NASA Technical Memorandum TM 107558

# Debris/Ice/TPS Assessment and Integrated Photographic Analysis for Shuttle Mission STS-54

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John F. Kennedy Space Center

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Space Administration

# DEBRIS/ICE/TPS ASSESSMENT
# AND
# PHOTOGRAPHIC ANALYSIS
# OF
# SHUTTLE MISSION STS-54

January 13, 1993

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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 (KSC) Photo/Video Analysis, reports from Johnson Space Center, Marshall Space Flight Center, and Rockwell International - Downey are also included in this document to provide an integrated assessment of the mission.


Shuttle Mission STS-54 was launched at 8:59 a.m. local 1/13/93

## 1.0 Summary

The pre-launch debris inspection of the pad and Shuttle vehicle was conducted on 12 January 1992. The detailed walkdown of Launch Pad 39B and MLP-2 also included the primary flight elements OV-105 Endeavour (3rd flight), ET-51 (LWT 44), and BI-056 SRB's. There were no vehicle anomalies. Handrails on the FSS-to-MLP crossover were now welded in place. Seven test sections of a new handrail design for the MLP perimeter were bolted and/or welded in place. A metal washer, 1.125 inches in diameter, lay against Orbiter tile on top of the Orbiter Access Arm inflated seal. After the washer was removed, a partial coating of white paint was found on the washer similar to that covering the nearby hypergolic fuel system access platform. No damage to Orbiter tiles was detected.

The vehicle was cryoloaded for flight on 13 January 1993. There were no Launch Commit Criteria, OMRS, or NSTS-08303 violations. There were no ice conditions outside of the established data base. The External Tank exhibited light condensate on the TPS acreage. The LH2 ET/ORB umbilical leak sensor detected no significant hydrogen leakage during the cryoload. No unusual vapors or cryogenic drips were visible during tanking, stable replenish, and launch. A 4-inch long crack was present in the -Y vertical strut cable tray forward surface TPS near the longeron closeout interface. The 1/4-inch wide crack exhibited no offset and was not filled with ice or frost. The appearance of the crack was expected due to the elimination of the stress relief gap at the factory. The condition was acceptable for launch per NSTS-08303 and CR S041254C.

A debris inspection of Pad 39B was performed after launch. No flight hardware was found with the exception of one Orbiter base heat shield Q-felt plug. EPON shim material on the south holddown posts was intact. There was no visual indication of a stud hang-up on any of the south holddown posts. No frangible nut/ordnance fragments were found. The GH2 vent line had latched properly. Damage to the facility overall was minimal. The seven test sections of the permanent MLP deck handrails were generally in good shape except for the east and west side removable sections, which exhibited minor deformation of the kickplates.

A total of 130 film and video items were analyzed as part of the post launch data review. No major vehicle damage or lost flight hardware was observed that would have affected the mission. Green flashes, which may be indicative of copper contaminants, occurred in the SSME #1 plume during ignition. No stud hang-ups occurred and no ordnance debris fell from any of the HDP DCS/stud holes. All T-0 umbilicals operated properly. GUCP disconnect from the External Tank was nominal.

On-orbit imagery, ET/ORB umbilical cameras and the flight crew handheld photography, revealed nominal SRB and ET separations. The right bipod jack pad TPS closeout was missing. Loss of TPS on the +Z side of the ET near the Orbiter nose is a potential threat to lower surface tiles. Divots (two 8" x 4" divots just forward of the LH2 tank-to-intertank flange closeout between the bipods; one 8" x 3" divot over a stringer head in the -Y+Z quadrant) occurred in the intertank acreage. Three divots measuring 4-6 inches in diameter occurred in the LH2 tank acreage just aft of the LH2 tank-to-intertank flange closeout. Although no IFA was taken on the divot problem, the ET manufacturer created an in-house team to evaluate the trend.

Three objects appeared in the LH2 ET/ORB umbilical camera field of view after the External Tank had separated and moved some distance away from the Orbiter (IFA STS-54-I-01). A metallic washer; metallic cotter pin, or bolt; and nylon wire tie/ identifier (or possibly some white RTV from a red seal repair) have not been positively identified as flight hardware, but appeared to originate from the LH2 ET/ORB umbilical area and may have been entrapped in the numerous cavities of the umbilical prior to purge barrier closeout. The IFA was closed by modifying the inspection requirement and procedure. Film analysis also showed orbiter flight performance, landing gear extension, wheel touchdown, and vehicle rollout after landing were normal.

The Solid Rocket Boosters were inspected at Hanger AF after retrieval. The RH frustum was missing no TPS, but had 31 MSA-2 debonds over fasteners. The LH frustum was missing no TPS, but had 18 MSA-2 debonds over fasteners and 7 acreage debonds. Several areas on the RH SRM segment cases exhibited missing paint and exposed metal substrate. None of the aft skirt HDP EPON shim material was lost at lift off. Although seated, a frangible nut web was wedged between the HDP #2 DCS plunger and the stud hole wall. The other Debris Containment System (DCS) plungers were seated properly.

A detailed post landing inspection of OV-105 was conducted on 19 January 1993. The Orbiter TPS sustained a total of 131 hits, of which 14 had a major dimension of one inch or greater. The Orbiter lower surface had a total of 80 hits, of which 14 had a major dimension of one inch or greater. Based on these numbers and comparison to statistics from previous missions of similar configuration, the total number of Orbiter TPS debris hits was near average and the number of hits one inch or larger was less than average. All three ET/Orbiter separation devices (EO-1, 2, and 3) and all ET/ORB umbilical separation ordnance retention shutters functioned properly. No flight hardware was found on the runway below the umbilicals when the ET doors were opened.

A post landing inspection of Runway 33 was performed immediately after landing. An 8 ounce, 2.5" x 2.25" x 0.5" thick, brass spray nozzle/elbow was found at the 3800 foot marker, 18 feet east of the runway centerline. This nozzle originated from the runway sweeper.

Unexpected flight hardware found on the runway consisted of three Q-felt plugs 8 feet from the runway centerline at the 5800 foot marker. Five pieces of black tile, the largest of which measured 8" x 1.25" x 0.75", lay in the vicinity of the pilot chute at the 6200 foot marker. These tile fragments originated from the vertical stabilizer "stinger" and were dislodged by contact with the drag chute riser lines during deployment.

This flight marked the sixth use of the Orbiter drag chute. Aside from the damage to the vertical stabilizer "stinger", the drag chute appeared to have functioned nominally. All drag chute hardware was recovered, appeared to be in good condition, and showed no signs of abnormal operation.

Orbiter post landing microchemical sample results revealed a variety of residuals in the Orbiter window samples from sources such as Orbiter TPS, SRB BSM exhaust residue, natural landing site products, organics, and paint. Wipe samples from RH wing RCC panels 20 and 21 revealed the presence of SRB BSM exhaust products, landing site products, paint, organics, and Orbiter TPS materials. This residual sampling data does not indicate a single source of damaging debris as all of the observed materials have been documented previously in post-landing sample reports. The residual sample data also showed no debris trends when compared to previous mission data.

A total of 7 Post Launch Anomalies, including 1 IFA candidate and 1 IFA, were observed during the STS-54 mission assessment.

## 2.0 PRE-LAUNCH BRIEFING

The Ice/Debris/TPS/Photographic Analysis Team briefing for launch activities was conducted on 12 January 1993 at 0800 hours with the following key personnel present:

| | | |
|---|---|---|
| B. Davis | NASA - KSC | STI, Ice/Debris Assessment |
| G. Katnik | NASA - KSC | Lead, Ice/Debris/Photo Team |
| S. Higginbotham | NASA - KSC | STI, Ice/Debris Assessment |
| B. Speece | NASA - KSC | Lead, ET Thermal Protection |
| B. Bowen | NASA - KSC | ET Processing, Ice/Debris |
| K. Tenbusch | NASA - KSC | ET Processing, Ice/Debris |
| P. Rosado | NASA - KSC | Chief, ET Mechanical Systems |
| J. Rivera | NASA - KSC | Lead, ET Structures |
| A. Oliu | NASA - KSC | ET Processing, Ice/Debris |
| J. Cawby | LSOC - SPC | Supervisor, ET Processing |
| R. Seale | LSOC - SPC | ET Processing |
| M. Jaime | LSOC - SPC | ET Processing |
| M. Dean | LSOC - SPC | ET Processing |
| M. Wollam | LSOC - SPC | ET Processing |
| W. Richards | LSOC - SPC | ET Processing |
| Z. Byrns | NASA - JSC | Level II Integration |
| S. Copsey | MMC - MAF | ET TPS Testing/Certif |
| J. Stone | RI - DNY | Debris Assess, LVL II Integ |
| K. Mayer | RI - LSS | Vehicle Integration |
| R. Hillard | MTI - LSS | SRM Processing |
| R. Kretz | MTI - LSS | SRM Processing |
| D. Mason | MMC - LSS | ET Processing |
| J. Fowler | NASA - KSC | Safety |
| H. Bowman | LSOC - SPC | Safety |

These personnel participated in various team activities, assisted in the collection and evaluation of data, and contributed to reports contained in this document.

## 2.1 PRE-LAUNCH SSV/PAD DEBRIS INSPECTION

A pre-launch debris inspection of the pad and Shuttle vehicle was conducted on 12 January 1992 from 0850 - 1020 hours. The detailed walkdown of Launch Pad 39B and MLP-2 also included the primary flight elements OV-105 Endeavour (3rd flight), ET-51 (LWT 44), and BI-056 SRB's. Documentary photographs were taken of facility anomalies, potential sources of vehicle damaging debris, and vehicle configuration changes.

Due to the continued concern over potential hydrogen leakage from the ET/ORB LH2 umbilical interface area during cryoload and launch, tygon tubes for hydrogen leak detectors LD54 and LD55 were installed at the LH2 ET/ORB umbilical. The tygon tubes are intended to remain in place during cryogenic loading and be removed by the Ice Team during the T-3 hour hold.

There were no significant vehicle anomalies or debris issues.

From a facility standpoint, untethered SSME platform handle pins on the inboard sides of the TSM's were identified for correction prior to the next vehicle flow.

Handrails on the FSS-to-MLP crossover were now welded in place. Seven test sections of a new handrail design for the MLP perimeter were bolted and/or welded in place.

A metal washer, 1.125 inches in diameter, lay against Orbiter tile on top of the Orbiter Access Arm (OAA) inflated seal. After the washer was removed, a partial coating of white paint was found on the washer similar to that covering the nearby hypergolic fuel system access platform. No damage to Orbiter tiles was detected.

The MLP deck and areas under the raised decks were swept/vacuumed again prior to launch to remove small debris items, such as sand, rust flakes, and paint chips. The washer contacting Orbiter tile on top of the OAA seal was the only item entered in S0007, Appendix K.

Seven test sections of a new handrail design for the MLP perimeter were bolted and/or welded in place

A metal washer lay against Orbiter tiles on top of the Orbiter Access Arm inflated seal. After removal, a partial coating of white paint was found on the washer similar to that covering the nearby hypergolic fuel system access platform. No damage to Orbiter tiles was detected.



ORIGINAL PAGE
COLOR PHOTOGRAPH

## 3.0 LAUNCH

STS-54 was launched at 13:59:29.989 GMT (8:59:30 a.m. local) on 13 January 1993.

### 3.1 ICE/FROST INSPECTION

The Ice/Frost Inspection of the cryoloaded vehicle was performed on 13 January 1993 from 0330 to 0530 hours during the two hour built-in-hold at T-3 hours in the countdown. There were no Launch Commit Criteria, OMRS, or NSTS-08303 violations. There were no conditions outside of the established data base. Ambient weather conditions at the time of the inspection were:

| | |
|---|---|
| Temperature: | 68.9 Degrees F |
| Relative Humidity: | 92.3 Percent |
| Wind Speed: | 10.0 Knots |
| Wind Direction: | 193 Degrees |

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, as shown in Figures 1 and 2.

### 3.2 ORBITER

No Orbiter tile or RCC panel anomalies were observed. All RCS thruster paper covers and water spray boiler plugs were intact. Typical ice/frost accumulations were present at the SSME #1 and #2 heat shield-to-nozzle interfaces. Condensate was present on the SSME #1 and #2 heat shields, but the base heat shield tiles were dry. An infrared scan revealed no unusual temperature gradients on the base heat shield or engine mounted heat shields. No unusual vapors originated from inside the SSME nozzles.

### 3.3 SOLID ROCKET BOOSTERS

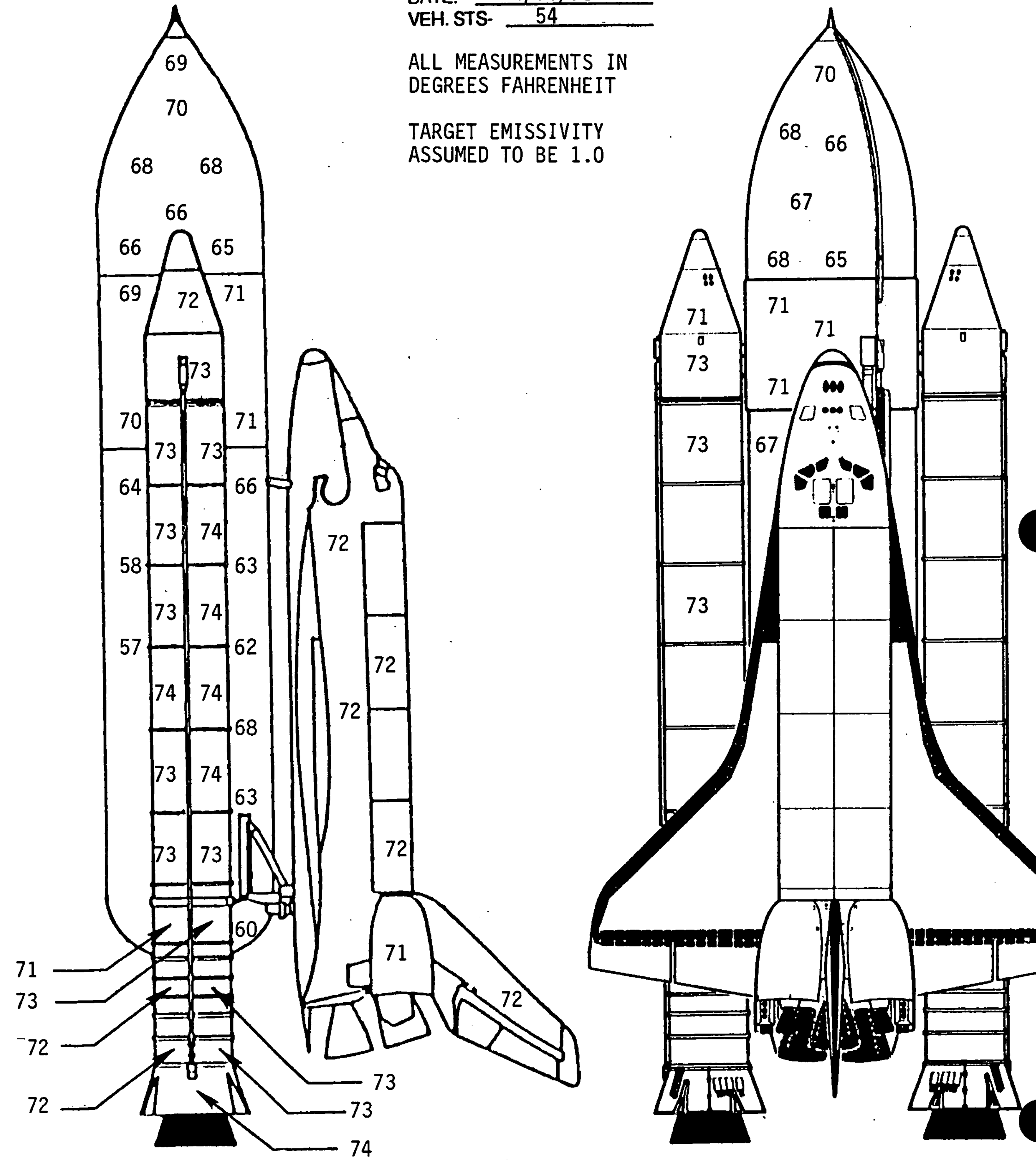
No SRB anomalies or loose ablator/cork were observed. The K5NA closeouts of the aft booster stiffener ring splice plates were intact. The STI portable infrared scanner recorded RH and LH SRB case temperatures between 68 and 74 degrees Fahrenheit (F). In comparison, temperatures measured by a hand-held Minolta/ Land Cyclops spot radiometer ranged from 68 to 72 degrees F and the SRB Ground Environment Instrumentation (GEI) measured temperatures ranging from 69 to 74 degrees F. All measured temperatures were above the 34 degrees F minimum requirement. The predicted Propellant Mean Bulk Temperature (PMBT) supplied by MTI was 70 degrees F, which was within the required range of 44-86 degrees F.

Figure 1. **SSV INFRARED SCANNER SURFACE TEMPERATURE SUMMARY DATA**

TIME: approx. 0430 EST
DATE: 1/13/93
VEH. STS- 54

ALL MEASUREMENTS IN DEGREES FAHRENHEIT

TARGET EMISSIVITY ASSUMED TO BE 1.0





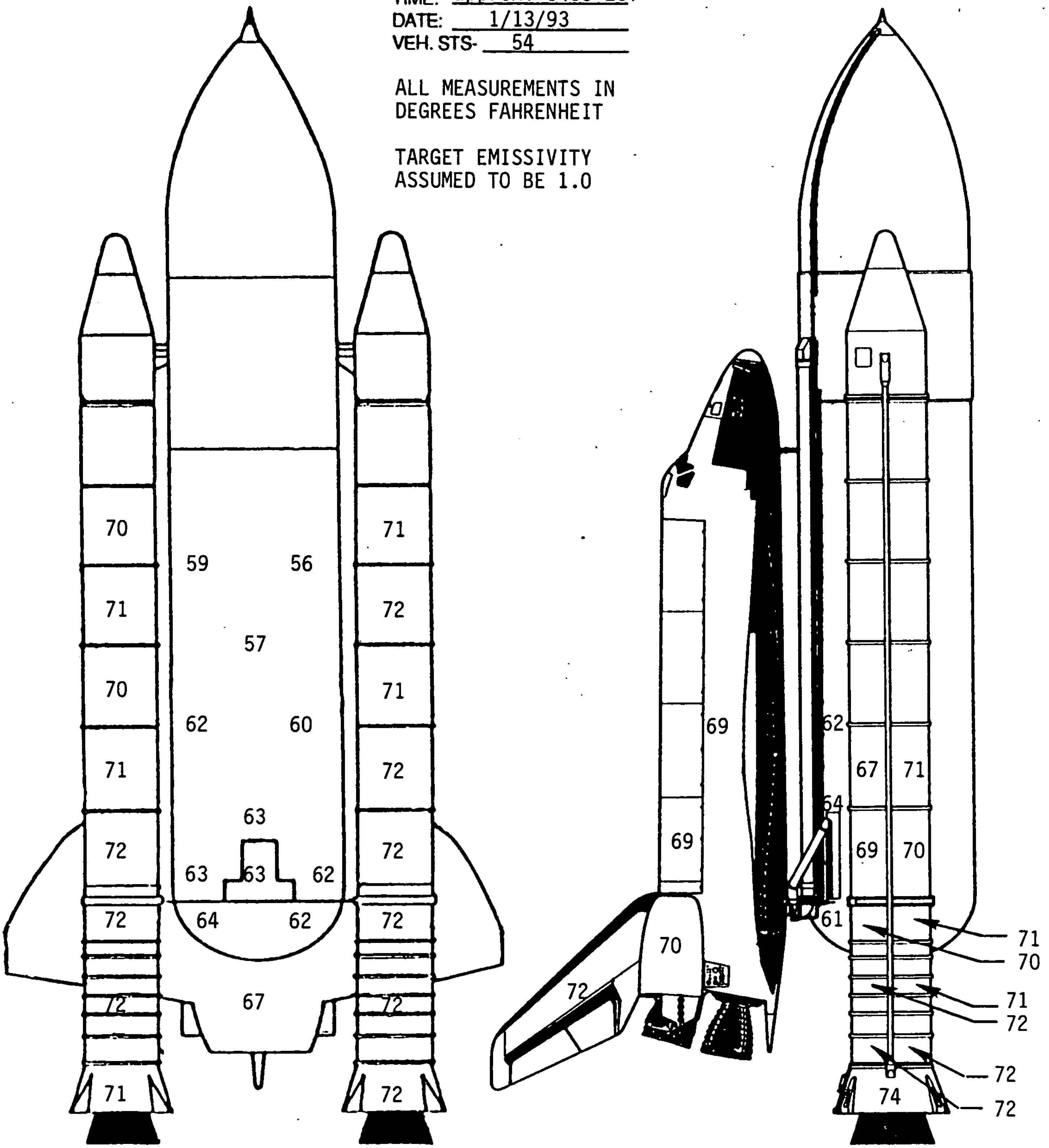

EGG/V -343I

Figure 2. **SSV INFRARED SCANNER SURFACE TEMPERATURE SUMMARY DATA**

TIME: approx. 0430 EST
DATE: 1/13/93
VEH. STS- 54

ALL MEASUREMENTS IN DEGREES FAHRENHEIT

TARGET EMISSIVITY ASSUMED TO BE 1.0






EGG/V-343C

## 3.4 EXTERNAL TANK

The ice/frost prediction computer program 'SURFICE' was run from 0100 to 0900 hours and the results tabulated in Figure 3. The program predicted condensate with no ice/frost accumulation on the TPS acreage surfaces during cryoload.

There was no condensate or ice/frost accumulations on the LO2 tank ogive. Some light condensate was present on the LO2 tank barrel section. There were no TPS anomalies. The tumble valve cover was intact. The pressurization line and support ramps were in nominal configuration. The portable STI measured surface temperatures that averaged 70 degrees F on the ogive and 67 degrees F on the barrel section. In comparison, the Cyclops radiometer measured temperatures that averaged 67 degrees F on the ogive and 64 degrees F on the barrel; SURFICE predicted temperatures of 62 degrees F on the ogive and 56 degrees F on the barrel.

The intertank acreage TPS was wet with condensate run-off. No frost spots appeared in the stringer valleys at the LH2 and LO2 tank-to-intertank flanges. Typical ice/frost accumulations and no unusual vapors were present on the ET umbilical carrier plate. The portable STI measured an average surface temperature of 71 degrees F on the intertank compared to 69 degrees as measured by the Cyclops radiometer.

There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost, was present on the acreage and aft dome. The portable STI measured surface temperatures that averaged 61 degrees F on the upper LH2 tank and 63 degrees F on the lower LH2 tank. In comparison, the Cyclops radiometer measured temperatures that averaged 61 degrees F on both the upper and lower LH2 tank; SURFICE predicted temperatures of 54 degrees F on the upper LH2 tank and 54 degrees F on the lower LH2 tank.

There were no anomalies on the bipods, bipod jack pad closeouts, PAL ramp, cable tray/press line ice/frost ramps, longerons, thrust struts, manhole covers, or aft dome apex. Some ice/frost was present in the ET/SRB cable tray-to-upper strut fairing expansion joints. Ice/frost covered the lower EB fittings outboard to the strut pin hole with condensate on the rest of the fitting. The struts were dry.

A 4-inch long crack was present in the -Y vertical strut cable tray forward surface TPS near the longeron closeout interface. The 1/4-inch wide crack exhibited no offset and was not filled with ice or frost. The appearance of the crack was expected due to the elimination of the stress relief gap at the factory.

Typical amounts of ice/frost were present in the LO2 feedline bellows and support brackets.

| STS- 54 | TEST S0007 LAUNCH | DATE: 13 January 1993 | T-0 TIME: 08:59:30 DATE: 1/13/93 | NASA KSC Ice/Frost/Debris Team |
|---|---|---|---|---|
| ORBITER 105 | ET 51, SRB BI-056, MLP 2, PAD B | LO2 CHILLDOWN TIME: 00:32, SLOW FILL TIME: 01:11, FAST FILL TIME: 01:23, REPLENISH TIME: 03:27 | LH2 CHILLDOWN TIME: 00:32, SLOW FILL TIME: 00:41, FAST FILL TIME: 01:05, REPLENISH TIME: 03:21 | |

| TIME | CONDITIONS | | | | | LO2 TANK STA 370 TO 540 | | | | | LO2 TANK STA 550 TO 852 | | | | | LH2 TANK STA 1130 TO 1380 | | | | | LH2 TANK STA 1380 TO 2058 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (EDT) | TEMP F | REL. HUM. % | DEW PT F | WIND VEL KNTS | WIND DIR DEG | REG | LOCAL VEL KNTS | SOFI TEMP | COND RATE IN/HR | ICE RATE IN/HR | REG | LOCAL VEL KNTS | SOFI TEMP | COND RATE IN/HR | ICE RATE IN/HR | REG | LOCAL VEL KNTS | SOFI TEMP | COND RATE IN/HR | ICE RATE IN/HR | REG | LOCAL VEL KNTS | SOFI TEMP | COND RATE IN/HR | ICE RATE IN/HR |
| 0100 | 70.40 | 87.0 | 66.48 | 8 | 187 | II | 4.72 | 61.14 | 0.0026 | -0.1639 | II | 4.72 | 56.67 | 0.0044 | -0.1337 | II | 3.36 | 52.44 | 0.0044 | -0.0871 | II | 3.04 | 51.35 | 0.0042 | -0.0774 |
| 0115 | 70.20 | 87.8 | 66.53 | 8 | 187 | II | 4.72 | 61.09 | 0.0027 | -0.1636 | II | 4.72 | 56.62 | 0.0044 | -0.1334 | II | 3.36 | 52.38 | 0.0044 | -0.0868 | II | 3.04 | 51.28 | 0.0043 | -0.0771 |
| 0130 | 70.20 | 87.8 | 66.53 | 8 | 190 | II | 4.72 | 61.09 | 0.0027 | -0.1636 | II | 4.72 | 56.62 | 0.0044 | -0.1334 | II | 3.36 | 52.38 | 0.0044 | -0.0868 | II | 3.04 | 51.28 | 0.0043 | -0.0771 |
| 0145 | 70.20 | 87.8 | 66.53 | 9 | 190 | II | 5.31 | 61.64 | 0.0027 | -0.1814 | II | 5.31 | 57.56 | 0.0045 | -0.1508 | II | 3.78 | 53.61 | 0.0045 | -0.0996 | II | 3.42 | 52.56 | 0.0044 | -0.0887 |
| 0200 | 70.20 | 87.8 | 66.53 | 8 | 193 | II | 4.72 | 61.09 | 0.0027 | -0.1636 | II | 4.72 | 56.62 | 0.0044 | -0.1334 | II | 3.36 | 52.38 | 0.0044 | -0.0868 | II | 3.04 | 51.28 | 0.0043 | -0.0771 |
| 0215 | 70.00 | 88.8 | 66.65 | 10 | 191 | II | 5.90 | 62.10 | 0.0028 | -0.1991 | II | 5.90 | 58.35 | 0.0047 | -0.1682 | II | 4.20 | 54.63 | 0.0047 | -0.1121 | II | 3.80 | 53.64 | 0.0046 | -0.1001 |
| 0230 | 69.80 | 88.4 | 66.33 | 8 | 188 | II | 4.72 | 60.78 | 0.0027 | -0.1614 | II | 4.72 | 56.29 | 0.0044 | -0.1312 | II | 3.36 | 52.02 | 0.0044 | -0.0851 | II | 3.04 | 50.92 | 0.0043 | -0.0754 |
| 0245 | 69.80 | 89.2 | 66.58 | 9 | 186 | II | 5.31 | 61.50 | 0.0028 | -0.1804 | II | 5.31 | 57.42 | 0.0046 | -0.1498 | II | 3.78 | 53.44 | 0.0046 | -0.0987 | II | 3.42 | 52.39 | 0.0045 | -0.0878 |
| 0300 | 69.20 | 90.8 | 66.48 | 7 | 199 | II | 4.13 | 59.94 | 0.0028 | -0.1426 | II | 4.13 | 54.95 | 0.0045 | -0.1128 | II | 2.94 | 50.32 | 0.0043 | -0.0714 | II | 2.66 | 49.18 | 0.0042 | -0.0629 |
| 0315 | 68.80 | 91.4 | 66.27 | 5 | 226 | II | 2.95 | 57.67 | 0.0027 | -0.1048 | II | 2.95 | 51.29 | 0.0041 | -0.0758 | II | 1.60 | 43.68 | 0.0036 | -0.0430 | II | 6.80 | 57.89 | 0.0053 | -0.1821 |
| 0330 | 69.40 | 91.2 | 66.81 | 9 | 231 | II | 5.31 | 61.49 | 0.0030 | -0.1803 | II | 5.31 | 57.39 | 0.0048 | -0.1497 | II | 2.88 | 50.42 | 0.0044 | -0.0711 | II | 12.24 | 62.06 | 0.0055 | -0.3430 |
| 0345 | 69.60 | 90.6 | 66.82 | 9 | 204 | II | 5.31 | 61.58 | 0.0029 | -0.1810 | II | 5.31 | 57.49 | 0.0047 | -0.1504 | II | 2.88 | 50.54 | 0.0043 | -0.0716 | II | 12.24 | 62.15 | 0.0054 | -0.3442 |
| 0400 | 69.40 | 90.8 | 66.68 | 8 | 201 | II | 4.72 | 60.84 | 0.0029 | -0.1619 | II | 4.72 | 56.35 | 0.0046 | -0.1317 | II | 3.36 | 52.05 | 0.0045 | -0.0853 | II | 3.04 | 50.95 | 0.0044 | -0.0756 |
| 0415 | 69.00 | 91.6 | 66.53 | 8 | 198 | II | 4.72 | 60.56 | 0.0029 | -0.1600 | II | 4.72 | 56.06 | 0.0046 | -0.1298 | II | 3.36 | 51.74 | 0.0046 | -0.0838 | II | 3.04 | 50.63 | 0.0044 | -0.0741 |
| 0430 | 68.80 | 92.6 | 66.64 | 10 | 188 | II | 5.90 | 61.59 | 0.0031 | -0.1950 | II | 5.90 | 57.81 | 0.0049 | -0.1641 | II | 4.20 | 54.02 | 0.0049 | -0.1087 | II | 3.80 | 53.02 | 0.0048 | -0.0968 |
| 0445 | 68.60 | 92.8 | 66.50 | 9 | 177 | II | 5.31 | 60.94 | 0.0031 | -0.1762 | II | 5.31 | 56.81 | 0.0048 | -0.1457 | II | 3.78 | 52.76 | 0.0048 | -0.0952 | II | 3.42 | 51.69 | 0.0046 | -0.0845 |
| 0500 | 68.40 | 93.6 | 66.54 | 11 | 181 | II | 6.49 | 61.77 | 0.0032 | -0.2103 | II | 6.49 | 58.27 | 0.0050 | -0.1792 | II | 4.62 | 54.67 | 0.0051 | -0.1195 | II | 4.18 | 53.71 | 0.0049 | -0.1068 |
| 0515 | 68.60 | 93.6 | 66.74 | 13 | 179 | II | 7.67 | 62.65 | 0.0032 | -0.2467 | II | 7.67 | 59.61 | 0.0052 | -0.2149 | II | 5.46 | 56.40 | 0.0053 | -0.1456 | II | 4.94 | 55.52 | 0.0052 | -0.1304 |
| 0530 | 68.40 | 93.8 | 66.60 | 13 | 177 | II | 7.67 | 62.47 | 0.0032 | -0.2449 | II | 7.67 | 59.43 | 0.0052 | -0.2132 | II | 5.46 | 56.21 | 0.0053 | -0.1442 | II | 4.94 | 55.33 | 0.0052 | -0.1291 |
| 0545 | 68.80 | 93.8 | 67.00 | 14 | 188 | II | 8.26 | 63.17 | 0.0032 | -0.2666 | II | 8.26 | 60.33 | 0.0053 | -0.2345 | II | 5.88 | 57.29 | 0.0054 | -0.1599 | II | 5.32 | 56.46 | 0.0053 | -0.1434 |
| 0600 | 69.20 | 93.2 | 67.22 | 14 | 194 | II | 8.26 | 63.48 | 0.0032 | -0.2700 | II | 8.26 | 60.65 | 0.0052 | -0.2378 | II | 5.88 | 57.63 | 0.0054 | -0.1624 | II | 5.32 | 56.80 | 0.0053 | -0.1458 |
| 0615 | 69.00 | 94.0 | 67.26 | 10 | 188 | II | 5.90 | 62.10 | 0.0032 | -0.1993 | II | 5.90 | 58.34 | 0.0051 | -0.1683 | II | 4.20 | 54.57 | 0.0050 | -0.1119 | II | 3.80 | 53.56 | 0.0049 | -0.0998 |
| 0630 | 68.80 | 93.8 | 67.00 | 10 | 192 | II | 5.90 | 61.84 | 0.0032 | -0.1971 | II | 5.90 | 58.07 | 0.0050 | -0.1662 | II | 4.20 | 54.28 | 0.0050 | -0.1102 | II | 3.80 | 53.27 | 0.0049 | -0.0982 |
| 0645 | 68.60 | 94.0 | 66.86 | 9 | 192 | II | 5.31 | 61.18 | 0.0031 | -0.1781 | II | 5.31 | 57.07 | 0.0049 | -0.1475 | II | 3.78 | 53.02 | 0.0049 | -0.0965 | II | 3.42 | 51.96 | 0.0047 | -0.0857 |
| 0700 | 68.20 | 94.2 | 66.52 | 7 | 189 | II | 4.13 | 59.51 | 0.0030 | -0.1400 | II | 4.13 | 54.49 | 0.0046 | -0.1102 | II | 2.94 | 49.80 | 0.0045 | -0.0692 | II | 2.66 | 48.61 | 0.0043 | -0.0607 |
| 0715 | 68.20 | 94.6 | 66.64 | 8 | 201 | II | 4.72 | 60.29 | 0.0031 | -0.1582 | II | 4.72 | 55.76 | 0.0048 | -0.1280 | II | 3.36 | 51.38 | 0.0047 | -0.0822 | II | 3.04 | 50.26 | 0.0045 | -0.0726 |
| 0730 | 67.80 | 94.8 | 66.30 | 7 | 202 | II | 4.13 | 59.17 | 0.0030 | -0.1380 | II | 4.13 | 54.14 | 0.0046 | -0.1082 | II | 2.94 | 49.42 | 0.0045 | -0.0676 | II | 2.66 | 48.22 | 0.0043 | -0.0592 |
| 0745 | 67.60 | 95.0 | 66.16 | 7 | 197 | II | 4.13 | 58.99 | 0.0031 | -0.1368 | II | 4.13 | 53.94 | 0.0046 | -0.1071 | II | 2.94 | 49.21 | 0.0045 | -0.0666 | II | 2.66 | 48.01 | 0.0043 | -0.0583 |
| 0800 | 68.00 | 95.2 | 66.62 | 5 | 201 | II | 2.95 | 57.50 | 0.0029 | -0.1041 | II | 2.95 | 51.11 | 0.0042 | -0.0750 | II | 2.10 | 45.63 | 0.0040 | -0.0434 | II | 1.90 | 44.31 | 0.0038 | -0.0416 |
| 0815 | 68.40 | 95.4 | 67.07 | 4 | 199 | II | 2.36 | 56.54 | 0.0027 | -0.0878 | II | 2.36 | 49.17 | 0.0040 | -0.0592 | II | 1.68 | 43.84 | 0.0037 | -0.0438 | II | 1.52 | 43.83 | 0.0037 | -0.0438 |
| 0830 | 69.00 | 95.4 | 67.67 | 6 | 185 | II | 3.54 | 59.80 | 0.0031 | -0.1288 | II | 3.54 | 54.25 | 0.0046 | -0.0991 | II | 2.52 | 49.21 | 0.0044 | -0.0614 | II | 2.28 | 48.01 | 0.0042 | -0.0538 |
| 0845 | 69.40 | 95.0 | 67.95 | 9 | 197 | II | 5.31 | 62.28 | 0.0033 | -0.1866 | II | 5.31 | 58.22 | 0.0051 | -0.1558 | II | 3.78 | 54.21 | 0.0050 | -0.1029 | II | 3.42 | 53.16 | 0.0049 | -0.0917 |
| T-0 | 69.80 | 94.4 | 68.17 | 7 | 188 | II | 4.13 | 61.36 | 0.0031 | -0.1518 | II | 4.13 | 56.45 | 0.0048 | -0.1216 | II | 2.94 | 51.85 | 0.0046 | -0.0782 | II | 2.66 | 50.68 | 0.0045 | -0.0692 |
| AVG. | 69.08 | 92.13 | 66.76 | 8.70 | S | | 5.13 | 60.88 | | | | 5.13 | 56.47 | | | | 3.58 | 52.04 | | | | 3.99 | 52.24 | | |

(shaded) Period of Ice Team Inspection

Figure 3. "SURFICE" Computer Predictions

There were no TPS anomalies on the LO2 ET/ORB umbilical. The purge barrier (baggie) was configured properly and was holding positive purge pressure. There were no accumulations of ice/frost on the acreage areas of the umbilical. Formation of ice/frost on the separation bolt pyrotechnic canister purge vents was typical. Normal venting of nitrogen purge gas had occurred during tanking, stable replenish, and launch.

Ice/frost in the LH2 recirculation line bellows and on both burst disks was typical. The LH2 feedline bellows were wet with condensate and some frost was beginning to form.

The usual amounts of ice/frost had accumulated on the top, aft, and outboard sides of the LH2 ET/ORB umbilical purge barrier. Typical ice/frost fingers had formed on the pyro canister and plate gap purge vents. Light ice/frost was present on both the aft and forward outboard pyrotechnic canister closeout bondlines indicating thermal shorts. The amount and location of the ice/frost was acceptable for launch per the NSTS-08303 criteria. A typical ice/frost ring had formed on the cable tray vent hole. No ice or frost had formed on the 17-inch flapper valve actuator access port foam plug closeout. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.

The ET/ORB hydrogen detection sensor tygon tubing was in proper position prior to removal. The tubing was successfully removed from the vehicle without contacting Orbiter tiles.

The summary of Ice/Frost Team observations/anomalies consisted of six OTV recorded items:

Anomaly 001 documented ice/frost with venting vapors on the test port closeout of the aft dome -Z manhole cover. The condition was acceptable per the NSTS-08303 criteria.

Anomaly 002 documented a 4-inch crack in the -Y vertical strut cable tray forward surface at the intersection to the ET/SRB cable tray transition fairing. The 1/4-inch wide crack exhibited no offset and was not filled with ice or frost. The condition was acceptable for launch per NSTS-08303 and CR S041254C.

Anomaly 003 documented ice/frost formations at the +Y thrust strut-to-longeron interface and at the +Y vertical strut-to-ET/SRB cable tray transition fairing drain hole. The formations were acceptable per the NSTS-08303 criteria.

Anomaly 004 (documentation only) recorded ice/frost formations in the LO2 feedline bellows and support brackets. The ice/frost formations were acceptable per NSTS-08303.

Anomaly 005 (documentation only) recorded ice/frost formations in the LH2 feedline bellows, LH2 recirculation line bellows and burst disks. The ice/frost formations were acceptable per NSTS-08303.

Anomaly 006 (documentation only) recorded ice/frost formations on the ET/ORB umbilical pyro canister purge vents and LH2 upper/outboard sections of the purge barrier (baggie). The ice and frost formations were acceptable per NSTS-08303.

