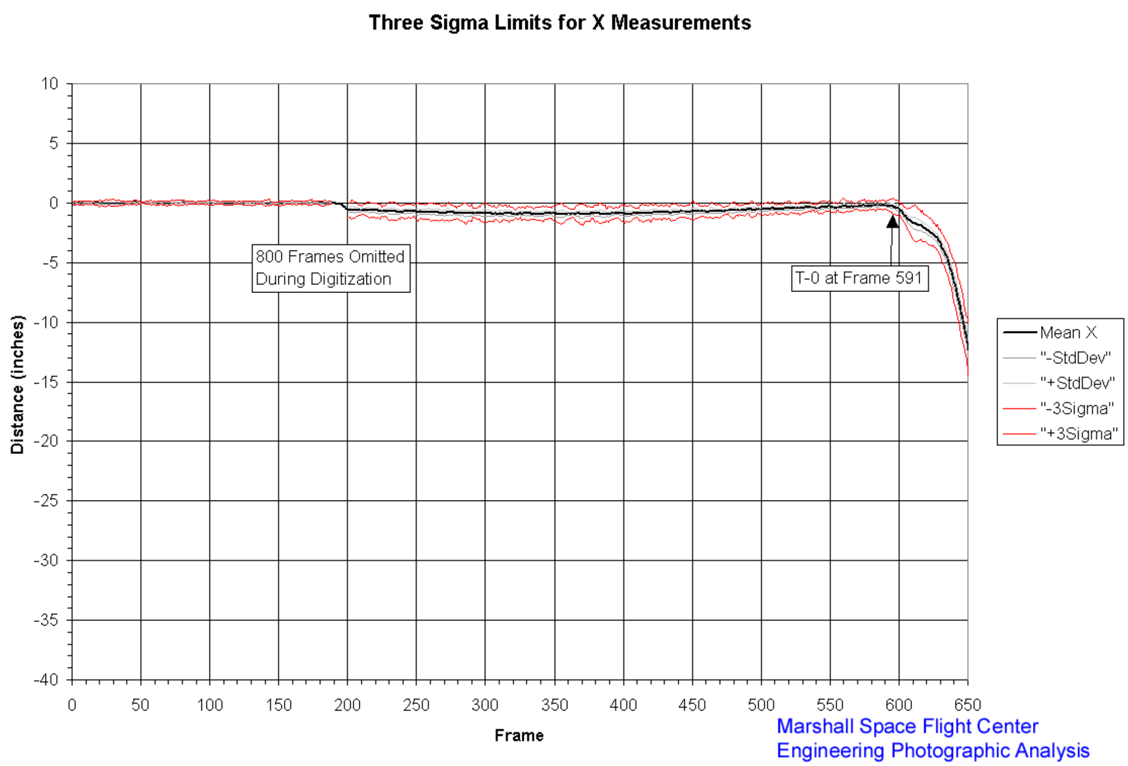


Figure 54. Three Sigma Bounds and X-Excursion Data at T-0

GUCP Separation Angle and Release at Pivot Point:

By visual inspection of the film, the time of GUCP release at the pivot point was determined, Table 6. A separate calculation was made for the angle at the GUCP release from the ET.

Mission	GUCP Release at Pivot Point by Visual Inspection	
	Frame	Time
STS108	646	0.275
STS104	645	0.270
STS102	644	0.265
STS97	645	0.270
STS106	645	0.270
STS95	645	0.270
STS61	643	0.260
STS58	646	0.275
STS52	645	0.270

Time:Seconds Relative T-0
T-0 is Frame 591

Table 6. GUCP Release Timing

To illustrate the generally consistent GUCP motion as it pivots away from the ET, a graph illustrating the separation angle observed in the image was created including all missions. The cosine of the angle was calculated using the dot product method for vectors illustrated in Figure 55. Results are shown in Figure 57.

