APPENDIX B. MSFC PHOTOGRAPHIC ANALYSIS SUMMARY

Space Shuttle Mission STS-101

Engineering Photographic Analysis Summary Report
Marshall Space Flight Center

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STS-101
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1. STS-101 Engineering Photographic Analysis

The launch of Space Shuttle Mission STS-101, the twenty-first flight of the Orbiter Atlantis (OV-104) occurred May 19, 2000, at approximately 5:11 AM Central Daylight Time from launch complex 39A, Kennedy Space Center (KSC), Florida. Launch time reported as 140:10:11:09.994 Universal Time Coordinated (UTC) by the MSFC Flight Evaluation Team.

Photographic and video coverage has been evaluated to determine proper operation of the flight hardware. Additional 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/sts.html.

2. Photographic Coverage

Video and high-speed film cameras providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), perimeter sites, Eastern Test Range tracking sites and onboard the vehicle. Seventy-one engineering photographic products consisting of launch video, ground-based engineering films and video and onboard film and video were received and reviewed at MSFC.

The view from two video cameras, OTV041 and OTV048, became overexposed at liftoff. The focus on film camera E13 was soft and the frame rate on film camera E20 was slow. Overall, good coverage of the launch was obtained. Video from the Left and Right SRB cameras was very good. Film from the 16mm umbilical camera FL102 was not received. Camera coverage received at MSFC for STS-101 is illustrated in the following table.

Table 1 . Camera Coverage

Camera Location	16mm	35mm	Video
MLP	19	0	4
FSS	5	0	3
Perimeter	0	7	6
Tracking	0	10	11
Onboard	1	2	3
Totals	25	19	27

The Photographic Acquisition Document Data (PADD) and information regarding individual camera status and assessments may be found on the website.

3. Individual Camera Assessments:

Notable assessments for individual cameras are listed below. The complete assessments for all individual cameras for flight STS-101 may be found on the website.

3.1 Video Camera Assessments

TV5 Glowing debris particles ejected from SRB plume prior to separation.

TV12	Glowing debris particles ejected from SRB plume prior to separation. Debris induced streak in SSME plumes at 140:10:12:03.2 UTC. SRB separation time at 140:10:13:13.75 UTC.
TV13	Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. SRB separation time at 140:10:13:13.717 UTC.
ET204	Glowing debris particles ejected from SRB plume after separation.
ET207	Glowing debris particles ejected from SRB plume after separation. Debris-induced streak in SSME plume. Linear optical distortions noted. Fast-moving streak of unknown origin moves through field of view. White ring observed inside SSME#2 nozzle. These phenomena will be investigated more closely with high-speed film from cameras E2 and E19.
ET212	Glowing debris particles ejected from SRB plume after separation. Debris-induced streak observed in SSME plume.
TV21A	Free burning Hydrogen noted.
OTV009	Ice/frost from LH2 17-inch disconnect strikes the umbilical doorsill at engine start-up. No damage observed.
OTV041	Free burning Hydrogen observed near the drag chute compartment. Image becomes overexposed at lift-off.
OTV048	View overexposed at liftoff.
OTV051	Free burning Hydrogen strikes the drag chute door. Mach diamonds form in 3-2-1 order.
OTV054	Ice/frost impacts the LO2 umbilical doorsill.
OTV070	Free burning Hydrogen strikes the drag chute door. Two ice chunks from LO2 TSM strike SSME#3 near number 8 hatband.
OTV071	Free burning Hydrogen rises past drag chute door.

3.2 Film Camera Assessments

E1	Free burning Hydrogen observed past aft edge of body flap.
E2	Free burning Hydrogen impinges on drag chute door.
E6	Vapors noted from ET-Orbiter aft vertical strut ET attach point.
E8	Holddown post M-2 PIC firing time at 140:10:11:10.003 UTC. Small debris particle appears to fall from hole in SRB holddown post foot.
E9	Holddown Post M-1 PIC firing time 140:10:11:10.001 UTC.
E12	Hold down Post M-5 PIC firing time 140:10:11:10.001 UTC.
E13	Holddown Post M-6 PIC firing time 140:10:11:10.001 UTC. Camera experienced soft focus.
E16	Free burning Hydrogen observed. Thermal curtain flexing observed at SRB ignition.
E17	Free burning Hydrogen observed. Noticeable ice/frost from LO2 T-0 umbilical noted.
E18	Free burning Hydrogen observed. Noticeable ice/frost from LH2 T-0 umbilical. Chipped tiles noted on aft base heat shield.
E19	Hot wall of SSME#2 appears nominal from this camera angle. Ice impacts SSME#3 nozzle. Free burning Hydrogen impinges on drag chute door.
E20	Free burning Hydrogen impinges on drag chute door. Camera frame rate is approximately 55 fps as opposed to the 400 fps expected.
E33	Ice/frost falls from GUCP prior to and after separation.
E34	Ice/frost from GUCP noted falling alongside ET. Vapors from rudder/speed brake observed.
E52	Debris-induced streaks in SSME plume. Free burning Hydrogen impinges on drag chute door.
E62	Free burning Hydrogen observed.
E63	Free burning Hydrogen observed.
E204	Glowing debris particles ejected from SRB plume after separation. Vehicle obscured by clouds several times early in flight. OMS burn noted after SRB separation.
E205	Glowing debris particles ejected from SRB plume after separation. Debris-induced streak in SSME plume. Flow recirculation noted. OMS burn noted after SRB separation.
E207	Debris-induced streak in SSME plume. Linear optical distortions noted. Flow recirculation noted. Debris of unknown origin appears to be located near orbiter between inboard orbiter elevon and right SRB. Light colored ring noted on hot wall of SSME#2 nozzle approximately halfway up the engine nozzle.

E208	Glowing debris particles ejected from SRB plume after separation. Linear optical distortions noted. OMS burn noted after SRB separation.
E212	Debris-induced streaks observed in SSME plume.
E220	Glowing debris particles ejected from SRB plume after separation. Debris-induced streak in SSME plume. OMS burn noted after SRB separation. Light colored ring noted on hot wall of SSME#2 nozzle.
E222	Debris induced streak in SSME plumes at 140:10:12:03.299 UTC.
E223	Debris-induced streaks in SSME plume. Debris ejected from SRB plume during ascent.
FL102	The -Y Thrust Panel is in shadow and +Y Thrust Panel is at an oblique view, no divots are noticeable on the Thrust Panels. Object shaped like a ring was observed moving aft, from top to bottom through field of view.

4. T-Zero Times

T-Zero times are determined from MLP cameras that view the SRB holddown posts numbers M-1, M-2, M-5, and M-6. These cameras record the explosive bolt combustion products.

Table 2. T-Zero Times

Holddown Post	Camera Position	Time (UTC)
M-1	E9	140:10:11:10.001
M-2	E8	140:10:11:10.003
M-5	E12	140:10:11:10.001
M-6	E13	140:10:11:10.001

5. SRB Separation Timing

SRB separation time, as recorded by observations of the BSM combustion products from long-range film camera E207, occurred at approximately 140:10:13:13.726 UTC.

6. Observations:

6.1 Video Camera OTV070 (A)

Free burning Hydrogen was observed, as a glowing reddish-orange gas, at engine start-up. This is a typical occurrence at start-up. The free burning Hydrogen was noted in this instance to impinge on the drag chute door as shown in the figure below.

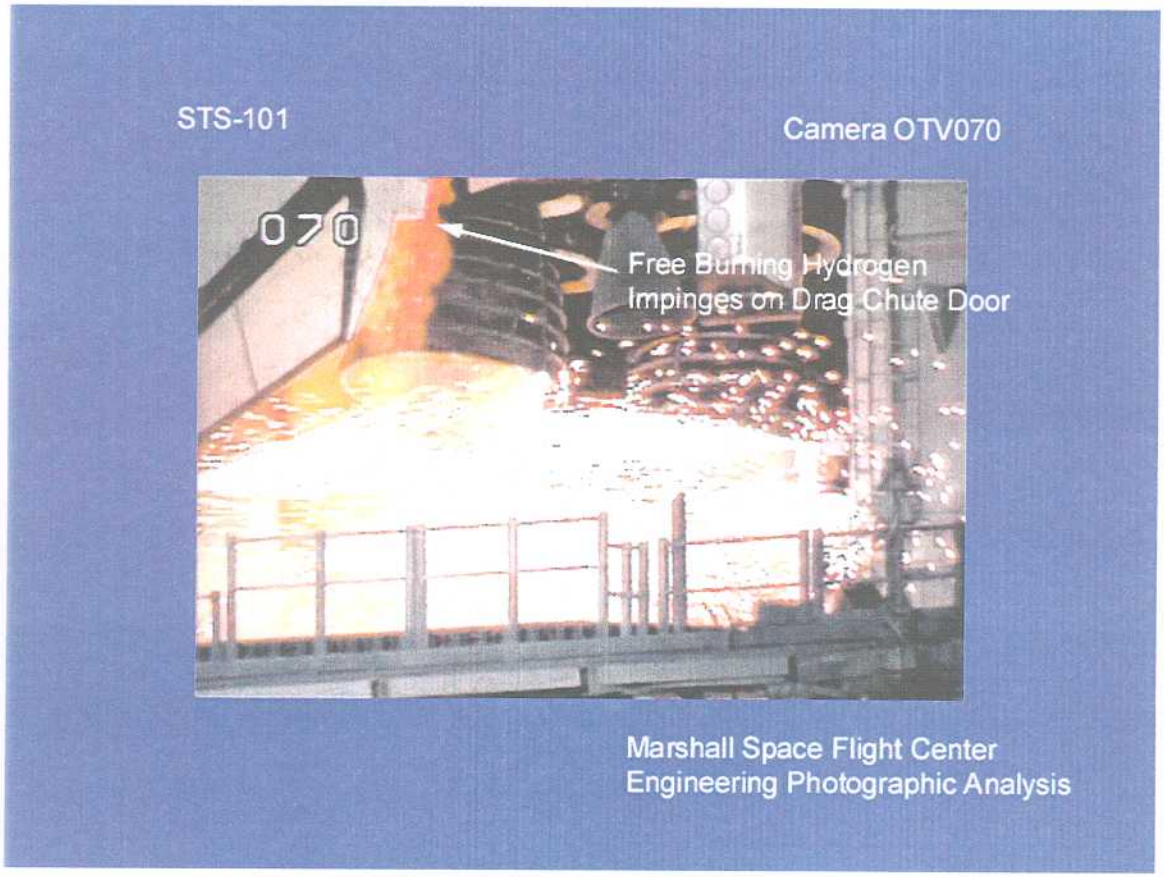

Figure 1. Free Burning Hydrogen at SSME Start-Up

6.2 Video Camera OTV070 (B)

Two pieces of ice debris from the LO2 TSM impacted SSME#3 nozzle near the eighth hatband. Images below show one of the ice masses impacting SSME#3 nozzle and breaking apart. No damage to the nozzle was observed from either ice impact.