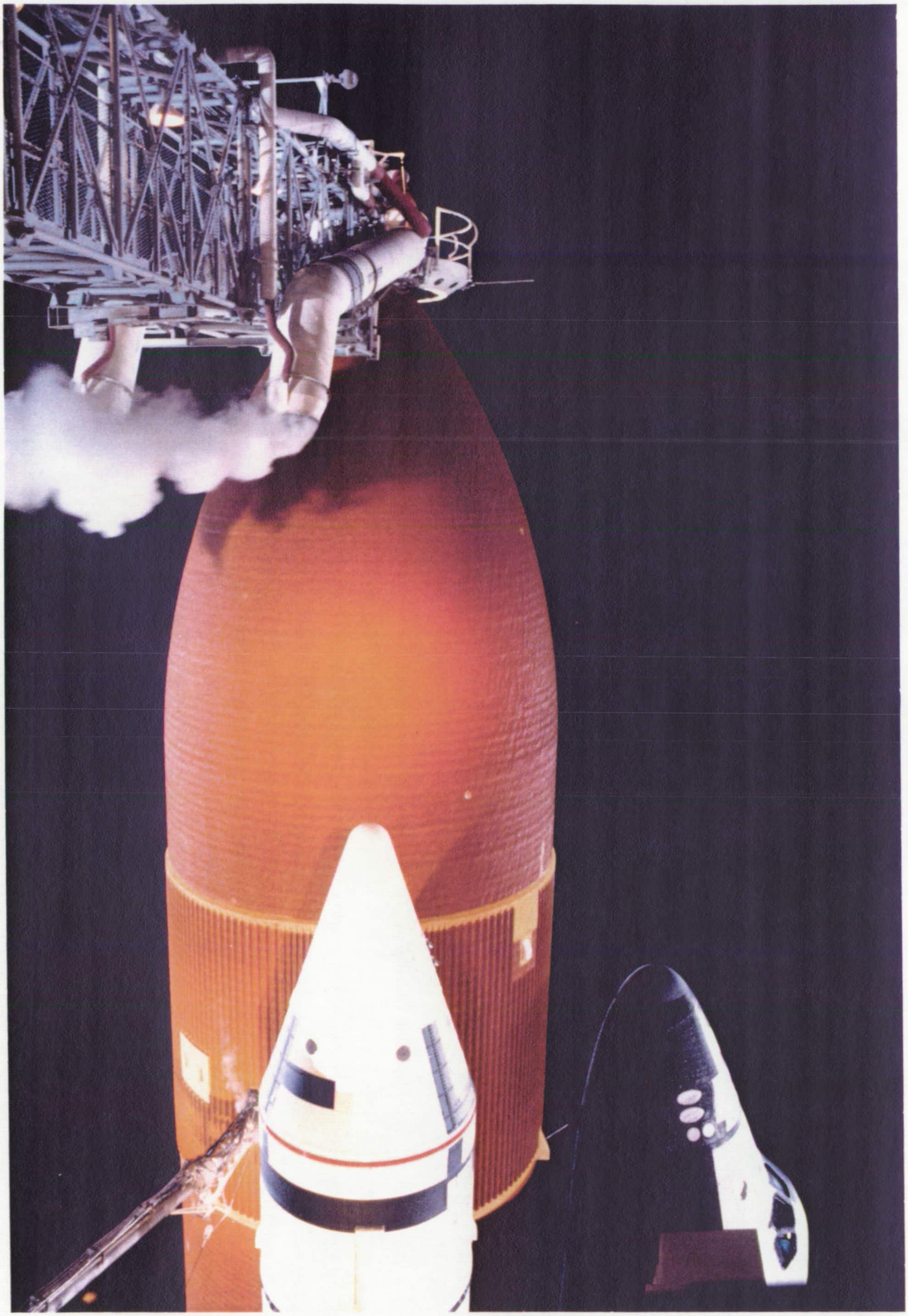
## 3.5 FACILITY

All SRB sound suppression water troughs were filled and properly configured for launch. There was no debris on the MLP deck or in the SRB holddown post areas.

No leaks were observed on either the LO2 or LH2 Orbiter T-0 umbilicals. Typical accumulations of ice/frost were present on the cryogenic lines and purge shrouds.

There was no apparent hydrogen leakage anywhere on the GH2 vent line or GUCP. Some ice and frost, which was expected, had accumulated on the GUCP legs and on the uninsulated parts of the umbilical carrier plate.

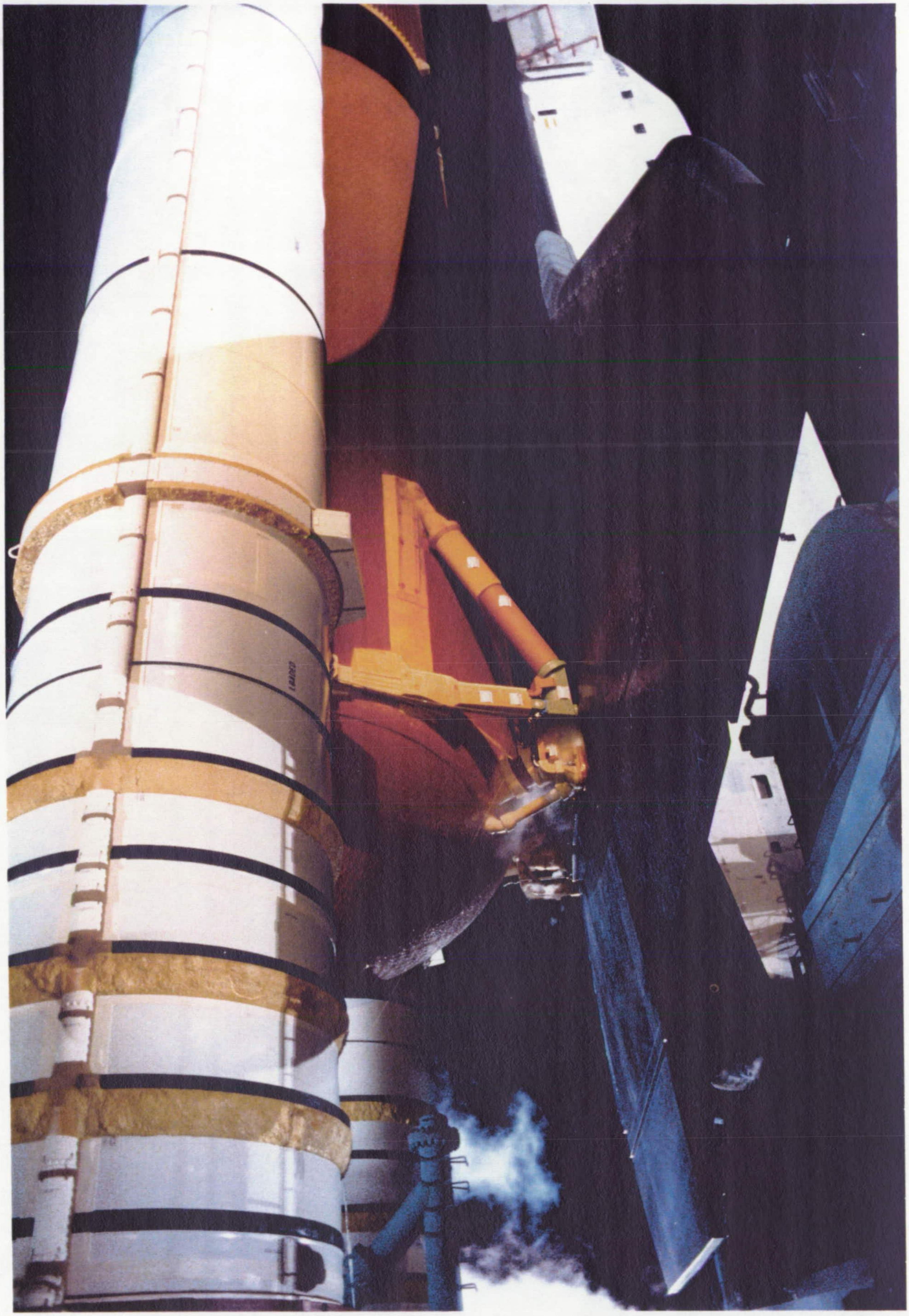
Visual and infrared observations of the GOX seals confirmed no leakage. No ET nosecone/footprint damage was visible after the GOX vent hood was retracted.. Small icicles less than 1/2 inch in length had formed on the north GOX vent duct, but had melted prior to the time of launch.



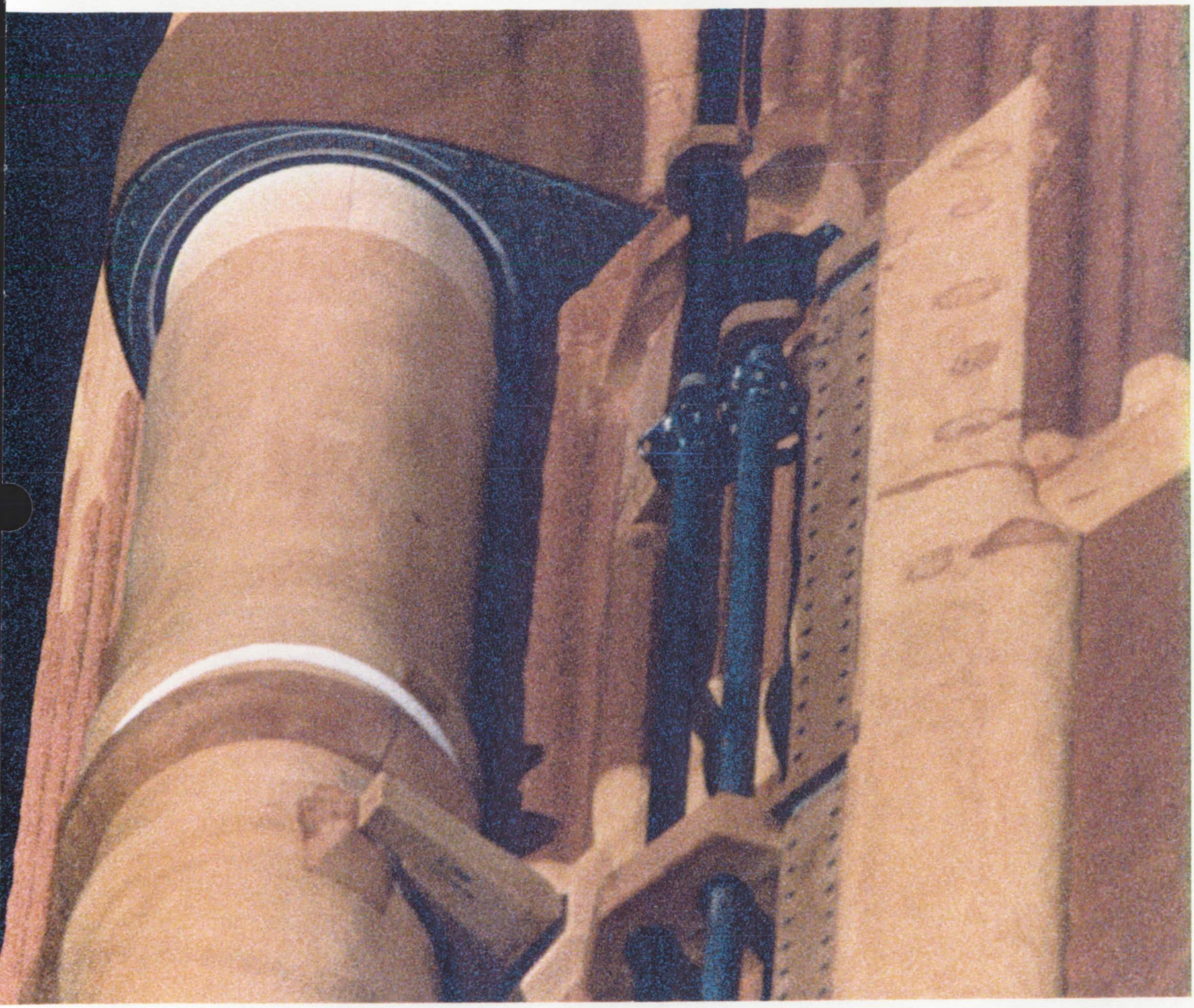
There were no TPS anomalies or ice/frost accumulations on the LO2 tank. Some light condensate was present on the LO2 tank barrel section.



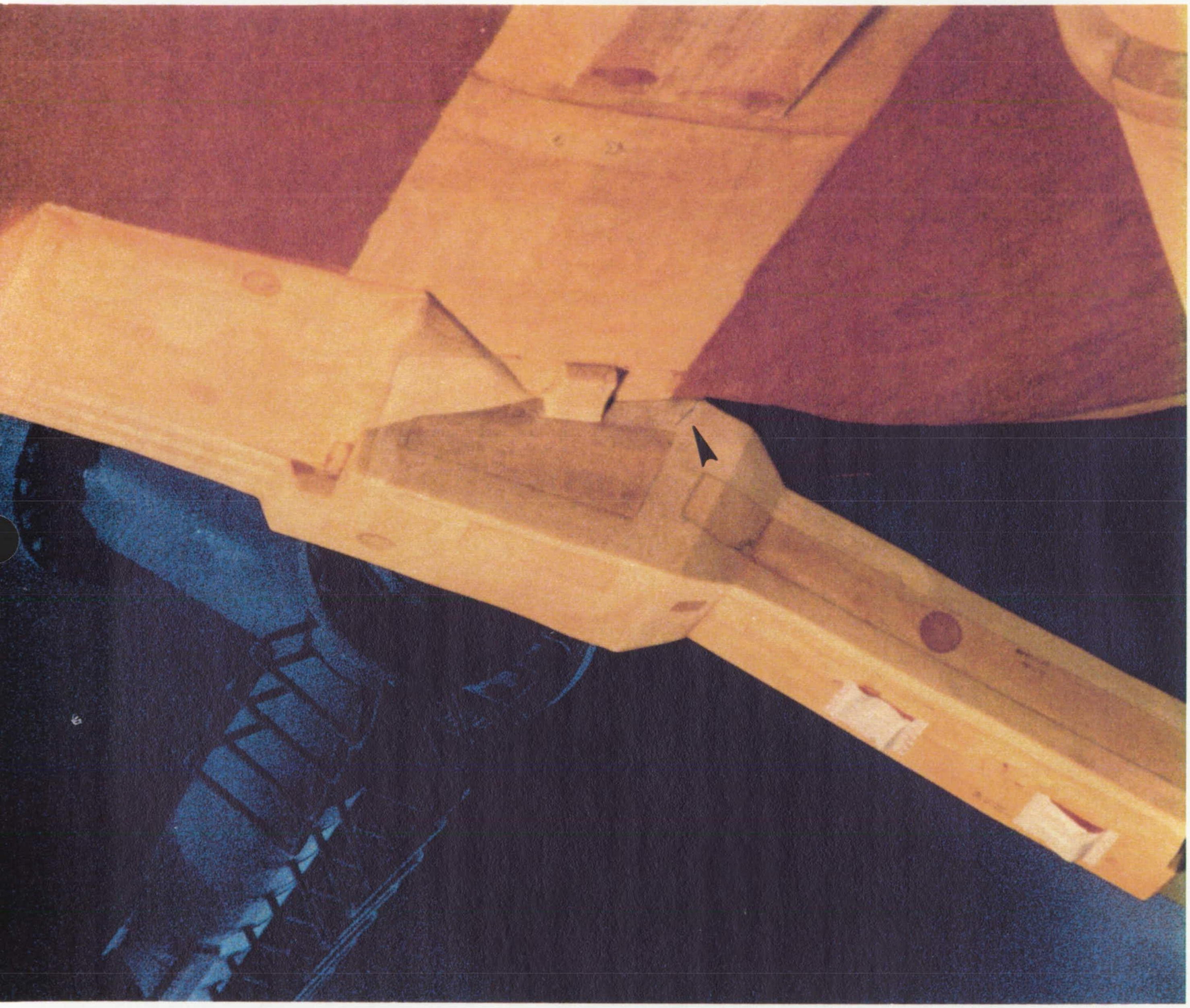
ORIGINAL PAGE
COLOR PHOTOGRAPH



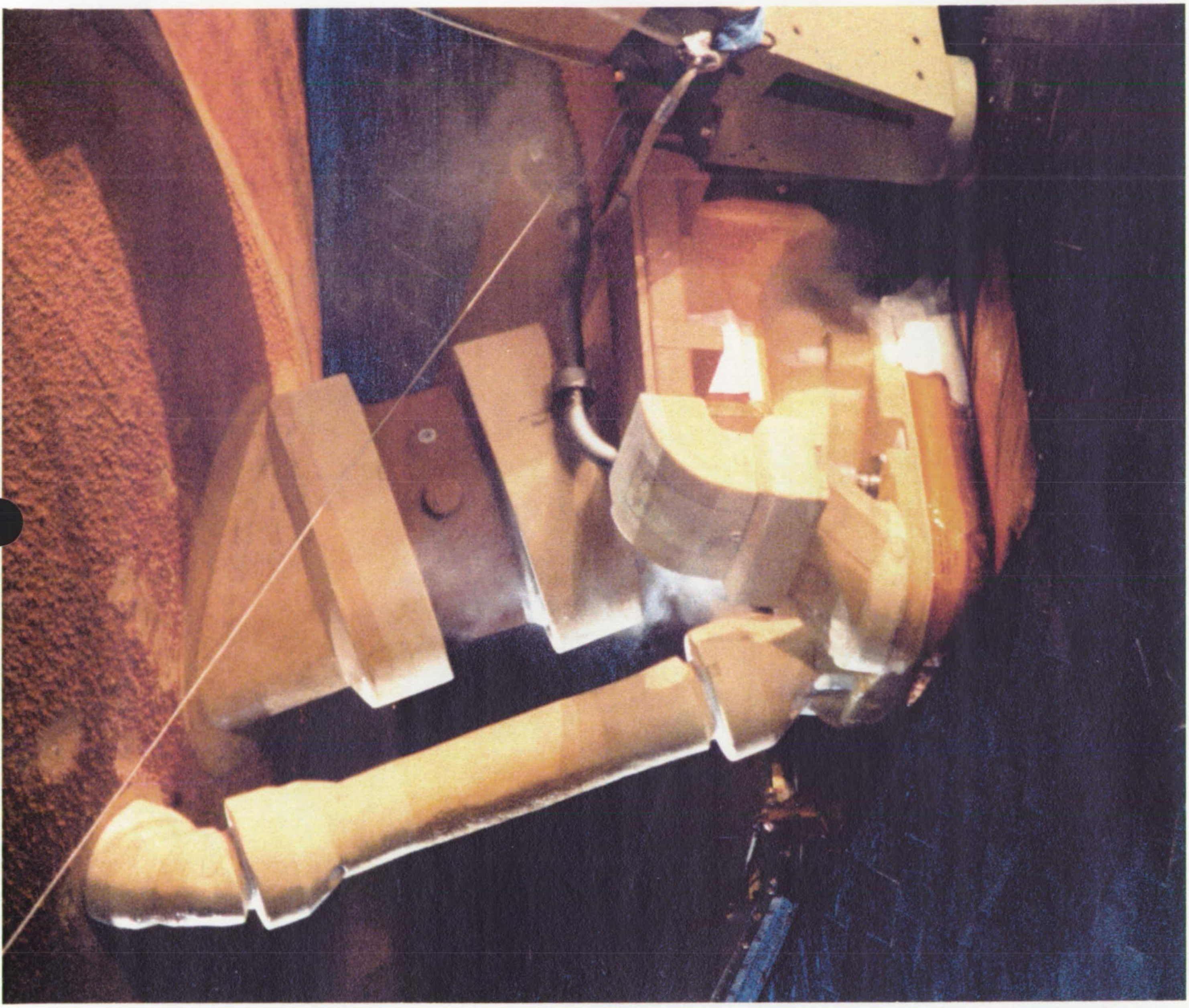
There were no LH2 tank TPS acreage anomalies. Light condensate, but no ice or frost, was present on the acreage and aft dome.



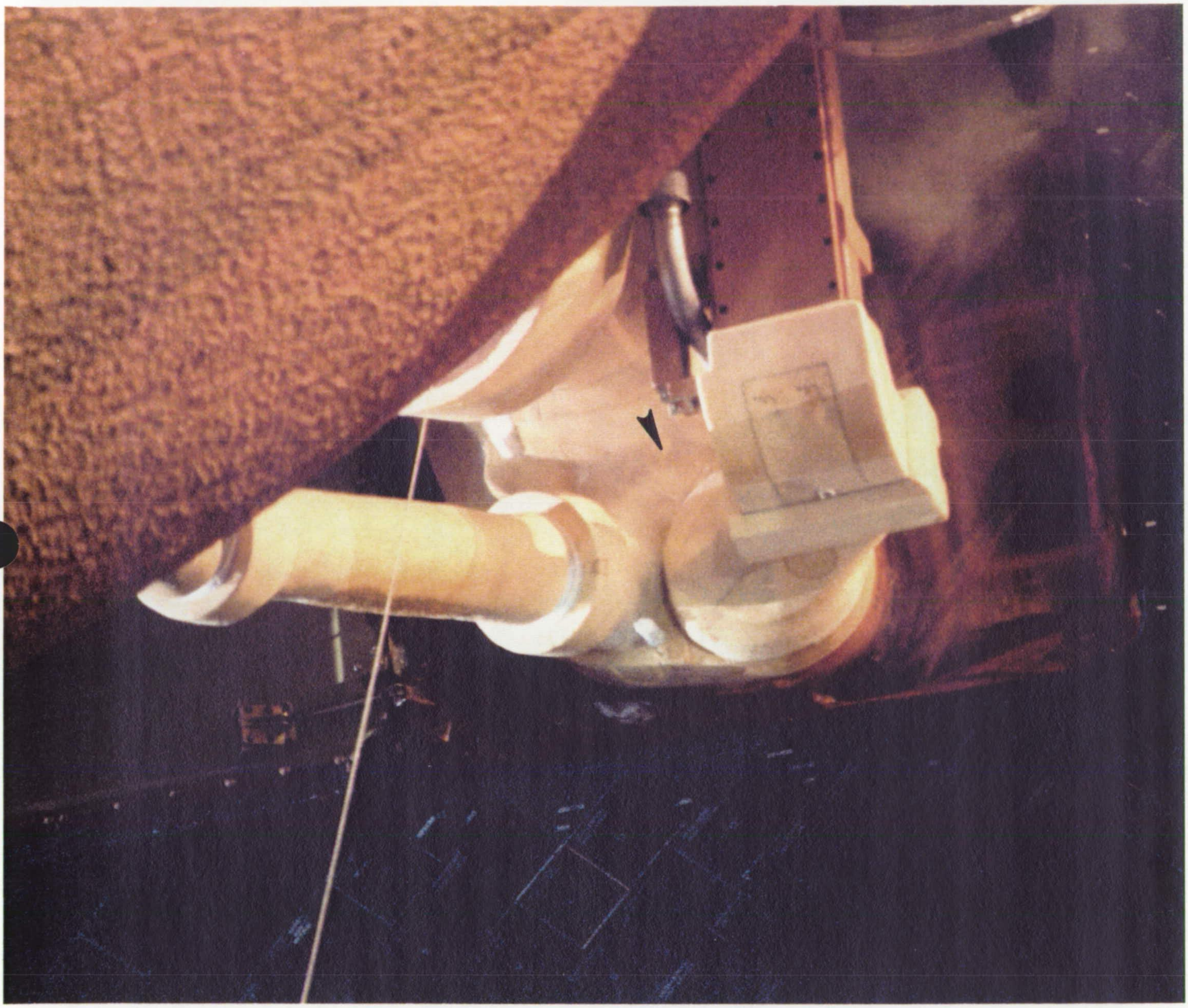
Typical amounts of ice/frost were present in the LO2 feedline
upper bellows and support brackets



A 4-inch long crack was present in the -Y vertical strut cable tray forward surface TPS near the longeron closeout interface. The 1/4-inch wide crack exhibited no offset and was not filled with ice or frost. The condition was acceptable for flight.



Ice/frost formations on the ET/ORB LH2 umbilical were typical. No unusual vapors or cryogenic drips had appeared during tanking, stable replenish, and launch.



Typical in size, ice/frost fingers had formed on the aft plate gap purge vent and LH2 umbilical cable tray vent hole. No ice or frost had formed on the 17-inch flapper valve actuator access port TPS plug closeout indicating a proper closeout.



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COLOR PHOTOGRAPH

## 4.0 POST LAUNCH PAD DEBRIS INSPECTION

The post launch inspection of the MLP, FSS, and the pad acreage was conducted on 13 January 1993 from Launch + 2 to 4 hours. No flight hardware or TPS materials were found with the exception of one Orbiter base heat shield Q-felt plug in the southwest area of the pad near the boxcars.

SRB holddown post erosion was typical. All south HDP shoe shim material was intact, but slightly debonded at the sidewalls of HDP #1, #2, #5, and #6. There was no visual indication of a stud hang-up on any of the south holddown posts (accelerometer data from Rockwell also showed no indications of a stud hang-up). There were no ordnance fragments found in the south holddown post stud holes. All of the north HDP doghouse blast covers were in the closed position and exhibited typical erosion. The HDP #4 cover was missing a triangular piece at one corner. The SRB aft skirt purge lines were in place, but slightly damaged. The SRB T-0 umbilicals exhibited minor damage.

The GOX vent arm, OAA, and TSM's showed typical plume effects. The GH2 vent arm appeared to have retracted nominally, was latched on the eighth tooth of the latching mechanism, and had no loose cables (static retract lanyard). No contact between the north latch and the north saddle stabilizer was apparent. The GH2 vent line showed the usual signs of SRB plume impingement. The ET intertank access structure also sustained typical plume heating effects.

Damage to the facility included:

1. A sound suppression pipe base mounting plate bolt north of the RH SRB exhaust hole was loose.

2. A safety warning sign on the MLP zero level access door was loose.

3. A 3'x 2.5' door from a nearby electrical box was found on the FSS 175 foot level.

4. A sign on the FSS 235 foot level near the staircase was missing.

5. Debris, in the form of 2 clamps, OIS connector cap, and a 5-inch diameter rubber electrical box cover, was found on the FSS 135 foot level.

All seven emergency egress slidewire baskets were secured on the FSS 195 foot level and sustained no launch damage.

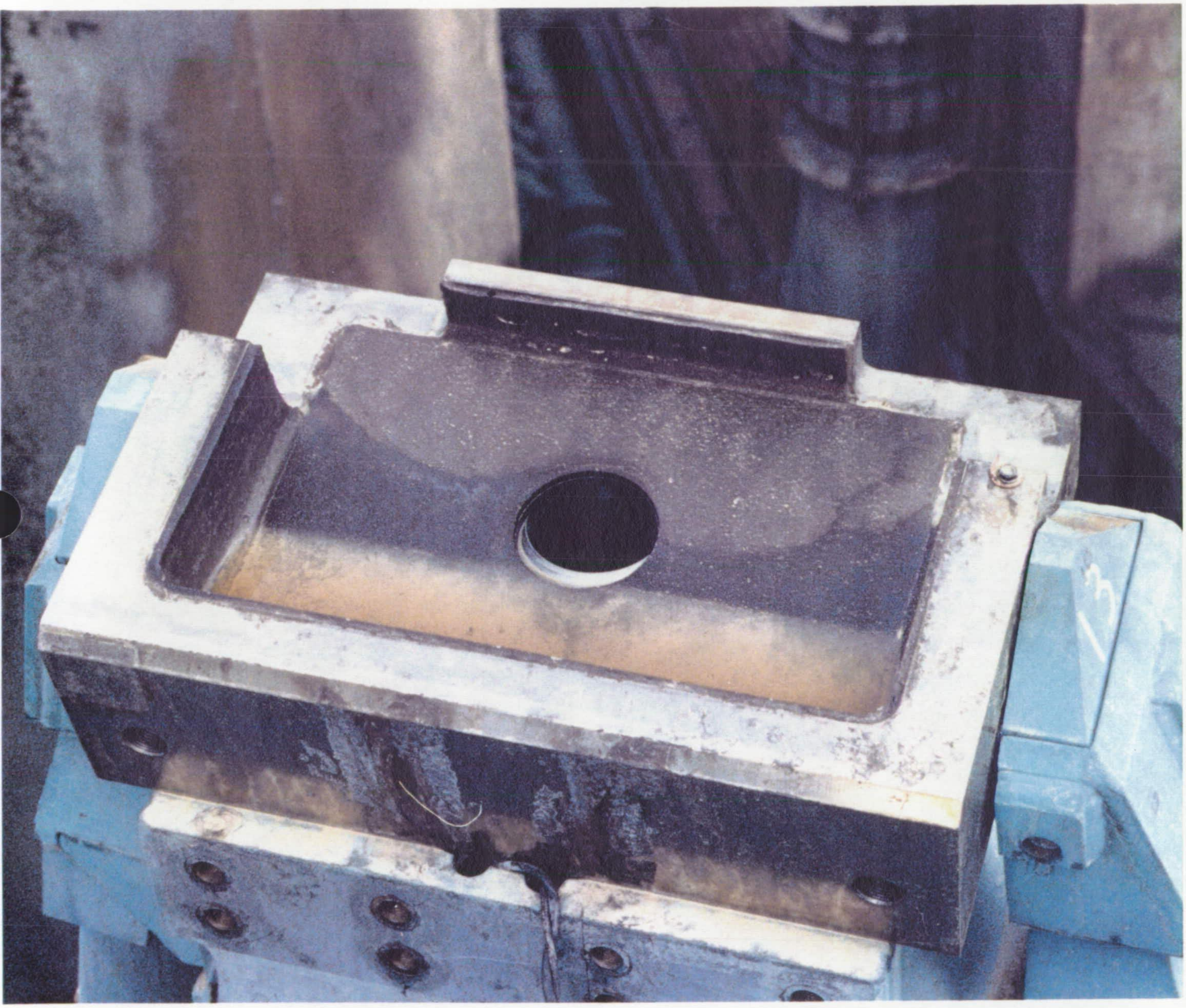
The seven test sections of the permanent MLP deck perimeter handrails were generally in good shape after launch except for the east and west side removable sections, which exhibited minor deformation of the kickplates.

An inspection of the beach from UCS-10 to Titan complex 40, the beach road, the railroad tracks, the water areas around the pad and under the flight path was completed. No flight hardware was found.

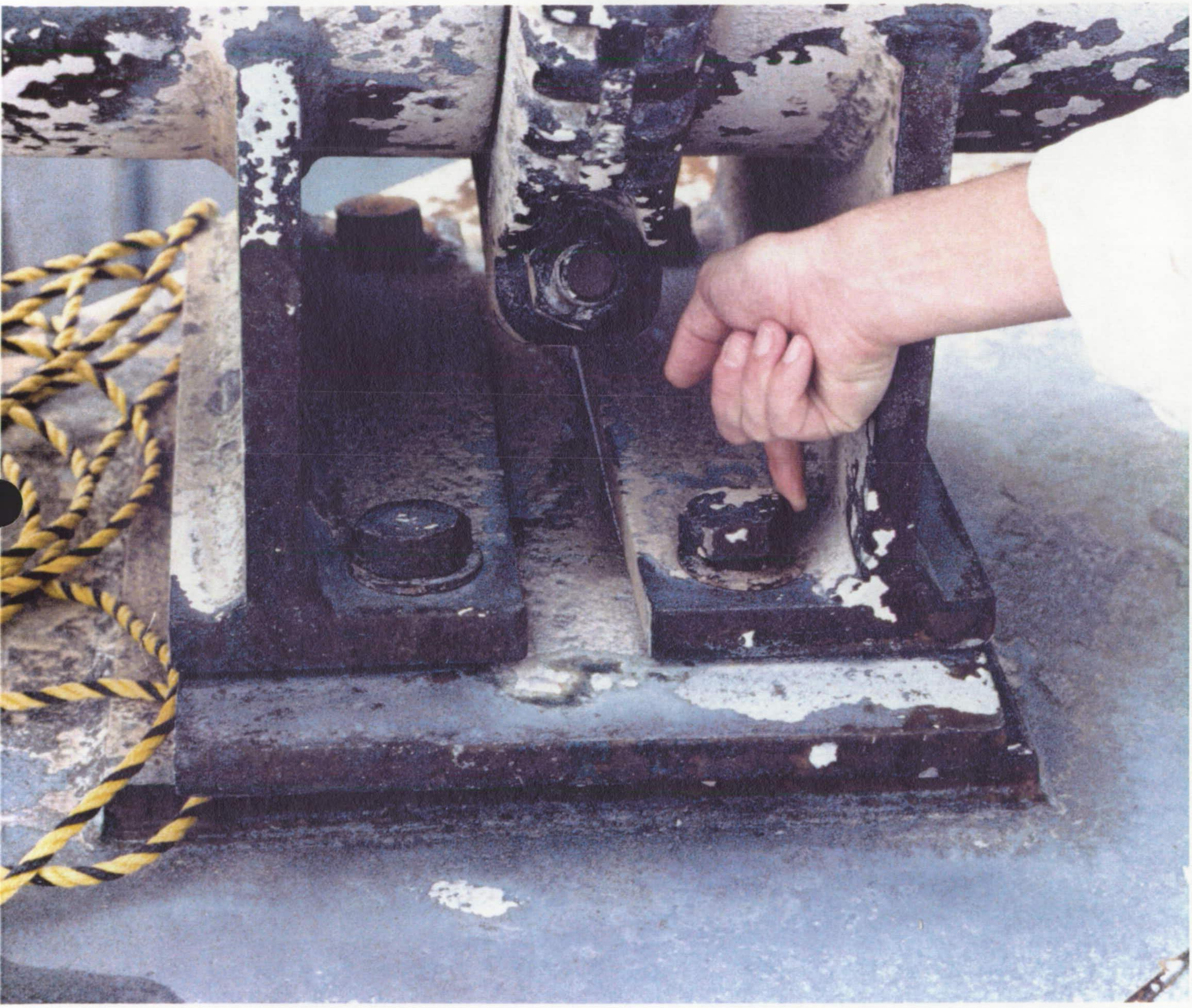
MLP-2 was configured with overpressure sensors at the top of both TSM's, at the bottom of both SRB exhaust holes, and at the bottom of the SSME exhaust hole. All sensor readings were consistent with previous launches and within nominal limits.

Patrick AFB and MILA radars were configured in a mode for increased sensitivity for the purpose of observing any debris falling from the vehicle during ascent but after SRB separation (due to the masking effect of the SRB exhaust plume). Most of the signal registrations were very weak and often barely detectable, which generally compares with the types of particles detected on previous Shuttle flights. A total of 51 particles were imaged in the T+138 to 363 second time period. Twenty-six of the particles were imaged by only one radar, 14 particles were imaged by two radars, and 11 particles were imaged by all three radars. Though the signal strength of the detected particles was comparable to previous missions, the number of detected particles (51) was distinctly lower than the STS-53 mission (69 particles).

Post launch pad inspection anomalies are listed in Section 9.



Plume erosion of the south SRB holddown posts was typical. EPON shim material was intact but slightly debonded from the sidewalls of the holddown post shoes.



A sound suppression pipe base mounting plate bolt north of the RH SRB exhaust hole was loose

The seven test sections of the permanent MLP deck perimeter handrails were generally in good shape after launch except for the east and west side removable sections, which exhibited minor deformation of the kickplates.

## 5.0 FILM REVIEW AND PROBLEM REPORTS

Post Launch Anomalies observed in the Film Review were presented to the Mission Management Team, Shuttle managers, and vehicle systems engineers. These anomalies are listed in Section 9.

## 5.1 LAUNCH FILM AND VIDEO SUMMARY

A total of 105 film and video data items, which included forty videos, forty-one 16mm films, twenty 35mm films, and four 70mm films, were reviewed starting on launch day.

No major vehicle damage or lost flight hardware was observed that would have affected the mission.

Prior to ignition, free burning hydrogen drifted up to the OMS pods and under the body flap. SSME ignition, Mach diamond formation, and gimbal profile appeared normal (RSS STI, C/S-2 STI, OTV 151, 163, 170, 171, E-1, 5). Flashes occurred in the SSME #2 plume (OTV 151, 170, E-2). Green flashes, which may be indicative of copper contaminants, occurred in the SSME #1 plume at GMT 13:59:26.913, 13:59:27.592, 13:59:27.941, and 13:59:27.970 (E-52, 76).

SSME ignition caused numerous pieces of ice/frost to fall from the ET/Orbiter umbilicals. There were no unusual vapors or cryogenic drips from the ET/ORB umbilicals during tanking, stable replenish, ignition, liftoff, or tower clear (OTV 109, 150, 154, 163, 164).

SSME ignition vibration/acoustics caused the loss of tile surface coating material from a tile on the LH aft RCS stinger (E-20) and from two areas on the base heat shield near SSME #3 (E-17). Film item E-77 provided another view of tile surface coating material loss on the LH aft RCS stinger near the L3A thruster.

A brown-colored object, 6 inches long by 1 inch wide, first appeared in the body flap hinge gap and fell aft at GMT 13:59:27.013 without damaging Orbiter tiles. The object is believed to be a brown GSE tile shim, or spacer. GSE tile shims are color coded (orange, yellow, pink, and brown) based on shim thickness (E-17).

Several ice particles from the LO2 feedline upper bellows fell aft but did not contact the vehicle (E-5, 6).

Fore-and-aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster occurred during engine start-up. The motion was similar to that observed on previous launches (E-76, 77).

The tumble valve cover was intact. Light frost was present in the ET GOX vent louvers. There was no TPS damage to the ET nose cone acreage, footprint, or fairing. (OTV 113, 160, 161, 162). ET "twang" was typical (E-79).

The Orbiter LH2 and LO2 T-0 umbilicals disconnected and retracted properly (OTV 149, 150, 163). GUCP disconnect from the External Tank was nominal (OTV 104). The GH2 vent line retracted and latched normally with no rebound. Some slack in the static retract lanyard caused the cable to contact the edge of the platform, rebound upwards, and contact the lower GUCP leg (E-41, 42, 48, 50).

Film item E-60 confirmed that water flowed properly from all MLP rainbirds.

A piece of duct tape was ejected upward out of the SRB exhaust hole shortly after T-0 (E-8).

No stud hang-ups occurred on any of the holddown posts. No debris fell from any of the aft skirt HDP DCS/stud holes.

A piece of debris from the south side of the FSS moved eastward but did not contact the vehicle (E-40).

A dark, rigid object, somewhat square in shape with a thin edge, appeared in the SSME plume south of the MLP. Trajectory characteristics showed the object had some mass and was most likely a piece of throat plug material (E-62; E-76 frame 1033).

Water vapor/condensate trailed from the split rudder speed brake drain hole after liftoff (E-54).

Condensate in the SRB stiffener rings and on the ET aft dome vaporized after liftoff (TV-4B).

SRB plumes appeared normal during ascent. There was no visual indication of the RH SRM chamber pressure 20 psi momentary increase at T+67 seconds MET.

Numerous flashes occurred in the SSME plume during ascent (E-54, 222).

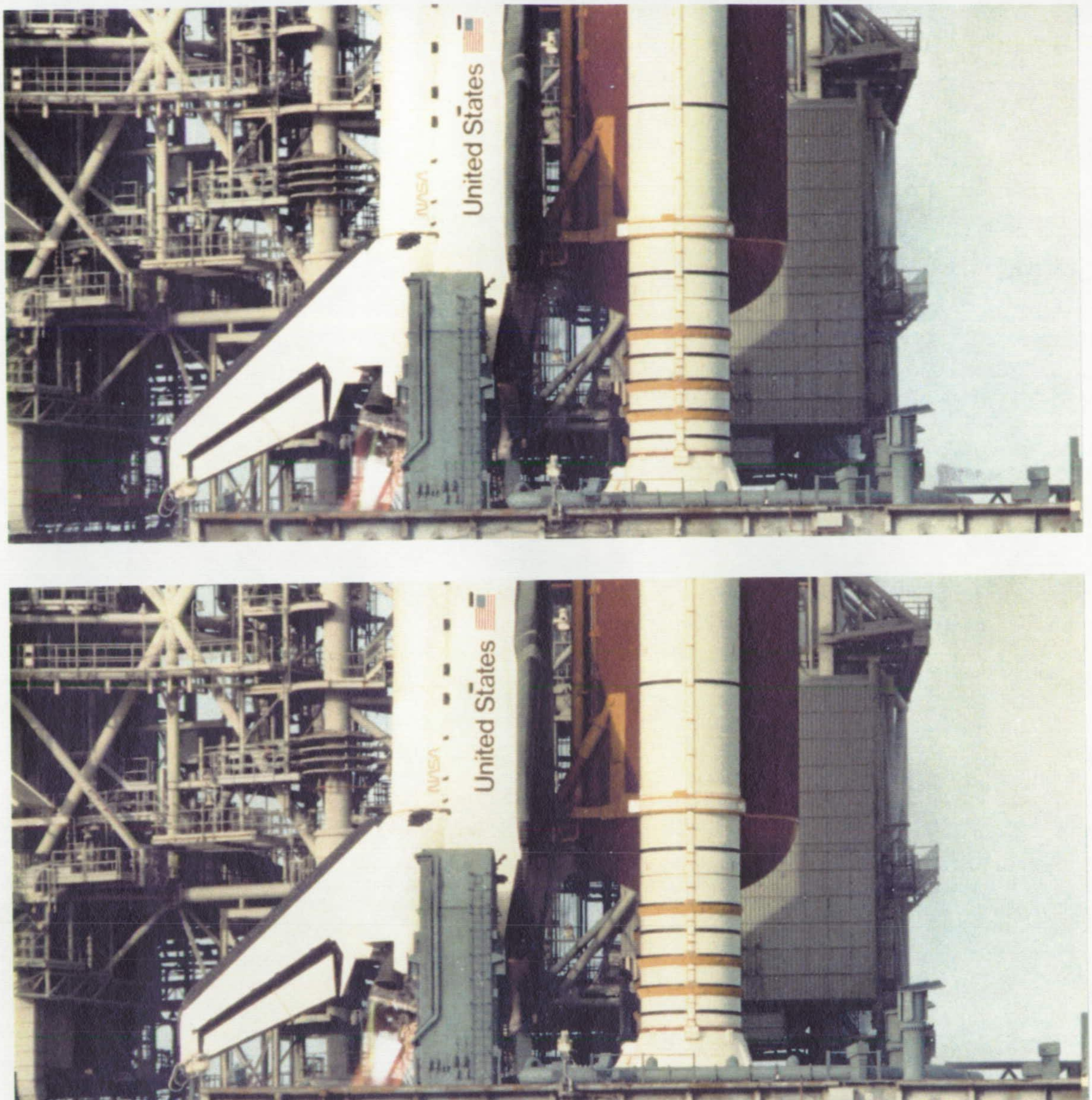
Clusters of particles falling aft of the Orbiter after the roll maneuver were traced to the forward RCS thrusters and were pieces of RCS paper covers. Other pieces of RCS paper covers were visible passing over the Orbiter wings (E-212, 220, 222).