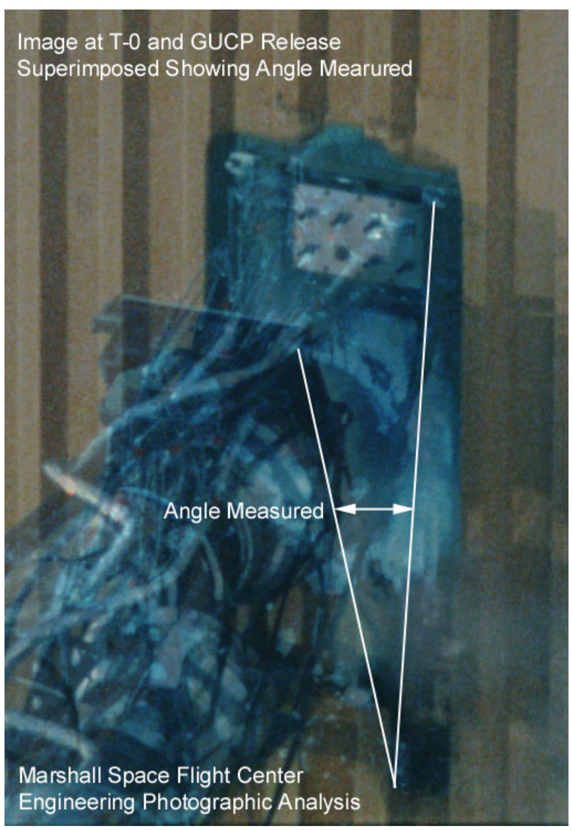


Figure 55. Separation Angle in Image Plane

To calculate the actual angle of separation between the GUCP and the ET surface, a point near the pivot axis, Point C in Figure 32, was tracked. The vector, from point C to the previously tracked point B, initially lies almost entirely in the x-direction of the plane of the GUCP and its motion follows the pivoting GUCP plane. This vector's motion may also be characterized analytically by equations rotating the vector about the pivot axis.

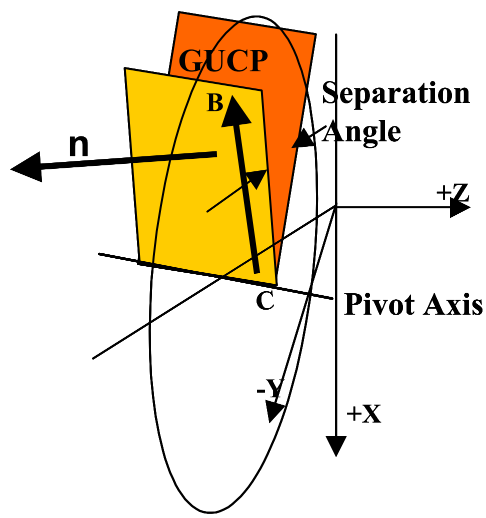


Figure 56. GUCP Separation Drawing

The motion of the GUCP as it pivots through an angle θ may be characterized by multiplying a vector representing a line through points B and C, $U = \left(\hat{U}_x \quad \hat{U}_y \quad \hat{U}_z\right)$, by a rotation matrix.

$$\begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0.0 \\ (\sqrt{3}/2)\cdot\sin(\theta) & (\sqrt{3}/2)\cdot\cos(\theta) & -0.5 \\ 0.5\cdot\sin(\theta) & 0.5\cdot\cos(\theta) & (\sqrt{3}/2) \end{bmatrix} \begin{bmatrix} \hat{U}_x \\ \hat{U}_y \\ \hat{U}_z \end{bmatrix} = \begin{bmatrix} U_x(\theta) \\ U_y(\theta) \\ U_z(\theta) \end{bmatrix} = U(\theta)$$

If $\mathbf{n}$ is the unit normal vector to the image plane, then $V = U(\theta) - \langle \mathbf{n}, U(\theta) \rangle \mathbf{n}$ is the projection of $U(\theta)$ into the image plane. The magnitude of V may be equated to the magnitude of the observed magnitude of $U(\theta)$. This generates a trigonometric equation that may be solved for the separation angle θ.