Figure 2. Ice Strikes SSME#3 Nozzle

6.3 Video Camera TV-12

A view from video camera TV12 of the debris induced streak in the SSME plumes. These debris induced streaks are typically the result of butcher paper or purge barrier material falling into a plume.

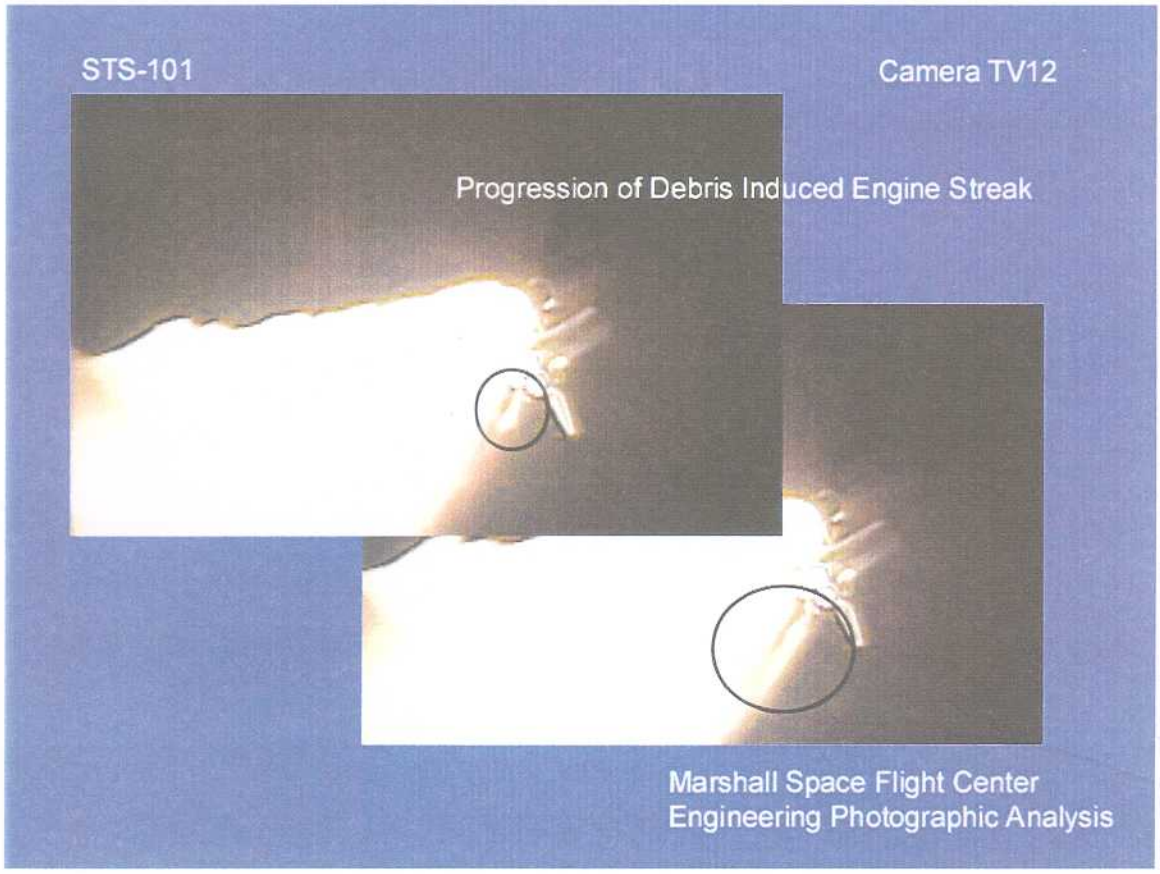

Figure 3. Debris Induced Streak Observed by Video Camera TV-12

6.4 Film Camera E223

A sequence of frames from the 35mm Film Camera E212 showing the debris induced streak originating in the SSME plumes. This is the same streak as shown in figure 3. The film cameras typically give better resolution of events. In the sequence of frames below, the streak can be seen originating in the plume at a distance from the nozzle. This separation from the nozzle exit plane is an indicator that a streak is caused by debris falling into the plume.

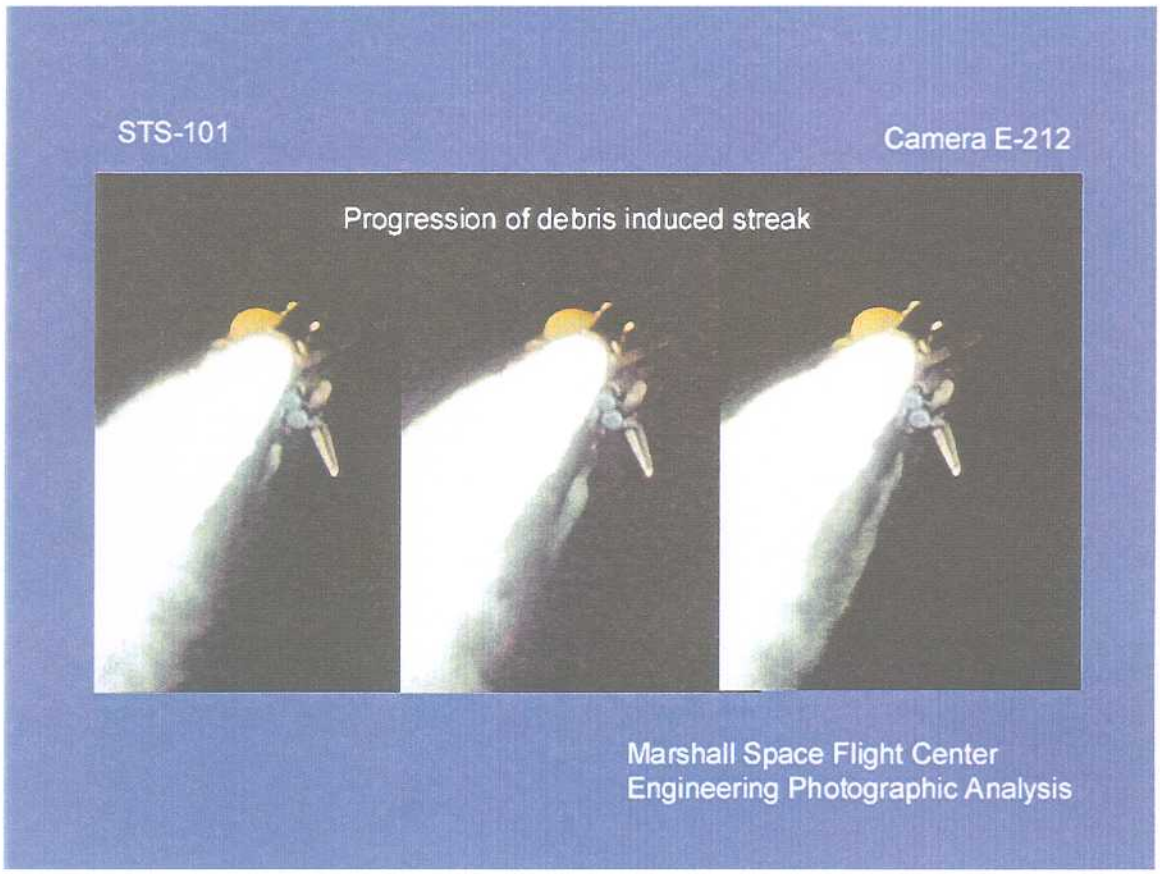

Figure 4. Debris Induced Streak Observed by Film Camera E212

6.5 Film Camera E207

A sequence of images from the 35mm Film Camera E207 that shows debris of unknown origin that caused a streak, not associated with plume streaking, which appears to be located near orbiter between inboard orbiter elevon and right SRB. This event was timed at 140:10:11:44.148 UTC. A similar event occurred on STS-26. The STS-26 event was identified as debris from tiles. Inspection of tiles after landing revealed a damage site which is suspected as the cause of this streak.