Movement of the body flap was similar to previous flights (E-207, 212).

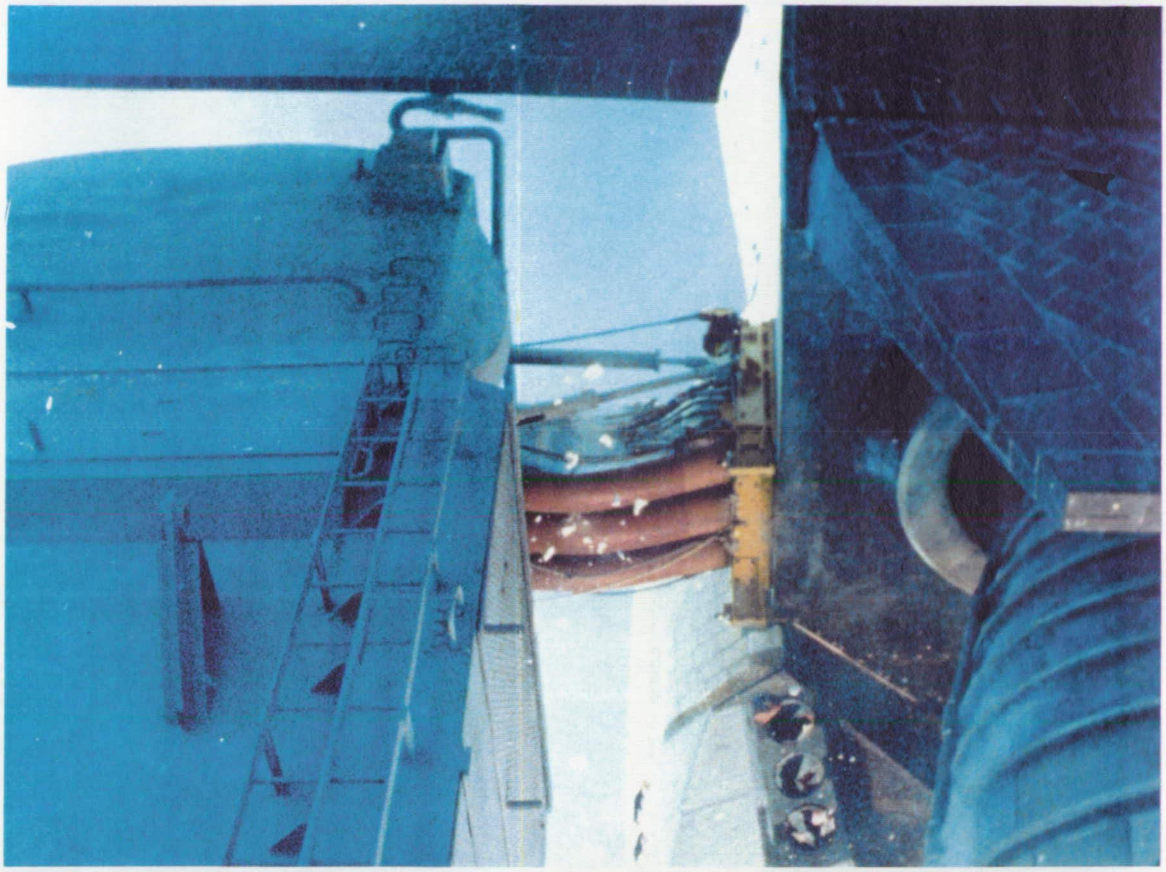
Local flow condensation at various points on the vehicle were typical (E-207, 220, 222).

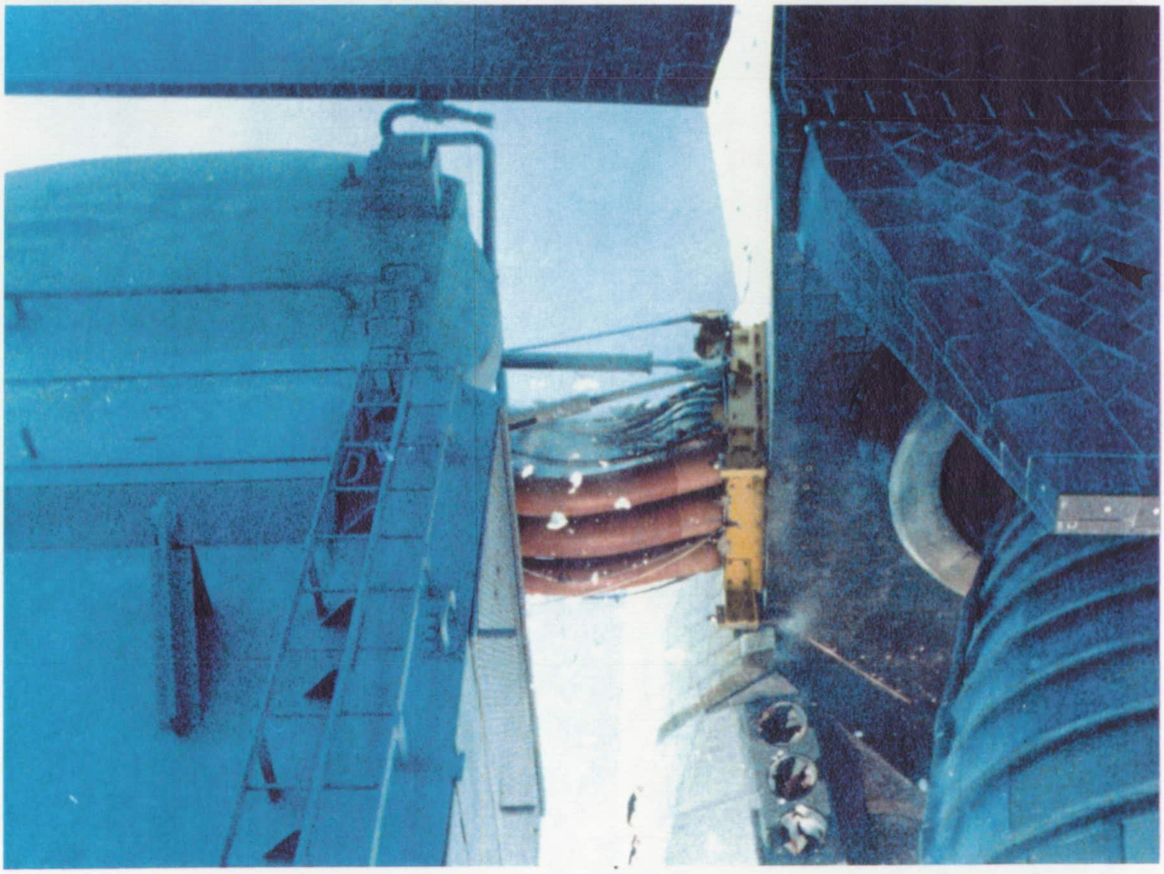
Exhaust plume recirculation, SRB plume tailoff, and SRB separation appeared nominal (E-207, 212).

Frustum separation from the forward skirts appeared normal. Main parachute deployment and reefing was nominal. Nozzle severance debris was typical (E-301, 302).

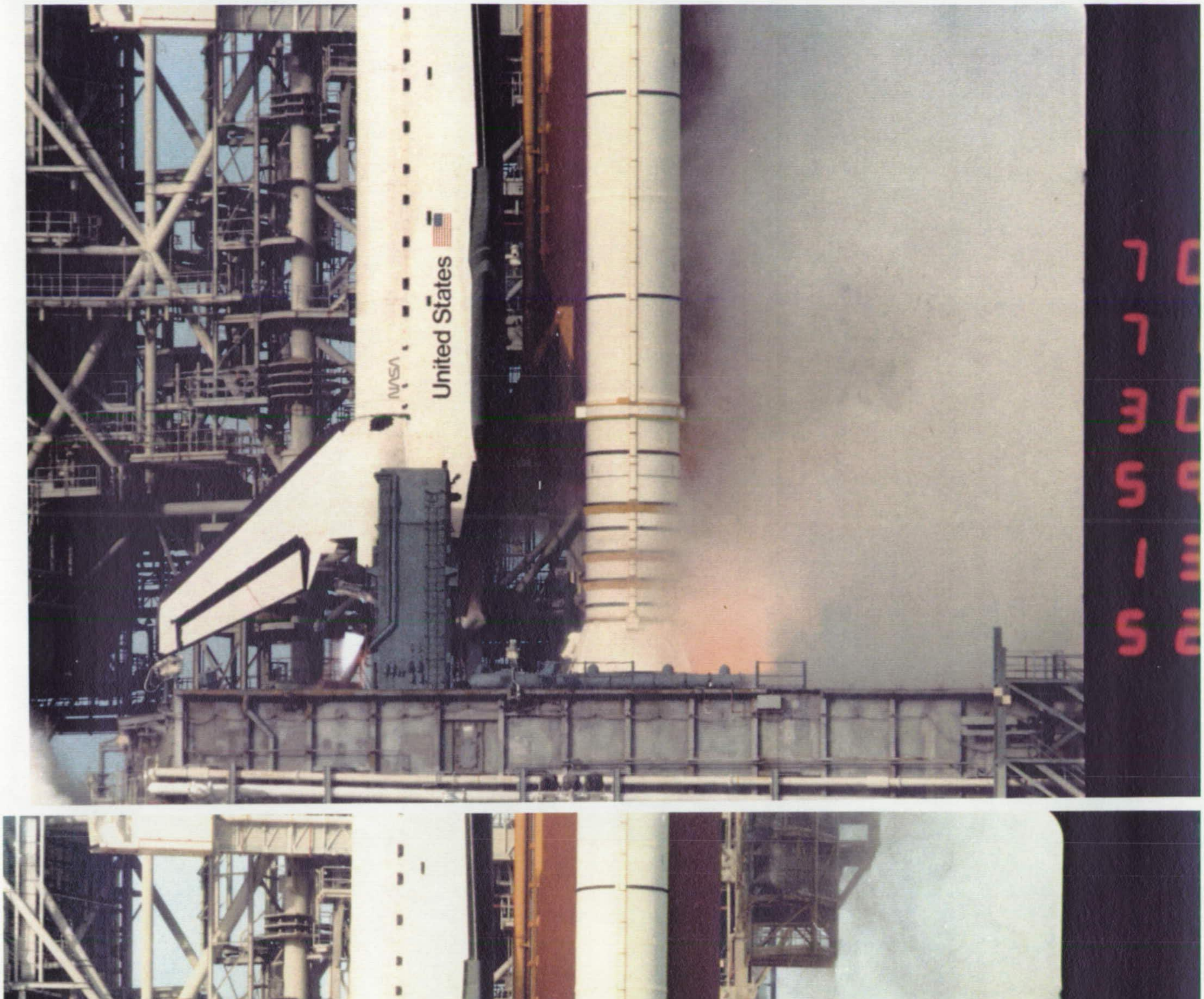



Green flashes, which may be indicative of copper contaminants, occurred in the SSME #1 plume during ignition





A brown-colored object, 6 inches long by 1 inch wide, appeared in the body flap hinge area and fell aft during SSME ignition. The object is believed to be a brown GSE tile shim, or spacer.




Shock wave from the SRB plume caused the momentary formation of a vapor cloud by condensing water vapor out of the atmosphere. This phenomenon, though not usually so visible, is an expected occurrence.

## 5.2 ON-ORBIT FILM AND VIDEO SUMMARY

DTO-0312 was performed by the flight crew and seventy-four 35mm still images were obtained of the ET after separation from the Orbiter. OV-105 was equipped to carry umbilical cameras: one 35mm and one 16mm with a 5mm lens. (The other 16mm camera with the 10mm lens had been deleted prior to launch due to an interference problem with the ET door latch drive shaft).

No major vehicle damage or lost flight hardware was observed that would have been a safety of flight concern.

IFA Candidate (ET): Loss of TPS on the +Z side of the ET near the Orbiter nose is a potential threat to lower surface tiles. Divots (two 8" x 4" divots just forward of the LH2 tank-to-intertank flange closeout between the bipods; one 8" x 3" divot over a stringer head in the -Y+Z quadrant) occurred in the intertank acreage. Three divots measuring 4-6 inches in diameter occurred in the LH2 tank acreage just aft of the LH2 tank-to-intertank flange closeout. The entire RH (+Y) bipod jack pad closeout was missing.

IFA STS-54-I-01 (General Debris): Three objects appeared in the LH2 ET/ORB umbilical camera field of view after the External Tank had separated and moved some distance away from the Orbiter. A metallic washer; metallic cotter pin, or bolt; and nylon wire tie/identifier (or possibly a piece of white RTV) have not been positively identified as flight hardware, but appeared to originate from the LH2 ET/ORB umbilical area and may have been entrapped in the numerous cavities of the umbilical prior to purge barrier closeout.

SRB separation from the ET was nominal. Separation of the -Y ET/SRB upper and diagonal struts appeared normal. No loss of TPS from the upper strut fairing was visible. No anomalies were observed on the LH SRB segment cases and joints, forward skirt, and frustum.

ET separation from the Orbiter appeared nominal. The BSM burn scars on the LO2 tank were typical. No anomalies were observed on the nosecone, LO2 tank acreage, PAL ramps, RSS antennae, flight door, bipod ramps, aft hard point, and aft dome acreage.

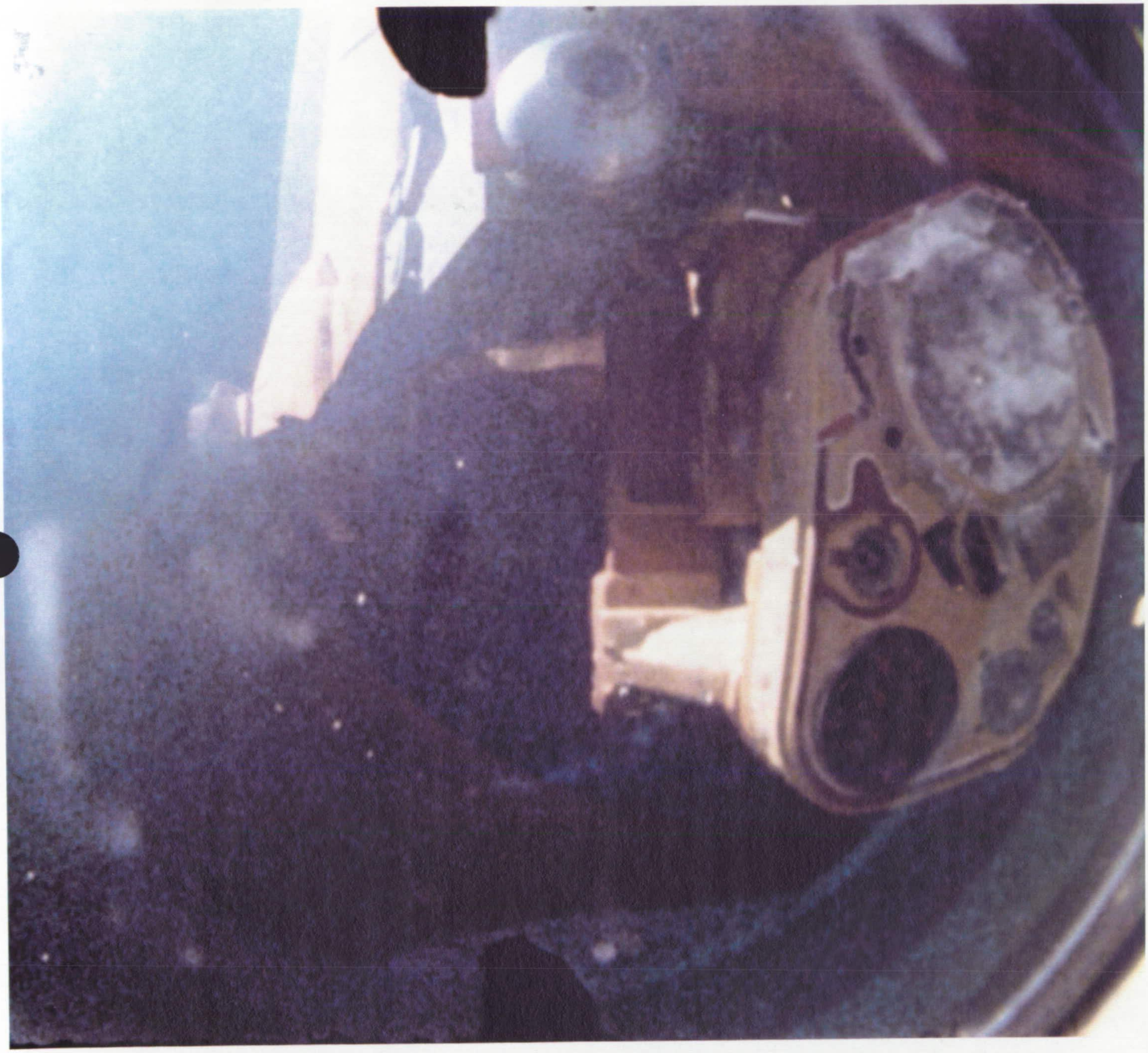
Three divots (two in the -Y+Z quadrant; one between the bipods) were present in the LH2 tank-to-intertank flange closeout. At least 12 small "popcorn" type divots occurred on intertank stringer heads in an area just forward of the bipods.

Erosion and "popcorning" on the LO2 feedline flange closeouts and +Y thrust strut flange closeout was typical.

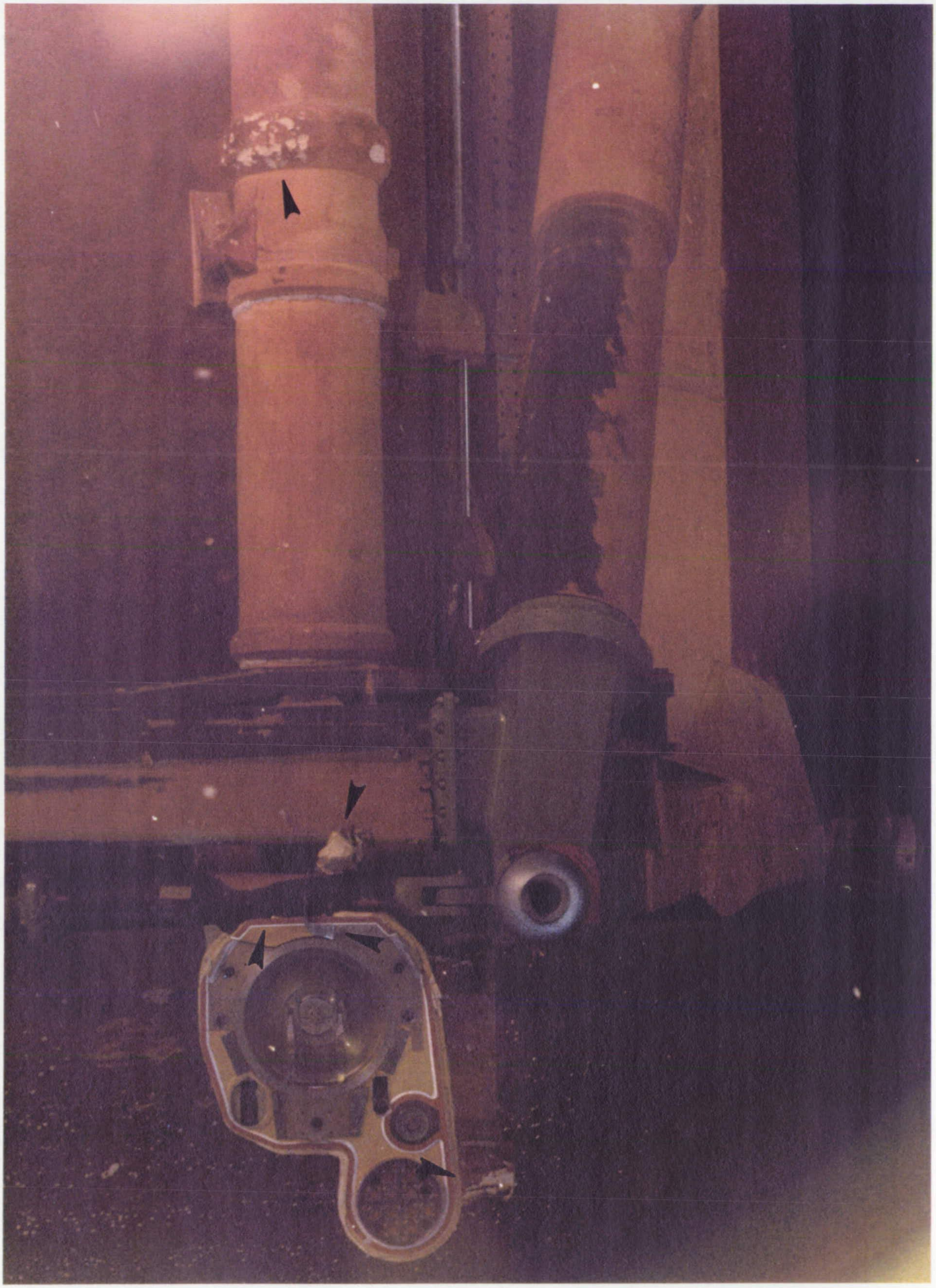
Frozen hydrogen, but no TPS or structural damage, was visible on the LH2 ET/ORB umbilical interface. Erosion and charring of TPS on the aft surfaces of the LH2 umbilical cable tray and the -Y vertical strut/cable tray was typical.

TPS damage was visible on the forward surface of the LO2 ET/ORB umbilical. A 6-8 inch diameter piece of foam wedged between the crossbeam and diagonal strut may have originated from this area. Sixty percent of the lightning contact strip was debonded and bent in the forward direction. All of this damage most likely occurred during umbilical separation. In addition, TPS was missing from the LO2 ET/ORB umbilical cable tray horizontal section and the underlying SLA was exposed. Erosion and numerous divots were visible on the cable tray vertical section.

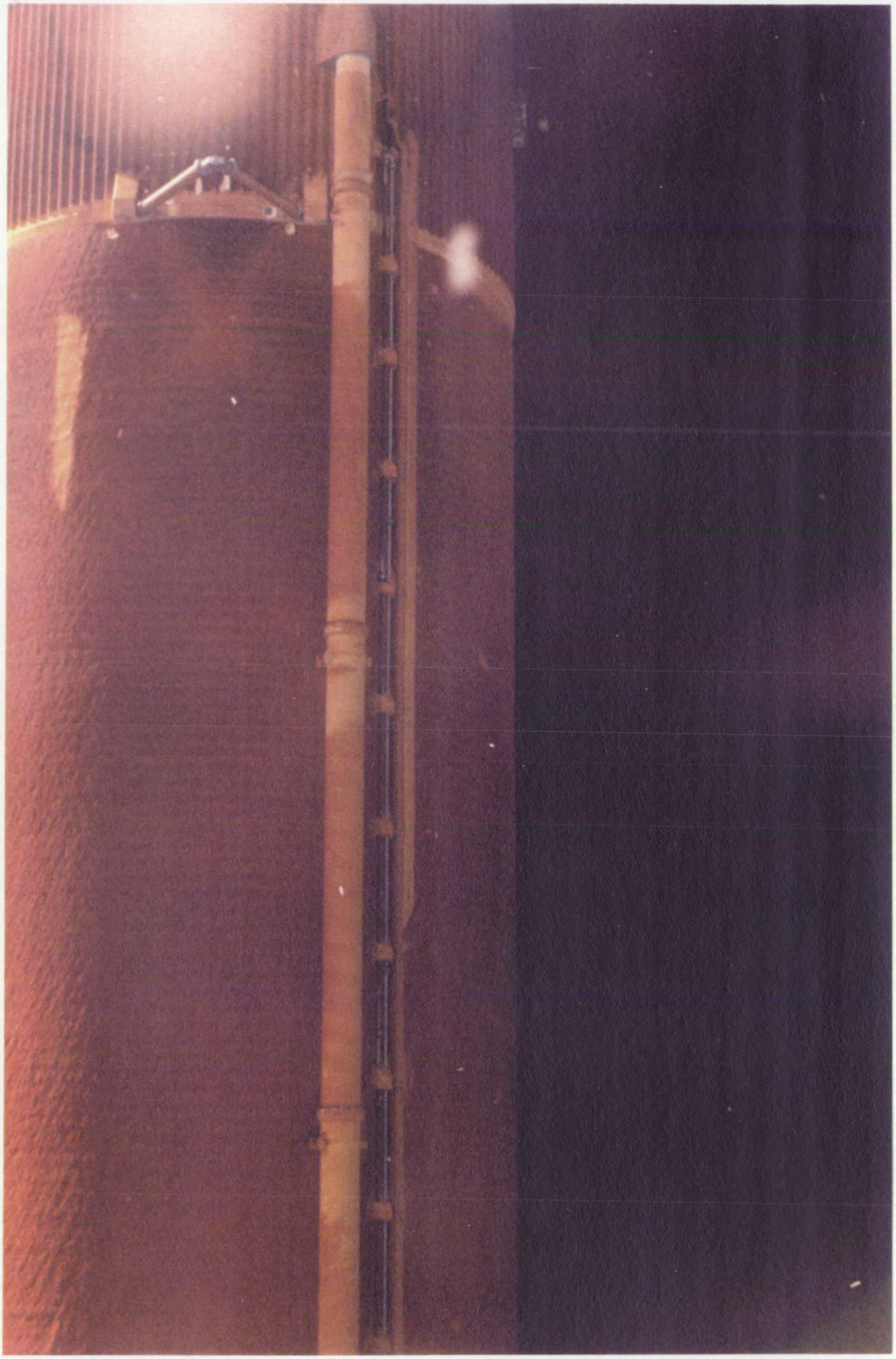
Plume recirculation and aft dome heating caused the usual charring and "popcorning" of the NCFI.



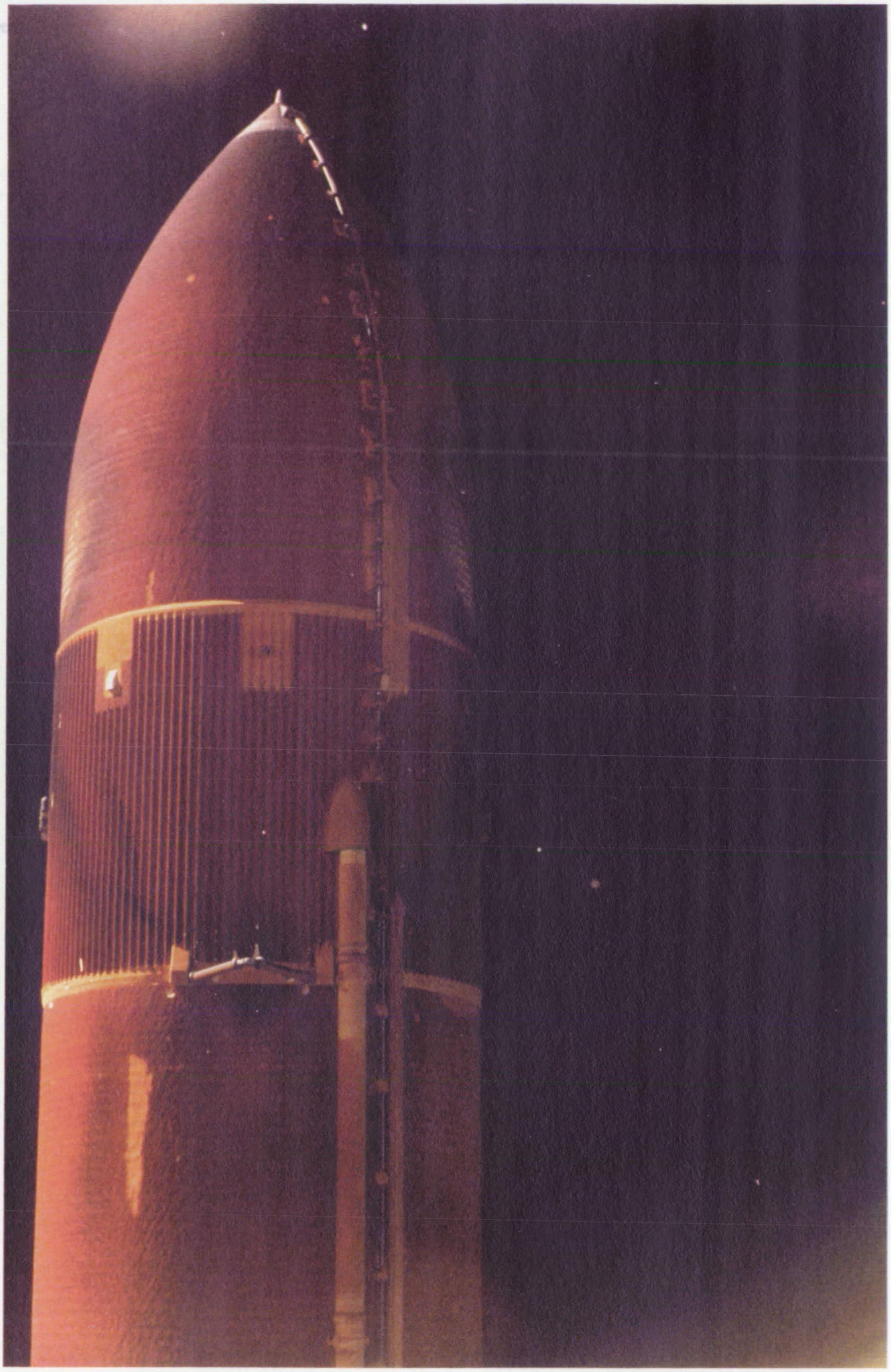
Frozen hydrogen, but no TPS or structural damage, was visible on the LH2 ET/ORB umbilical interface. Erosion and charring of TPS on the aft surfaces of the LH2 umbilical cable tray and the -Y vertical strut/cable tray was typical.



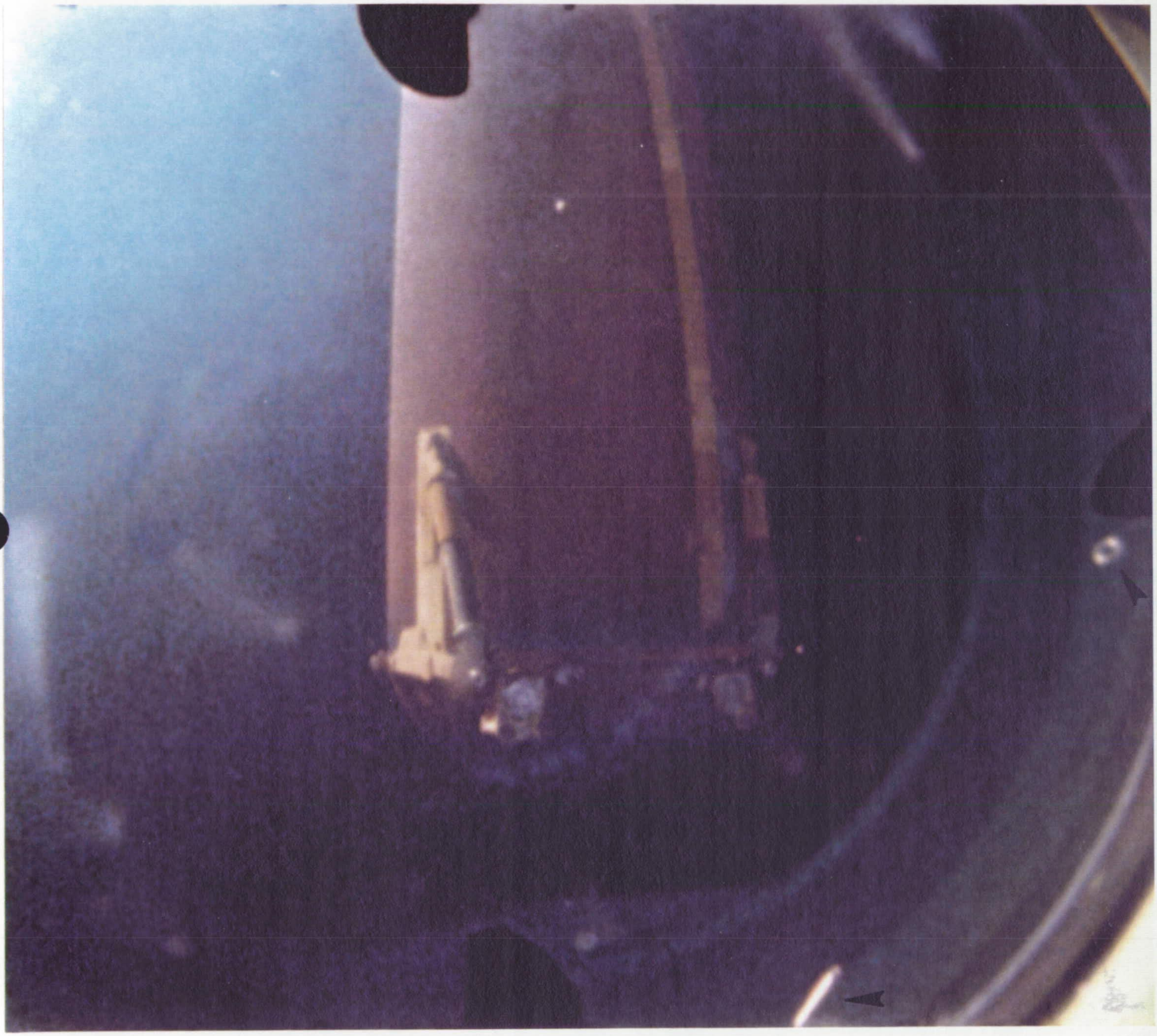
TPS damage was visible on the forward surface of the LO2 ET/ORB umbilical. A 6-8 inch diameter piece of foam wedged between the diagonal strut and the crossbeam may have originated from this area. Sixty percent of the lightning contact strip was debonded and bent in the forward direction. TPS was missing from the cable tray horizontal section and the underlying SLA was exposed. Some TPS had eroded from the LO2 feedline flange closeout.



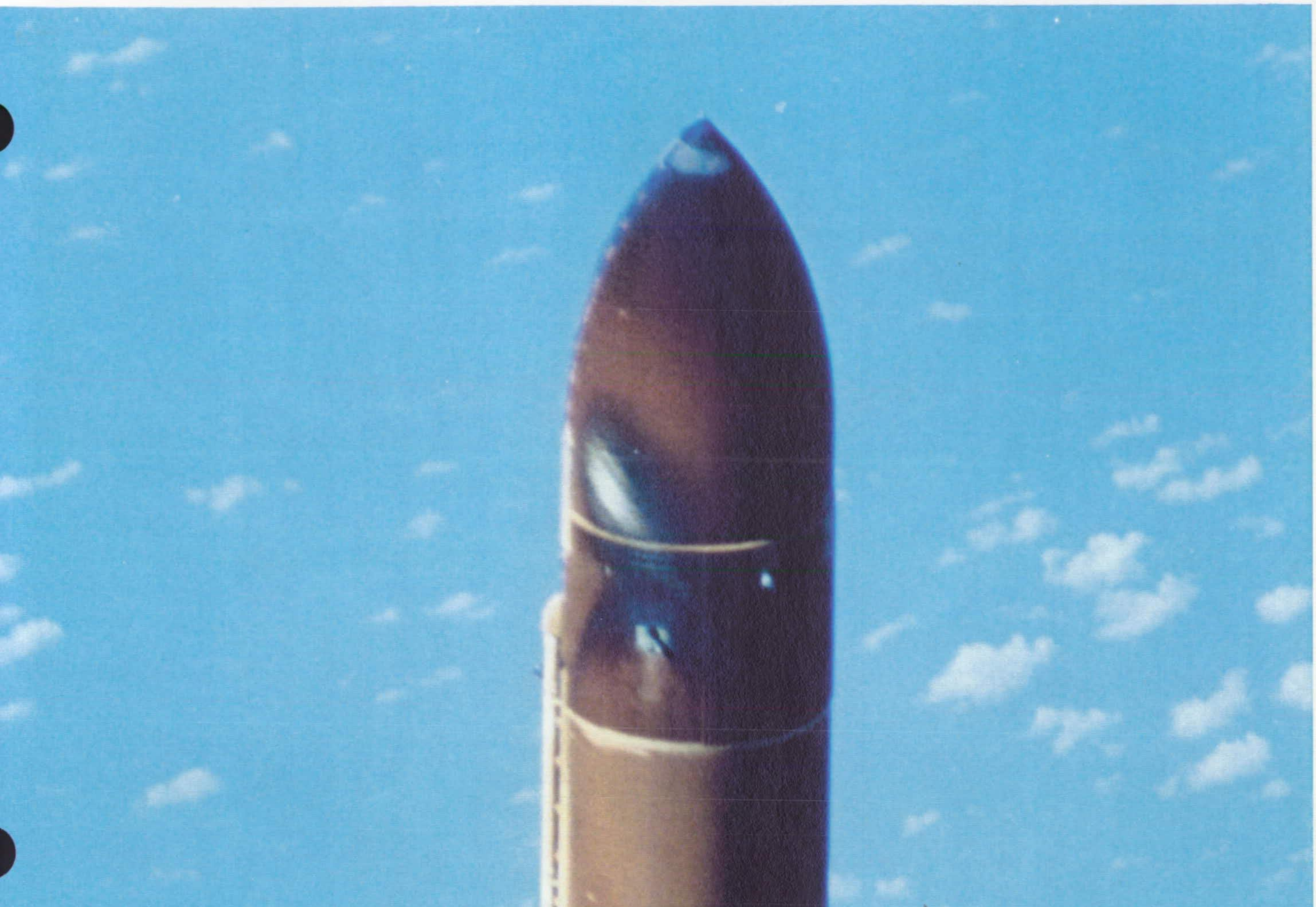
Loss of TPS on the +Z side of the ET near the Orbiter nose is a potential threat to lower surface tiles. Divots occurred on the intertank acreage, in the upper LH2 tank acreage, and in the LH2 tank-to-intertank flange closeout. The entire RH (+Y) bipod jack pad closeout was missing.



No anomalies were observed on the nosecone, LO2 tank acreage, PAL ramps, RSS antenna, or bipod ramps. PDL foam spill discoloration on the LH2 tank acreage below the left (-Y) bipod was present prior to launch.



After ET separation from the Orbiter, two metallic objects (a thin washer and a cotter, or shear, pin) drifted into the field of view of the LH2 ET/ORB umbilical camera. The debris may have been entrapped in the numerous cavities of the umbilical prior to purge barrier closeout.



BSM burn scar on the LO2 tank was typical. No anomalies were observed on the +Y-Z side of the LO2 tank, intertank, LH2 tank, or aft hardpoint closeout.

Samples of residue that appeared on the Orbiter windows during ascent revealed the presence of SRB BSM exhaust particles, Orbiter TPS fibers, and RTV from either the Orbiter TPS or the material used to bond paper covers to the forward RCS thrusters

## 5.3 LANDING FILM AND VIDEO SUMMARY

A total of 22 film and video data items, which included nine videos, six 16mm high speed films, and seven 35mm large format films, were reviewed.

Orbiter performance in the Heading Alignment Circle (HAC) and final approach appeared nominal. The landing gear extended properly. The Orbiter touched down on the runway at the 1200 foot marker. Touchdown of the left main landing gear occurred first.

Drag chute was deployed just after breakover, but before the nose gear contacted the runway. Drag chute deployment appeared nominal although the parachute risers contacted the vertical stabilizer "stinger" tiles (EL-001,012). A slight crosswind blew the drag chute somewhat eastward relative to the Orbiter.

Touchdown of the nose landing gear was smooth. There were no anomalies during rollout.