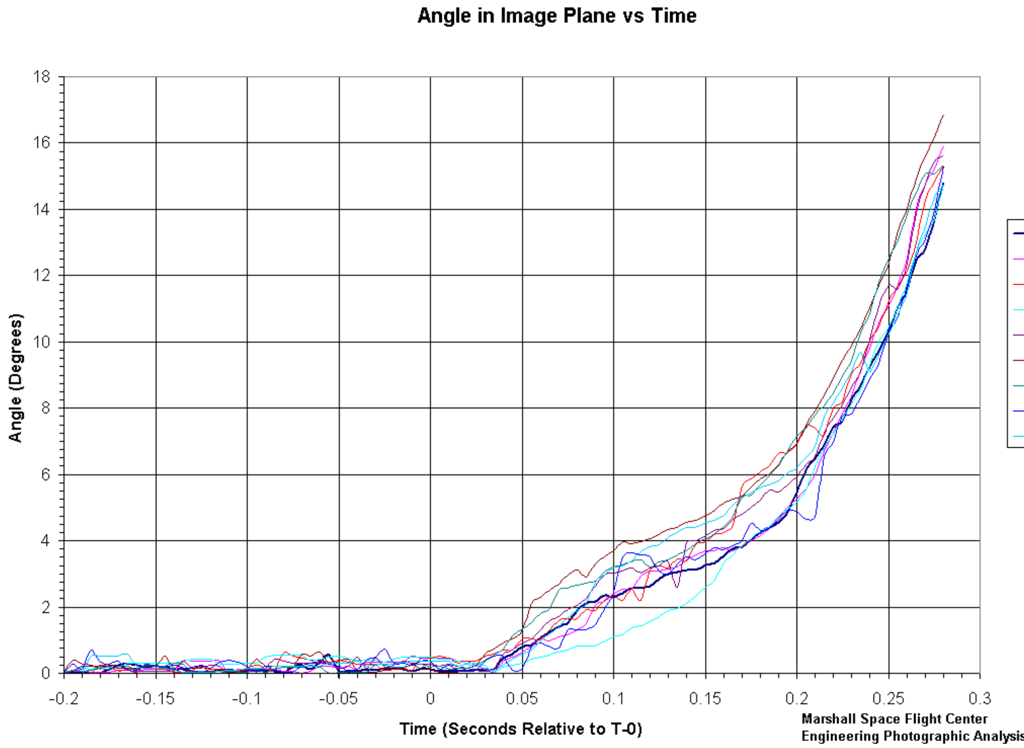


Figure 57. GUCP/ET Separation Angle in Image Plane

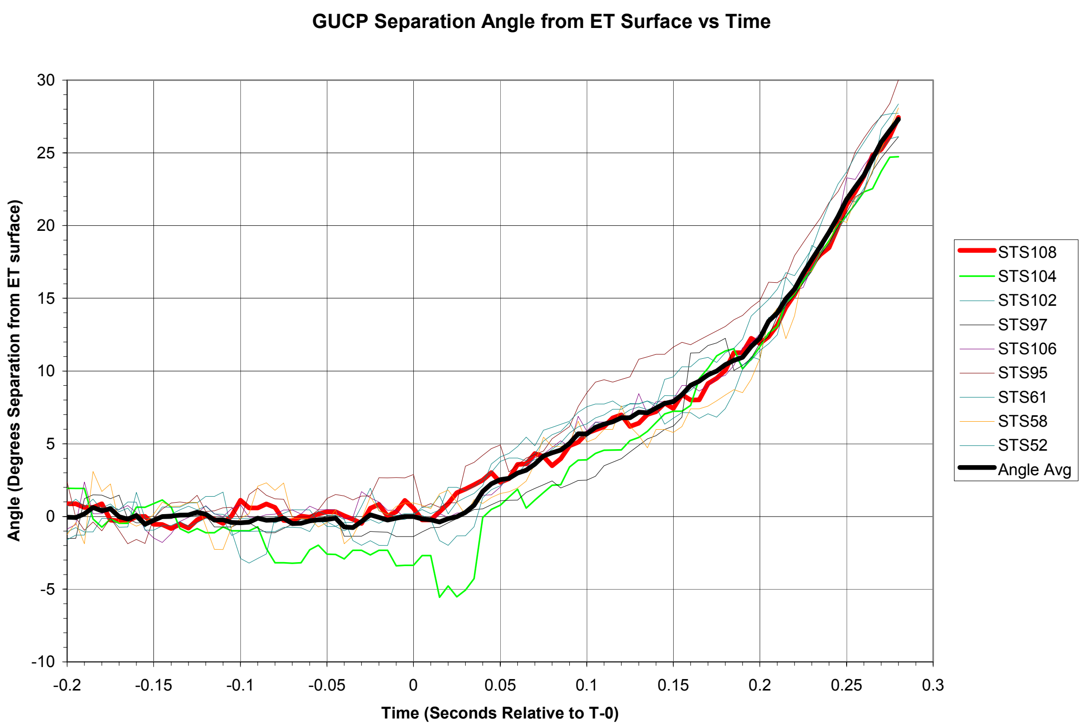


Figure 58. GUCP/ET Separation Angle

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-108 may also be found on the website.

Video Camera Assessments

TV4B	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks observed in SSME plume. Free burning Hydrogen noted near the vertical stabilizer. Pad debris noted north of MLP at liftoff. Forward RCS paper noted falling past orbiter wing.
TV7B	Pad debris noted rising and falling.
TV13	Glowing debris particles ejected from SRB plume prior to, during and after separation. SRB separation time recorded as: 339:22:21:31.9 UTC. OMS burn noted after SRB separation, 339:22:21:42.2 UTC.
TV21B	Free burning Hydrogen observed near orbiter base heat shield at SSME startup.
OTV109	Ice/frost strikes umbilical well doorsill. No damage noted. Camera loses focus as orbiter begins to lift off.
OTV141	Free burning Hydrogen observed at SSME startup. Camera overexposed at liftoff.
OTV148	Camera loses track of vehicle at liftoff.
OTV151	Little detail visible due to overexposure of SSME plumes.
OTV154	Video was not available.
OTV160	Video overexposed after liftoff.
OTV161	Typical debris observed falling aft of vehicle. Small white colored object noted aft of the bipod between the ET and orbiter. This object appears to travel upward out of field of view. A second small white colored object was noted forward of the aft attach points between the ET and orbiter.
OTV163	Ice/frost from 17 inch disconnects impacts the umbilical well door sill. No damage to vehicle noted. Typical pad debris.
OTV170	Typical debris observed falling aft of vehicle. Free burning Hydrogen noted near base heat shield.
OTV171	Video was not available.
ET207	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks observed in SSME plume. Linear optical distortions noted. Flow recirculation noted. Typical body flap motion observed.
ET208	Glowing debris particles ejected from SRB plume prior to, during and after separation. SRB separation: 339:22:21:31.91 UTC. OMS burn noted approximately 10 seconds after SRB separation.
ET212	Glowing debris particles ejected from SRB plume after separation. Debris-induced streaks observed in SSME plume. Linear optical distortions noted.
ET213	Debris-induced streaks observed in SSME plume. Debris ejected from SRB plumes during ascent.

Film Camera Assessments

E1	Typical ice/frost from 17-inch disconnects. Debris from SRB exhaust hole observed moving away from vehicle.
E2	Free Hydrogen burning noted. Three engine streaks were noted in the SSME#1 plume, all emanating from approximately the 1 o'clock position. These streaks occurred at 339:22:19:28.979, 339:22:19:30.047, and 339:22:19:30.085 UTC.