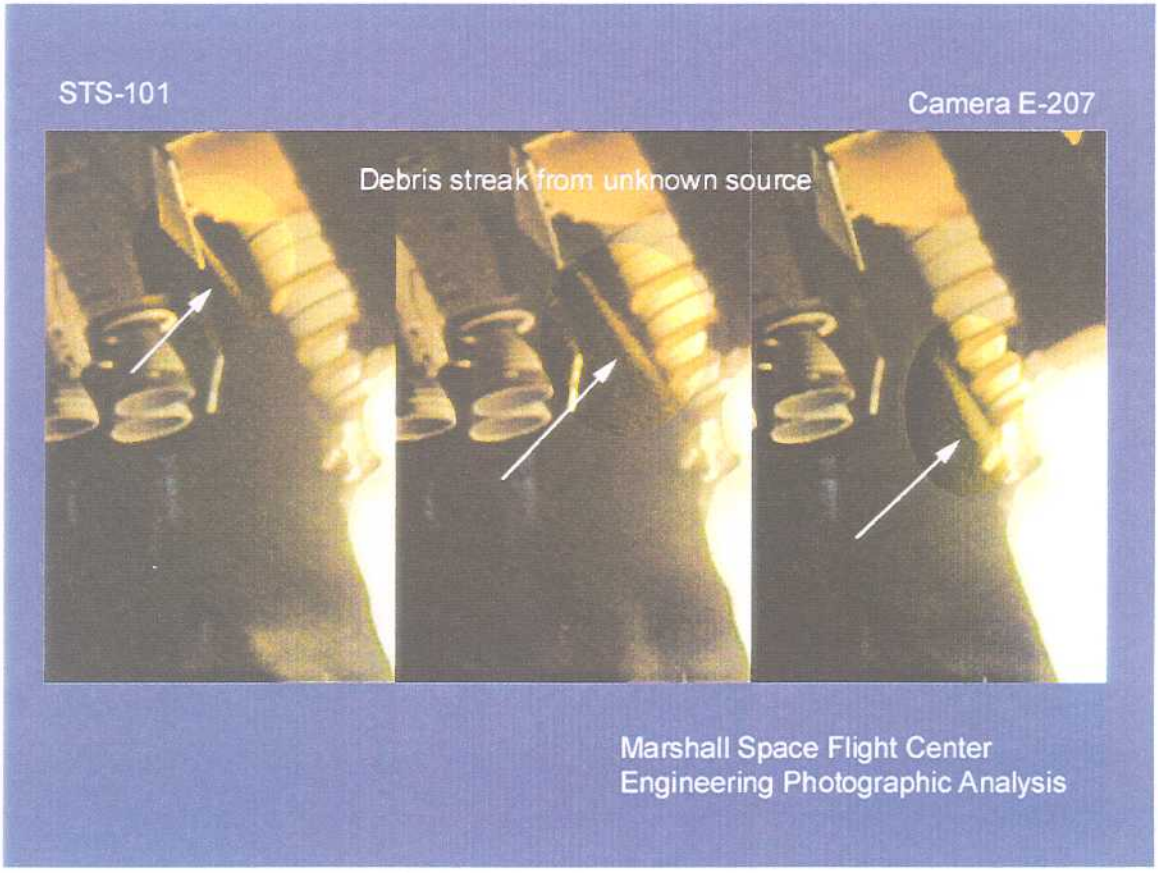

Figure 5. Debris Streak Observed by Film Camera E207

6.6 Left SRB Video Camera

Views of the External Tank from the left Solid Rocket Booster Video Camera early (0:16), just before (2:03) and just after (2:04) separation from vehicle, showing a progression of the condition of the Thermal Protective Surface on the –Y Thrust Panel.

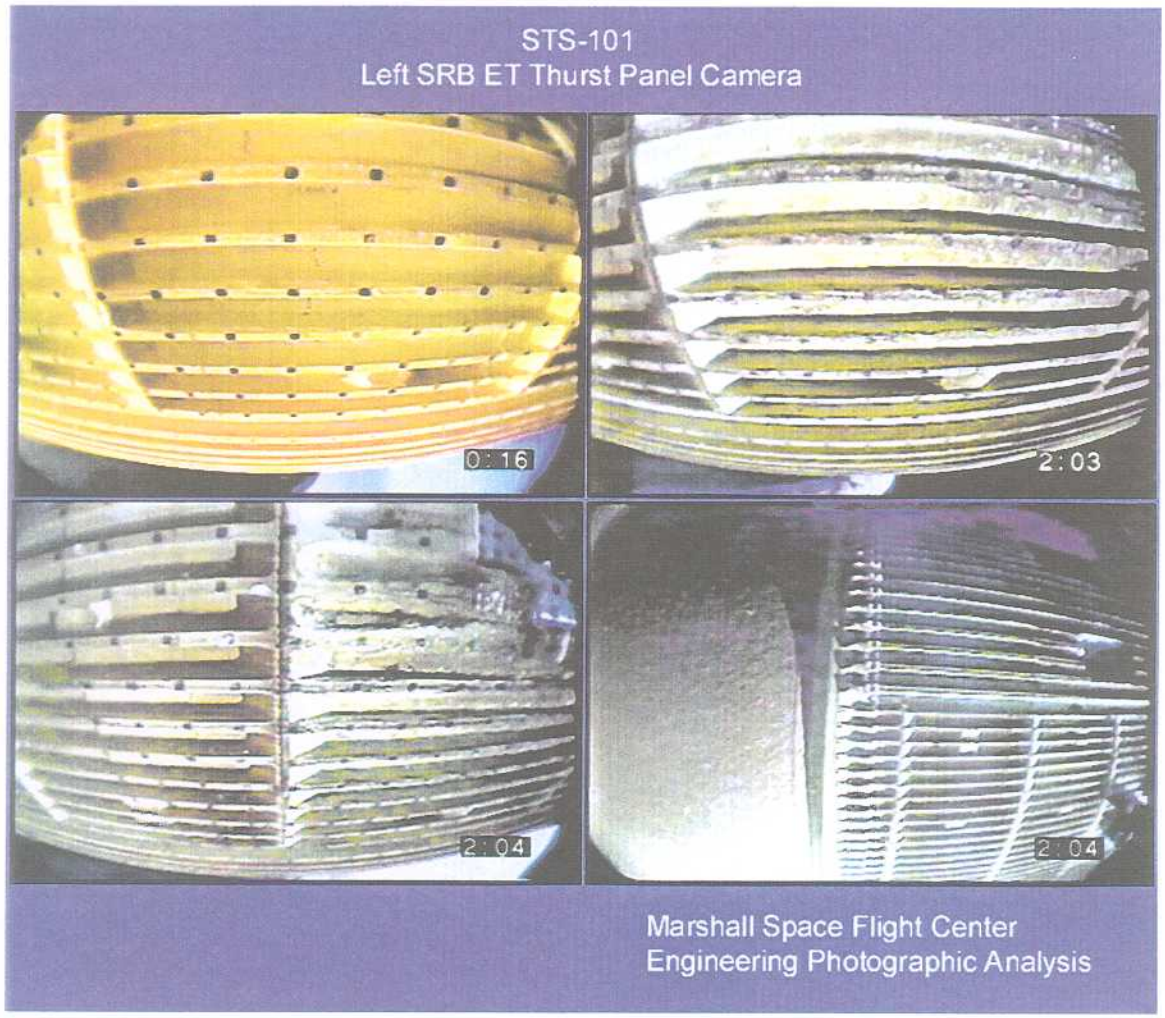

Figure 6. Left SRB Video Camera

6.7 Right SRB Video Camera

Views of the External Tank from the right Solid Rocket Booster Video Camera early (0:13), just before (2:03) and just after (2:04) separation from vehicle, showing a progression of the condition of the Thermal Protective Surface (TPS) on the +Y Thrust Panel.