## 6.0 SRB POST FLIGHT/RETRIEVAL DEBRIS ASSESSMENT

Both Solid Rocket Boosters were inspected for debris damage and debris sources at CCAFS Hangar AF on 15 January 1993 from 0800 to 1030 hours. From a debris standpoint, both SRB's were in excellent condition.

## 6.1 RH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The RH frustum was missing no TPS, but had 31 MSA-2 debonds over fasteners. Minor localized blistering of the Hypalon paint had occurred along the 395 ring (Figure 4). All BSM aero heat shield covers were locked in the fully opened position though the lower left cover attach ring had been bent by parachute riser entanglement.

The RH forward skirt exhibited no debonds or missing TPS. Both RSS antennae covers/phenolic base plates were intact, but the plate on the +Z antenna was delaminated. Minor blistering of the Hypalon paint occurred on the systems tunnel cover and around the ET/SRB attach point (Figure 5). No pins were missing from the frustum severance ring. The forward separation bolt and electrical cables appeared to have separated cleanly.

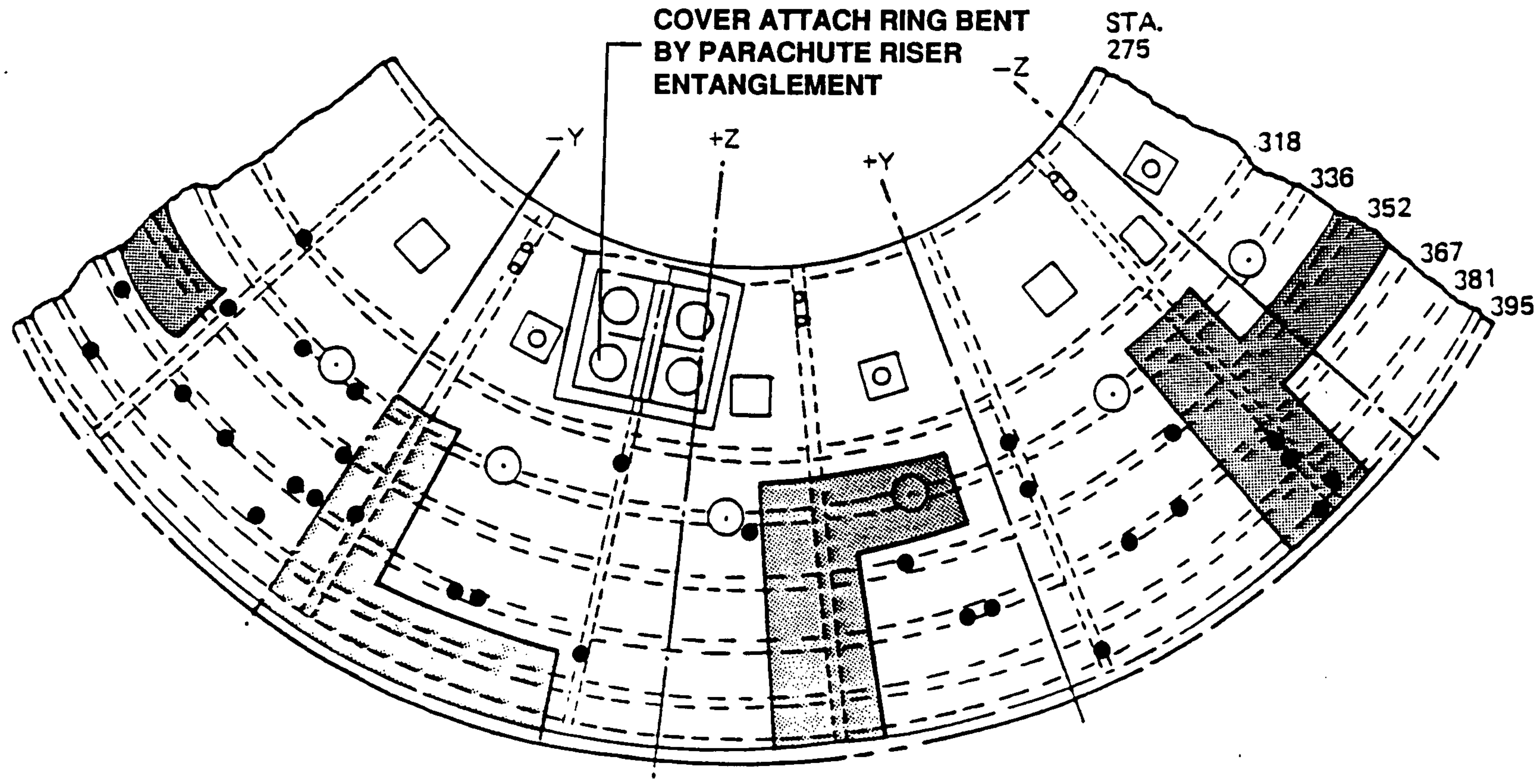
The Field Joint Protection System (FJPS) closeouts were generally in good condition. Minor trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension. Several areas on the SRM segment cases exhibited missing paint and exposed metal substrate.

Separation of the aft ET/SRB struts appeared normal. The ET/SRB aft struts, ETA ring, IEA, and IEA covers appeared undamaged. No K5NA closeout material was missing from the upper strut fairing. All three aft booster stiffener rings also appeared undamaged. The aft booster stiffener ring splice plate closeouts were intact and no K5NA material was missing.

The phenolic material on the kick ring was delaminated. The K5NA closeouts (protective domes) on the kick ring forward and aft fasteners had been eliminated. RTV-133 replaced the K5NA over the forward fasteners (Figure 6).

None of the aft skirt HDP EPON shim material was lost at lift off. Although seated, a frangible nut web was wedged between the HDP #2 DCS plunger and the stud hole wall. The other three Debris Containment System (DCS) plungers were seated properly.

Figure 4. **RIGHT SRB FRUSTUM**




MISSING TPS
NONE

DEBONDS
● 31

Figure 5. **RIGHT SRB FWD SKIRT**

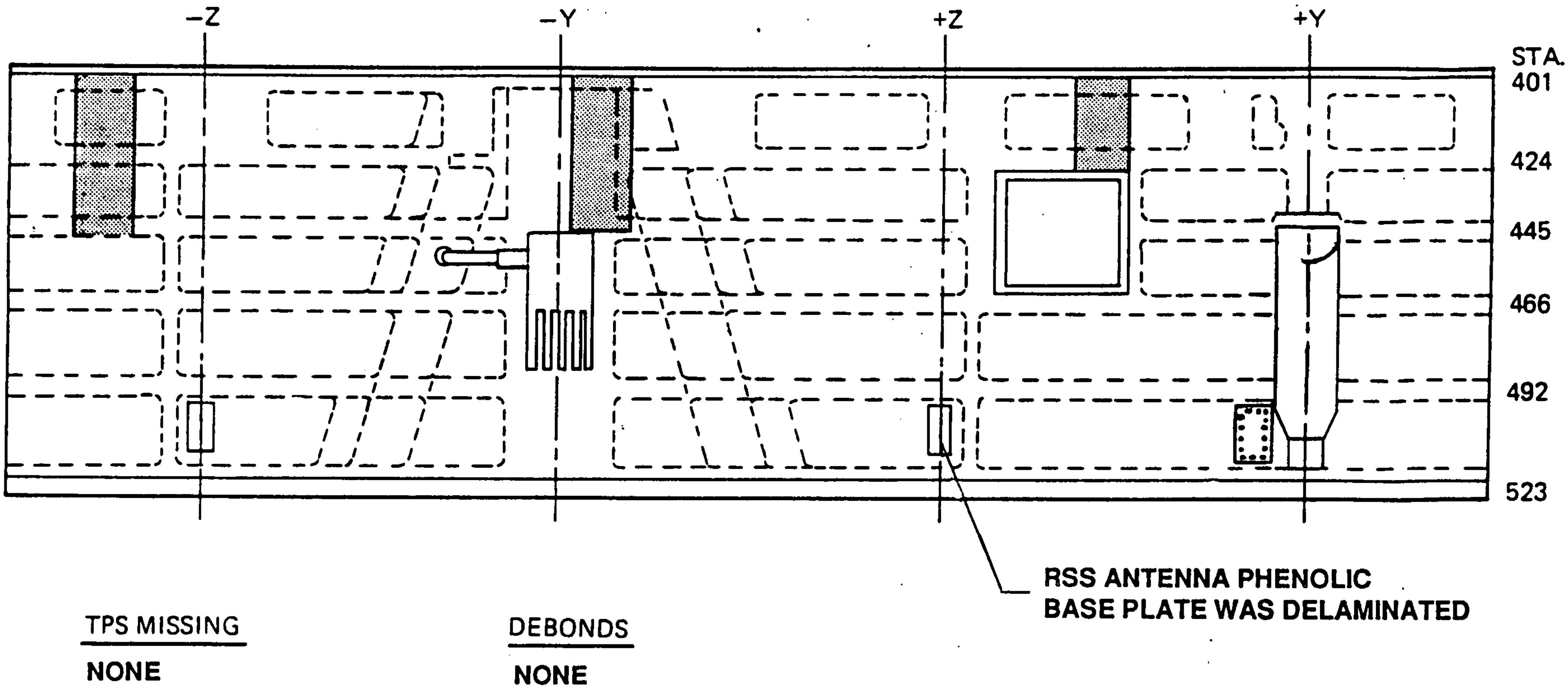
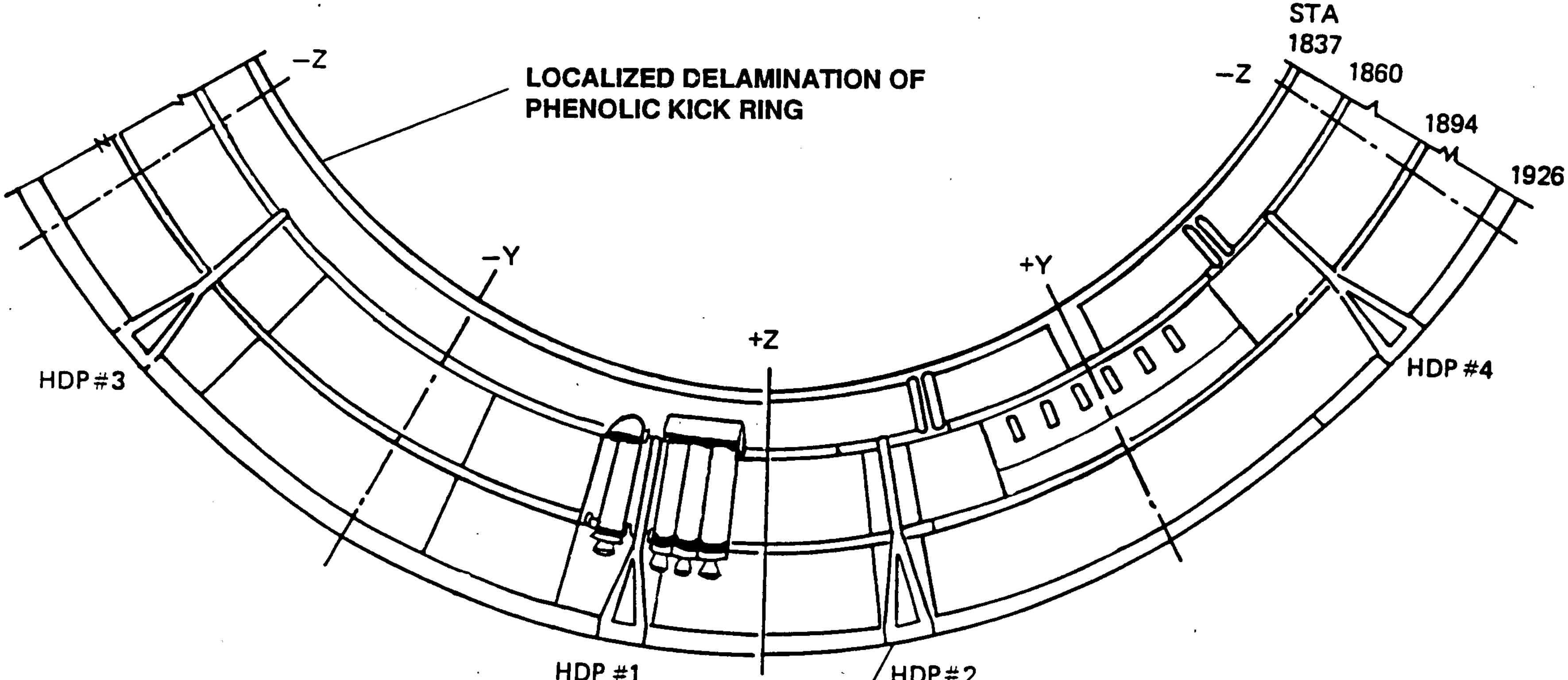
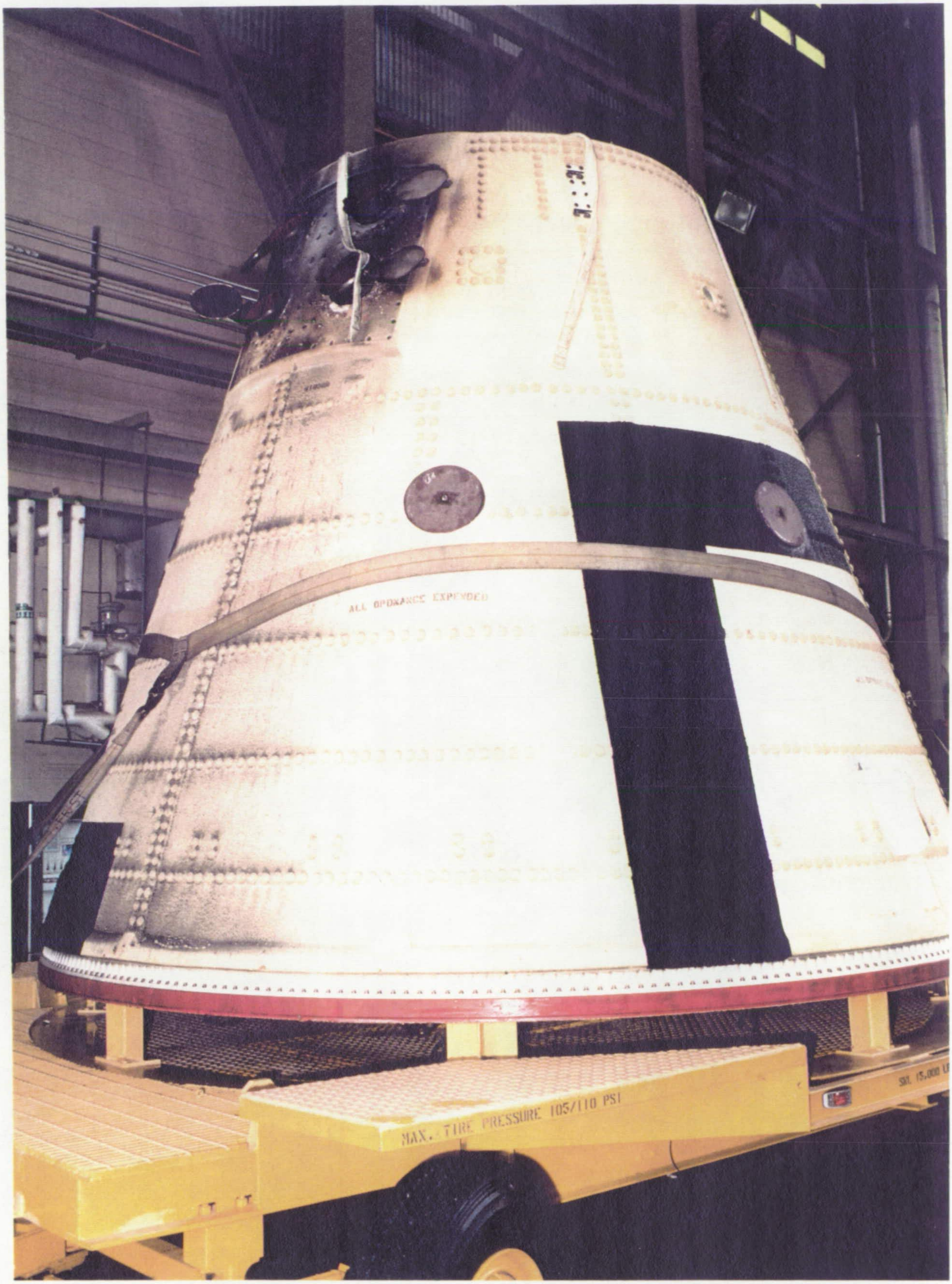


Figure 6. **RIGHT SRB AFT SKIRT EXTERIOR TPS**

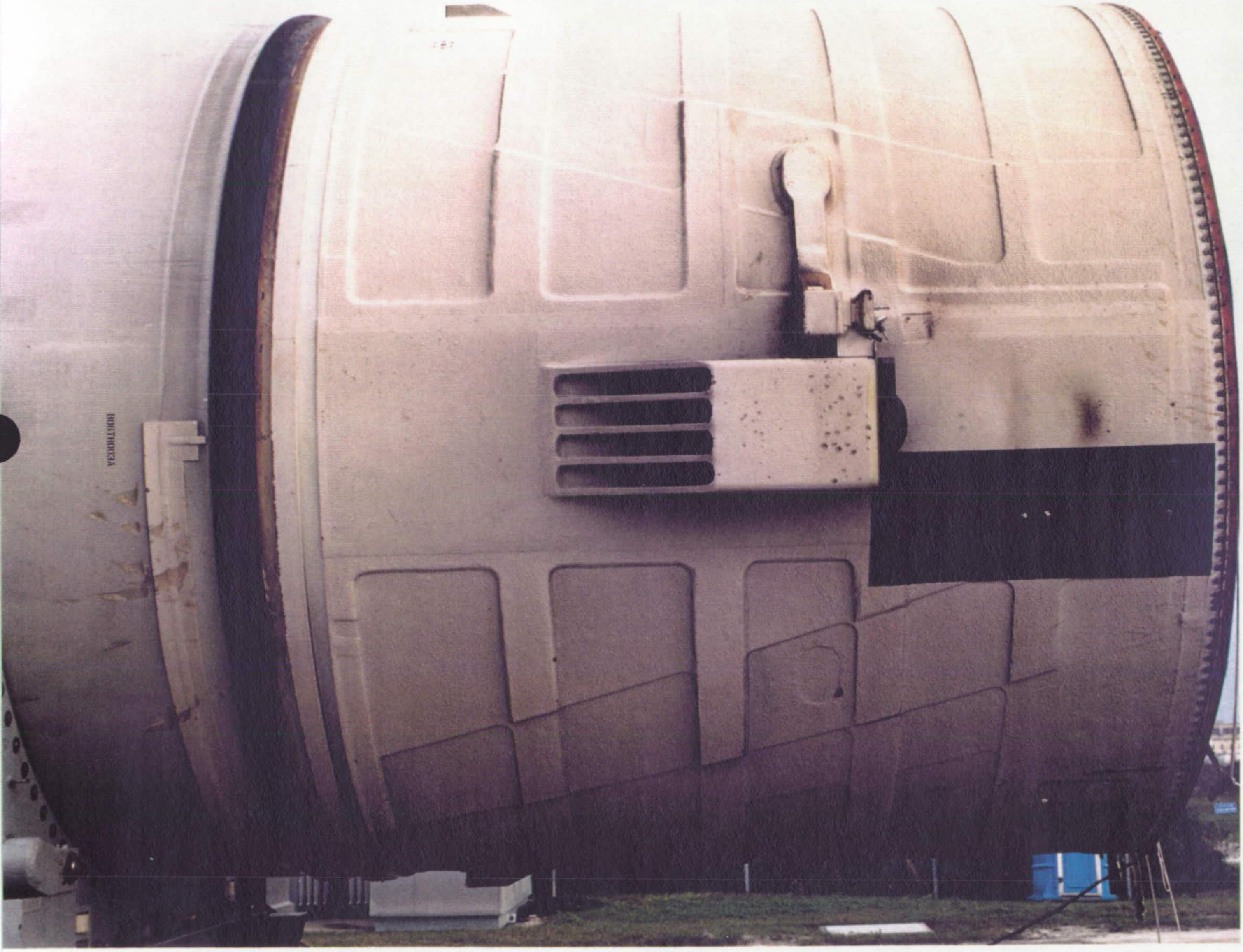



ALL DCS DEBRIS PLUNGERS WERE SEATED

FRANGIBLE NUT WEB WEDGED BETWEEN DCS PLUNGER AND STUD HOLE WALL

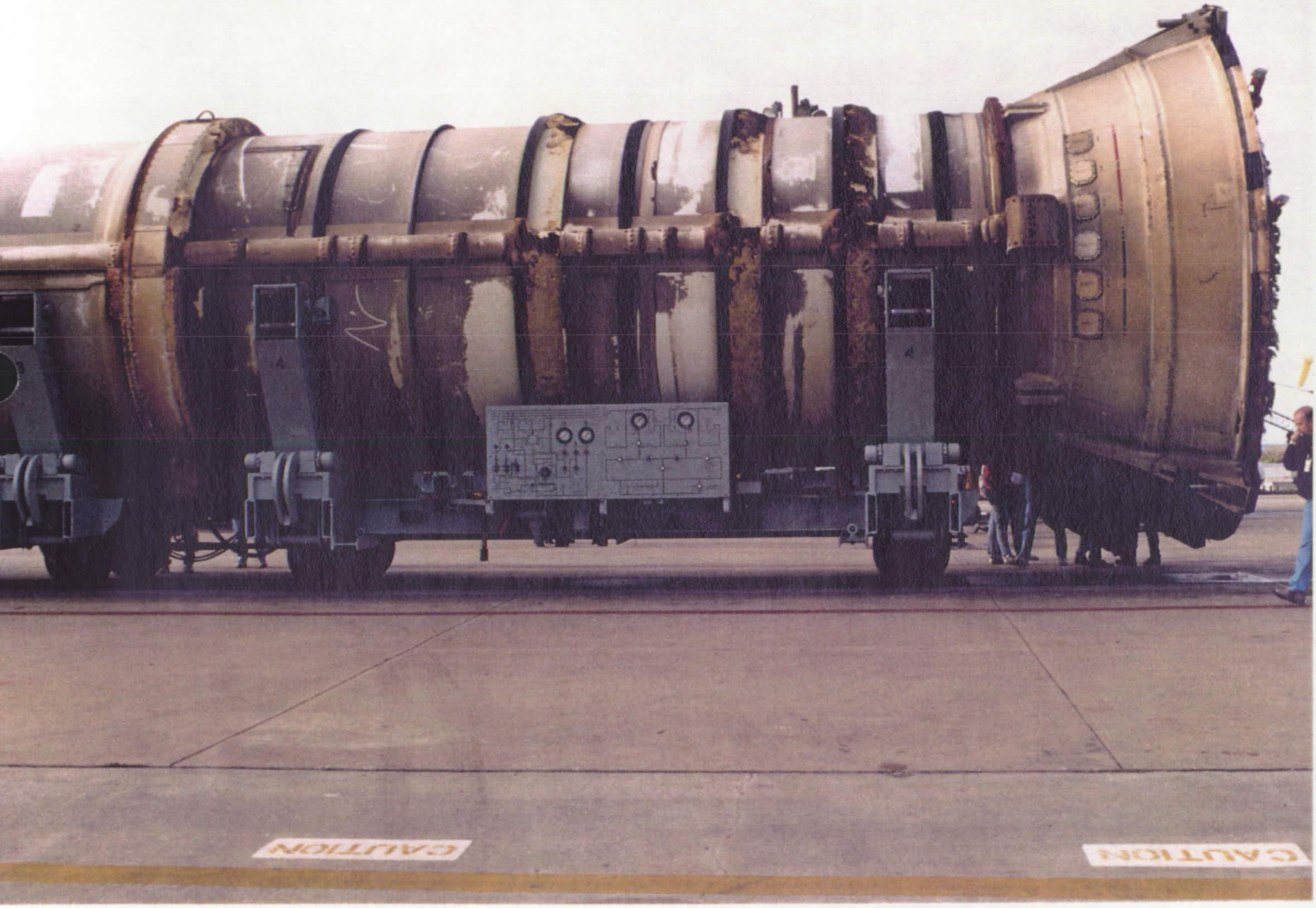



The RH frustum was missing no TPS, but had 31 MSA-2 debonds over fasteners. All BSM aero heat shield covers were locked in the fully opened position though the lower left cover attach ring had been bent by parachute riser entanglement.



The RH forward skirt exhibited no debonds or missing TPS. Minor blistering of the Hypalon paint occurred on the forward ET/SRB attach point. Both RSS antenna covers/TPS were intact.

Several areas on the SRM segment cases exhibited missing paint and exposed metal substrate.




Post flight condition of the aft booster and aft skirt. The ET/SRB aft struts, ETA ring, IEA, and IEA covers appeared undamaged.

## 6.2 LH SOLID ROCKET BOOSTER DEBRIS INSPECTION

The LH frustum was missing no TPS, but had 18 MSA-2 debonds over fasteners and seven acreage debonds (Figure 7). Minor localized blistering of the Hypalon paint had occurred along the 395 ring. The BSM aero heat shield covers were locked in the fully opened position, though the lower left cover attach ring had been bent by parachute riser entanglement.

The LH forward skirt exhibited no debonds or missing TPS. The phenolic plates on both RSS antennae were intact, but the -Z plate was delaminated. Minor blistering of the Hypalon paint occurred near the ET/SRB attach point and on the systems tunnel cover (Figure 8). No pins were missing from the frustum severance ring. The forward separation bolt and electrical cables appeared to have separated cleanly.

The Field Joint Protection System (FJPS) closeouts were in good condition. In general, minor trailing edge damage to the FJPS and the GEI cork runs were attributed to debris resulting from severance of the nozzle extension.

Separation of the aft ET/SRB struts appeared normal. The ET/SRB aft struts, ETA ring, IEA, and IEA covers appeared undamaged. No K5NA closeout material was missing from the upper strut fairing. Two aft booster stiffener rings sustained water impact damage. The stiffener ring splice plate closeouts were intact and no K5NA material was missing.

The phenolic material on the kick ring was delaminated in only localized areas. The K5NA closeouts (protective domes) on the kick ring forward and aft fasteners had been eliminated. RTV-133 replaced the K5NA over the forward fasteners (Figure 9)

All four Debris Containment System (DCS) plungers were properly seated. None of the aft skirt HDP EPON shim material was lost prior to water impact.

Figure 7. **LEFT SRB FRUSTUM**

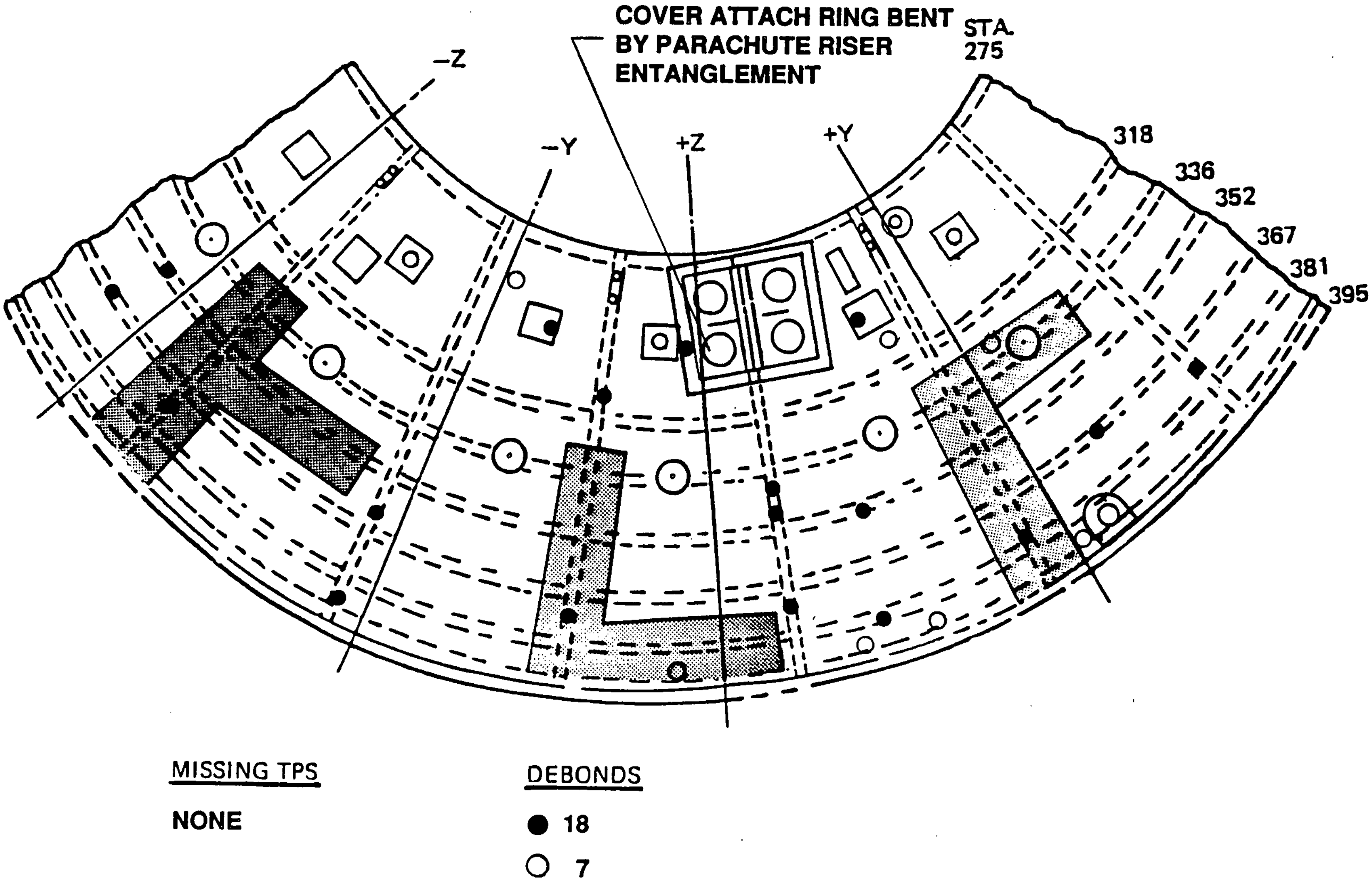
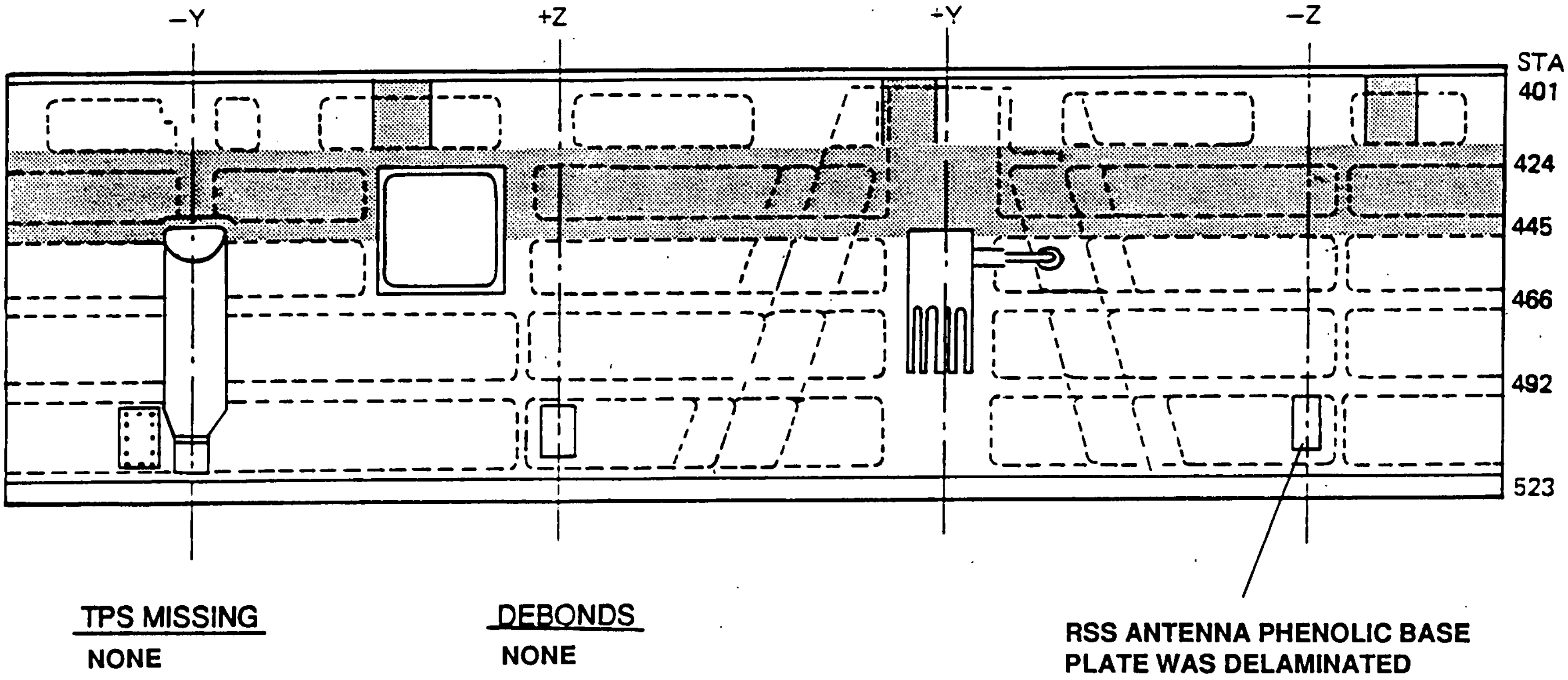
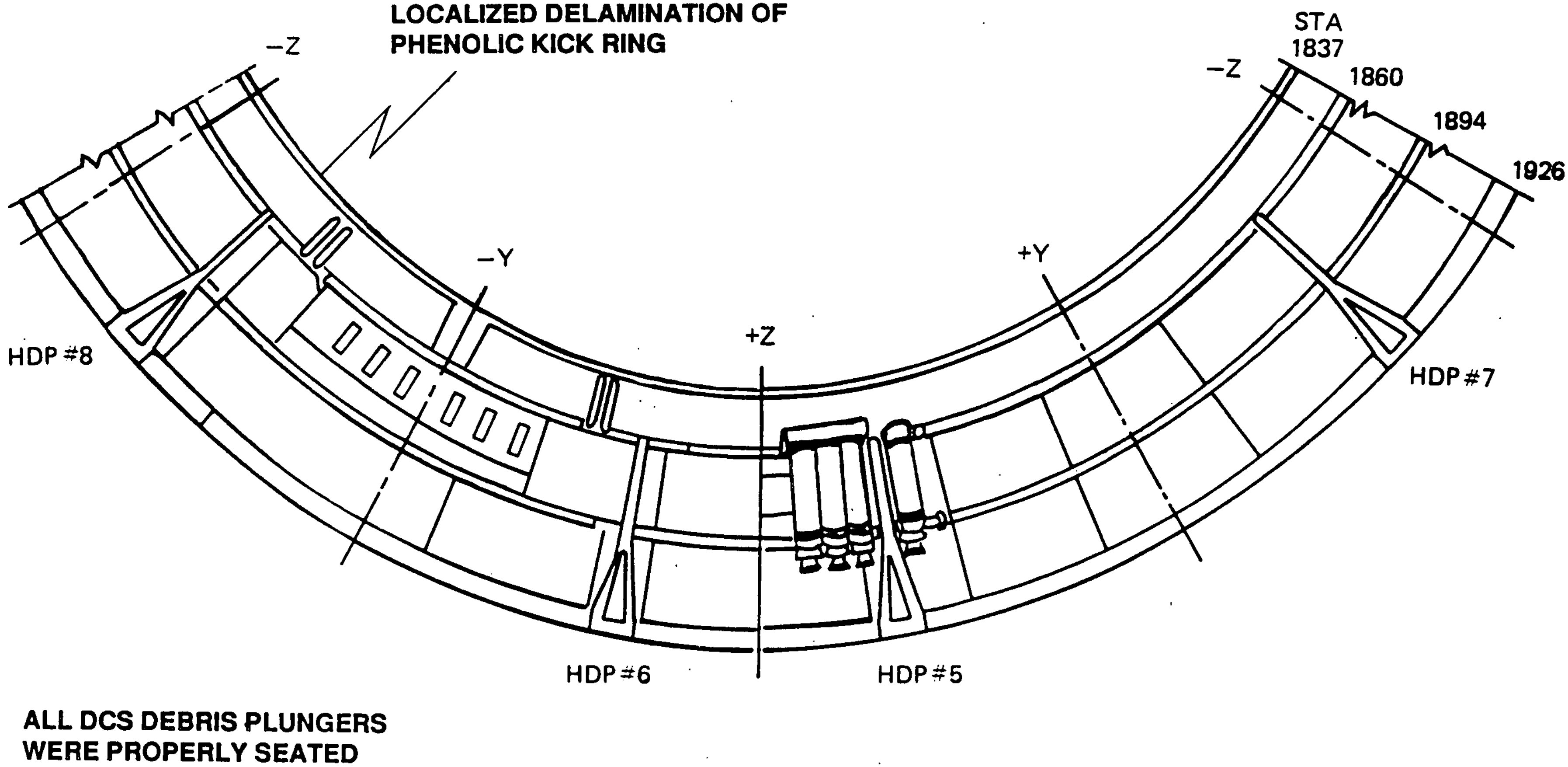


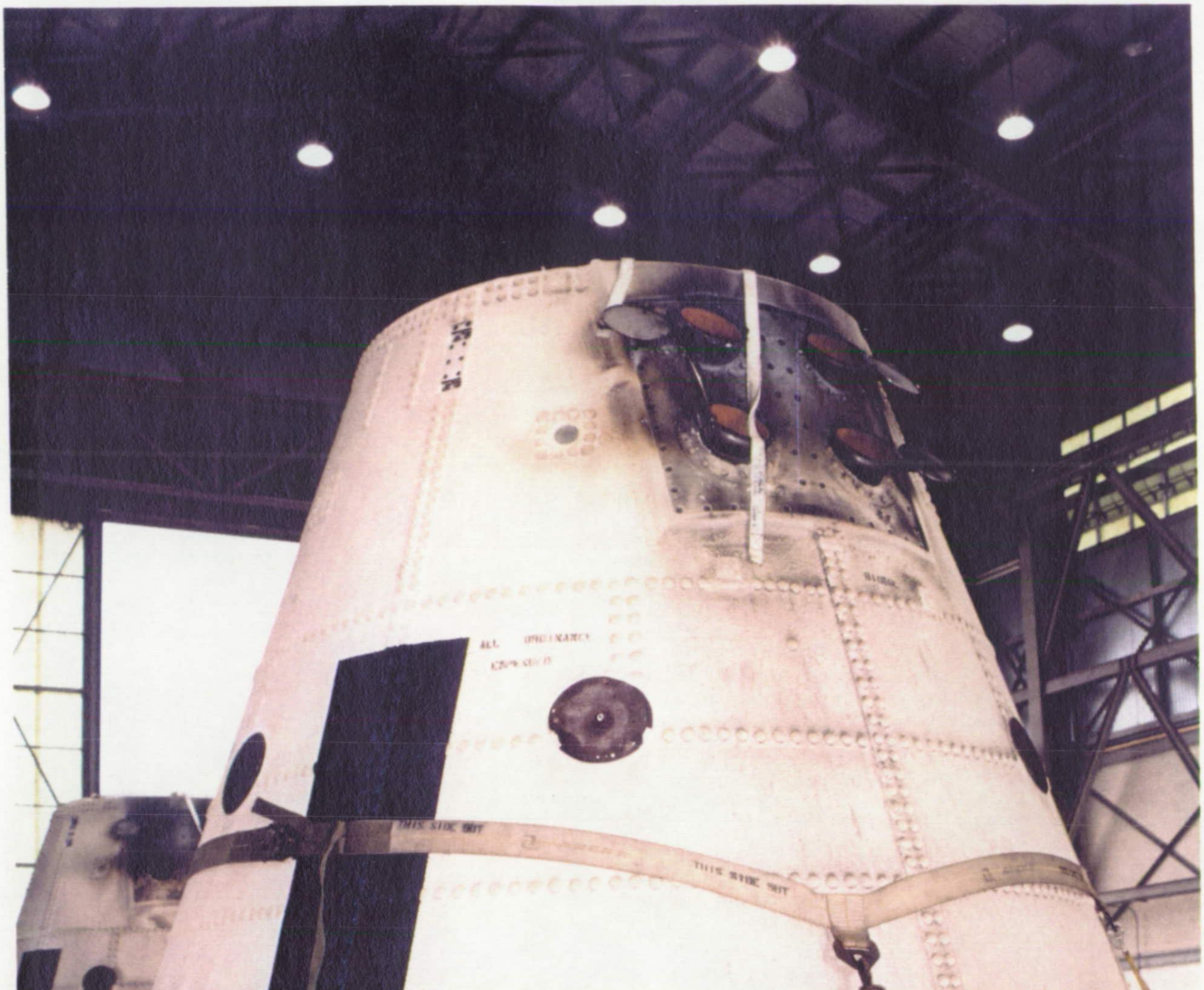
Figure 8. **LEFT SRB FWD SKIRT**



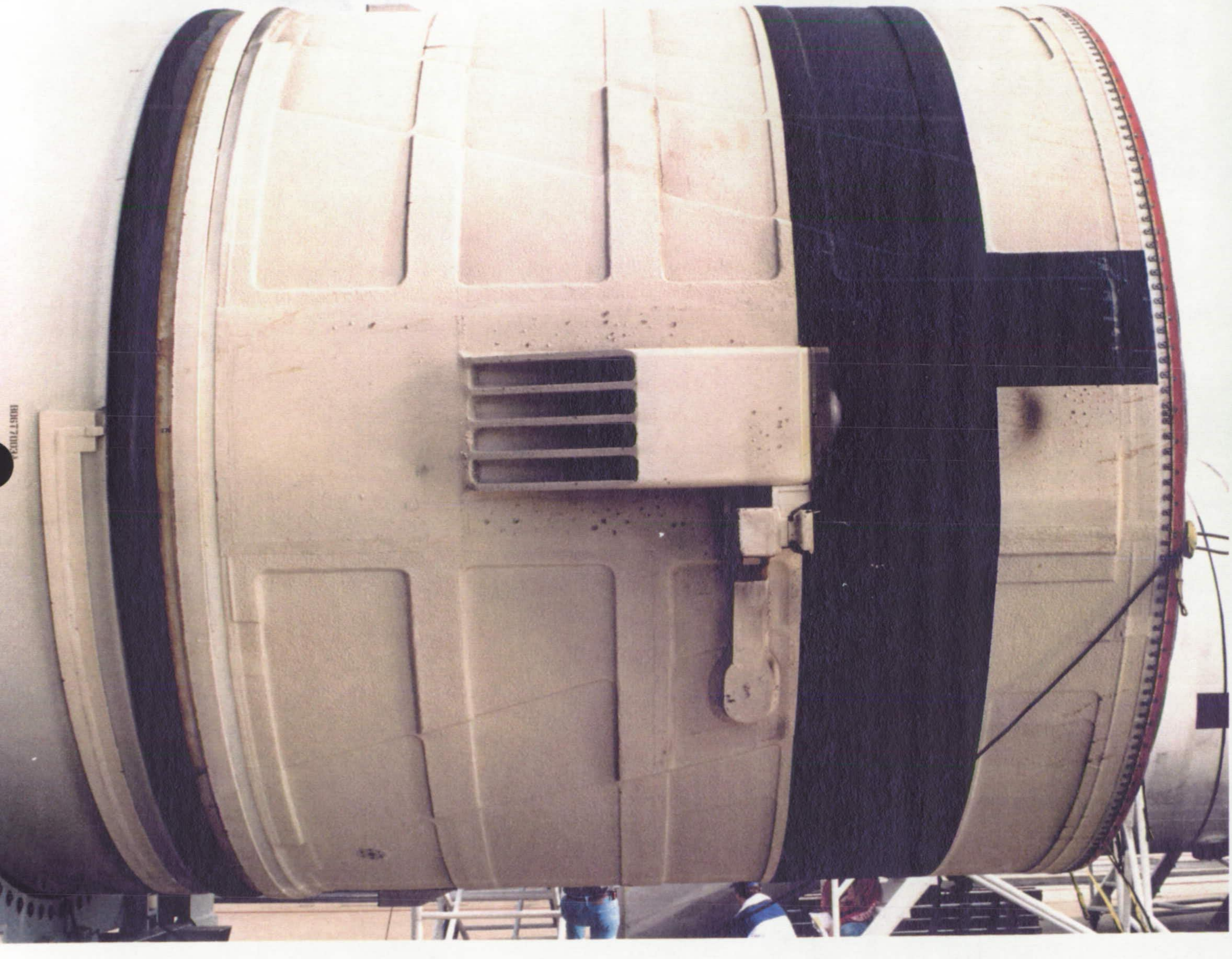

EGG/V-3260

Figure 9. **LEFT SRB AFT SKIRT EXTERIOR TPS**






The LH frustum was missing no TPS, but had 18 MSA-2 debonds over fasteners. The BSM aero heat shield covers were locked in the fully opened position, though the lower left cover attach ring had been bent by parachute riser entanglement.