E3	Several engine streaks noted in SSME#1 plume at 339:22:19:27.204, 339:22:19:27.250, 339:22:19:28.000, 339:22:19:28.707, and 339:22:19:30.088 UTC.
E4	Pad debris noted rising and falling.
E6	Typical ice/frost from 17-inch disconnects. Tape-like debris material falling out of field of view observed.
E7	Pad debris noted rising and falling. SRB Aft Skirt Foam observed emanating from SRB Exhaust Hole.
E8	SRB Holddown Post M2 PIC Firing time at 339:22:19:27.996 UTC. SRB Aft Skirt foam debris observed emanating from SRB Exhaust Hole.
E9	SRB Holddown Post M1 PIC firing time noted at 339:22:19:27.996 UTC. Debris observed emanating from Debris Containment System of HDP M1 just after PIC firing.
E10	Pad debris noted rising and falling.
E11	Dark colored debris noted falling through field of view. Typical SRB exhaust hole debris.
E12	SRB Holddown Post M5 PIC firing time at 339:22:19:27.995 UTC. Typical SRB exhaust hole debris. Loose string between SRB thermal curtains was noted.
E13	SRB Holddown Post M6 PIC firing time at 339:22:19:27.994 UTC.
E14	Typical pad debris observed.
E15	Pad debris noted rising and falling. Typical ice/frost from 17-inch disconnects.
E16	Pad debris noted rising and falling.
E17	Typical ice/frost from LO2 disconnect. Engine streak noted in SSME#3 plume.
E18	Typical ice/frost from 17-inch disconnects.
E19	Free burning Hydrogen noted. Mach diamond formation in 3-2-1 order.
E20	Free burning Hydrogen noted.
E31	Film was of little engineering value due to poor focus.
E33	Frost noted falling from GUCP during ET tip deflection.
E34	GH2 Vent Line retraction appears normal. GH2 Vent Line rebound unable to be observed.
E36	GH2 Vent Line retraction observed. Although the GH2 Vent Line was mostly obscured by vapors/mist, possible rebound from FSS was observed. No contact with vehicle was observed.
E40	Typical debris observed falling aft of vehicle.
E52	Typical debris observed falling aft of vehicle. Typical ice/frost from 17-inch disconnects. Free Burning Hydrogen observed at SSME ignition. GH2 Vent Line rebound observed. No contact with vehicle noted.
E54	Typical debris observed falling aft of vehicle.
E57	Camera loses track of vehicle after liftoff.
E59	Camera loses track of vehicle after liftoff.
E60	GH2 Vent Line rebound observed.
E62	Pad debris noted rising and falling. Free burning Hydrogen noted.
E63	Pad debris noted rising and falling.
E204	Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted. OMS motor burn after SRB separation noted.
E205	Glowing debris particles ejected from SRB plume prior to, during and after separation. Debris-induced streaks observed in SSME plume. Flow recirculation noted. SRB separation: 339:22:21:39.919 UTC. Forward RCS motor firing observed during SRB separation.
E207	Typical debris observed falling aft of vehicle. Debris-induced streaks observed in SSME plume. Linear optical distortions noted. Flow recirculation noted. SRB separation: 339:22:21:31.921 UTC. Forward RCS motors noted firing during SRB separation. Purge barrier material noted falling from orbiter at 339:22:19:43.142 UTC. Bright ring inside SSME#3 nozzle noted during ascent.
E212	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to, during and after separation. Linear optical distortions noted. Vehicle partially obscured by clouds. Forward RCS motors firing noted during SRB separation. OMS motor burn noted after SRB separation.
E213	Typical debris observed falling aft of vehicle. Glowing debris particles ejected from SRB plume prior to separation. Fluctuating bright area on Left OMS POD observed, probably flapping butcher paper.

E220	Typical debris observed falling aft of vehicle. Purge barrier debris material noted at 339:22:19:55.337 UTC. Bright spots noted near Left OMS Pod nozzle. Debris observed on -Z side of ET emanating from forward of the SRB/ET aft attach point.
E222	Pad debris noted rising and falling. Typical debris observed falling aft of vehicle. Debris ejected from SRB plumes during ascent.
E223	Typical debris observed falling aft of vehicle. Debris-induced streaks observed in SSME plume. Linear optical distortions noted. SRB separation: 339:22:21:31.923 UTC.
E224	Typical debris observed falling aft of vehicle. Debris ejected from SRB plumes at 339:22:20:24.749 UTC.
FL101	Slight twang noted at separation on Left ET/SRB at Upper Aft Attach EB-9. ET/Orbiter separation occurred in darkness. Typical ablative debris observed.
FL102	Limited visibility of ET/Orbiter due to darkness. Slight twang noted at ET/SRB separation at Aft Upper Attach EB-9. Typical debris observed.

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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Boeing-Huntington Beach

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

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