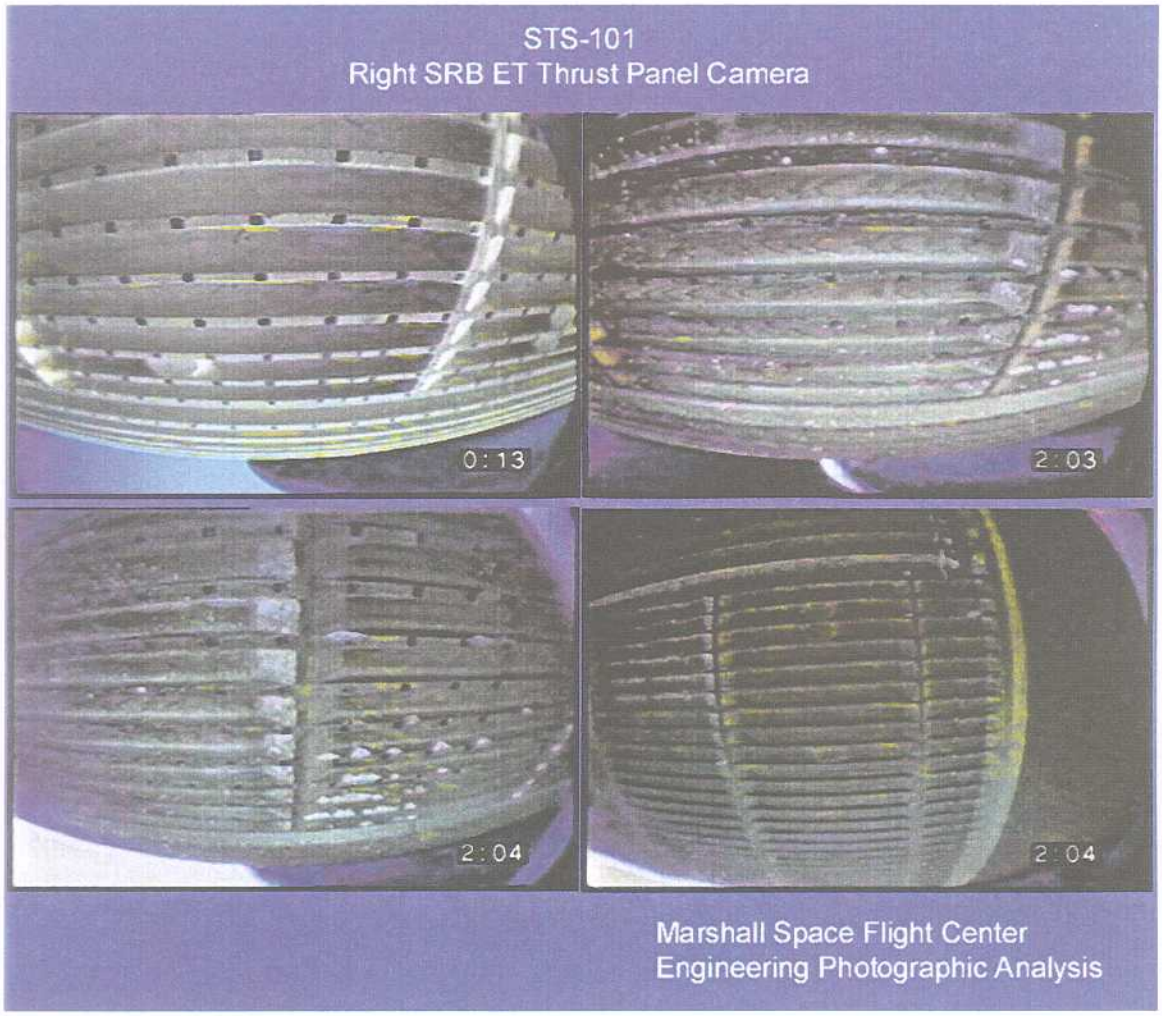

Figure 7. Right SRB Video Camera

6.8 On Board Hand Held Camera(ET –Y Side)

Views of the –Y side of External Tank (ET) after separation from vehicle, showing the condition of the Thermal Protective Surface (TPS). No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal.

Figure 8. View of –Y side of the ET from On-board 35mm Hand-held Camera

6.9 On Board Hand Held Camera(ET Top View)

Views of the top side of External Tank (ET) after separation from vehicle, showing the LO2 Feedline and the condition of the Thermal Protective Surface (TPS). No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal.

Figure 9. View of Top Side of the ET from On-board 35mm Hand-held Camera

6.10On Board Hand Held Camera(ET +Y Side)

Views of the +Y side of External Tank (ET) after separation from vehicle, showing the condition of the Thermal Protective Surface (TPS). No obvious or large scale TPS divoting is observed, scarring of TPS from BSM motor firing appears normal. Charring of the TPS on the aft dome of the LOX tank appears normal.

Figure 10. View of –Y side of the ET from On-board 35mm Hand-held Camera

6.11 Film Camera FL-102

A ring-shaped debris object was noted moving from top to bottom of the field of view after SRB separation. The object was out of focus, indicating that it was near the camera, rather than the ET. It is suspected that the object is an O-ring from one of the 17" disconnects.

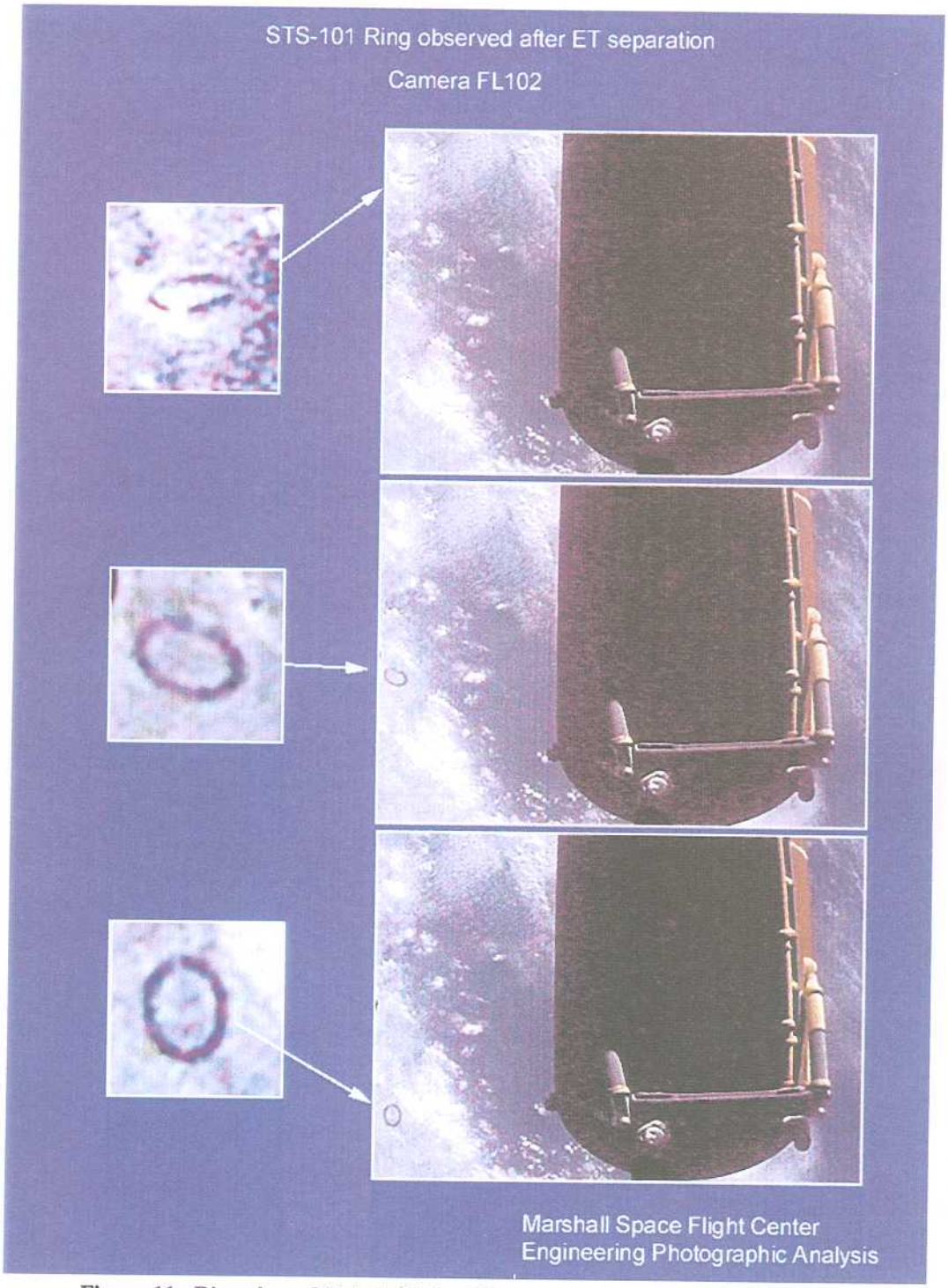

Figure 11. Ring shaped Debris Object Observed After SRB Separation

6.12 Astronaut Hand Held Video Camera

Two conspicuous debris objects were observed from the astronaut hand held video. One was an odd shaped debris item, noted in the upper right corner of the left hand frame below and appears to be ice. The other debris object is most likely ice floating between the camera and the ET. Typical GUCP venting was also observed.

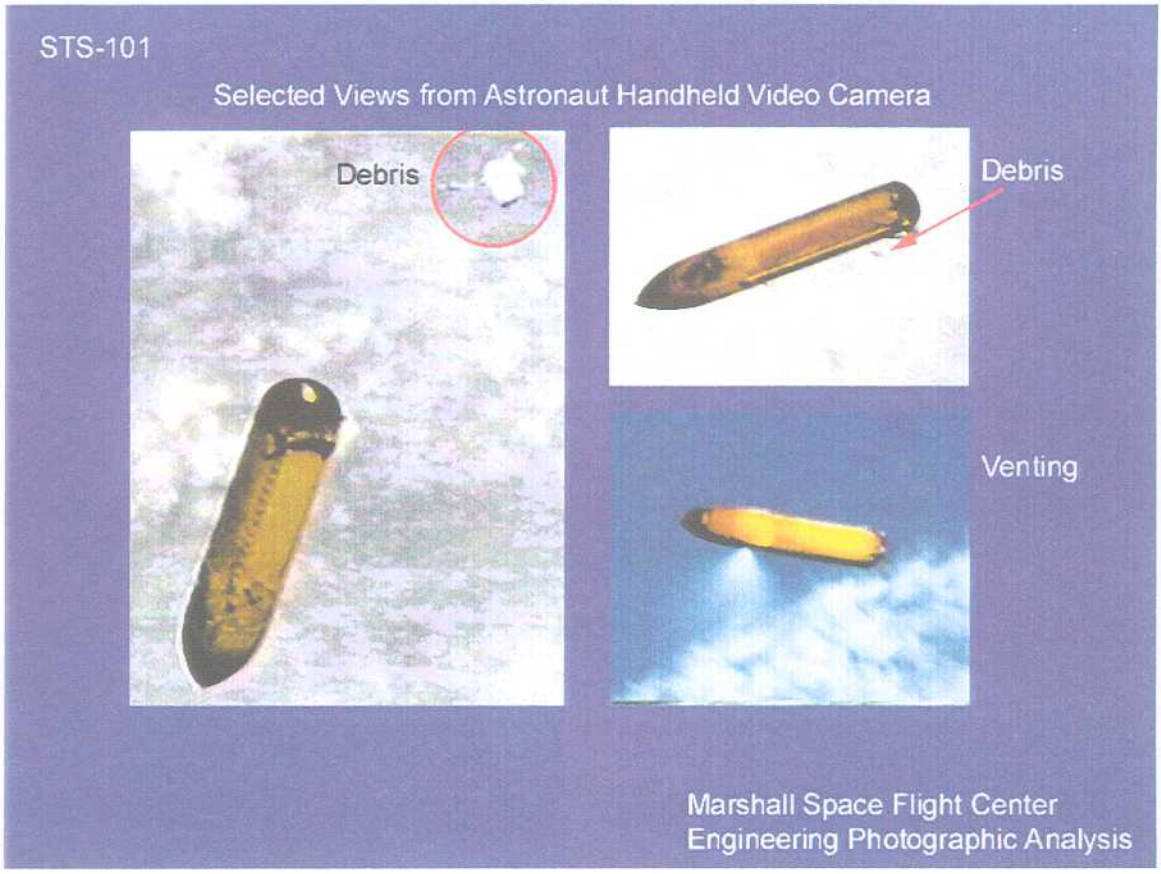

Figure 12. Selected Views from the Astronaut Hand Held Video

6.13 Umbilical Well 35mm Still Camera

Ice was observed on the ET after separation, as noted in the frame below. Because of a late +X translation, the forward portion of the ET was not imaged by the still camera. Image fog degraded several of the last exposures on the 35mm film roll, creating a reddened cast to the images.