The LH forward skirt exhibited no debonds or missing TPS. The phenolic plates on both RSS antennae were intact. Minor blistering of the Hypalon paint occurred near the ET/SRB forward attach point.


Post flight condition of the aft booster and aft skirt. The ET/SRB aft struts, ETA ring, IEA, and IEA covers appeared undamaged.

## 6.3 RECOVERED SRB DISASSEMBLY FINDINGS

Post flight disassembly of the Debris Containment System (DCS) housings revealed an overall system retention of 99 percent and individual holddown post retention percentages as listed:

| HDP # | % of Nut without 2 large halves | % of Ordnance fragments | % Overall |
|---|---|---|---|
| 1 | 99 | 99 | 99 |
| 2 | 99 | 99 | 99 |
| 3 | 99 | 99 | 99 |
| 4 | 99 | 99 | 99 |
| 5 | 99 | 99 | 99 |
| 6 | 99 | 98 | 99 |
| 7 | 99 | 96 | 99 |
| 8 | 99 | 98 | 99 |

STS-54 was the thirteenth flight to utilize the new "optimized" frangible links in the holddown post DCS's. The link was designed to increase the DCS plunger velocity and improve the seating alignment while leaving the stud ejection velocity the same. The design was intended to prevent ordnance debris from falling out of the DCS yet not increase the likelihood of a stud hang-up. According to NSTS-07700, the Debris Containment System should retain a minimum of 90 percent of the ordnance debris.

SRB Post Launch Anomalies are listed in Section 9.

## 7.0 ORBITER POST LANDING DEBRIS ASSESSMENT

A post landing debris inspection of OV-105 (Endeavour) was conducted on January 19-20, 1993, at the Kennedy Space Center on Shuttle Landing Facility (SLF) Runway 33 and in the 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 131 hits, of which 14 had a major dimension of one inch or greater. This total does not include the numerous hits on the base heat shield attributed to SSME vibration/acoustics and exhaust plume recirculation. A comparison of these numbers to statistics from 37 previous missions of similar configuration (excluding missions STS-23, 25, 26, 26R, 27R, 30R, and 42 which had damage from known debris sources), indicates that the total number of hits is near average and the number of hits one inch or larger is less than average. The TPS debris damage assessment for STS-54 is shown in Figures 10-13.

The Orbiter lower surface sustained a total of 80 hits, of which 14 had a major dimension of one inch or greater. The distribution of hits on the lower surface does not suggest a single source of ascent debris, but indicates a shedding of ice and Thermal Protection System (TPS) debris from random sources.

The following table breaks down the STS-54 Orbiter debris damage by area:

| | HITS > 1" | TOTAL HITS |
|---|---|---|
| Lower surface | 14 | 80 |
| Upper surface | 0 | 34 |
| Right side | 0 | 5 |
| Left side | 0 | 0 |
| Right OMS Pod | 0 | 10 |
| Left OMS Pod | 0 | 2 |
| TOTALS | 14 | 131 |

No TPS damage was attributed to material from the wheels, tires, or brakes. The main landing gear tires were considered to be in good condition for a landing on the KSC runway.

Protruding gap fillers were visible on the left wing lower surface just forward of the outboard elevon hinge line, right wing upper surface just aft of RH RCC T-seal #12, LO2 ET/ORB umbilical door, and in two places on the left hand inboard elevon.

All three ET/Orbiter separation devices (EO-1, 2, and 3) appeared to have functioned nominally. All ET/Orbiter umbilical separation ordnance retention shutters were closed properly. No flight hardware was found on the runway below the umbilicals when the ET doors were opened.

STS-54

Figure 10. **DEBRIS DAMAGE LOCATIONS**

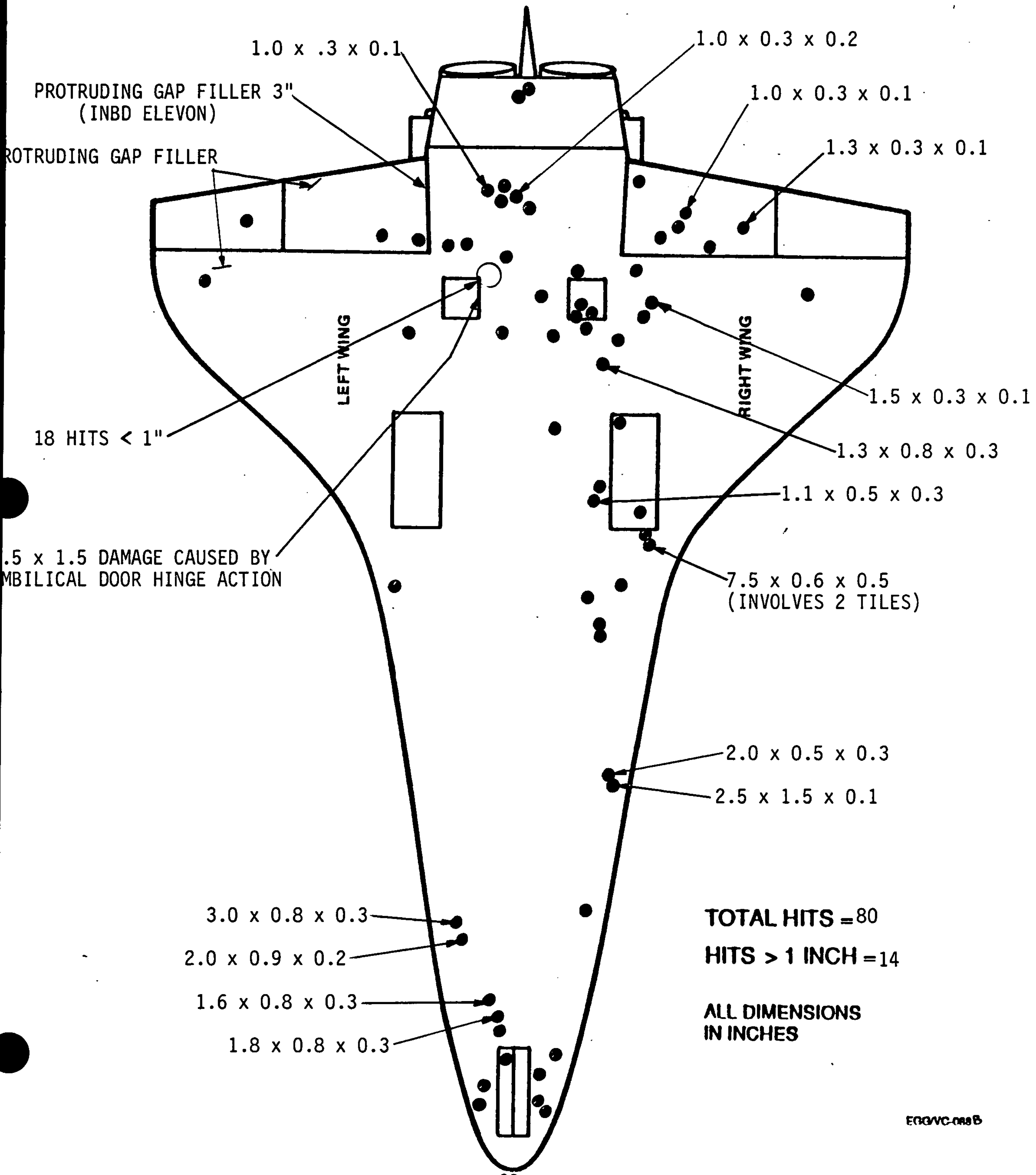
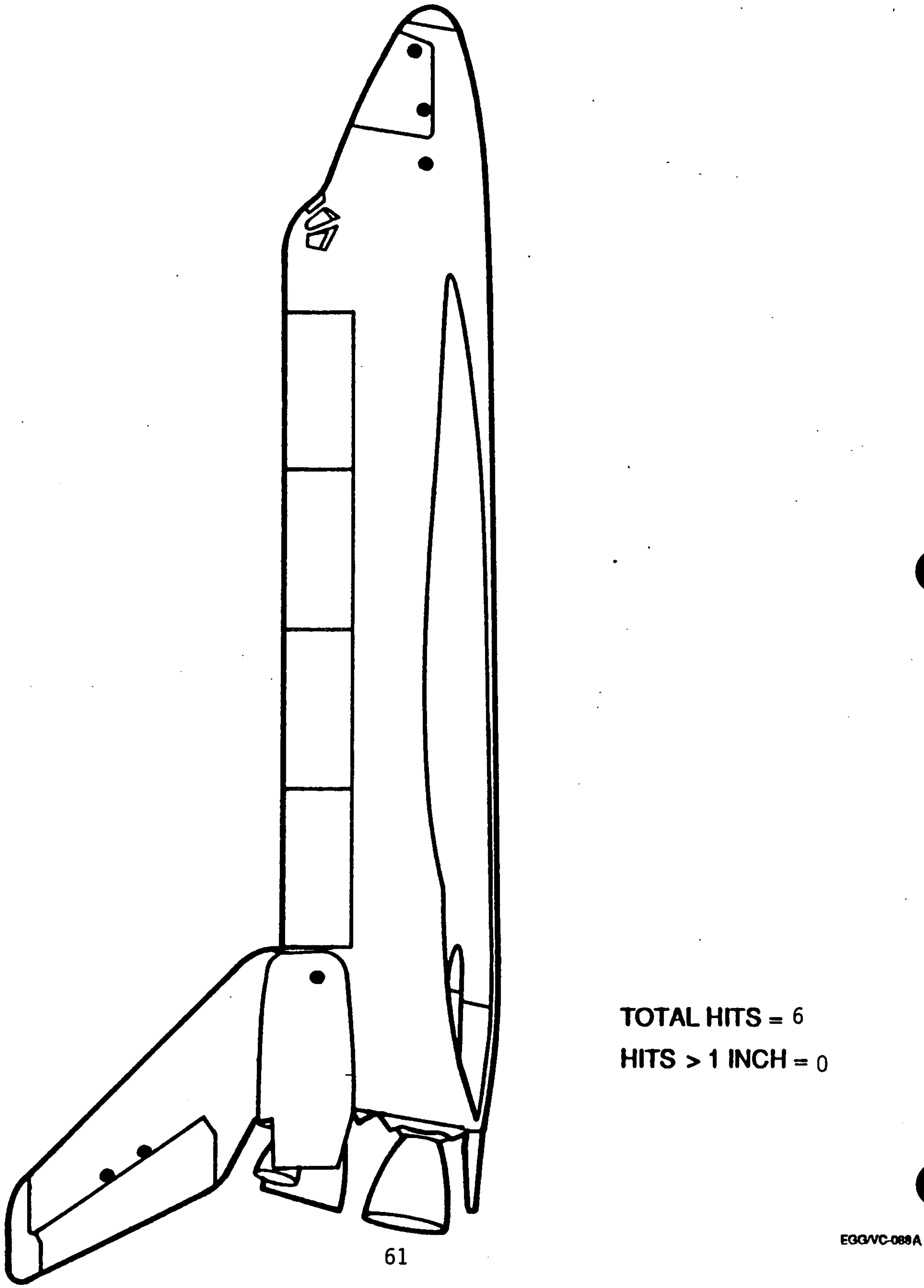
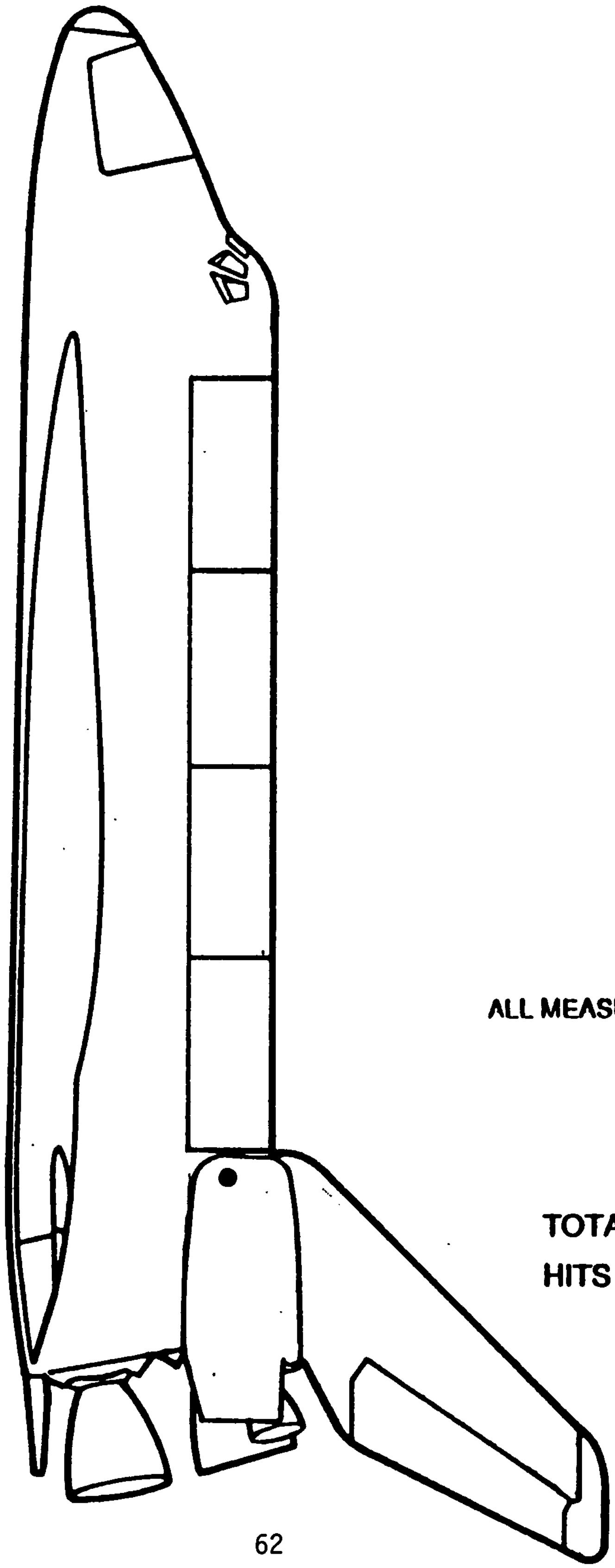


Figure 11. **DEBRIS DAMAGE LOCATIONS**



STS-54

Figure 12. **DEBRIS DAMAGE LOCATIONS**



ALL MEASUREMENTS IN INCHES

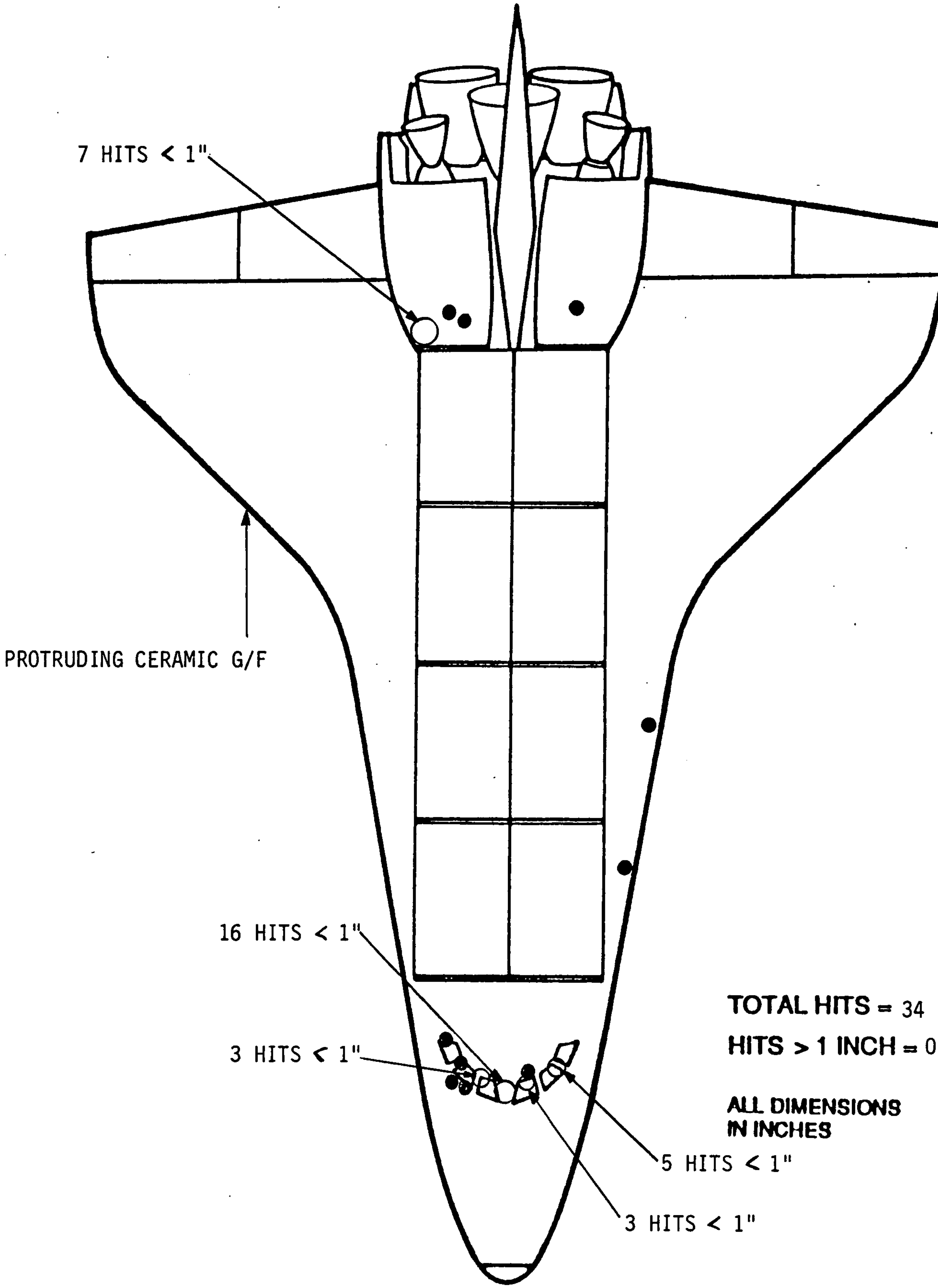
TOTAL HITS = 1

HITS > 1 INCH = 0

EGG/VC-088

STS-54

Figure 13. **DEBRIS DAMAGE LOCATIONS**



Damage to the base heat shield tiles was much less than average. The SSME Dome Mounted Heat Shield (DMHS) closeout blanket sacrificial panels were partially detached and some material was missing from 9:00 to 9:30 o'clock on SSME #3. The outer edge of the SSME #2 panels from 2:30 to 3:30 were detached and the underlying batting was exposed. Some of the sacrificial panel and batting was missing. The outer blanket edge from 5:30 to 7:00 on SSME #1 was frayed. All of the remaining DMHS blankets were in excellent condition.

Orbiter windows #3 and #4 exhibited moderate hazing and several streaks. Only a very light haze was present on the other forward facing windows. Surface wipes were taken from Windows #1 through #9 for laboratory analysis (reference Figure 14).

Wipes of stains on the right hand RCC panel #20, panel #21, and T-seal #21 were also taken for laboratory analysis (reference Figure 14).

Runway 33 was inspected and swept by KSC EG&G SLF personnel on January 18, 1992 for potentially damaging debris.

A post landing inspection of Runway 33 was performed immediately after landing. Two non-flight debris items were found on the runway. An 8 ounce, 2.5" x 2.25" x 0.5" thick, brass spray nozzle/elbow was found at the 3800 foot marker, 18 feet east of the runway centerline. This nozzle originated from the runway sweeper. The partial recent remains of a bird were found at the 6400 foot marker, five feet west of the runway centerline. No evidence of contact from either of these items was found on the Orbiter.

Unexpected flight hardware found on the runway consisted of three Q-felt plugs 8 feet from the runway centerline at the 5800 foot marker. Five pieces of black tile, the largest of which measured 8" x 1.25" x 0.75", lay in the vicinity of the pilot chute at the 6200 foot marker. These tile fragments originated from the vertical stabilizer "stinger" and were dislodged by contact with the drag chute riser lines during deployment.

This flight marked the sixth use of the Orbiter drag chute. Aside from the damage to the vertical stabilizer "stinger", the drag chute appeared to have functioned nominally. All drag chute hardware was recovered, appeared to be in good condition, and showed no signs of abnormal operation (reference Figure 15 for recovery locations).

STS-54

Figure 14. **CHEMICAL SAMPLE LOCATIONS**

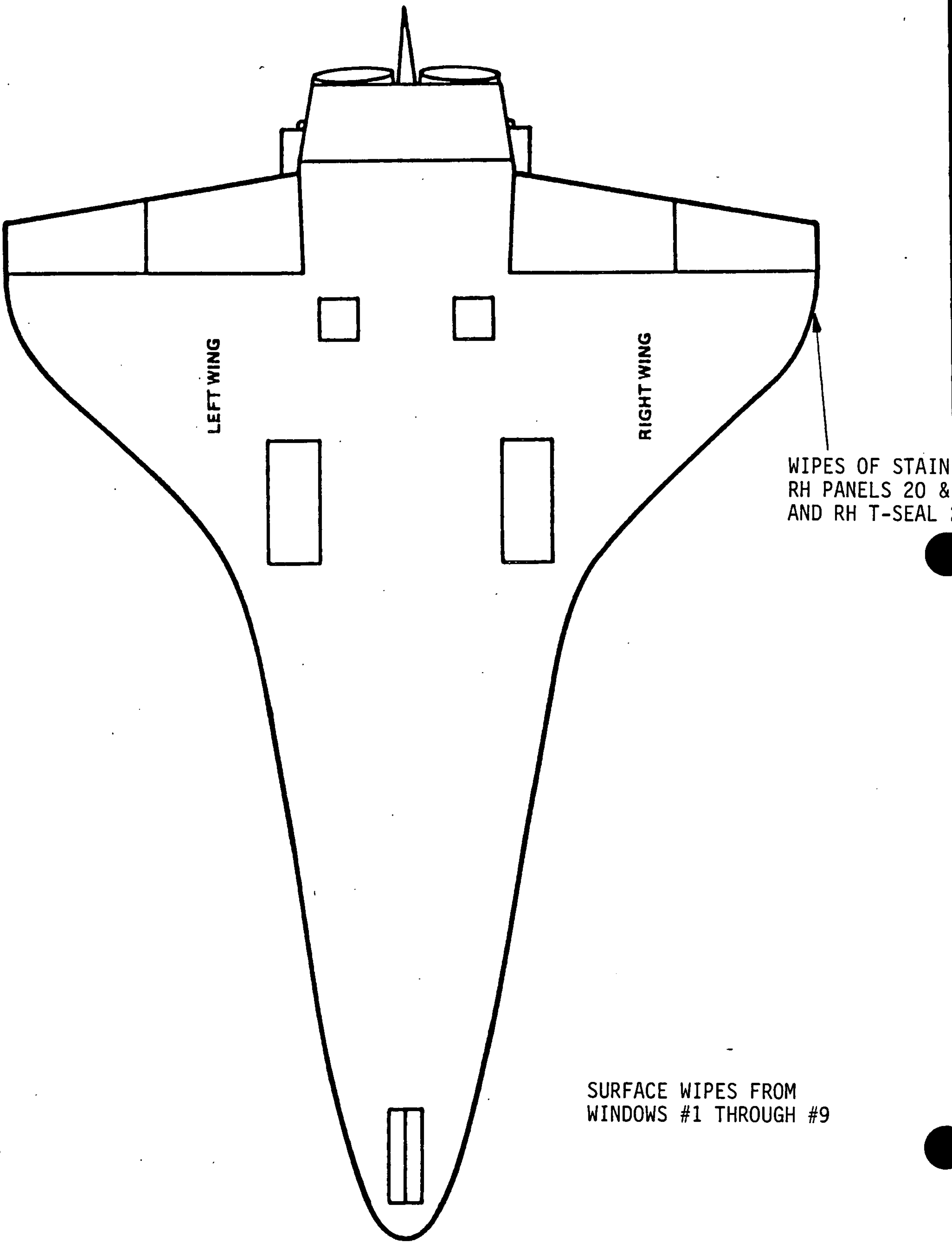
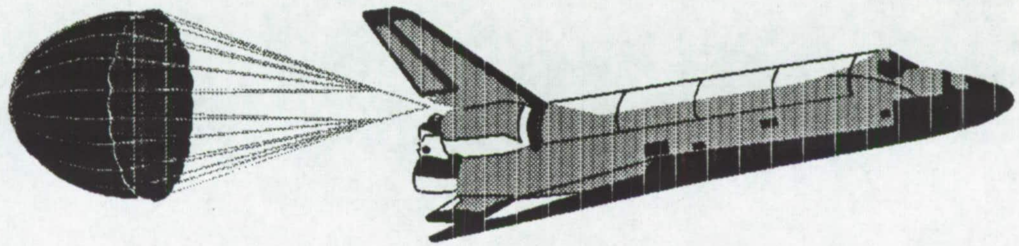
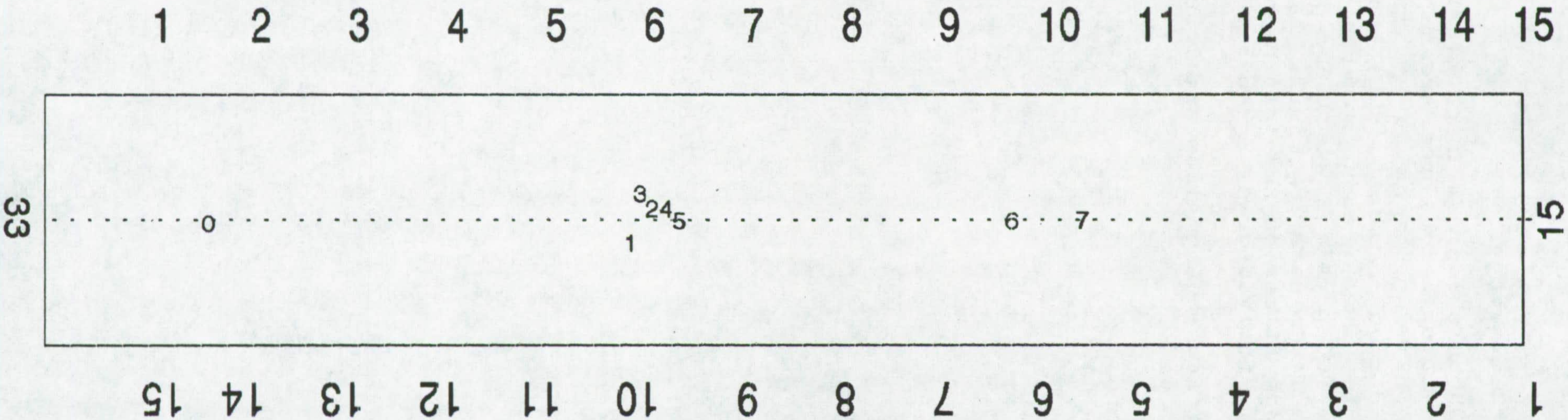


Figure 15.

# RECOVERY LOCATIONS OF DRAG CHUTE COMPONENTS






0 (MLG TOUCHDOWN):1536'
1 (MORTAR COVER): 5800', 28' R OF C/L
2 (SABOT): 5950', 18' L OF C/L
3 (DOOR): 5900', 25' L OF C/L
4 (PILOT CHUTE): 5975', 18' L OF C/L
5 (NLG TOUCHDOWN): 6247'
6 (MAIN CHUTE): 9600', ON C/L
7 (WHEEL STOP): 10259'

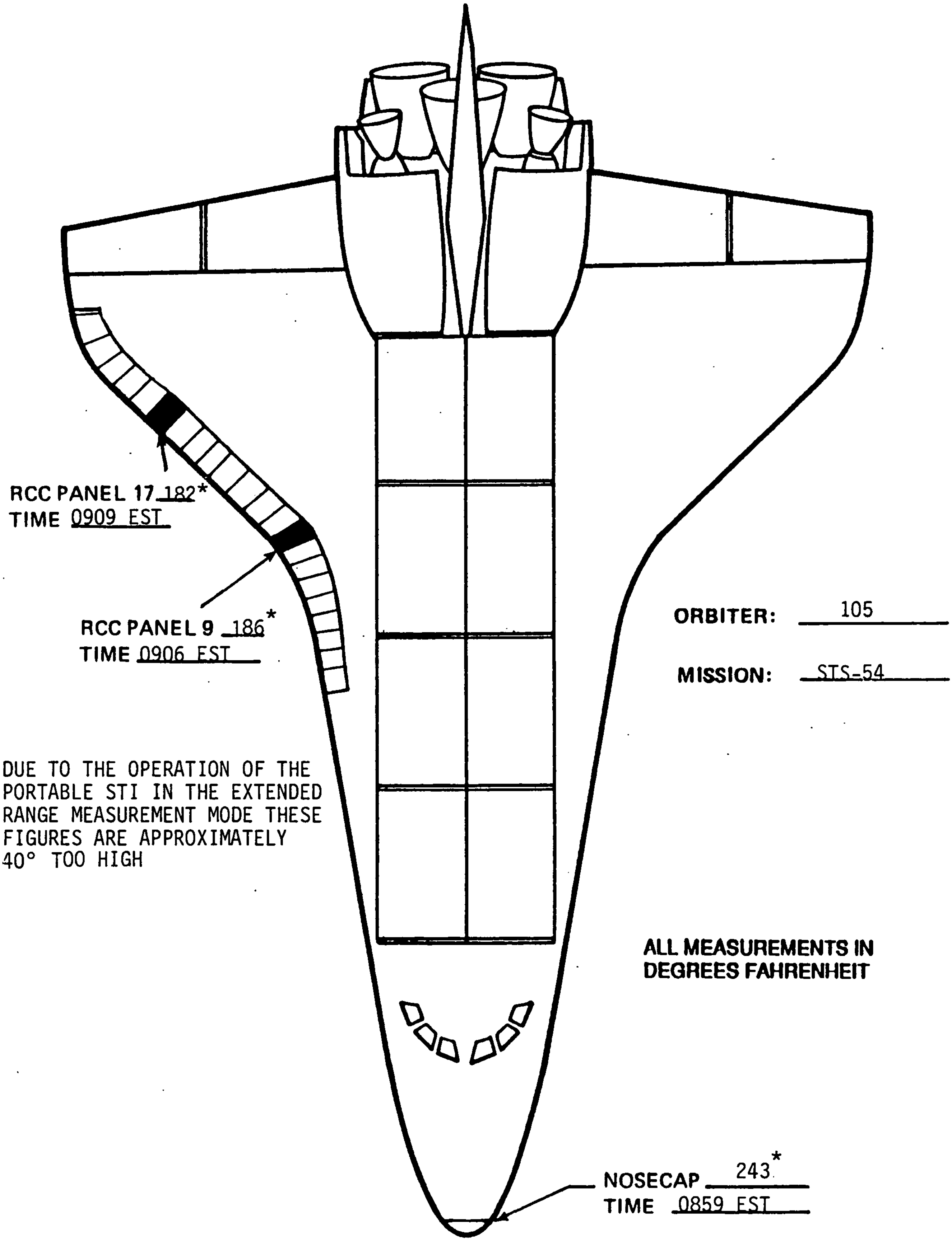
STS-54
OV-105
ENDEAVOUR
1/19/93

FIGURE 8

A portable Shuttle Thermal Imager (STI) was used to measure the surface temperatures of three areas on the Orbiter (per OMRSD V09AJ0.095). Twenty-one minutes after landing, the Orbiter Reinforced Carbon-Carbon (RCC) nosecap was 243 degrees Fahrenheit (F). Twenty-eight minutes after landing the RH wing leading edge RCC panel #9 was 186 degrees F, and panel #17 was 182 degrees F (reference Figure 16). Due to the use of an extended range filter on the instrument, these measurements are approximately forty degrees F too high.

Orbiter Post Launch Anomalies are listed in Section 9.