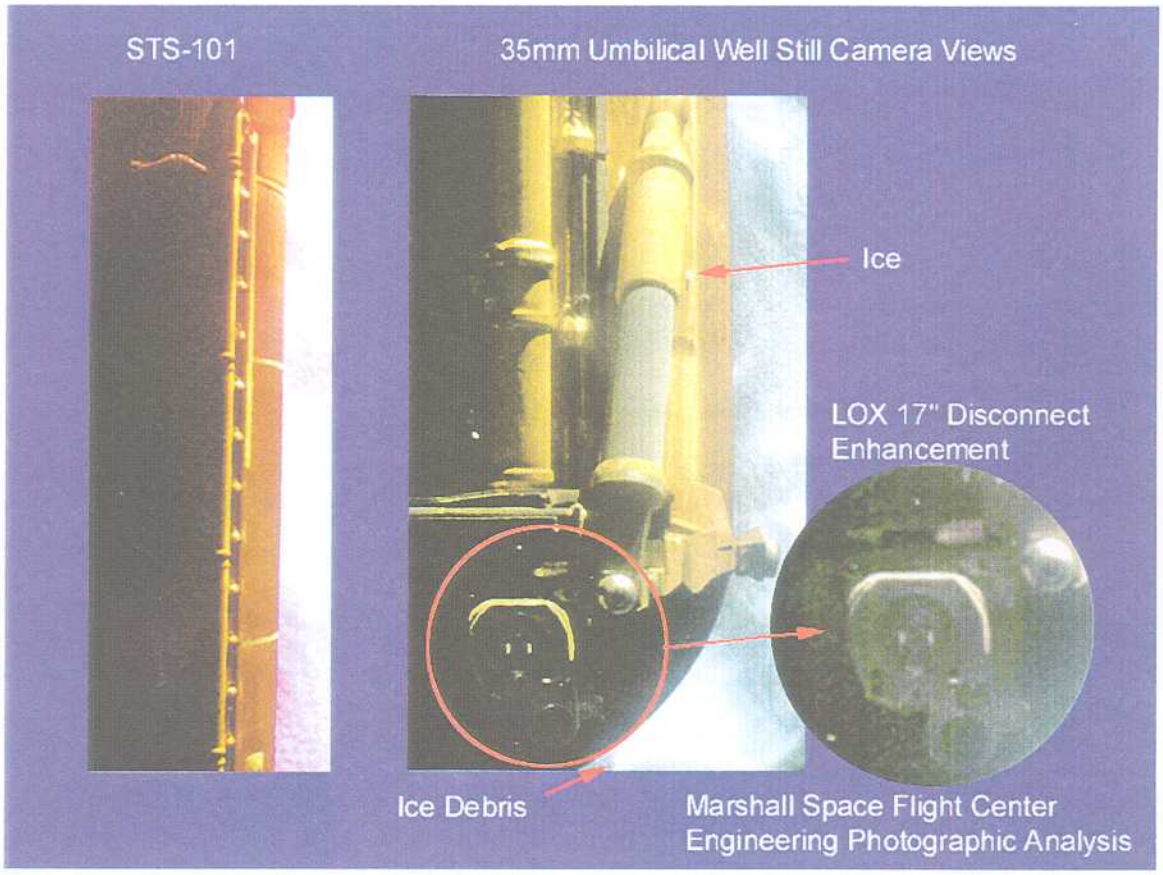

Figure 13 Umbilical Well 35mm Still Camera

7. Analyses

STS-101 carried video cameras on both the left and right SRBs. The purpose of the video cameras was to document TPS foam loss events occurring on the ET thrust panels. ET thrust panel TPS has been vented as a device to reduce both the size and the amount of foam loss events. The SRB videos, examples in Figure 6 and Figure 7, were analyzed to determine the quantity and location of foam loss events on the +Y and –Y ET thrust panels. The results of these analyses are presented below.

7.1 STS-101: -Y Thrust Panel

Figure 14 illustrates all tabulated foam loss events on the -Y Thrust Panel of the ET for flight STS-101. White lines in the figure enclose vented areas. There were 100 total foam loss events recorded. The number of events recorded during each 0.5 second time interval and the total number of events from approximately T+90.0 seconds are shown in Figure 15. Using a fourth order polynomial approximation to trend the count data, the maximum foam loss activity appears to peak just after T+ 110.0 seconds. The maximum number of events recorded during any 0.5 second time interval was seven. Figure 16 and Table 3 compare vented and non-vented areas.

Table 3. STS-101 -Y Thrust Panel: Vented and Non-Vented Foam Loss Events

Category	Count
Vented	95
Non-Vented	5
Total	**100**

Figure 17 illustrates the timeline for accumulated foam loss in each category and Table 4 shows the final count for each category.

Table 4. STS-101 -Y Thrust Panel: Foam Loss Events by Category

Category	Count
Valley	42
Stringer	4
Longitudinal Rib	53
Circumferential Rib	0
Hi-Lock	0
Ramp	1
Total	**100**