Figure 16. **STS-54 RCC TEMPERATURE MEASUREMENTS AS RECORDED BY THE SHUTTLE THERMAL IMAGER**




* DUE TO THE OPERATION OF THE PORTABLE STI IN THE EXTENDED RANGE MEASUREMENT MODE THESE FIGURES ARE APPROXIMATELY 40° TOO HIGH

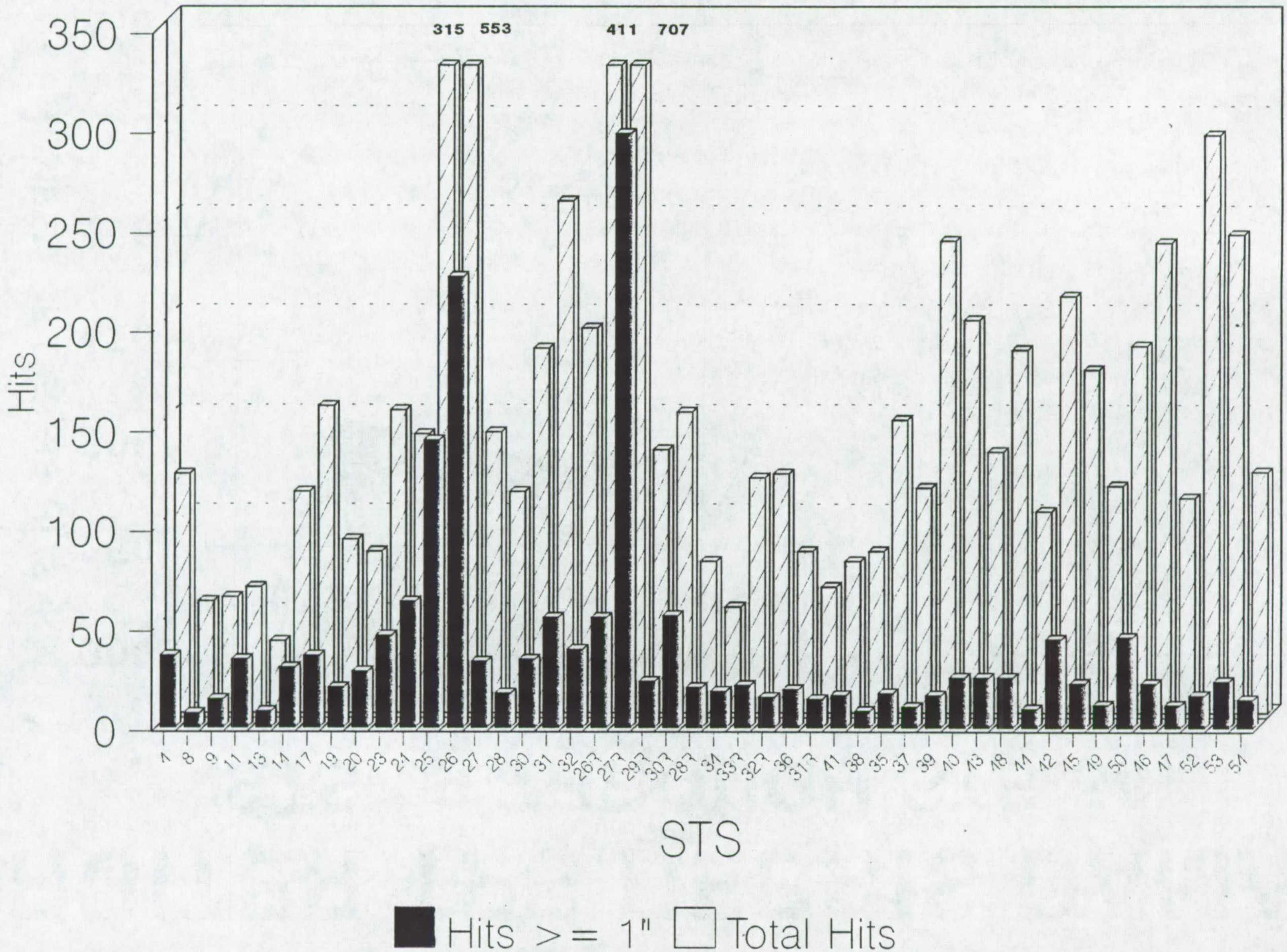
*FIGURE 17: ORBITER POST FLIGHT DEBRIS DAMAGE SUMMARY*

| | LOWER SURFACE | | ENTIRE VEHICLE | |
|---|---|---|---|---|
| | HITS > 1 INCH | TOTAL HITS | HITS > 1 INCH | TOTAL HITS |
| STS-6 | 15 | 80 | 36 | 120 |
| STS-8 | 3 | 29 | 7 | 56 |
| STS-9 (41-A) | 9 | 49 | 14 | 58 |
| STS-11 (41-B) | 11 | 19 | 34 | 63 |
| STS-13 (41-C) | 5 | 27 | 8 | 36 |
| STS-14 (41-D) | 10 | 44 | 30 | 111 |
| STS-17 (41-G) | 25 | 69 | 36 | 154 |
| STS-19 (51-A) | 14 | 66 | 20 | 87 |
| STS-20 (51-C) | 24 | 67 | 28 | 81 |
| STS-27 (51-I) | 21 | 96 | 33 | 141 |
| STS-28 (51-J) | 7 | 66 | 17 | 111 |
| STS-30 (61-A) | 24 | 129 | 34 | 183 |
| STS-31 (61-B) | 37 | 177 | 55 | 257 |
| STS-32 (61-C) | 20 | 134 | 39 | 193 |
| STS-29 | 18 | 100 | 23 | 132 |
| STS-28R | 13 | 60 | 20 | 76 |
| STS-34 | 17 | 51 | 18 | 53 |
| STS-33R | 21 | 107 | 21 | 118 |
| STS-32R | 13 | 111 | 15 | 120 |
| STS-36 | 17 | 61 | 19 | 81 |
| STS-31R | 13 | 47 | 14 | 63 |
| STS-41 | 13 | 64 | 16 | 76 |
| STS-38 | 7 | 70 | 8 | 81 |
| STS-35 | 15 | 132 | 17 | 147 |
| STS-37 | 7 | 91 | 10 | 113 |
| STS-39 | 14 | 217 | 16 | 238 |
| STS-40 | 23 | 153 | 25 | 197 |
| STS-43 | 24 | 122 | 25 | 131 |
| STS-48 | 14 | 100 | 25 | 182 |
| STS-44 | 6 | 74 | 9 | 101 |
| STS-45 | 18 | 122 | 22 | 172 |
| STS-49 | 6 | 55 | 11 | 114 |
| STS-50 | 28 | 141 | 45 | 184 |
| STS-46 | 11 | 186 | 22 | 236 |
| STS-47 | 3 | 48 | 11 | 108 |
| STS-52 | 6 | 152 | 16 | 290 |
| STS-53 | 11 | 145 | 23 | 240 |
| AVERAGE | 14.7 | 93.5 | 22.2 | 132.5 |
| SIGMA | 7.6 | 47.2 | 10.9 | 63.3 |
| STS-54 | 14 | 80 | 14 | 131 |

*MISSIONS STS-23, 24, 25, 26, 26R, 27R, 30R, AND 42 ARE NOT INCLUDED IN THIS ANALYSIS SINCE THESE MISSIONS HAD SIGNIFICANT DAMAGE CAUSED BY KNOWN DEBRIS SOURCES*

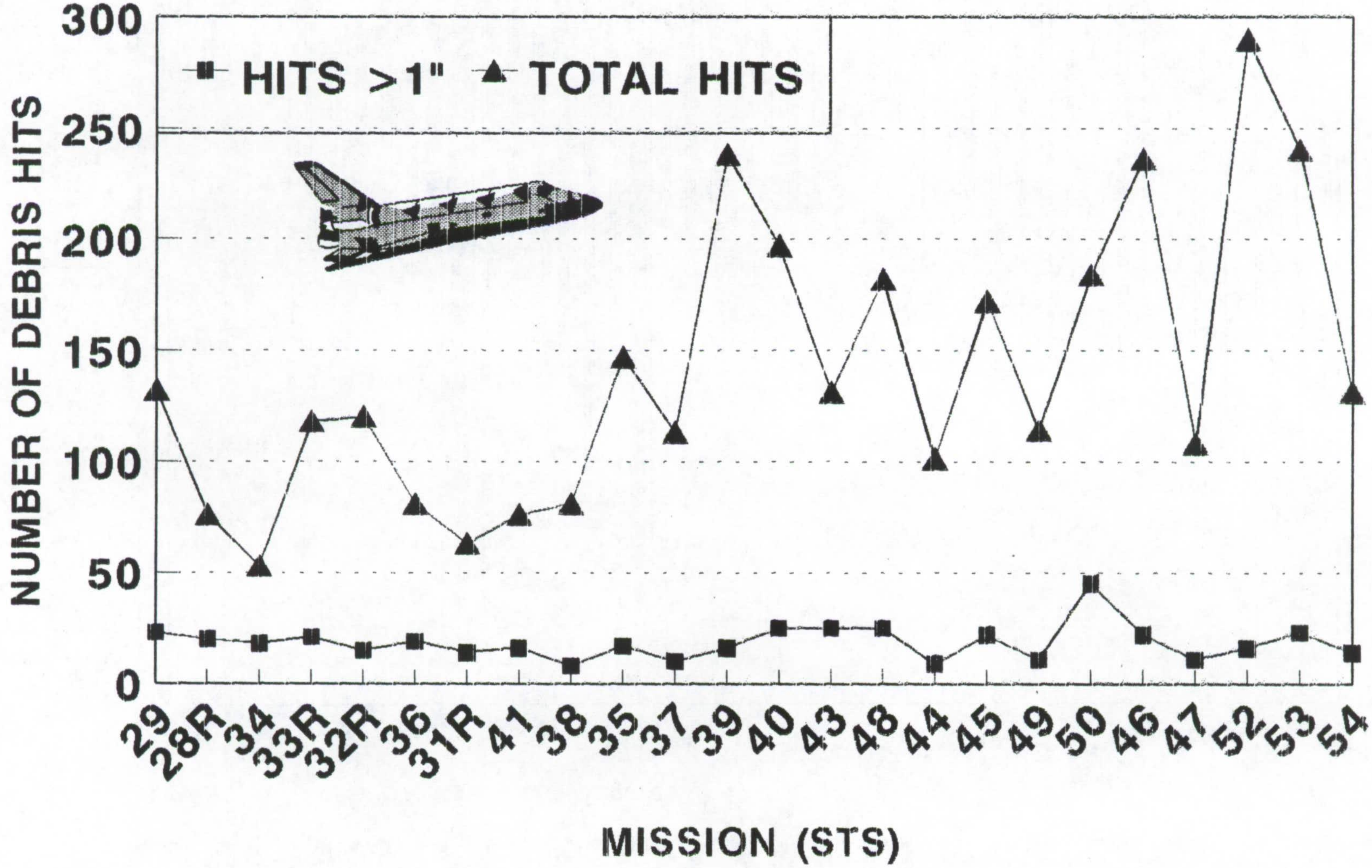
# COMPARISON TABLE

Figure 18.



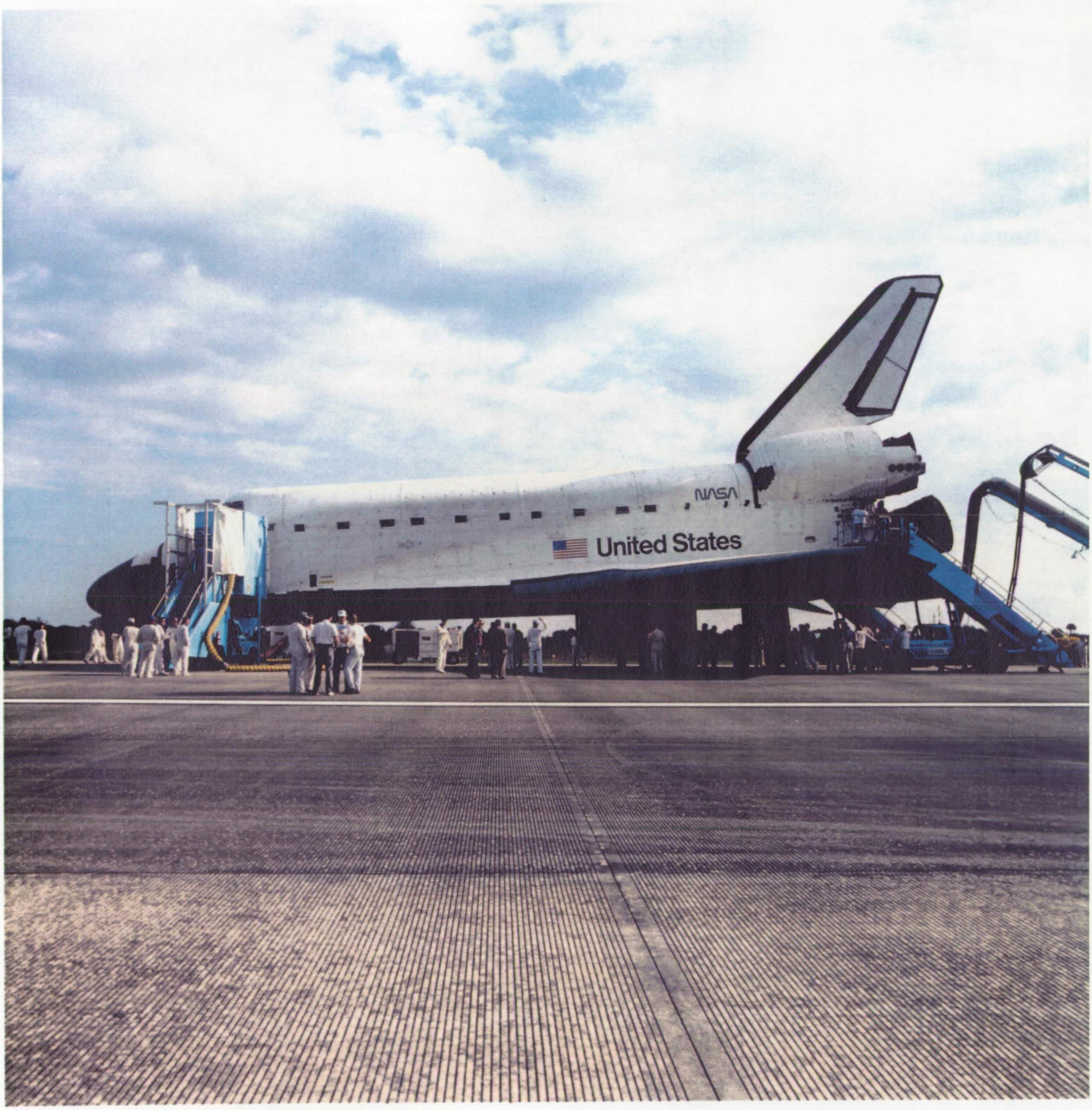
# ORBITER TPS DEBRIS DAMAGE
## STS-29 THROUGH STS-54

Figure 19.

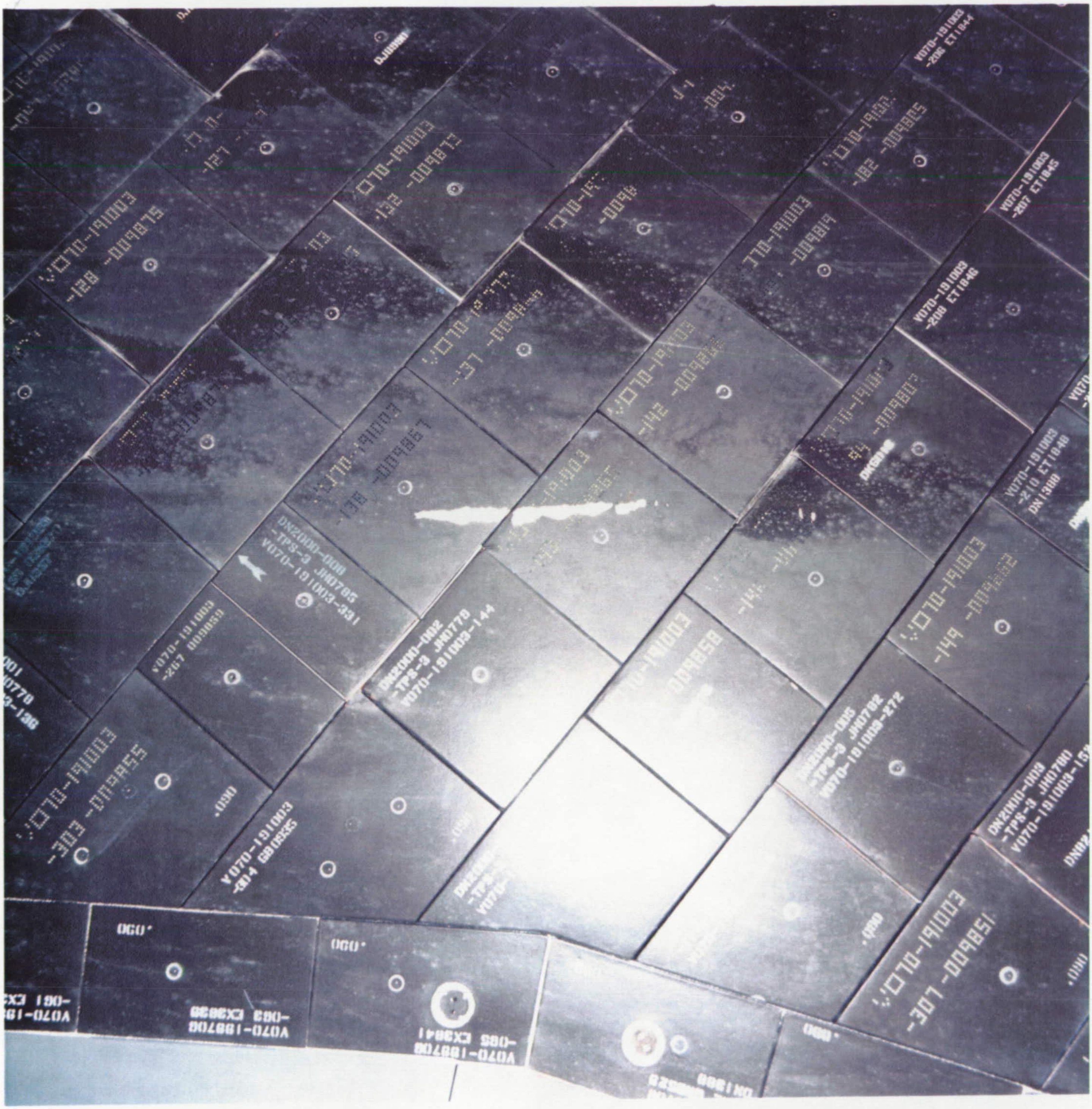


OV-105 Endeavour made the 14th KSC landing on SLF Runway 33


Overall view of Orbiter right side

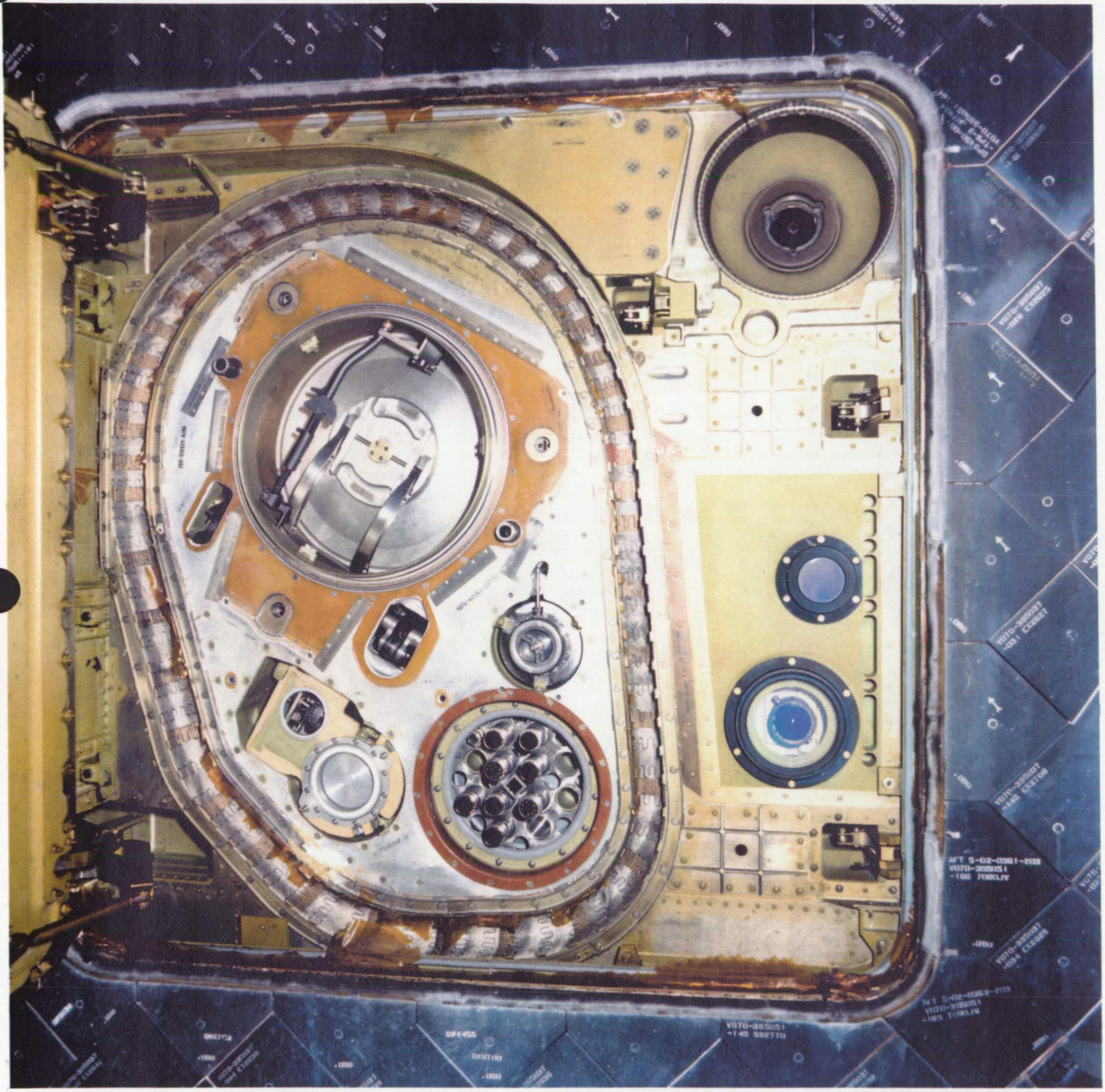



Overall view of Orbiter left side



The Orbiter lower surface tiles sustained a total of 80 hits (less than average), of which 14 had a major dimension of 1-inch or greater (average).

Tile damage on the base heat shield was much less than average. The outer edge of SSME #2 Dome Mounted Heat Shield closeout blanket sacrificial panels were detached and the underlying batting material was exposed. Some of the sacrificial panel and batting material was missing.



Overall view of the LH2 ET/ORB umbilical. All separation ordnance devices functioned properly. No flight hardware was found on the runway below the umbilical when the ET door was opened.

Overall view of the LO2 ET/ORB umbilical. All separation ordnance devices functioned properly. No flight hardware was found on the runway below the umbilical when the ET door was opened.


Orbiter windows #3 and #4 exhibited moderate hazing and several streaks. Only a very light haze was present on the other forward facing windows.

Five tile fragments found on the runway originated from the vertical stabilizer "stinger" and had been dislodged by contact with the drag chute riser lines during deployment.

An 8 ounce, 2.5" x 2.25" x 0.5" thick, brass spray nozzle/elbow was found at the 3800 foot marker 18 feet east of the runway centerline. The nozzle originated from the runway sweeper.

## 8.0 DEBRIS SAMPLE LAB REPORTS

A total of ten samples were obtained from OV-105 Endeavour during the STS-54 post landing debris assessment at Kennedy Space Center (reference Figure 14). The ten submitted samples consisted of 8 window wipes (Windows 1-8) and 2 sample wipes from right hand wing RCC panels 20 and 21. The samples were analyzed by the NASA KSC Microchemical Analysis Branch (MAB) for material composition and comparison to known STS materials. Debris analysis involves the placing and correlating of particles and residues with respect to composition, thermal (mission) effects, and availability. Debris sample results and analyses are listed by Orbiter location in the following summaries.

### Orbiter Windows

Results of the window sample analysis revealed the presence of the following materials:

1. Metallics, Cerium Oxide
2. RTV, silica-rich tile, insulation glass fibers
3. Paints, primer, rust, Aluminum Oxides
4. Organics
5. Earth compounds

Debris analysis provides the following correlations:

1. Metallic particles (zinc, aluminum, carbon and stainless steel alloys) are common to SRB BSM exhaust residue, but are not considered to be a debris concern in this quantity (micrometer) and have not generated a known debris effect. Also noted was Cerium Oxide, an Orbiter window polish residue.

2. RTV, silica-rich tile, and insulation glass fibers originated from Orbiter thermal protection system (TPS)

3. Paints and primer are of flight hardware/facility/GSE origin; rust is an SRB BSM exhaust residue. Also noted was aluminum oxides suspected to be of BSM exhaust residue origin because of 'fused' appearance.

4. Organics are being analyzed by chemical fingerprint (Infrared Spectroscopy) method; results are pending. Preliminary results indicated materials previously recorded in organic sampling.

5. Earth compounds (alpha-quartz, calcite, and salt components) originated from the landing site.

**RH Wing RCC Panels 20 and 21**

Results of the RH wing RCC panels 20 and 21 wipe samples indicated the presence of the following materials:

1. Metallics
2. Tile and insulation material
3. Paint and rust
4. Earth compounds
5. Organics

Debris analysis provides the following correlations:

1. Metallics (Aluminum, zinc, brass, and carbon steel alloy) have previously been reported as SRB BSM exhaust residue.

2. Tile and insulation material originated from Orbiter thermal protection system (TPS).

3. Paint is of flight hardware/facility/GSE origin; rust is of SRB BSM exhaust origin.

4. Earth compounds (calcium-silica and salt components) originated from the landing site.

5. Organics are being analyzed by infrared spectroscopy; results are pending. This detailed process is more difficult due to the small sample quantity.

**STS-53 Organic Analysis**

Results of the STS-53 Organic analysis indicated the presence of the following materials:

1. Polymeric
2. Rubbery
3. Fibrous
4. Grease

Debris analysis provides the following correlations:

1. Polymeric materials included items as dimethyl silicone, polyurethane, polyethylene, aromatic polyamide, and cellulosic characteristics. This variety is similar to that observed in STS-52 samples and appear to originate from Orbiter window protective covers.

2. Rubbery material was found to be a greyish-black substance similar to previous samples and most likely originated from Orbiter window protective covers.

3. Fibrous material detected in this sampling was primarily of sample cloth origin though some of the material originated from protective covers.

4. Grease (hydrocarbon-silicate filled) material probably originated from ground processing.

**Conclusions**

The STS-54 mission sustained Orbiter tile damage to a lesser than average degree. The chemical analysis results from post flight samples did not indicate a single source of damaging debris.

Orbiter window samples provided evidence of SRB BSM exhaust, Orbiter TPS, landing site products, organics, and paint. The presence of 'fused' aluminum oxides, as from SRB BSM exhaust residue, was also noted.

The RH wing RCC samples provided an indication of exposure to SRB BSM exhaust, Orbiter TPS, landing site products, organics, and paint.

An interesting finding in this sampling set is the presence of carbon steel spheres in all particulate samples. Quantity of this material ranged from trace to approximately 2% of sample. The most probable source for this is launch site structures.

The variety of residuals attributed to known sources did not seem to change significantly when compared to previous sample data (reference Figure 20). Included in this report are the results of the STS-53 organic analysis. The results of this analysis are similar to that of previous missions in that new entries do not appear to be related to a debris problem.

A new finding in the window sample set was the presence of aluminum oxide with 'fused' appearance. This material is being attributed to the SRB BSM exhaust as a most probable source. No damage has been related to this residual finding.

| STS | Sample Location | | | | |
|---|---|---|---|---|---|
| | Windows | Wing RCC | Lower Tile Surface | Umbilical | Other |
| 54 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite,Alpha-Quartz,Salt(Landing Site)<br>Organics<br>Paint | Metallics - BSM Residue (SRB)<br>Tile, Insulation Glass (ORB TPS)<br>Calcium - Silica, Salt (Landing Site)<br>Organics<br>Paint | | | |
| 53 | Metallics - BSM Residue (SRB)<br>- Solder (Launch Site)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Organics - Fibrous mat'l,RTV,Grease<br>Organics-filled rubber,plastic polymers<br>Paint | | | LO2 Umbilical Door -<br>- Closeout Mat'l (ORB TPS)<br>- Hydrocarbon "grease-like" sub. | RH SRB Aft Skirt Damage site -<br>- Tile, Tile coating mat'l (ORB TPS) |
| 52 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Organics-Fibrous mat'l,red RTV<br>Organics-filled rubber,plastic polymers<br>Paint | | | | HRSI Tile Damage Site-<br>-Tile Mat'l and silicon carbide (ORB TPS)<br>-Paints<br>-Calcite,salts (Landing Site) |
| 47 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Window Polish Residue (ORB)<br>Organics-Fibrous mat'l,red RTV<br>Organics-filled rubber,plastic polymers<br>Paint | | Silica-rich Tile (ORB TPS) | | |
| 46 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite,Alpha-Quartz,Salt(Landing Site)<br>Organics-Adhesive,Foam,red RTV<br>Organics-filled rubber,plastic polymers<br>Paint | | | | Crew Hatch Window<br>- Metallics - BSM Residue (SRB)<br>- Alpha-Quartz, Salt (Landing Site)<br>- RTV, Tile (ORB TPS)<br>- Paint<br>- Organics |
| 50 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Window Polish Residue (ORB)<br>Mica, Calcium, Salt (Landing Site)<br>Organics-Adhesive,Foam<br>Organics-Plastic Polymers<br>Paint | | Silica-Rich Tile (ORB TPS) | | Orbiter Vertical Stabilizer<br>- Tile Coating (ORB TPS)<br>- Structural Coating Glass "E-Glass" |

Figure 20. Orbiter Post Landing Microchemical Sample Results

| STS | Sample Location | | | | |
|---|---|---|---|---|---|
| | Windows | Wing RCC | Lower Tile Surface | Umbilical | Other |
| 49 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Mica, Calcium, Salt (Landing Site)<br>Organics<br>Paint | RTV, Tile (ORB TPS)<br>Rust - BSM Residue (SRB)<br>Muscovite, Salt (Landing Site)<br>Organics<br>Paint | RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Rust - BSM Residue (SRB)<br>Calcium Mat'l,Salt (Landing Site Soil)<br>Organics<br>Paint | | |
| 45 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Window Polish Residue (ORB)<br>Organics<br>Paint | | Iron - Rich Mat'l<br>Paint | | |
| 42 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Muscovite (Landing Site)<br>Organics<br>Paint | | Metallics - BSM Residue (SRB)<br>Tile, Tile Coating (ORB)<br>Salt (Landing Site)<br>Paint | Organics | RH Fuselage - Tile Coating (ORB) |
| 44 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Muscovite (Landing Site)<br>Organics<br>Paint | | | Organics<br>Silica-Magnesium Mat'l | |
| 48 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Muscovite (Landing Site)<br>Organics<br>Paint | | | Metallics<br>Silica - Rich Mat'l (Landing Site)<br>Orb Umbilical C/O Mat'l (ORB)<br>Paints | |
| 43 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Window Polish Residue (ORB)<br>Organics<br>Paint | | RTV, Tile (ORB TPS)<br>Metallics - BSM Residue (SRB)<br>Salt (Landing Site)<br>Organics<br>Paint | | Runway - FRSI Coating (ORB) |

Figure 20. Orbiter Post Landing Microchemical Sample Results

| STS | Sample Location | | | | |
|---|---|---|---|---|---|
| | Windows | Wing RCC | Lower Tile Surface | Umbilical | Other |
| 40 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insullation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Window Polish Residue (ORB)<br>Organics<br>Paint | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB)<br>Insulation Glass (ORB TPS)<br>Ensolite Foam (RCC Prot. Covers)<br>Organics<br>Paint | RTV,Tile (ORB TPS) | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Organics (ORB Umb C/O)<br>Paint | |
| 39 | | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB)<br>Insulation Glass (ORB TPS)<br>Ensolite Foam (RCC Prot. Covers)<br>Organics<br>Paint<br>Hypalon Paint (SRB) | Tile (ORB TPS)<br>Insulation Glass (ORB TPS) | | |
| 37 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insullation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Organics | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB)<br>Insulation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Organics<br>Paint | RTV, Tile ((ORB TPS)<br>Insulation Glass (ORB TPS)<br>Metallics - BSM Residue (SRB)<br>Calcite, Salt (Landing Site)<br>Organics | | |
| 35 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insullation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Window Polish Residue (ORB)<br>Organics<br>Paint | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB)<br>Organics | RTV, Tile (ORB TPS)<br>Metallic - Rust, Aluminum<br>Welding Slag (Facility) | | |
| 38 | | RTV, Tile (ORB TPS)<br>Hypalon Paint (SRB)<br>Ensolite Foam (RCC Prot. Cover) | Tile (ORB TPS) | | |
| 41 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insullation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Organics | Tile (ORB TPS)<br>Salt (Landing Site) | Tile (ORB TPS) | Calcite (Landing Site)<br>Fluorocarbon (Viton-ORB Umb)<br>Foam (ORB C/O) | Fwd FRSI - Silicon Mat'l (ORB TPS) |
| 31R | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insullation Glass (ORB TPS)<br>Calcite, Salt (Landing Site)<br>Organics | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Mica (Landing Site)<br>Organics<br>Foam Insulation (ET/SRB)<br>Paint | RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Mica (Landing Site)<br>Paint | | |
| 36 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insullation Glass (ORB TPS)<br>Mica, Salt (Landing Site)<br>Paint | Rust - BSM Residue (SRB)<br>Tile (ORB TPS)<br>Paint<br>Organics | RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Mica (Landing Site)<br>Organics<br>Microballoon (ET/SRB) | Rust - BSM Residue (SRB)<br>RTV, Insulation Glass (ORB TPS)<br>Microballoon (ET/SRB)<br>Calcite (Landing Site)<br>Foam, Organics (ORB Umb C/O) | |

Figure 20. Orbiter Post Landing Microchemical Sample Results

| STS | Sample Location | | | | |
|---|---|---|---|---|---|
| | Windows | Wing RCC | Lower Tile Surface | Umbilical | Other |
| 32R | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Mica, Salt (Landing Site)<br>Paint | | Metallics - BSM Residue (SRB)<br>Tile (ORB TPS)<br>Carbon Fibers<br>Titanium | Metallics - BSM Residue (SRB)<br>RTV, Insulation Glass (ORB TPS)<br>Phenolic Microballoon (ET/SRB)<br>Quartz, Calcite (Landing Site)<br>Organics | |
| 33R | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Micaceous Mat'l, Salt (Landing Site)<br>Window Polish Residue (ORB)<br>Paint | Metallics - BSM Residue (SRB)<br>Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Mica, Spar, Salt (Landing Site)<br>Organics | RTV, Tile (ORB TPS) | Rust - BSM Residue (SRB)<br>RTV, Insulation Glass (ORB TPS)<br>Phenolic Microballoon (ET/SRB)<br>Paint<br>Organics | Crew Hatch Window<br>- Rust - BSM Residue (SRB)<br>- Alpha Quartz (TPS/Landing Site)<br>- Paint<br>- Organics |
| 34 | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Alpha-Quartz, Silicates, Salt (L/S)<br>Window Polish Residue (ORB) | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Paint | RTV, Tile (ORB TPS)<br>Stainless Steel Washer | RTV (ORB)<br>Foam (ORB)<br>Viton Rubber (ORB)<br>Metallics - BSM Residue (SRB)<br>Phenolic Microballoon (ET/SRB)<br>Silicates, Calcium (Landing Site)<br>Paint | |
| 28R | Silicone (ORB FRCS Cover Adhesive) | Silicates (Landing Site)<br>Paint<br>Charred Silicone<br>Brass Chip | RTV, Tile (ORB TPS)<br>Clay, Sand, Quartz (Landing Site)<br>Metallics - BSM Residue (SRB) | Sand, Silicates (Landing Site)<br>Foam (ORB)<br>RTV (ORB TPS)<br>Koropon, Kapton (ORB)<br>Metallics - BSM Residue (SRB) | OMS Pod - PVC Laminate<br>(ORB TPS 'Shim') |
| 30R | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Clay, Salt (Landing Site)<br>Paint | | Metallics - BSM Residue (SRB)<br>RTV, Tile (ORB TPS)<br>Gap Filler (ORB TPS)<br>Clay, Feldspar (Landing Site) | | Upper Tile - Tile,Gap Filler (ORB TPS) |
| 29R | RTV, Tile (ORB TPS)<br>Metallics - BSM Residue (SRB)<br>Ablator, Hypalon Paint (SRB) | | Tile (ORB TPS)<br>Insulation Glass (ORB TPS)<br>Paint<br>Muscovite - Metallics (Landing Site) | Tile (ORB TPS)<br>Umbilical Foam (ORB)<br>Paint<br>Ablator, Hypalon Paint (SRB)<br>Metallics - BSM Residue (SRB) | Upper Tile - Tile (ORB TPS) |
| 27R | RTV, Tile (ORB TPS) | Hypalon Paint (SRB) | RTV, Tile (ORB TPS)<br>Ablator, Hypalon Paint (SRB) | | OMS Pod - Iron Fiber<br>- PDL Foam, FRL Paint (ET)<br>- Ablator, Hypalon Paint (SRB) |
| 26R | | | RTV, Tile (ORB TPS)<br>Paint<br>Rust | | |

Sample locations vary per mission and not all locations are sampled for every mission.
( ) - identifies the most probable source for the materail.
Metallics - includes mostly Aluminum and Carbon Steel alloys

Figure 20. Orbiter Post Landing Microchemical Sample Results

## 9.0 POST LAUNCH ANOMALIES

Based on the debris inspections and film/video review, seven Post Launch Anomalies, including one IFA and one IFA candidate, were observed on the STS-54 mission.

### 9.1 LAUNCH PAD/SHUTTLE LANDING FACILITY

1. An 8 ounce, 2.5" x 2.25" x 0.5" thick, brass water spray nozzle/elbow was found at the 3800 foot marker, 18 feet east of the runway centerline. This nozzle originated from the runway sweeper.

### 9.2 EXTERNAL TANK

1. IFA Candidate (ET): Loss of TPS on the +Z side of the ET near the Orbiter nose is a potential threat to lower surface tiles. Divots (two 8" x 4" divots just forward of the LH2 tank-to-intertank flange closeout between the bipods; one 8" x 3" divot over a stringer head in the -Y+Z quadrant) occurred in the intertank acreage. Three divots measuring 4-6 inches in diameter occurred in the LH2 tank acreage just aft of the LH2 tank-to-intertank flange closeout. The entire RH (+Y) bipod jack pad closeout was missing. Although no IFA was taken on the divot problem, the ET manufacturer created an in-house team to evaluate the trend.

2. IFA STS-54-I-01: Three objects appeared in the LH2 ET/ORB umbilical camera field of view after the External Tank had separated and moved some distance away from the Orbiter. A metallic washer; metallic shear pin, or bolt; and nylon wire tie/identifier have not been positively identified as flight hardware, but appeared to originate from the LH2 ET/ORB umbilical area and may have been entrapped in the numerous cavities of the umbilical prior to purge barrier closeout. The IFA was closed by modifying the OMRS inspection requirement (RCN) and the purge barrier installation procedure (Dev to S0004).

### 9.3 SOLID ROCKET BOOSTERS

1. The RH frustum was missing no TPS but had 31 MSA-2 debonds over fasteners. The LH frustum had 7 acreage debonds and 18 MSA-2 debonds over fasteners.

2. Paint was missing and metal substrate was exposed in several areas of the RH SRM segment cases.

## 9.4 ORBITER

1. A brown-colored object, 6 inches long by 1 inch wide, originated in the body flap hinge gap at GMT 13:59:26.942 and fell aft without damaging Orbiter tiles. The object is believed to be a brown GSE tile shim, or spacer. GSE tile shims are color coded (orange, yellow, pink, and brown) based on shim thickness.

2. Green flashes, which may be indicative of copper contaminants, occurred in the SSME #1 plume at GMT 13:59:26.913, 13:59:27.592, 13:59:27.941, and 13:59:27.970.

# Appendix A. JSC Photographic Analysis Summary

Lockheed
Engineering & Sciences Company

ENGINEERING AND SCIENCE PROGRAM
2400 NASA Road 1, P. O. Box 58561, Houston, Texas 77258-8561 (713) 333-5411

March 12, 1993

Greg Katnik
MC/TV-MSD-22
OSB Room 5203R
KSC, Florida 32899

Dear Greg,

The following Summary of Significant Events report is from the Johnson Space Center NSTS Photographic and Television Analysis Project, STS-54 Final Report, and was completed JMarch 12, 1993. Publication numbers are LESC-30677 and JSC-25994-54. The actual document can be obtained through the LESC library/333-6594 or Christine Dailey /483-5336 of the NSTS Photographic and Television Analysis Project.

Christine Dailey, Supervisor
Image Analysis Section

# 2.0 Summary of Significant Events

## 2.1 Debris

### 2.1.1 Debris Near the Time of SSME Ignition

#### 2.1.1.1 LH2 and LO2 Umbilical Disconnect Debris

*(Cameras E-1, E-5, E-6, E-16, E-18, E-19, E-25, E-26, E-30, E-31, E-34, E-40, E-52, E-54, E-65, E-79, E-222, OTV-109, OTV-150, OTV-154 and OTV-163)*

Normal ice debris was noted falling from the LH2 and LO2 umbilical disconnect areas at Space Shuttle Main Engine (SSME) ignition through liftoff. None of the debris was observed to strike the vehicle. No follow-up action has been requested.

#### 2.1.1.2 Debris from Body Flap Hinge Gap

*(Camera E-17)*

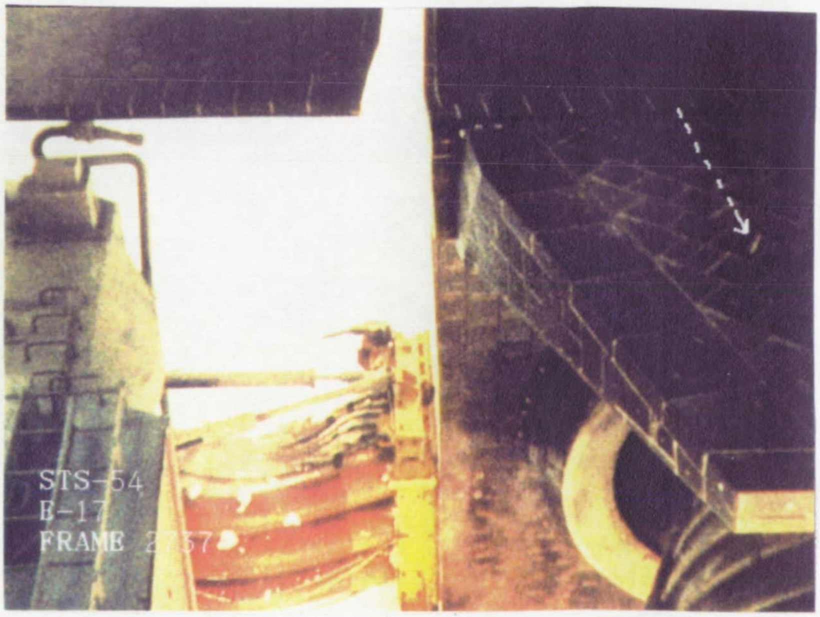



**Figure 2.1.1.2 Debris from Body Flap Hinge Gap**

A small, thin piece of debris which was light on one side and dark on the other was first seen emerging from the Orbiter body flap hinge gap. This piece of debris traveled aft along the body flap out of the field of view (FOV). Using the thickness of the body flap (5.78 inches) as a reference, an approximate size of this object was estimated to be 3 inches by 1 inch. This debris was later identified by KSC as possibly a brown tile shim or spacer. No damage to the Orbiter was noted.

### 2.1.2 Debris Near Time of SRB Ignition

#### 2.1.2.1 SRB Flame Duct Debris *(Task #7)*
*(Cameras E-8, E-9, E-10, E-11, E-12, E-13, E-14 and E-26)*

As on previous missions, several pieces of debris were noted originating from the Solid Rocket Booster (SRB) flame duct area after SRB ignition.