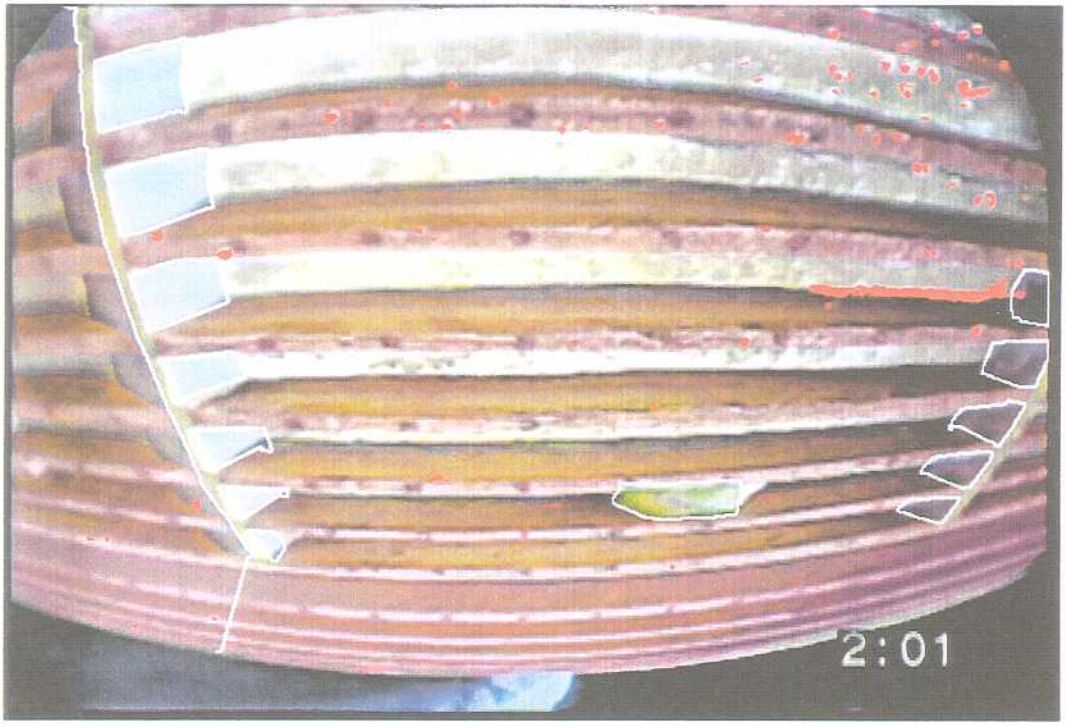

Figure 14. STS-101 -Y Thrust Panel

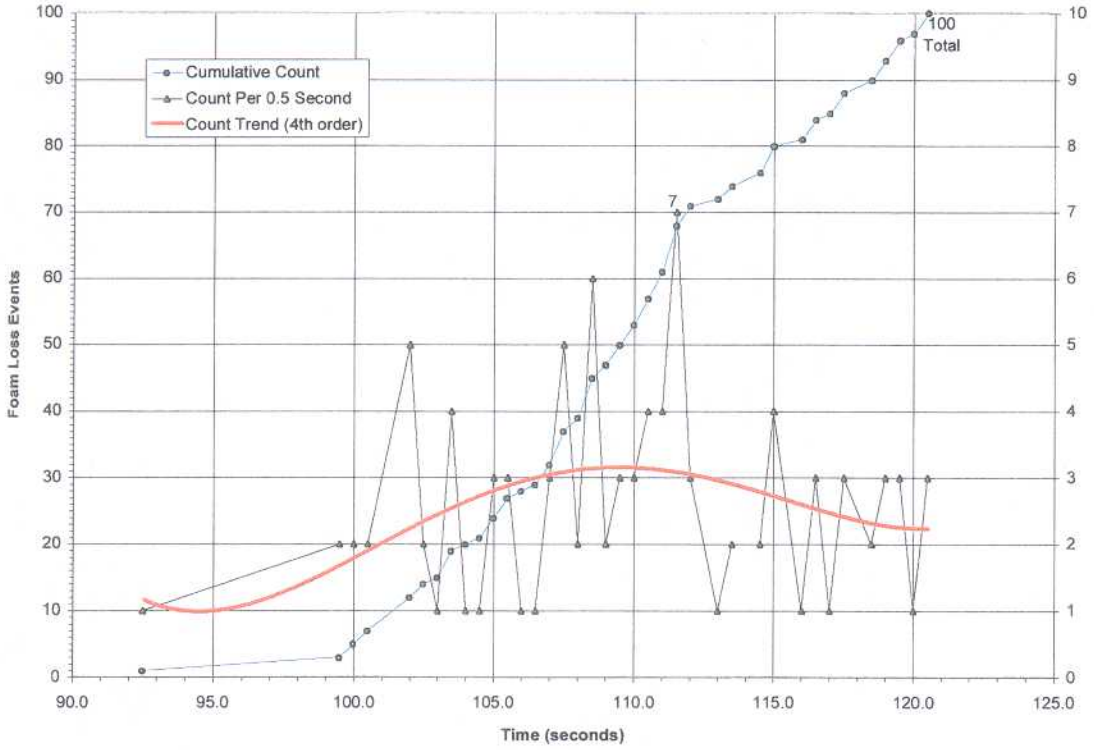

Figure 15. STS-101 -Y Thrust Panel: Foam Loss Event Timeline

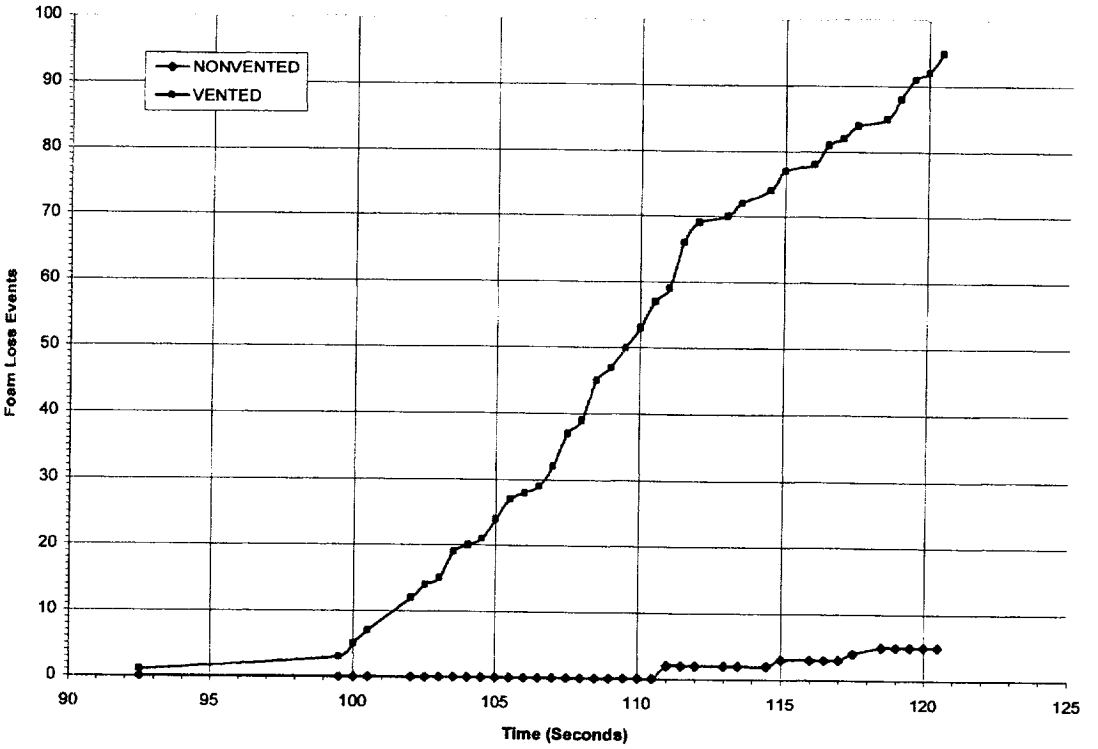

Figure 16. STS-101 -Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas

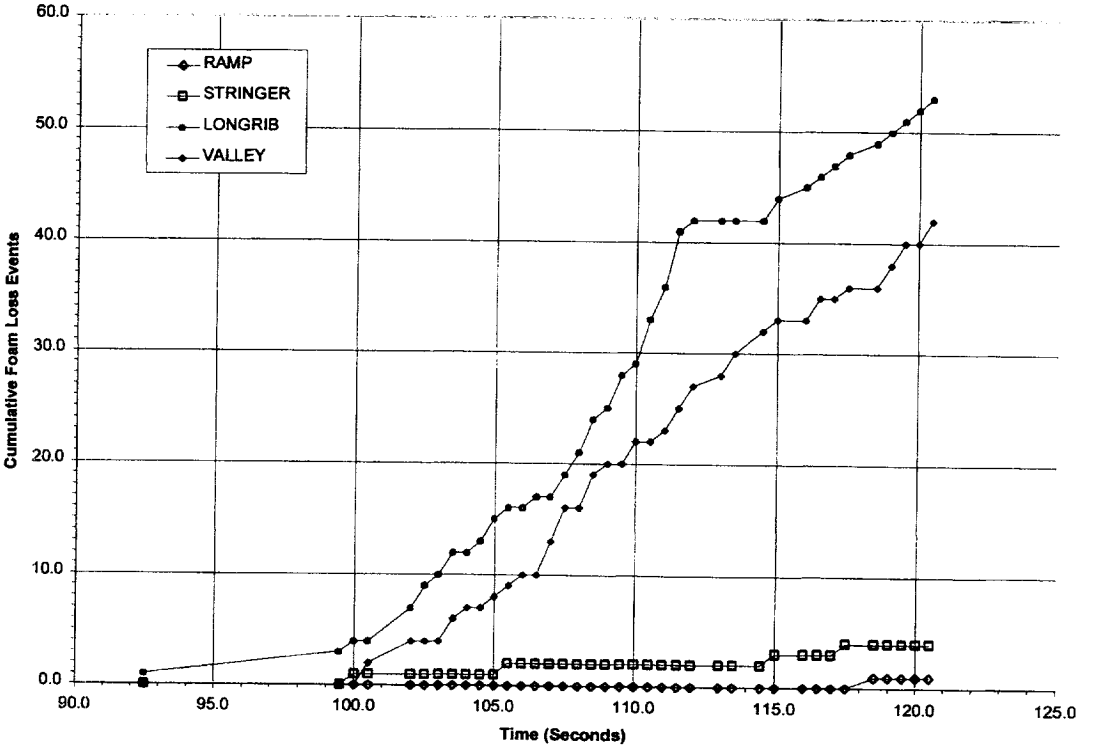

Figure 17. STS-101 -Y Thrust Panel: Foam Loss Timeline for Categories of Events

7.2 STS-101: +Y Thrust Panel

Figure 18 illustrates all tabulated foam loss events on the +Y Thrust Panel of the ET for flight STS-101. White lines in the figure enclose vented areas. There were 258 total foam loss events recorded. The number of events recorded during each 0.5 second time interval and the total number of events from approximately T+90.0 seconds are shown in Figure 19. Using a third order polynomial approximation to trend the count data, the maximum foam loss activity appears to peak at approximately T+ 110.0 seconds. The maximum number of events recorded during any 0.5 second time interval was 23. Table 5 and Figure 20 compare vented and non-vented areas.

Table 5. STS-101 +Y Thrust Panel: Vented and Non-Vented Foam Loss Events

Category	Count
Vented	206
Non-Vented	52
Total	**258**

Figure 21 illustrates the timeline for accumulated foam loss in each category and Table 6 shows the final count for each category.

Table 6. STS- 101 +Y Thrust Panel: Foam Loss Events by Category

Category	Count
Valley	77
Stringer	35
Longitudinal Rib	132
Circumferential Rib	2
Hi-Lock	10
Ramp	2
Total	**258**

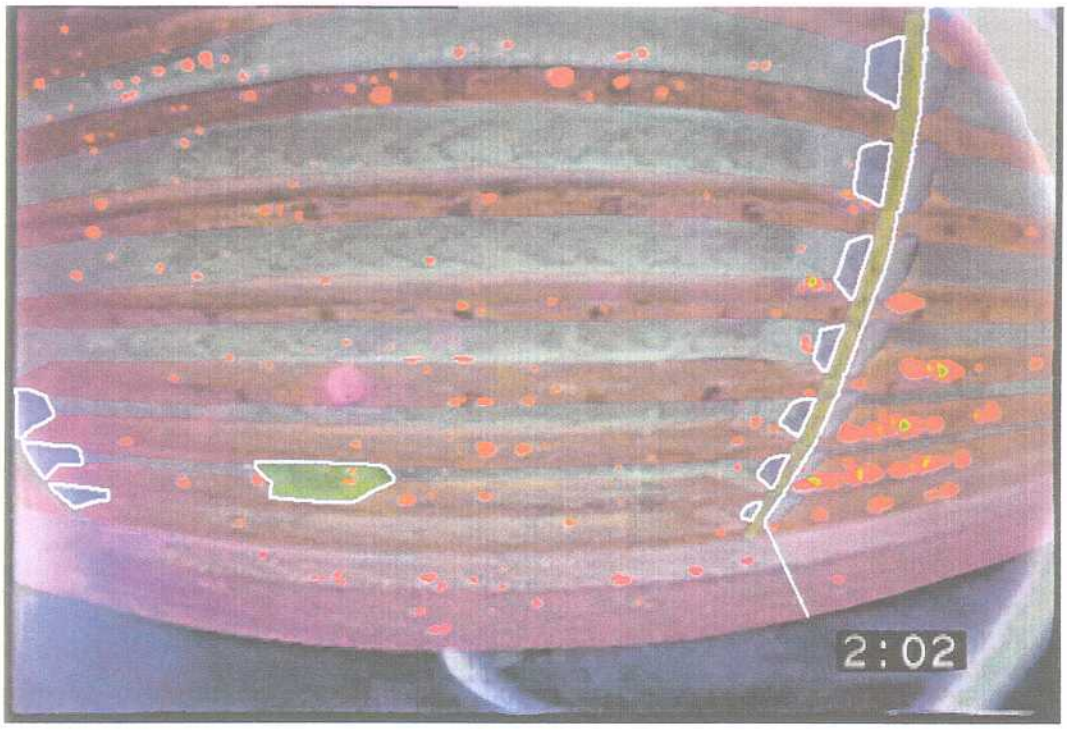

Figure 18. STS-101 +Y Thrust Panel

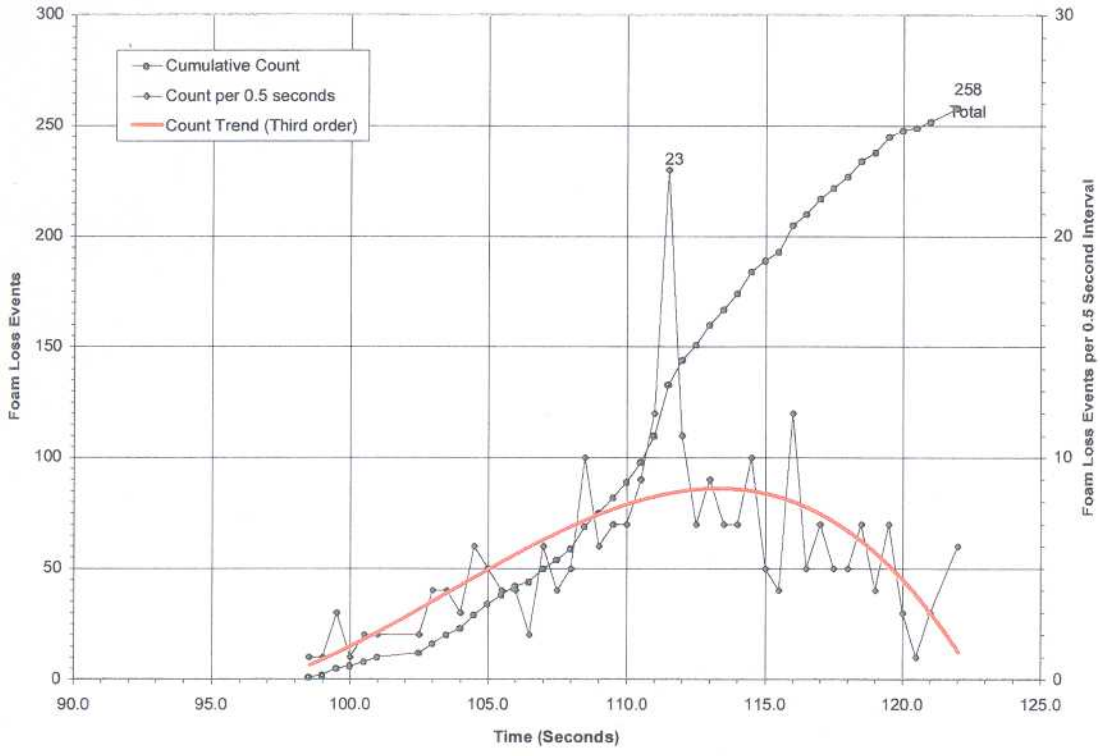

Figure 19. STS-101 +Y Thrust Panel: Foam Loss Event Timeline

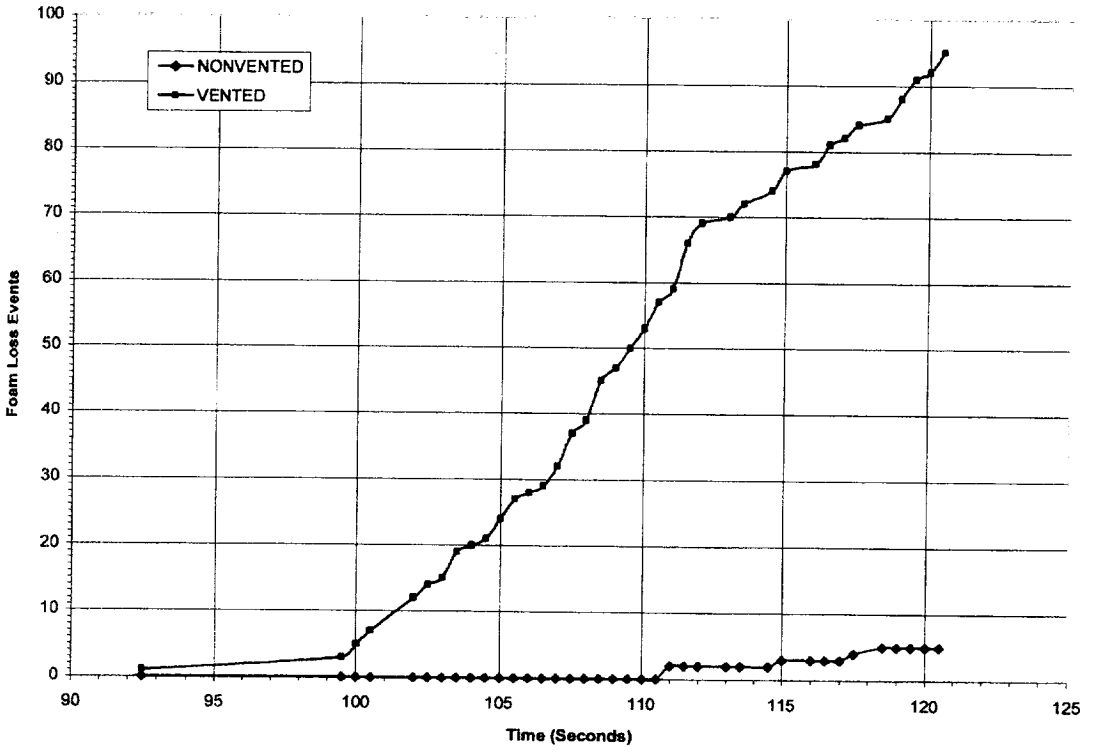

Figure 20. STS-101 +Y Thrust Panel: Foam Loss Timeline for Vented and Non-Vented Areas

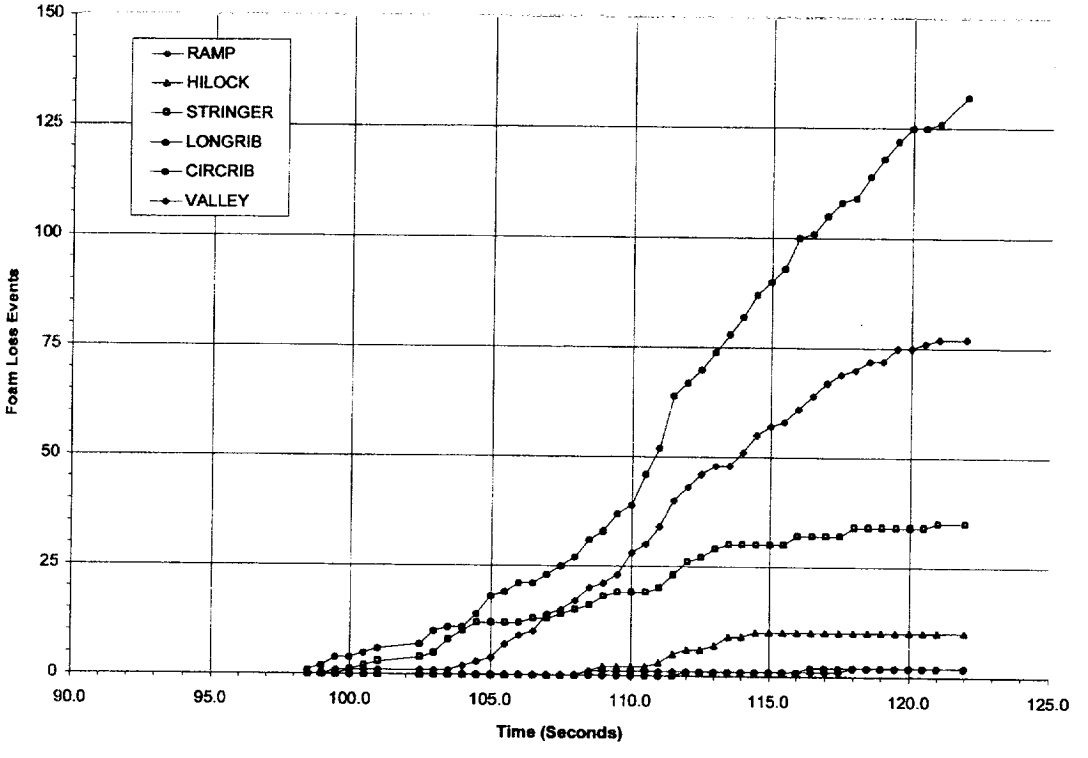

Figure 21. STS-101 +Y Thrust Panel: Foam Loss Timeline for Categories of Events

7.3 STS-101: Thrust Panel Comparison

Figure 22 and Figure 23 compare the number of foam loss events for each thrust panel recorded by each camera for each flight. STS-95 was not equipped with a camera to record the +Y thrust panel.