**Figure 2.1.2.1 Flexible Debris from SRB Flame Duct**

The size and velocity of two pieces of debris that apparently came from the SRB flame ducts were measured. The first piece of debris was a large piece of tape-like debris (possibly thermal curtain tape) seen coming from the right SRB flame duct at liftoff. The position of the debris was digitized for 31 frames from camera E-8. The scale marker on the shoe of the SRB holddown post was used for scale and the object was assumed to be moving in the same plane (i.e. the same distance from the camera) as the M-2 holddown post. Velocity was determined by fitting a linear regression line to the distance of the debris from its initial position versus time. The slope of the regression line was then used as the velocity of the debris. The two dimensional (2D) velocity of the debris was found to be 119 ft/sec and the length of the debris was approximately 10.8 inches. This debris did not appear to strike the vehicle. For more details and a plot of the debris distance versus time see Appendix D, Task #7.



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The second piece of debris traveled up along the left SRB, then out toward the ET [The debris began to move out toward the External Tank (ET) at the left SRB aft attach ring.] and then fell back along the left SRB at liftoff. Although the debris was not seen coming out of the SRB flame duct it was assumed that it did originate from the flame duct based on its trajectory and the time it was first observed (at SRB ignition). The position of the debris was digitized for 199 frames from camera E-26. The distance of the debris from an initial position near the left SRB aft attach ring was determined for each frame. The diameter of the left SRB near the initial position of the debris was used for the scale until the debris began to fall back. As the debris fell back downward, its apparent size increased and new scales were derived at sampled intervals as the debris fell. Scales were then interpolated for the entire downward flight of the debris. A regression equation was fitted to the first part of the debris distance versus time curve (showing the debris going out toward the ET). Another regression curve was fitted to the distance versus time data as the debris fell back along the left SRB. The derivatives of the regression equations were then used to find the velocity of the debris at different times.

The maximum 2D velocity of the debris going out was found to be 41.3 ft/sec and the maximum 2D velocity of the debris coming down was found to be 63.1 ft/sec. The length of the debris was approximately 3.3 inches. (The left most and right most points on the debris were used to determine length.) For more details and a plot of the debris distance versus time see Appendix D, Task #7.

### 2.1.3 Debris after Liftoff
*(Cameras E-52, E-54, E-65, E-212, E-224, E-207, E-213 and E-222)*

Multiple pieces of debris were seen falling aft of the Shuttle Launch Vehicle (SLV) at liftoff, throughout the roll maneuver, and beyond on the launch tracking views. Most of the debris sightings were probably reaction control system (RCS) paper or ice from the ET/Orbiter umbilicals. None of the debris was observed to strike the vehicle. No follow-up action has been requested.

#### 2.1.3.1 Debris Reported by Crew *(Task #10).*

No debris report was generated by the crew for STS-54.

## 2.2 MLP Events

### 2.2.1 TPS Erosion on Left RCS Stinger
*(Cameras E-20, E-77 and OTV-171)*

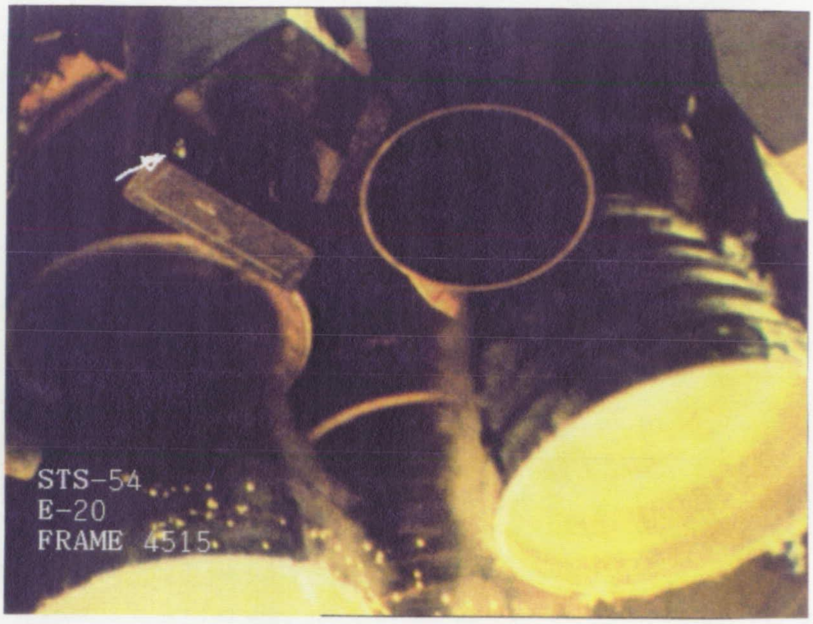


**Figure 2.2.1 TPS Erosion on Left RCS Stinger**

Thermal protection system (TPS) erosion occurred on the left RCS stinger approximately five seconds prior to SSME ignition. Unlike previously observed occurrences of TPS erosion, the tile erosion noted here appeared to disintegrate into fine particles rather than erode as a flake or chip. This event was presented to a Johnson Space Center (JSC) subsystem engineer. No follow up action has been requested.

### 2.2.2 Orange Vapor (Possibly Free Burning Hydrogen)
*(Cameras E-2, E-3, E-17, E-18, E-30, E-36, E-41 and OTV-163)*

On E-17, E-18, E-30, E-36, E-41 and OTV-163, an orange vapor (possibly free burning hydrogen) was seen curling under the body flap at T-5.37 seconds MET. An orange vapor was noted below the SSME bells on E-2 and E-3 prior to SSME ignition.


**Figure 2.2.2** **Orange Vapor Curling under Body Flap**

This orange vapor has been observed on previous missions prior to SSME ignition and no follow up analysis has been requested.

## 2.2.3 Green Streaks in SSME #1 Plume prior to Liftoff

*(Cameras E-2, E-3, E-19 and E-77)*


**Figure 2.2.3 Green Streak in SSME #1 Plume**

A minimum of six green streaks were seen as depicted in the above photo in SSME #1 plume prior to liftoff. These streaks occurred at 13:59:26.913, 13:59:27.592, 13:59:27.941, 13:59:27.970, 13:59:29.181 and 13:59:29.840 UTC. These green streaks were reported to the Mission Evaluation Room Manager. No follow-up analysis has been requested.



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### 2.2.4 Flashes in SSME Plumes prior to Liftoff
*(Cameras E-2, E-3, E-5, E-19, E-62 and OTV-170)*

Multiple flashes were noted in both SSME #1 and #3 plumes from 13:59:27.592 UTC through 13:59:29.417 UTC. These flashes in SSME exhaust plumes have been seen on prior missions. No follow-up analysis has been requested.

### 2.2.5 Discoloration on Forward Segment of Right SRB
*(Cameras E-65 and E-79)*

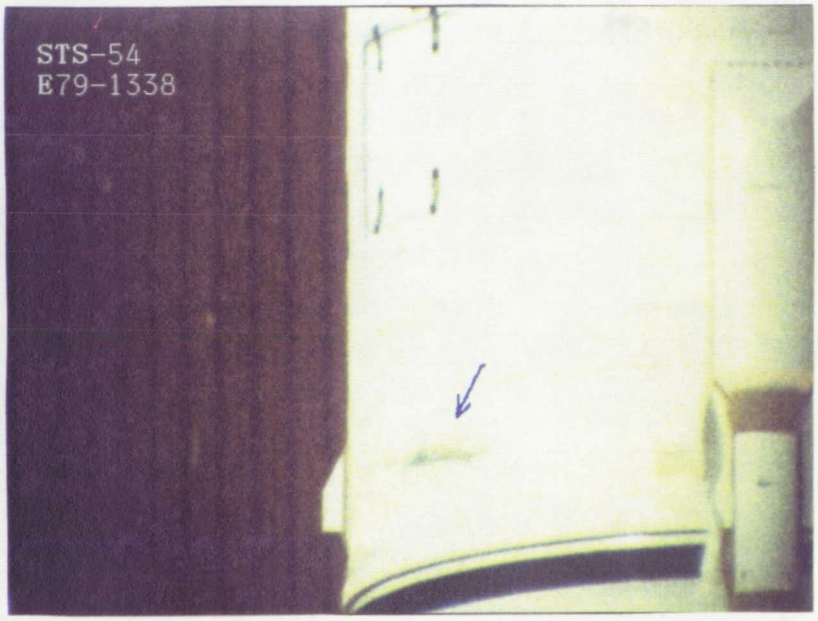


**Figure 2.2.5 Dark Discoloration on Forward Segment of Right SRB**

A dark discoloration was noted prior to SSME ignition on the forward segment of the right SRB between the systems tunnel and the antenna. KSC stated that the dark discoloration was probably caused by a rubber bumper on the access walkway being rubbed against the right SRB during high winds sometime prior to launch. This event was reported to the MER; however, no follow-up action has been requested.



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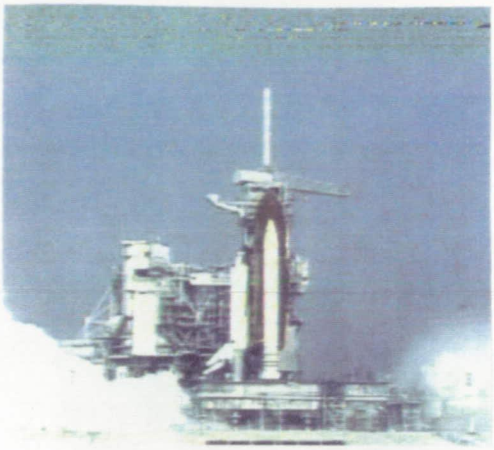
### 2.2.6 Slack in GUCP Static Retract Lanyard
*(Cameras E-41, E-42 and E-50)*

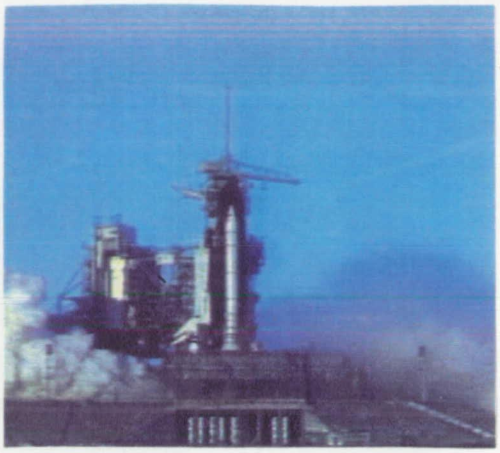
The static retract lanyard of the Ground Umbilical Carrier Plate (GUCP) had slack in it during latchback . This slack caused the cable to contact the platform, rebound upwards, and contact the lower GUCP leg. No follow-up action has been requested.

### 2.2.7 Pressure Wave at Liftoff *(Task #12)*
*(Cameras E-1, E-4, E-15, E-25, E-26, E-30, E-34, E-35, E-36, E-41, E-50, E-54, E-59, E-60, E-62, E-222, E-223, E-224, ET-207, ET-213 and KTV-7B)*

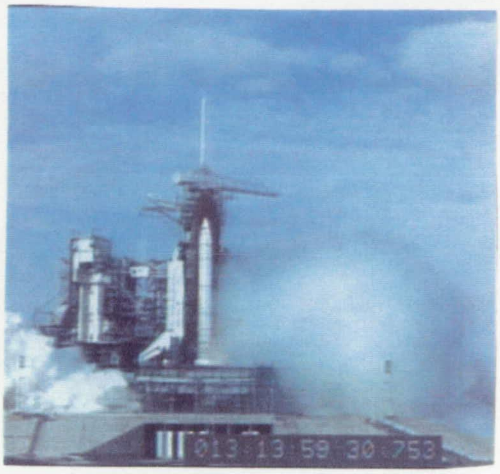
A large cloud of vapor was seen moving north from the base of the SLV at liftoff. A statement was provided to Jeff Carr/AP3 by the Photographic and Television Analysis Project that this event was believed to be a manifestation of a shock wave typically seen at launch. Due to the existing temperature (72 degrees Fahrenheit) and dew point (69 degrees Fahrenheit) conditions, a large condensation cloud which showed the pulsing characteristics of pressure waves was generated at liftoff. This event is similar to the condensation which forms around the vehicle during some launches as it travels through moist layers in the atmosphere after liftoff. [Before reaching these conclusions, the image analysis teams at both KSC and Marshall Space Flight Center (MSFC) were consulted.]



STS-28



STS-32




STS-54

**Figure 2.2.7** **Composite Photo of Pressure Wave on STS-28, STS-32 and STS-54**

Missions since reflight with over 80% humidity at the time of launch were investigated to determine if a large pressure wave was noted at SRB ignition. Of these previous missions, five flights were found to have this phenomenon. They were STS-28, STS-32, STS-37, STS-39 and STS-40. A composite photo was made of the missions (STS-28 and STS-32) with the largest and most visible waves along with STS-54 for comparison. The pressure waves for STS-37 and STS-40 were not as pronounced. Camera KTV-7 was used as the view of choice.

The pressure waves noted on the five missions previously mentioned are characteristically the same as seen on STS-54 in shape and color. The wave seen on STS-54; however, was much larger than those seen on other missions.

This phenomenon occurs when the initial shock wave is emitted at SRB ignition causing an increase in the air pressure thus reducing the ability of the air to hold water in a gaseous state.

Therefore, the water changes from vapor to liquid and a cloud forms. The cloud quickly dissipates as the air pressure returns to normal. Clouds formed by subsequent shock waves emitted after the initial wave produce a pulsing effect which also has been noted on many prior missions. This effect is prevalent during times of high relative humidity (meaning the air is nearly saturated). The SLV undergoes a similar effect when it travels through a moist layer in the atmosphere and a collar of condensation forms around the leading edges. The temperature and relative humidity are listed below for each of the five missions of interest as well as STS-54.

| Mission | Temperature (degrees F) | Relative Humidity |
|---|---|---|
| STS-28 | 81 | 82% |
| STS-32 | 54 | 100% |
| STS-37 | 74 | 83% |
| STS-39 | 75 | 91% |
| STS-40 | 68 | 82% |
| STS-54 | 72 | 91% |

### 2.3 Ascent Events

#### 2.3.1 SRB Thermal Curtain Flexing
*(Cameras E-3, E-7, E-8, E-10, E-13, E-207 and E-212)*

A flexing motion of the thermal curtain on both SRBs was noted at liftoff and after the roll maneuver. This flexing of the thermal curtain has been seen on STS-49 and STS-50. This flexing motion is considered a normal event. No follow-up action has been requested.

#### 2.3.2 Venting from Rudder/Speed Brake
*(Camera E-52)*

A venting from the drain plug of the rudder/speed brake was noted on camera E-52 after tower clear. No follow-up action has been requested.

#### 2.3.3 SRB Pressure Surge *(Task #14)*

During launch a pressure spike was detected in the right SRB between 67 and 70 seconds MET. The Photo/TV Analysis Project was requested by the MER to review the video launch replays from cameras ET-207 (right side) and ET-212 (left side) with special attention given to the period between 60 to 75 seconds Mission Elapsed Time (MET). During rescreening it was noted that the SRB plumes experienced discoloration due to clouds on both cameras but no significant change was noted during the time of the pressure spike. No debris was seen coming from the right SRB plume on either camera during this time frame.

#### 2.3.4 Body Flap Motion *(Task #4)*
*(Cameras E-212 and E-220)*

During ascent very slight body flap motion was noted on cameras E-212 and E-220 at approximately 57 to 61 seconds MET. The magnitude of the motion seen on the STS-54 views was not sufficient to warrant further analysis.

### 2.3.5 Recirculation *(Task #1)*
*(Cameras E-212, E-218, ET-208, ET-212 and KTV-13)*

The recirculation or expansion of burning gases at the aft end of the SLV prior to SRB separation has been seen on nearly all previous missions. For STS-54, the start of recirculation was observed at about 94 seconds MET and the end was noted at approximately 108 seconds MET on Camera E-212. See Appendix D, Task #1 for a summary of recirculation start and stop times for all missions since reflight.

**Cameras on which recirculation was observed for STS-54**

| CAMERA | START (seconds MET) | STOP (seconds MET) |
|---|---|---|
| KTV-13 | - | - |
| ET-208 | 93 | - |
| ET-212 | - | - |
| E-212 * | 94 | 108 |
| E-218 | frame 8193 | - |

*** Best View of Recirculation**

NOTE: **Intermittent LOV due to the SRB and SSME plumes prevented acquisition of specific start and stop times for recirculation on camera KTV-13, ET-208, ET-212 and E-218.**

## 2.4 On Orbit

### 2.4.1 Analysis of Onboard Photography of the ET from DTO-312 *(Task #6)*

The onboard handheld photography of the external tank were taken by astronaut Marion Runco with the assistance of Gregory Harbaugh. At the time of the first photograph, the ET was approximately 1.4 kilometers from the Orbiter. The approximate separation velocity of the external tank from the Orbiter was calculated from the photography to be approximately 5.75 meters per second. The ET tumbled one revolution in approximately 6.47 minutes based on analysis of the handheld film.

Two rolls of 35mm film were exposed with a Nikon F4 camera equipped with a 300mm lens and a 2x extender (an effective focal length of 600mm). Magazines 27 and 28 each contained 37 photographs with excellent exposure. The first frame on magazine 27 was acquired at 13:14:13:45 UTC (5 minutes and 26 seconds after ET separation) and the last frame was taken at 13:14:15:33 UTC (7 minutes and 14 seconds after ET separation). The first frame on magazine 28 was acquired at 13:14:16:37 UTC or one minute and four seconds after the last frame on magazine 27 (8 minutes and 18 seconds after ET separation). The last frame taken from magazine 28 occurred at 13:14:20:49 UTC (12 minutes and 30 seconds after ET separation). Seven additional frames were taken on magazine 36, frames 1 through 4 and 9 through 11. Magazine 36 frame 1 was taken at 13:14:23:40 UTC (15 minutes and 21 seconds after ET separation) and frame 11 was taken at 13:14:25:54 UTC (17 minutes and 35 seconds after ET separation). The duration of ET acquisition from the first frame on magazine 27 to the last frame on magazine 36 was 12 minutes and 9 seconds.

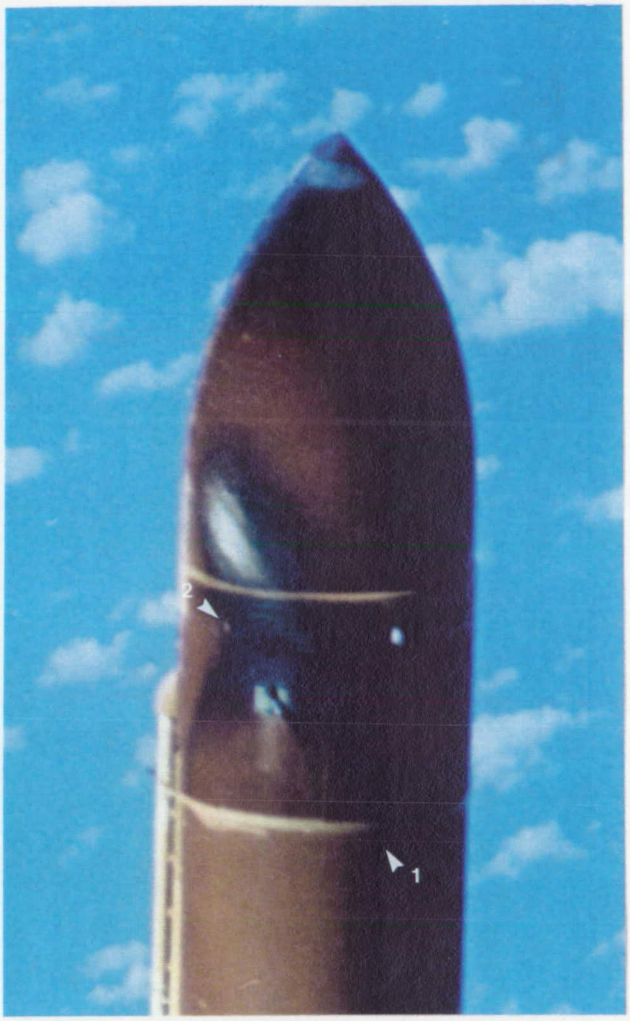



**Figure 2.4.1 (A)** **Handheld Camera View of the Right Side (+Y Axis) of ET**
(Frame STS-54-27-024)

Magazine 27 viewed the nose cone/O-Give and the right side (+Y axis) of the ET. From frame 13 through frame 24 a possible small divot was observed on the LH2 intertank interface (1). A second possible divot was noted in the intertank area below the right SRB burn separation motors (BSM) burn scar (2). The second divot could not be confirmed since a close-out photograph of this region was not available.



ORIGINAL PAGE
COLOR PHOTOGRAPH

**Figure 2.4.1 (B)** **Handheld Camera View of the Nose and -Y/+Z Axis of the ET** (Frame STS-54-28-024)

Magazine 28 showed the aft dome, nose and the left side (-y/+z axis) of the ET. Several possible divots were seen between the legs of the forward bipod on the above view. The divots seen on the handheld films showing the +Z axis of the ET were confirmed during the analysis of the 35mm umbilical well photography.

Detailed notes for the handheld camera photographic screening of the external tank are located in Appendix D, Task #6.

**2.4.2 Umbilical Well Camera Analysis** *(Task #5)*

**2.4.2.1 16mm Views of SRB Separation**
(Magazine 57 - 5mm lens )

Separation of the left SRB from the external tank appeared normal on this 16mm umbilical well camera. No anomalies were observed on the left SRB. Multiple divots were visible on the base of the external tank electrical cable tray. Multiple small pieces of debris [possibly chips or flakes from the thermal protection system (TPS)] were in view throughout the entire SRB separation sequence. Small pieces of the TPS were seen to ablate from the ET electrical cable tray. The aft ET/Orbiter attach brace and the ET aft dome showed charring similar to that seen on previous mission's umbilical films.

**Figure 2.4.2.1 16mm View (5mm Lens) of Left SRB Separation**
(Frame STS-54-57-1464)

Numerous pieces of small debris were seen in the 16mm umbilical camera views of the left SRB before, during and after SRB separation. The debris appeared to be small pieces of TPS that had ablated off the external tank.

### 2.4.2.2 16mm Views of ET Separation
(Magazine 57- 5mm lens)

The ET/Orbiter umbilicals appeared normal during the ET separation sequence.

White debris (probably ice) of various sizes and shapes were seen before, during and after ET separation on the 16mm umbilical camera.

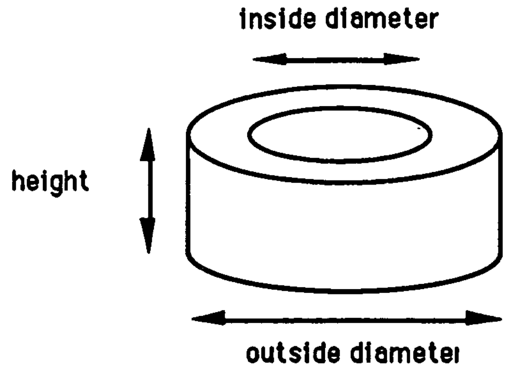
A disk shaped object, a rod shaped object and a flexible strap-like object were seen shortly after the STS-54 external tank separated from the Orbiter on the 16mm high speed motion picture film. All NASA centers reviewed these events in order to identify the objects and assess their significance to flight safety. A JSC Structures and Mechanics Division engineer and JSC Systems Division, Booster Systems Section/DF65-RSO engineers viewed the film, but were unable to provide an identification of these objects. KSC reported that the objects had not been positively identified as flight hardware. KSC also stated that these objects may have been entrapped in the numerous cavities of the umbilical prior to the purge barrier close-out. These three debris objects were declared an inflight anomaly (IFA #STS-54-I-01).

Measurement of the length/width ratios for the above mentioned objects were made using a film motion analyzer. The actual size of these objects were not able to be determined because there was no reference in FOV to use as a scale. The relative sizes of these objects were not linear along their trajectories due to the optical distortion of the 5mm lens and the objects were not near the center of the field of view.

> Disk Shaped Object: The ratio of the outside diameter to the height was determined to be 4.2 to 1 (frame 7511). The ratio of the outside diameter to the inner diameter of this object was 3.2 to 1 (frame 7461).
>
> Rod Shaped Object: The ratio of the major axis to the diameter was determined to be 16.2 to 1. The measurements of the rod shaped object were made on frame number 7448.
>
> Strap-Like Object: The longest dimension of the strap-like object was 13.6 analyzer units (frame 7935). The width of the tape like object was determined to be 2.5 analyzer units (frame 7913). The thickness dimension was 1.2 analyzer units (frame 7936).

#### 2.4.2.2.1 Comparison of Debris Size with Previous Missions

The aspect ratio of the disk shaped object seen on STS-54 was compared to the aspect ratio of the of the unknown metallic debris object seen on the STS-47 16mm umbilical well film. (The Orbiter on STS-47 was also Endeavour.) The STS-54 disk shaped object was also compared to a cylindrical shaped debris object seen on STS-40 (Columbia). The cylindrical shaped object seen on STS-40 was believed to have been a mating guide pin sleeve.




The ratio of the STS-47 unknown metallic object outside diameter (longest dimension) to height was 2.98 to 1. The outer diameter to the inner diameter ratio was 2.04 to 1.

The ratio of the STS-40 imaged suspect mating guide pin sleeve outside diameter to height was between 1.12 and 1.395 to 1. (The mating guide pin sleeve had a known outside diameter to height ratio of 1.22 to 1).

Based on these ratios, the STS-54 disk shaped debris object did not appear to have the same shape as the objects that were photographed on the STS-47 and the STS-40 umbilical well films. The STS-54 disk shaped object had a smaller inside diameter than the objects seen on the STS-47 and STS-40 films.

### 2.4.2.2.2 Debris Observation Times and Comparison with Previous Missions

The STS-54 disk shaped object was seen between 08:59.325 and 09:00.130 MET as determined from the timing marks on the 16mm film. The disk shaped object was first seen at approximately 11.335 seconds after ET separation.

The STS-54 rod shaped debris object was seen between 08:59.640 and 09:05.723 MET as read from the timing marks on the 16mm film. The rod shaped object was first seen at 11.65 seconds after ET separation.

The STS-54 strap-like debris was seen between 09:01.620 and 09: 02.425 MET as determined from the timing marks on the 16mm film. The strap-like debris was first seen at 13.63 seconds after ET separation.

NOTE: The STS-54 ET separation time was 08:49.002 MET according to the mission summary report. The ET separation time was 08:47.990 MET as determined from the timing marks on the 16mm film. Therefore the times read from the film as stated above are assumed to be approximately one second slower than actual MET time.

The STS-47 debris object was seen at approximately 2.7 seconds prior to ET separation.

The STS-40 suspect guide pin sleeve was seen at 43.45 seconds after ET separation.

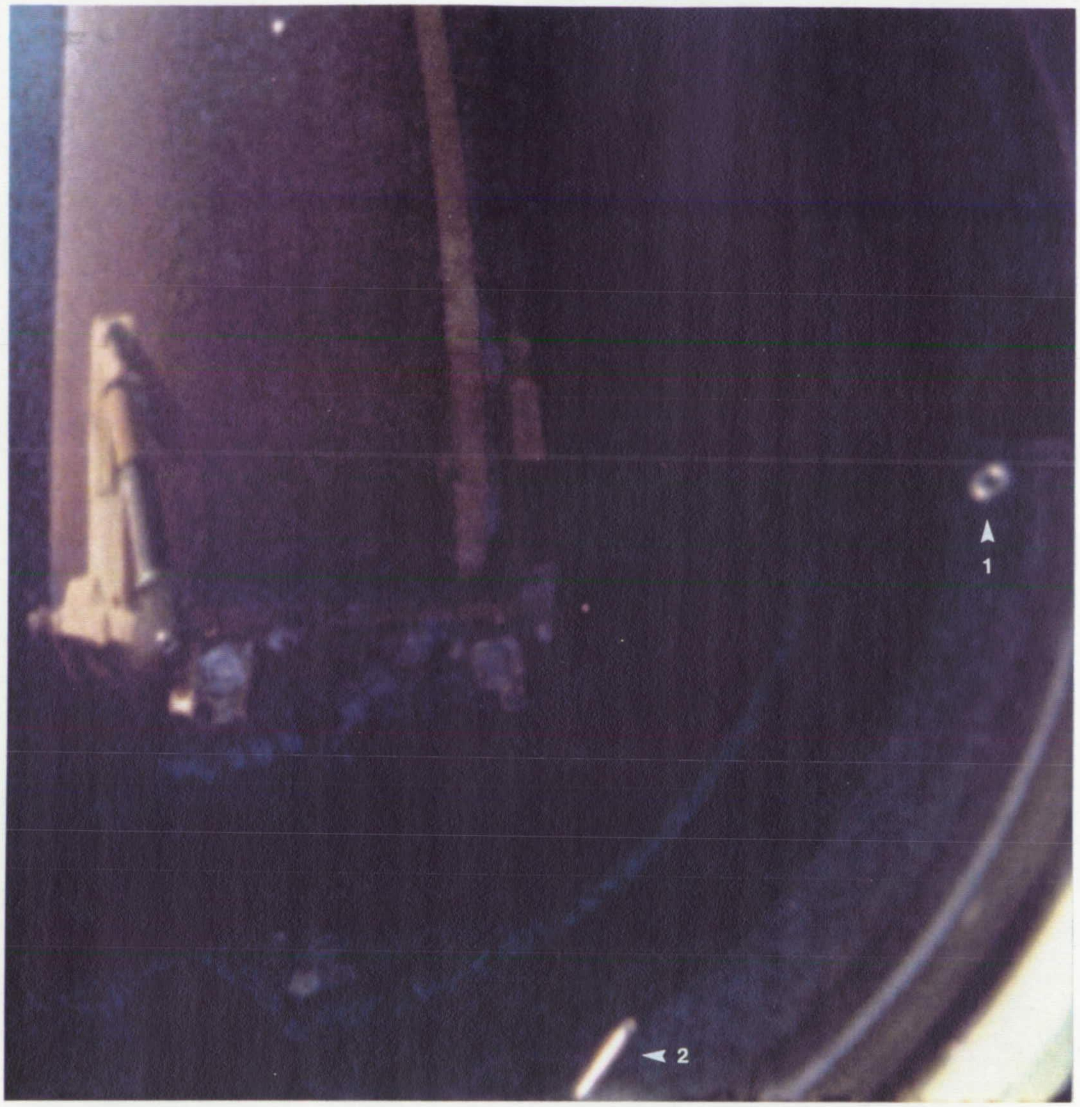



**Figure 2.4.2.2.2 (A)** **Disk Shaped Debris and Rod Shaped Debris Visible after ET Separation** (Frame STS-54-57-7446)

A single disk shaped piece of debris was noted as it traveled down the right side of the FOV after ET separation (arrow 1). KSC described this object as possibly a washer. A small rod shaped piece of debris was seen in the lower portion of the field of view after ET separation (arrow 2). KSC described this object as possibly a metallic shear pin or bolt.

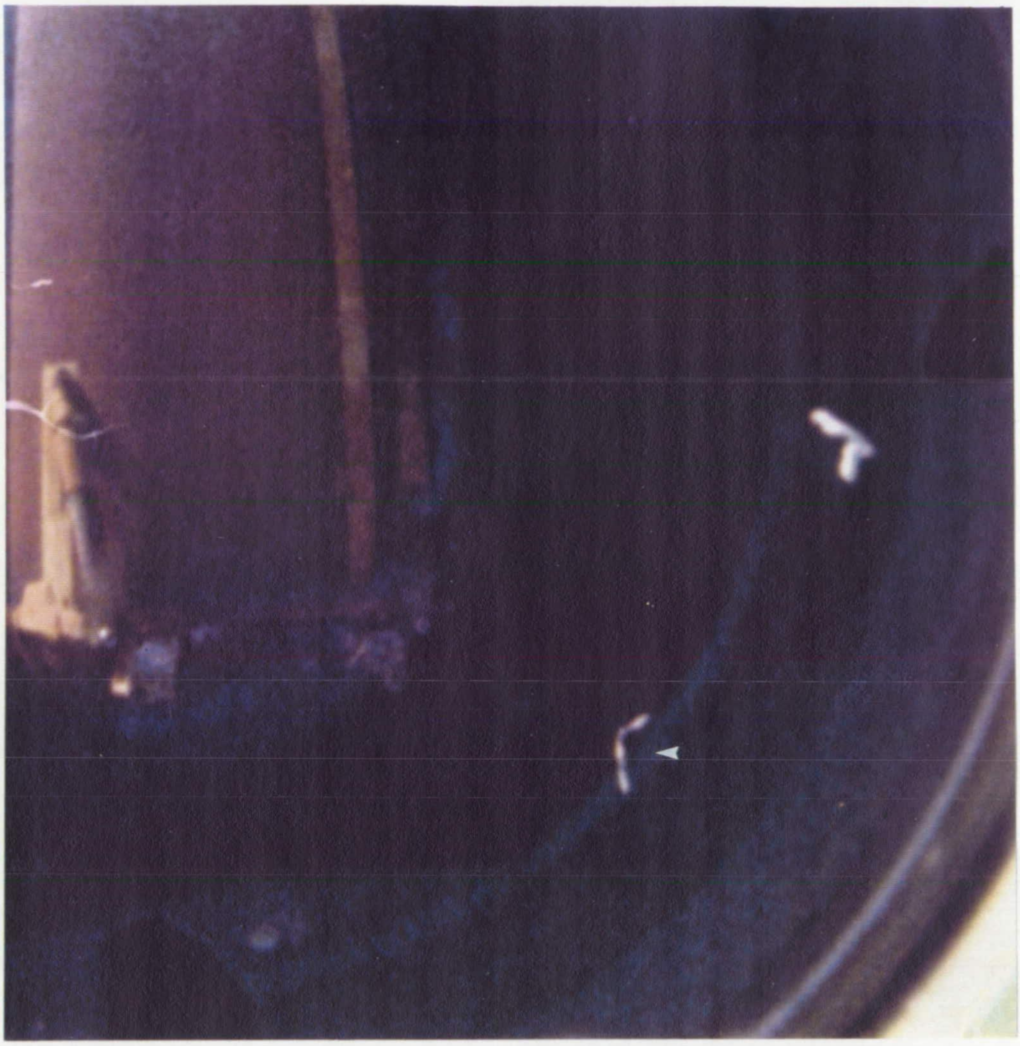


**Figure 2.4.2.2.2 (B)** **Flexible Strap-Like Debris after ET Separation**
(Frame STS-54-57-7956)

A small flexible strap-like piece of debris was seen after ET separation. KSC described this object as possibly a nylon wire tie/identifier.

Multiple pieces of white debris (possibly ice from the umbilical vent purge) were seen throughout the ET separation sequence. White debris was seen to strike the ET electrical cable tray and break into smaller pieces just prior to ET separation.

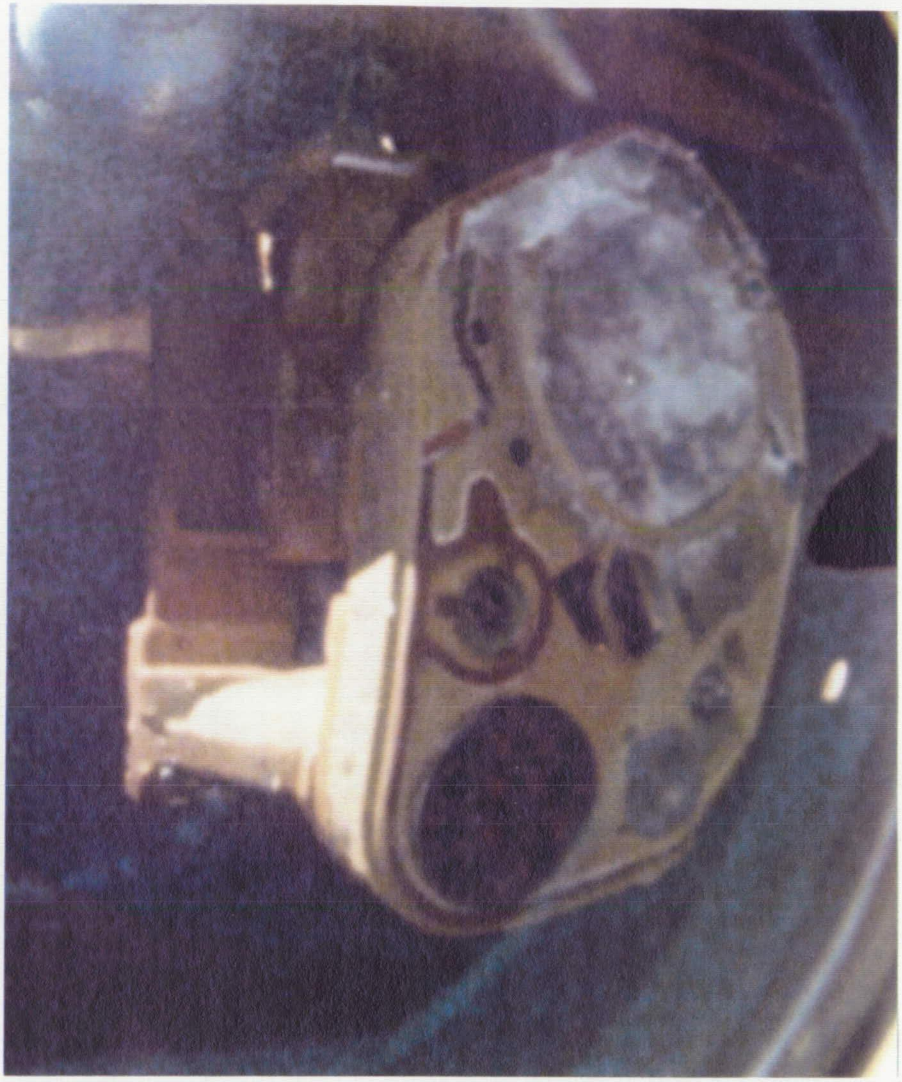


**Figure 2.4.2.2.2 (C)** **ET LH2 Umbilical after ET Separation**
(Frame STS-54-57-5228)

A blistered appearance was noted on the TPS on the left side of the LH2 umbilical as the ET began to move away from the Orbiter. Ice was visible in the orifice of the LH2 17 inch line as the LH2 umbilical came into full view. The bushing sleeves appeared to be in their proper positions.

### 2.4.2.3 35mm Umbilical Well Camera Views of the ET Separation *(Magazine 51)*

Sixty good quality frames of the external tank were screened on magazine 51 from the 35mm umbilical well camera. The visible portions of the LH2 tank TPS (+Z side of the ET), the aft dome and the ET nose appeared to be in excellent condition. The SRB separation burn scars appeared normal.