The foam loss events from the –Y thrust panels are bounded by a maximum of approximately 250 total events. The foam loss events from the +Y thrust panels are bounded by a maximum of approximately 650 total events. This maximum was achieved on mission STS-96 where a majority of the foam loss events recorded by the right SRB camera were noted to be in areas of the +Y thrust panel that were not vented.

No venting of the ET foam was performed for mission STS-95 and partial venting for STS-96 and STS-93. More extensive venting was done for Missions STS-103 and STS-101. The noticeable reduction in foam loss events in STS-103 and STS-101 is most probably attributable to the venting of more extensive areas of the thrust panels.

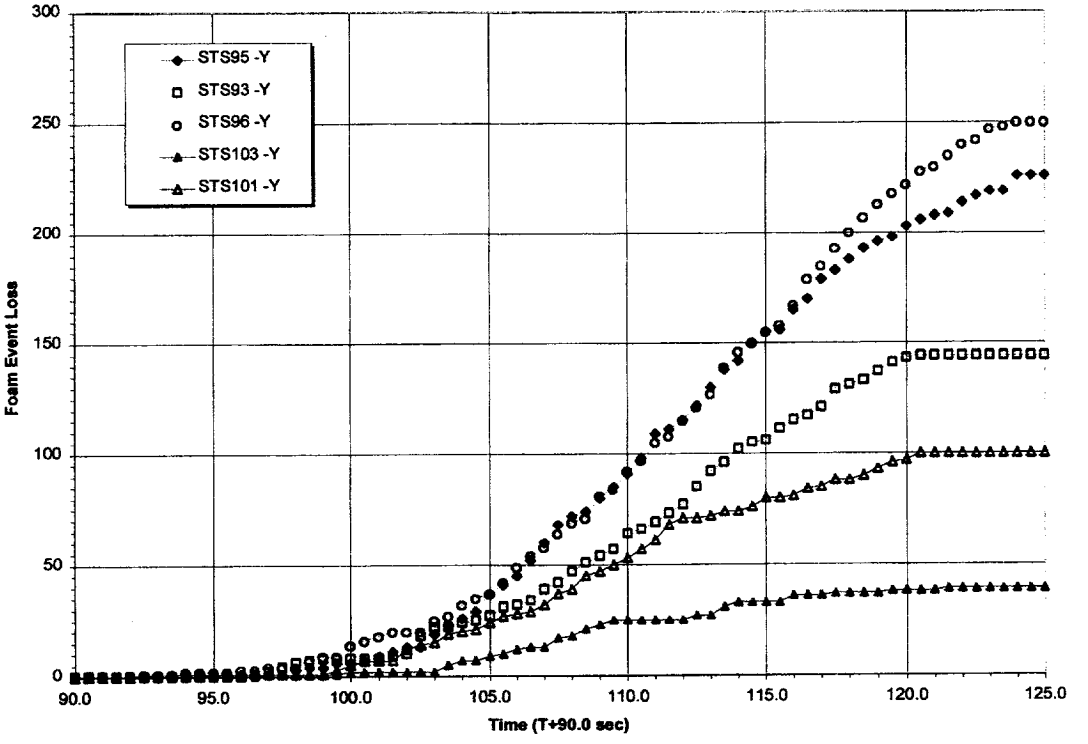

Figure 22. Foam Loss Comparison for -Y Thrust Panels

Figure 24 compares the number of foam loss events recorded by each camera for each flight. Most event timelines fall in the lower cluster, again, with only the STS-96 Right SRB camera recording the anomalous timeline.

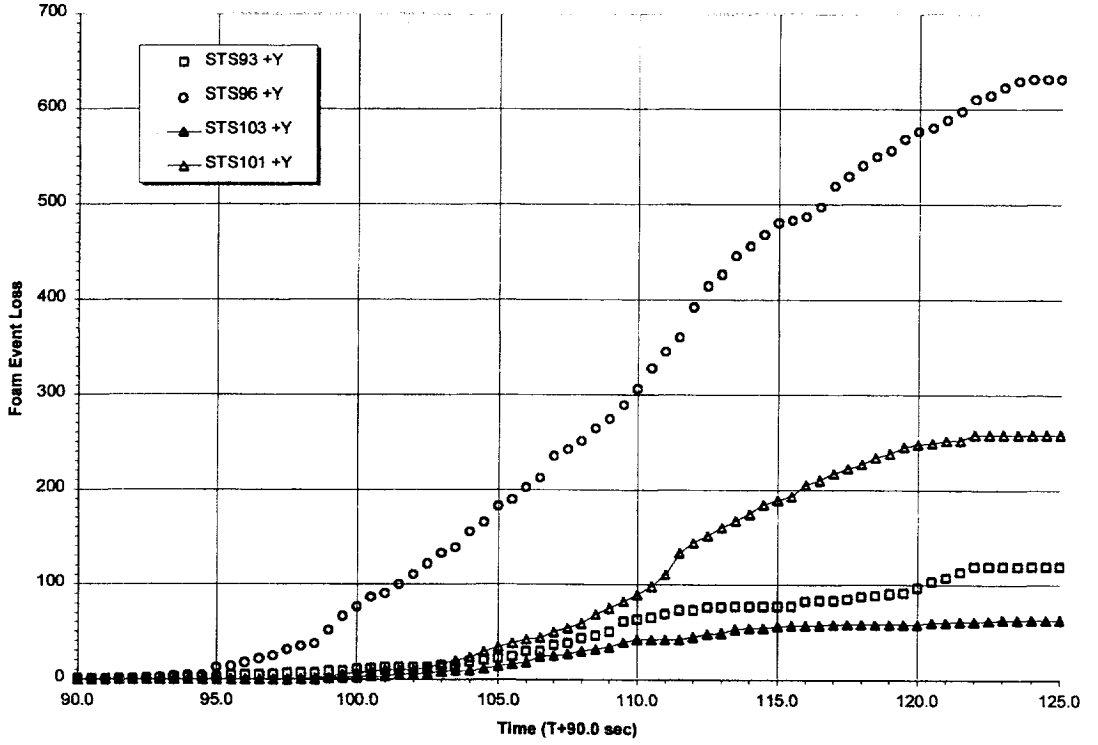

Figure 23. Foam Loss Comparison for +Y Thrust Panels

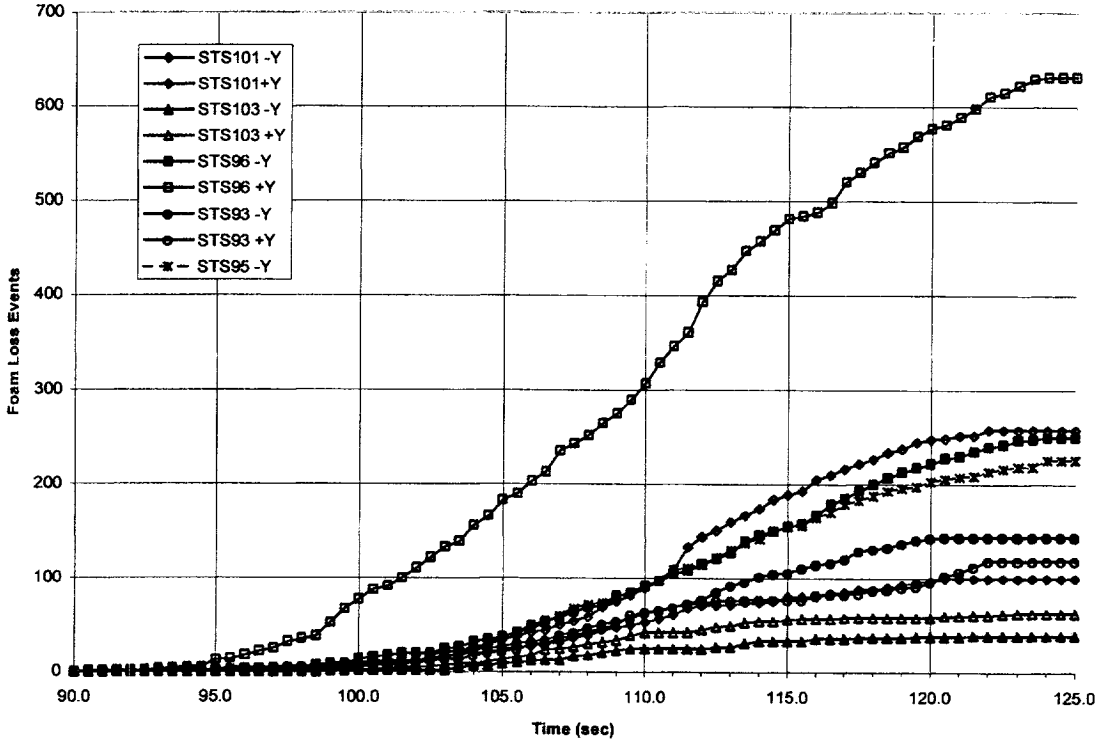

Figure 24. Comparison of Foam Loss Events from all SRB Cameras

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

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