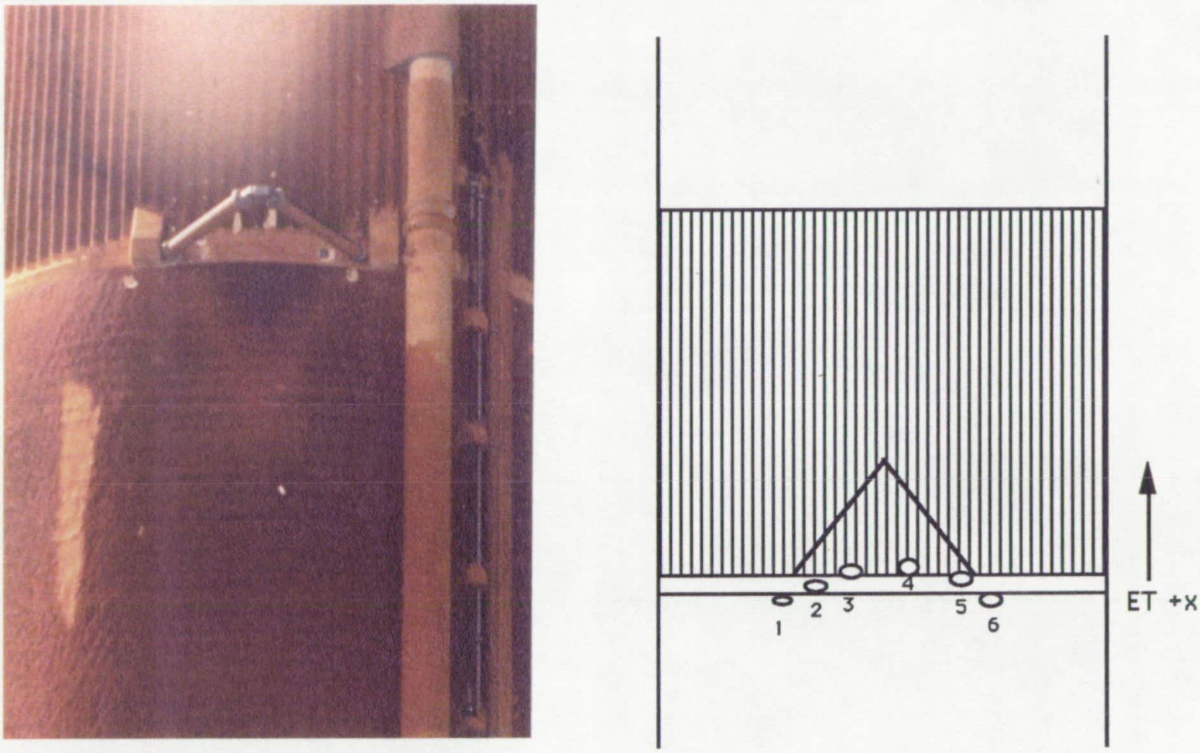
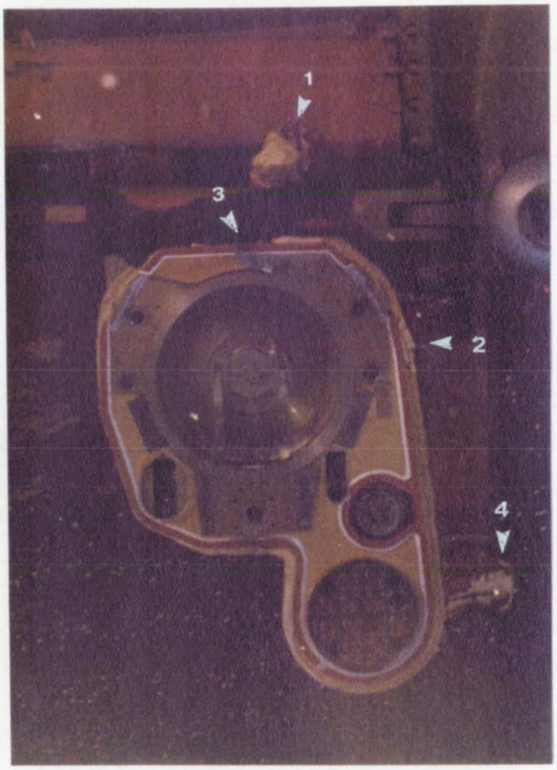



**Figure 2.4.2.3 (A)** **Divots Seen on ET TPS**
(Frame STS-54-51-042)

Six possible divots were seen near the forward ET/Orbiter attach bipod. Several marks on or near the LH2 tank/intertank TPS left of the bipod in the +Y direction were visible. Also seen (but not shown in the figure above) was a white vertical mark on the intertank TPS to the left of the forward bipod and two divots toward the left limb of the ET (+Y direction from the forward bipod) - one divot on the LH2 tank TPS and the other on the LH2 tank/intertank close-out TPS.

Divots have been seen near the forward ET/Orbiter attach bipod, along the intertank close-out and on the intertank TPS on previous mission films. Since reflight, divots in these same regions were reported on STS-28R, STS-29R, STS-32R, STS-41R, STS-35, STS-37, STS-40, STS-42, STS-45 and STS-47. (The divot on STS-47 was declared an inflight anomaly.) Similar divots were also seen on films from several missions prior to reflight including STS-51R, STS-51F, STS-61A and STS-61C.



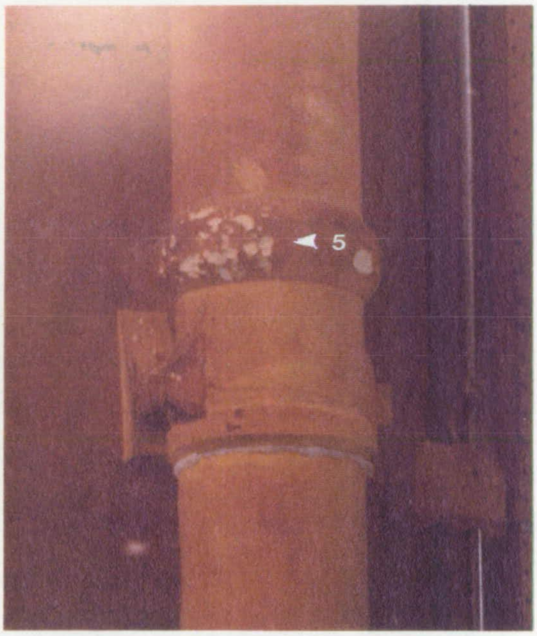


**Figure 2.4.2.3 (B) and (C) Loose Insulation and Other Marks on/near LO2 Umbilical**
(Frame STS-54-51-009)

Other items noted during the screening of the STS-54 35mm umbilical well film of the external tank included a piece of loose insulation just above the ET LO2 umbilical (1), a small white mark on the upper right rim of the ET LO2 umbilical (2), a small piece of gray colored material on top of the LO2 umbilical (3), a small amount of TPS erosion and small, white "popcorn" marks on the lower right side of the LO2 umbilical (4), and small TPS erosion marks on the aft bracket over the LO2 feed line (5). Also seen (but not shown in the figure above) was a small amount of TPS erosion on the forward end of the ET/Orbiter attach brace, a small white horizontal mark above the aft ET horizontal attach brace, small, white "popcorn" marks on the second and third brackets (forward from the LO2 umbilical) over the LO2 feed line, and small white debris (probably ice) between the Orbiter and the ET (visible on several frames). Detailed analysis on the umbilical well films can be found in Appendix D, Task #5.

### 2.4.3 Debris near Payload Bay *(Task #13)* *(Payload Bay Camera A)*

Numerous pieces of debris were observed on orbit from the Payload Bay Camera A between 13:22:01:44 UTC and 13:22:21:31 UTC after the Tracking and Data Relay Satellite (TDRS) deploy. Payload Bay Camera A was pointed toward the aft end of the Orbiter and none of the debris appeared to originate from within the payload bay. Most of the debris were small, but three large pieces were chosen for more detailed study as well as one small slow moving piece of debris that moved in an arced trajectory. The exact origin or composition of this debris is unknown (The most likely explanation is that the debris was ice from a water dump.) since the debris does not pass in front of a known object, the exact distance from the camera to the debris cannot be determined. Without knowing the debris' origin or its distance from the camera, the true size and velocity of the debris cannot be determined. The larger pieces of debris are, however, seen to pass behind the aft edge of the payload bay and this does allow for a minimum distance to be determined; therefore, a minimum size and velocity can also be found.

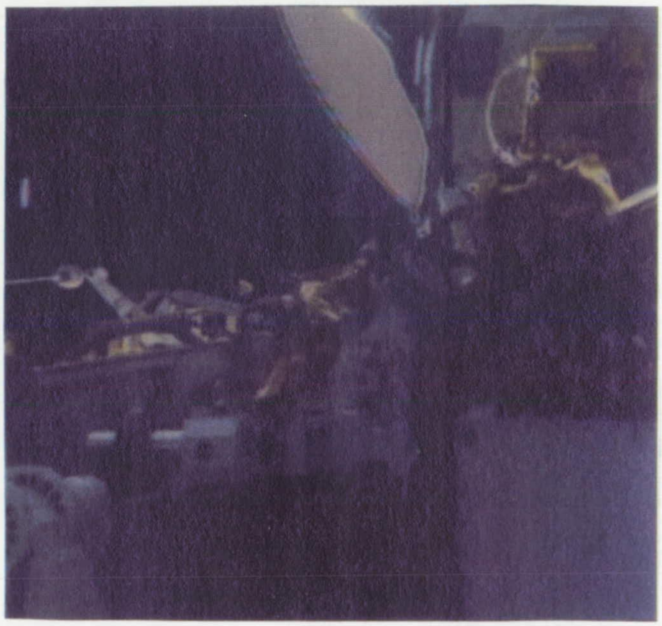


**Figure 2.4.3** **Debris Observed near Payload Bay**

For this study the debris was assumed to be close to the Orbiter and at the distance of the aft +y corner of the Payload Bay. (This represents a minimum distance since the debris was seen to be beyond the Payload Bay.) The distance from the camera to the aft +y corner of the payload bay was found to be approximately 726 inches. Another assumption was that all the debris motion was in the image plane of the camera. Since some of the debris motion was probably perpendicular to the image plane the velocities found in this study represent only two dimensional (2D) velocities. For more details on the determination of debris sizes and velocities see Appendix D, Task 13. A detailed timeline of the major debris events is also presented in Appendix D, Task 13.

The first piece of large debris, seen at 13:22:04:40.522 UTC, was elongated in shape and was seen on the +y side of the field of view (FOV) towards the aft end of the cargo bay and moved in the +y direction out of the FOV. The minimum length of the debris was 1.26 inches and its width was .5 inches and its minimum 2D velocity was 1.7 inches per second.

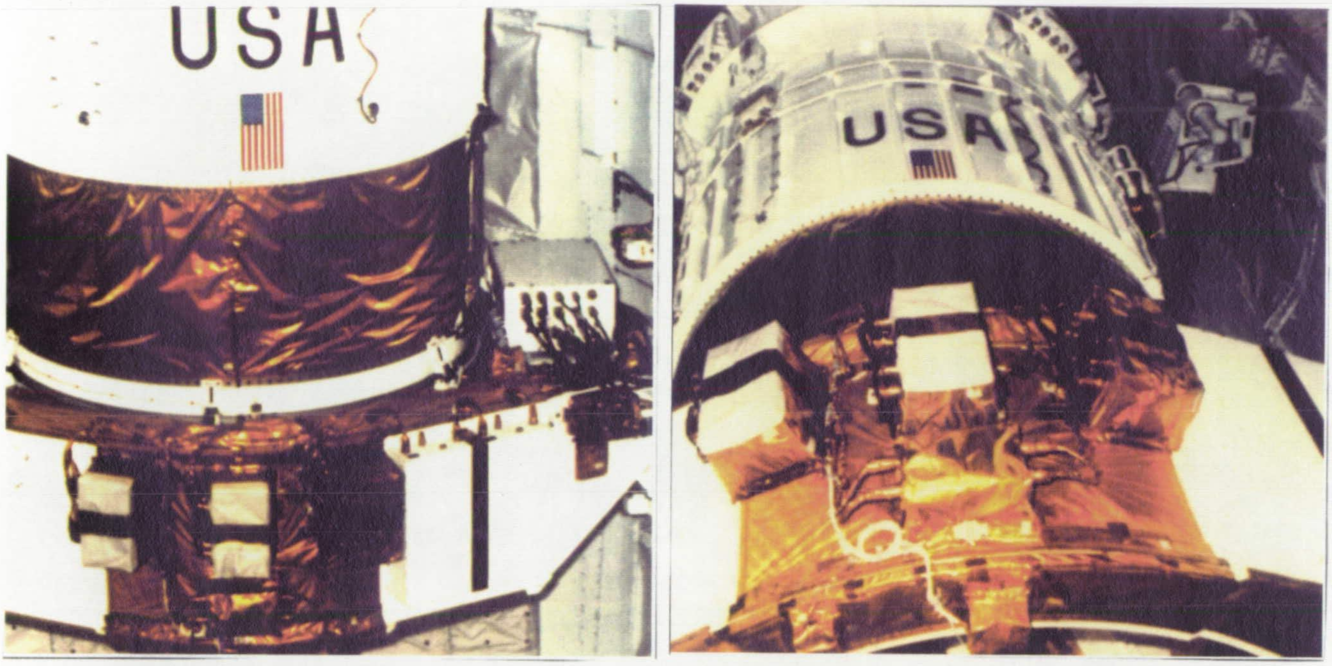
The second large piece of debris, seen at 13:22:12:06 UTC, was very large, rectangular in shape and was tumbling. Like the first large piece of debris, it was also observed toward the aft end of the payload bay on the +y side. The debris moved both in the +z and +y direction until it disappeared from the FOV. The minimum size of the object was approximately 3.2 inches x 3.4 inches x 1.2 inches and the approximate minimum velocity was 3 inches per second. The tumble rate of the debris was approximately 514 degrees per second.

A small slow moving piece of debris was noted to move in a curved trajectory at 13:22:14:29.749 UTC. This debris was unusual because it moved very slowly compared to the other debris and it moved in a curved trajectory (almost all the other debris was seen to move in a straight line trajectory). The debris was approximately 0.8 inches in length and the minimum 2D velocity of the debris was found to be .81 feet per second.

A third large piece of debris, seen at 13:22:18:11.923, was very bright, circular in shape, pulsated in brightness, and appeared to change color. The debris was seen moving in the -z and -y direction. (Note that this was one of only two pieces of debris seen moving in the -y direction.) The size of the debris was not measured because it appeared to be over saturated and the blooming of the brightness would make the object appear larger than it really was. The frequency of the pulsations was irregular and a graph of the brightness versus time is presented in Appendix D, Task 13.

### 2.4.4 Payload Bay Battery Analysis *(Task #15)* *(Payload Bay Cameras A, B and C)*

Onboard video coverage of six batteries in the aft Orbiter payload bay was provided by the INCO. Also provided were two prelaunch closeout pictures of the six batteries. The INCO requested that an analysis of this visual data be performed in order to determine if any post launch damage to the batteries could be detected.




**Figures 2.4.4 (A) and (B) Prelaunch Closeout Views of the Batteries**

A visual comparison was made between the closeout views and the onboard video views . No obvious signs of damage to any of the six batteries or associated structures could be detected. The edges of the battery boxes appeared straight and the covers to the battery box appeared intact (similar to the closeout views). The multi-layer insulation wrapping on the batteries was not seen to be torn, discolored or misshapen at the level of detail present in the INCO's videos. The multi-layer insulation covering over the individual batteries did have a "wrinkled" appearance which was consistent with the prelaunch closeout pictures. No liquid or vapor was detected in any of the onboard video views. The following is a summary by individual camera:

### 2.4.4.1 Camera A

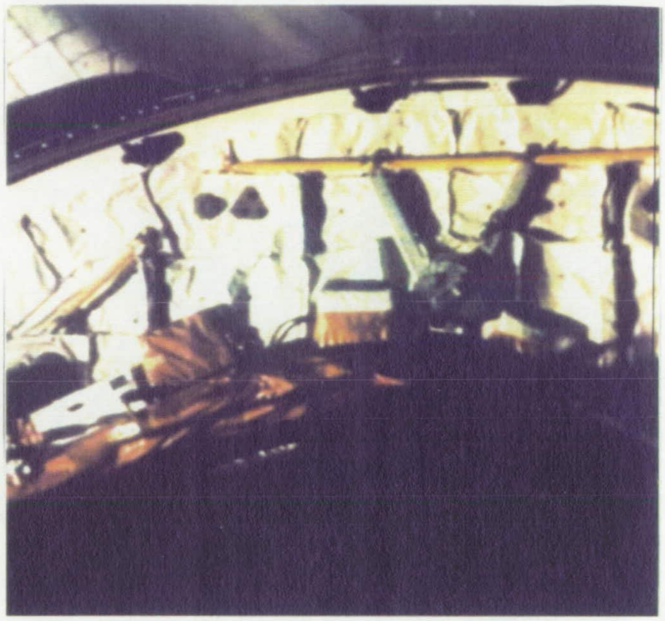


**Figure 2.4.4.1 View of Batteries from Payload Bay Camera A**

A discoloration was present on the white cover of the port forward battery; however, this was determined to be due to shadowing when viewed over a period of time. The cabling going to the middle group of batteries appeared to be positioned normally. The wrinkling of the multi-layer insulation on the starboard forward battery did not appear excessive when compared to the prelaunch closeout pictures.

### 2.4.4.2 Camera B

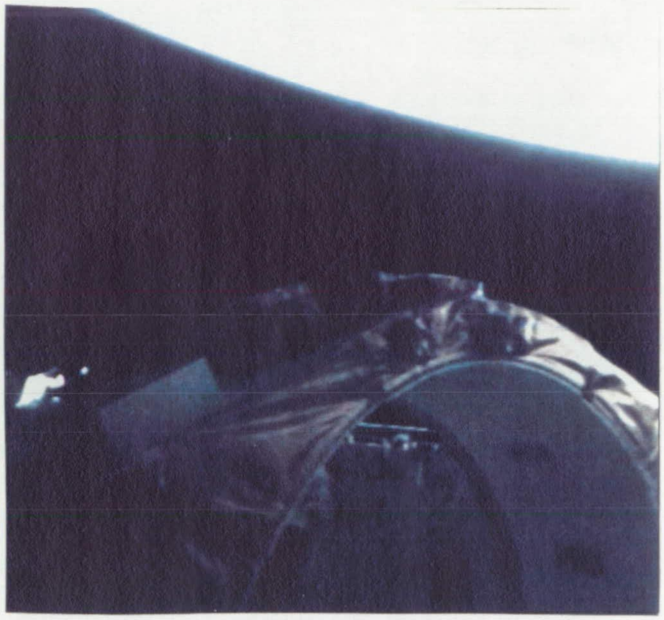


**Figure 2.4.4.2 View of Batteries from Payload Bay Camera B**

Wrinkling of the multi-layer insulation covering on the port rear and center rear batteries was visible. The covering over the top of these two batteries appeared intact.

### 2.4.4.3 Camera C

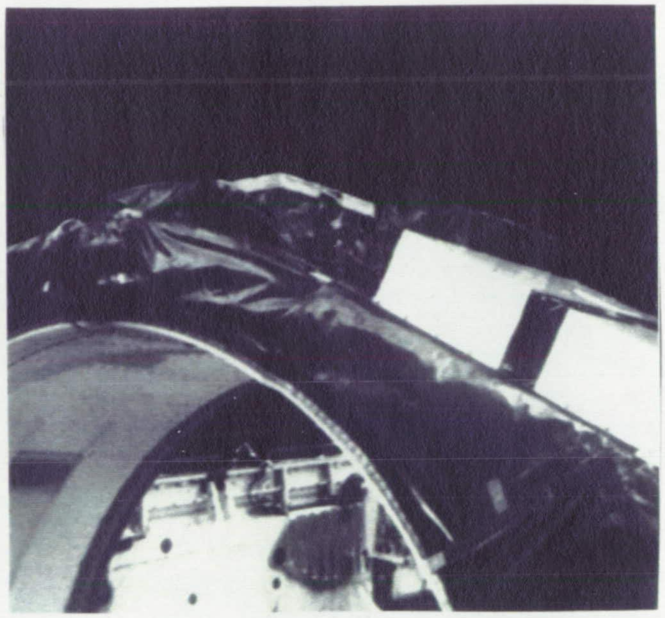


**Figure 2.4.4.3 View of Batteries from Payload Bay Camera C**

The visible portion of the starboard aft battery appeared in very good condition. The right side of the forward and aft center batteries were uneven in appearance - probably due to a wrinkling of the multi-layer insulation. The tops of the two batteries had a normal appearance. The tape-like stripping material between the two center batteries had an uneven appearance but this could not be confirmed to be abnormal due to the lighting and viewing angle.

## 2.5 Landing Events

### 2.5.1 Landing Sink Rate Analysis Using Film *(Task #3)* *(Cameras EL-12 and EL-15)*

Camera EL-15 film was used to determine the sink rate of the main gear before the initial contact and landing. Landing occurred at 13:37:48.221 GMT; however, the initial contact came at 13:37:46.665 GMT. The initial contact was made by the left main gear only. Scalar information was determined by a system of equations which took into account the orientation of the camera relative to the orbiter. Data was gathered approximately 1 second prior to initial contact of the left main gear through contact and prior to landing through touchdown at a rate of 48 frames per second which is the temporal resolution of the camera. The equations were solved for each observation which took into account the change in perspective as well as increase in size. The distance between the bottom of the wheel and the runway was computed and a linear regression was applied on this normalized vertical distance versus time data to find the actual sink rate. The rate before initial contact was determined to be 4.04 feet per second, and the rate before landing was determined to be 1.42 feet per second which is well within the current threshold limits.

Nose gear touchdown occurred approximately 14 seconds after main gear touchdown. Camera EL-012 was used to determine the nose gear sink rate in the same manner EL-15 was used for the main gear sink rate. This raw data was corrected for the vertical change in scale at each frame. The distance between the bottom of the wheel and the runway was computed and a linear regression was applied on this normalized vertical distance vs. time data to find the actual sink rate. This rate was determined to be 3.08 feet per second.

Graphs depicting the above data can be seen in Task #3 Appendix D.

### 2.5.2 Landing Sink Rate Analysis Using Video *(Task #3)* *(Camera TV-33)*

Camera TV-33 was used to determine the video sink rate of the main gear. Data was gathered approximately 1.6 seconds prior to landing through touchdown at a rate of 30 frames per second. The points digitized were right main gear, left main gear and top left (in the FOV) corner of the 4000 ft. marker. For main gear sink rate, the scale was found using the distance between the main landing gear struts. An assumption was made that the plane of the camera was parallel with the Orbiter's y-z plane. The y distance between the average position of the main gear and the 4000 foot marker was then multiplied by the scale to find the height of the main gear above the runway. These heights were then regressed with respect to time. The slope of the regression line was equal to the main gear sink rate. The analysis showed that the main gear sink rate was 4.34 feet per second for TV-33.

Nose gear touchdown occurred approximately 14 seconds after main gear touchdown. Camera TV-33 Video was used to determine the sink rate of the nose gear. Scalar information was determined by a system of equations which took into account the orientation of the camera relative to the orbiter. Data was gathered approximately 1 second prior to landing through touchdown at a rate of 30 frames per second which is the temporal resolution of the RTMOV program. The equations were solved for each observation which took into account the change in perspective as well as increase in size. The distance between the bottom of the wheel and the runway was computed and a linear regression was applied on this normalized vertical distance versus time data to find the actual sink rate. This rate was determined to be 2.99 feet per second

Graphs depicting the above data can be seen in Task #3 Appendix D.

### 2.5.3 Drag Chute Performance *(Task #9)* *(Camera EL-9)*

The landing of Endeavour at the end of mission STS-54 marked the sixth deployment of the Orbiter drag chute. All components of the drag chute appeared to deploy as expected. Standard analysis techniques of the drag chute angles were hampered by the extremely poor visibility at landing. Final analysis consisted of determining the drag chute heading angle as a function of time using the view from camera EL-9. This analysis will be used to support the improvement of the aerodynamic math models currently in use.

Relative position data of the vertical stabilizer and the center of the drag chute were collected using a 35mm film motion analyzer and photography from camera EL-9. This camera was located on the center line at the approach end of the runway. The rate which the film was sampled was approximately 25 frames per second for approximately 14 seconds. Timing information was not present on the film and was estimated based on the drag chute deploy initiation and the drag chute release positions on the photography. Using the relative position of the vertical stabilizer with respect to the center of the drag chute and the drag chute radius, an approximate heading angle was able to be calculated.

Graphical representation of the results of this analysis may be found in Appendix D, Task #9.

### 2.5.4 Nozzle from Sweeper Truck

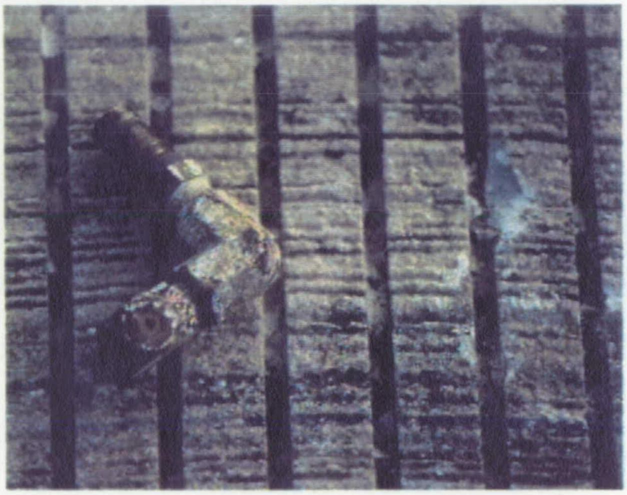


**Figure 2.5.4 Nozzle from Sweeper Truck**

A piece of debris was found on the runway after the landing of the Endeavour at KSC. This debris was identified by KSC as a nozzle from a sweeper truck used to clean the runway prior to Orbiter landings. A JSC engineer from Structures and Mechanics indicated that the shape of this piece of debris might possibly have been the cause of tire damage incurred during landing.

### 2.6 Other Normal Events

Other normal events observed include: FSS deluge water; ice buildup on the SSME vent nozzles; ice debris and vapor from the ET/Orbiter umbilical disconnects at SSME startup through



ORIGINAL PAGE
COLOR PHOTOGRAPH

liftoff; slight vapor from the gaseous oxygen (GOX) vent on the ET, flashes in the SSME plume prior to liftoff; slight motion of the body flap between SSME ignition and liftoff; base heat shield erosion during SSME startup; ice and vapor from the GUCP during SSME startup and arm retraction; ice and vapor from both Tail Service Mast (TSM) umbilicals at liftoff; debris in the exhaust cloud at the pad after liftoff; RCS paper debris prior to and after liftoff; ET aft dome outgassing and vapor from the SRB stiffener rings after liftoff; charring of the ET aft dome during ascent; debris in the SSME exhaust plume from liftoff through the roll maneuver; flares in the SSME exhaust plume after the roll maneuver; expansion waves; linear optical distortion; condensation around the Space Launch Vehicle (SLV) during ascent; SRB plume brightening; slag debris in the SRB exhaust plume during and after SRB separation.

# Appendix B. MSFC Photographic Analysis Summary

National Aeronautics and
Space Administration

**George C. Marshall Space Flight Center**
Marshall Space Flight Center, Alabama 35812
AC(205)544-2121

NASA

y to Attn of: EP53 (93-05)

TO: Distribution

FROM: EP53/Tom Rieckhoff

SUBJECT: Engineering Photographic Analysis Report for STS-54

Enclosed is the Engineering Photographic Analysis Report for the Space Shuttle Mission STS-54. For additional copies, or for further information concerning this report, contact Tom Rieckhoff at 544-7677, or Darlene Busing, Rockwell at 971-3174.

Tom Rieckhoff

Tom Rieckhoff

Enclosure

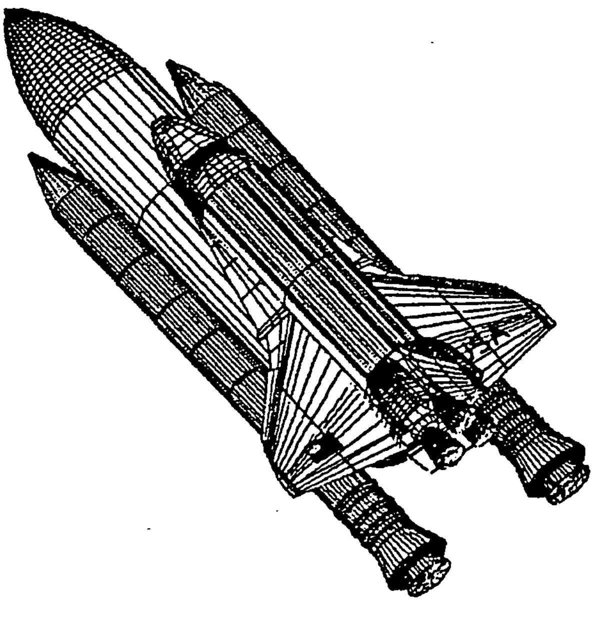
NASA
National Aeronautics and
Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

# SPACE SHUTTLE

# ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

# STS-54



MSFC - Form 454 (Rev. October 1976)

# ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

STS-54

FINAL

PREPARED BY:

D.BUSING, J. HIXSON, B. VIGER
PHOTOGRAPHIC ANALYSIS/ROCKWELL/HSV

SUBMITTED BY:

for JIM ULM
SUPERVISOR, LAUNCH OPERATIONS/ROCKWELL/HSV

APPROVED BY:

T. RIECKHOFF, MSFC/EP53
B. LINDLEY-ANDERSON, MSFC/EP53

# STS-54 ENGINEERING PHOTOGRAPHIC ANALYSIS REPORT

## TABLE OF CONTENTS



* Photographs in the individual camera assessments are representative photographs and are not necessarily photographs taken from this particular launch.

February 08, 1993

## I. INTRODUCTION

Space Shuttle Mission STS-54, the third flight of the Orbiter Endeavour was conducted January 13, 1993 at approximately 7:59 A.M. Central Standard Time from Launch Complex 39B (LC-39B), Kennedy Space Center (KSC), Florida. Extensive photographic and video coverage was provided and has been evaluated to determine proper operation of the ground and flight hardware. Cameras (video and cine) providing this coverage are located on the fixed service structure (FSS), mobile launch platform (MLP), LC-39B perimeter sites, onboard, and uprange and downrange tracking sites.

## II. ENGINEERING ANALYSIS OBJECTIVES:

The planned engineering photographic and video analysis objectives for STS-54 included, but were not limited to the following:

a. Overall facility and Shuttle vehicle coverage for anomaly detection
b. Verification of cameras, lighting and timing systems
c. Determination of SRB PIC firing time and SRB separation time
d. Verification of Thermal Protection System (TPS) integrity
e. Correct operation of the following:
   1. Holddown post blast covers
   2. SSME ignition
   3. LH2 and LO2 17" disconnects
   4. GH2 umbilical
   5. TSM carrier plate umbilicals
   6. Free hydrogen ignitors
   7. Vehicle clearances
   8. GH2 vent line retraction and latch back
   9. Vehicle motion

There was one special test objective for this mission:

a. DTO-0312, ET photography after separation

## III. CAMERA COVERAGE ASSESSMENT:

Film was received from fifty-six of fifty-seven requested cameras as well as video from twenty-three of twenty-four requested cameras. The following table illustrates the camera data received at MSFC for STS-54.

CAMERA DATA RECEIVED FOR STS-54

| | 16mm | 35mm | Video |
|---|---|---|---|
| MLP | 22 | 0 | 4 |
| FSS | 7 | 0 | 2 |
| Perimeter | 3 | 3 | 6 |
| Tracking | 0 | 15 | 11 |
| Onboard | 3 | 3 | 0 |
| Totals | 35 | 21 | 23 |

A detailed individual motion picture camera assessment is provided as Appendix B. Appendix C contains detailed assessments of the video products received at MSFC.

a. Ground Camera Coverage:

Photographic coverage of STS-54 was considered good. Coverage from some tracking cameras was limited due to cloud coverage. Camera E-211 did not run due to a mechanical problem. Camera E-213 experienced a tracking problem. No engineering data were obtained from these cameras. Video camera OTV-5 was not received, at MSFC, due to a circuit malfunction.

b. Onboard Camera Assessment:

A camera was flown on each SRB forward skirt to record the main parachute deployment. Both cameras operated properly, with the exception that neither camera recorded water impact. The astronauts carried two 35mm hand-held cameras, one of which had a 2X extender to record film for evaluating the ET TPS integrity after ET separation. A 35mm still and a 16mm high speed film camera were flown on board Endeavour in the 17" umbilical wells to record SRB and ET separation.

IV. ANOMALIES/OBSERVATIONS:

a. General Observations:

While viewing the film, several events were noted which occur on most missions. These included: pad debris rising and falling as the vehicle lifts off; debris induced streaks in the SSME plume; ice falling from the 17" disconnects and umbilicals; and debris particles falling aft of the vehicle during ascent, which consist of RCS motor covers, hydrogen fire detectors and purge barrier material.

At SSME start, orange vapors were noticed pulsating in the boattail area. These vapors may be a result of shock waves and high humidity. At 13:59:30.060, the plume in SSME #1 brightens slightly. This observation has been seen on other missions.

b. Green Streaks in SSME #1:

Figure one is a frame of film from camera E-2 showing several green streaks noted in SSME #1, starting at 13:59:27.941. These streaks were noted in several other cameras. This type of green streak has been observed in the engine plume on single engine tests. However, this is the first occurrence of a green streak on a flight engine.

c. Condensation Cloud Noted:

Figure two is a frame of film taken from camera E-62 showing a large condensation cloud which is thought to be caused by the combination of high humidity and the SRB shock wave. This event was also observed on several other cameras.

d. Debris From Body Flap Area:

Figure three is a frame of film taken from camera E-17 showing a dark, oblong piece of debris originating from between the body flap and the Orbiter. This debris is noted traveling down the body flap and does not strike the Orbiter.

e. ET TPS Divots:

Figure four is a frame of film taken from the 35mm umbilical well camera showing eight or more TPS divots noted around the LH2 tank/intertank interface, on the +Z axis.

f. ET Separation Debris:

Figure five is a frame of film taken from the 16mm umbilical well camera showing two metallic objects. The first object is a cylindrical shaped object with a hollow center, most likely a washer. The second is a small rod shaped object, most likely a cotter pin.

g. SRB Plume Study:

The following films were reviewed to support the analysis of the right SRB chamber pressure increase:

| | |
|---|---|
| STS-37 | STS-46 |
| STS-40 | STS-48 |
| STS-42 | STS-54 |
| STS-44 | |

The film analysis has revealed no observable changes in plume brightness or anomalous changes in plume shape. Also, there were no unusual particles noted exiting the plume.

An analysis using image processing techniques was done on the SRB plume from STS-54 to determine if there were any changes in plume intensity that may have been undetectable to the human eye. For comparison purposes, this analysis was repeated on the plume from STS-40 which had a similar pressure increase. The results from this study are inconclusive due to the excessive noise induced into the data during the digitization process.

## V. ENGINEERING DATA RESULTS:

### a. T-Zero Times:

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

| POST | CAMERA POSITION | TIME (UTC) |
|---|---|---|
| M-1 | E-9 | 013:13:59:29.998 |
| M-2 | E-8 | 013:13:59:29.996 |
| M-5 | E-12 | 013:13:59:29.998 |
| M-6 | E-13 | 013:13:59:29.997 |

### b. ET Tip Deflection:

Maximum ET tip deflection for this mission was determined to be approximately 31.9 inches. Figure six is a data plot showing the measured motion of the ET tip in both the horizontal and vertical directions. These data were derived from camera E-79.

### c. SRB Separation Time:

SRB separation time for STS-52 was determined to be 013:14:01:35.68 UTC taken from camera E-212.

Figure 1

Green Streaks Noted in SSME #1

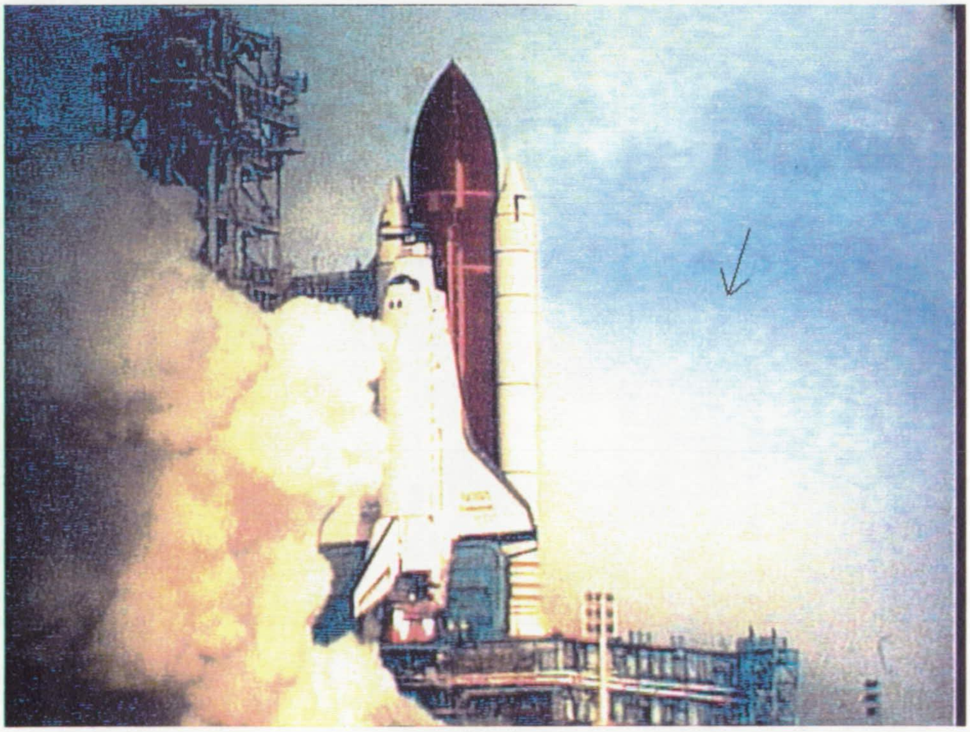


Figure 2

Large Condensation Cloud

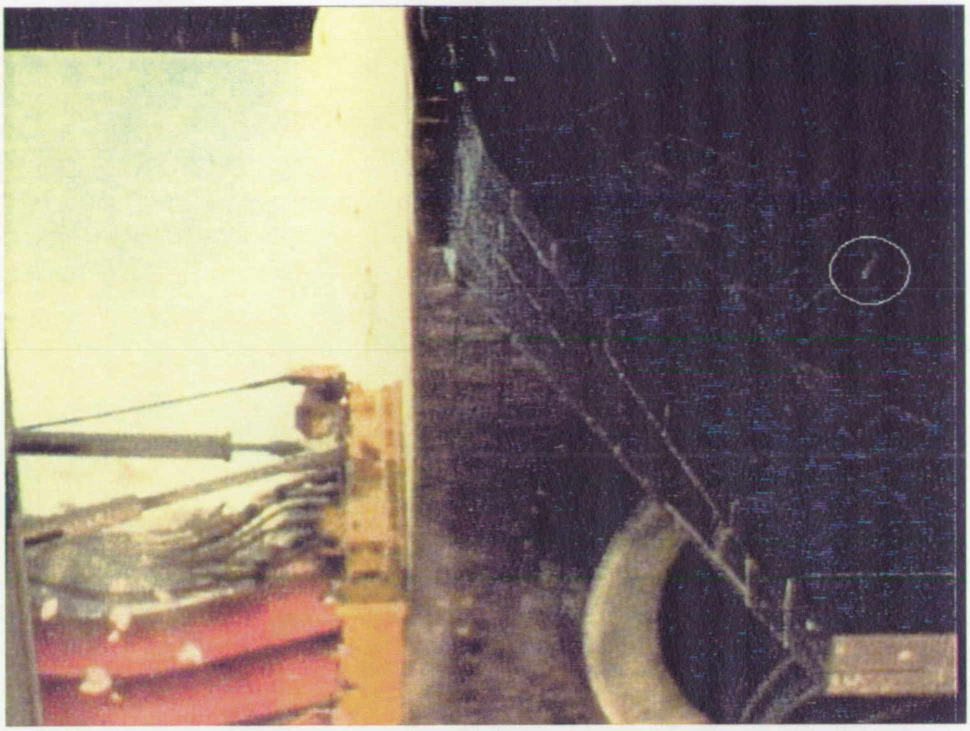


Figure 3

Debris From Body Flap Area

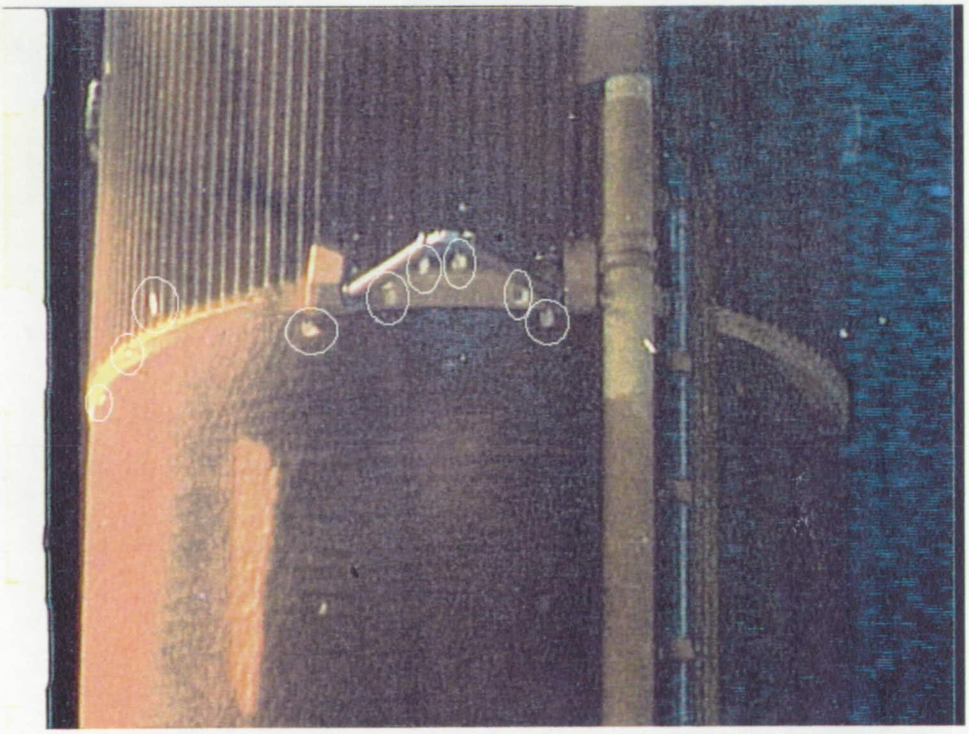


Figure 4

TPS Divots

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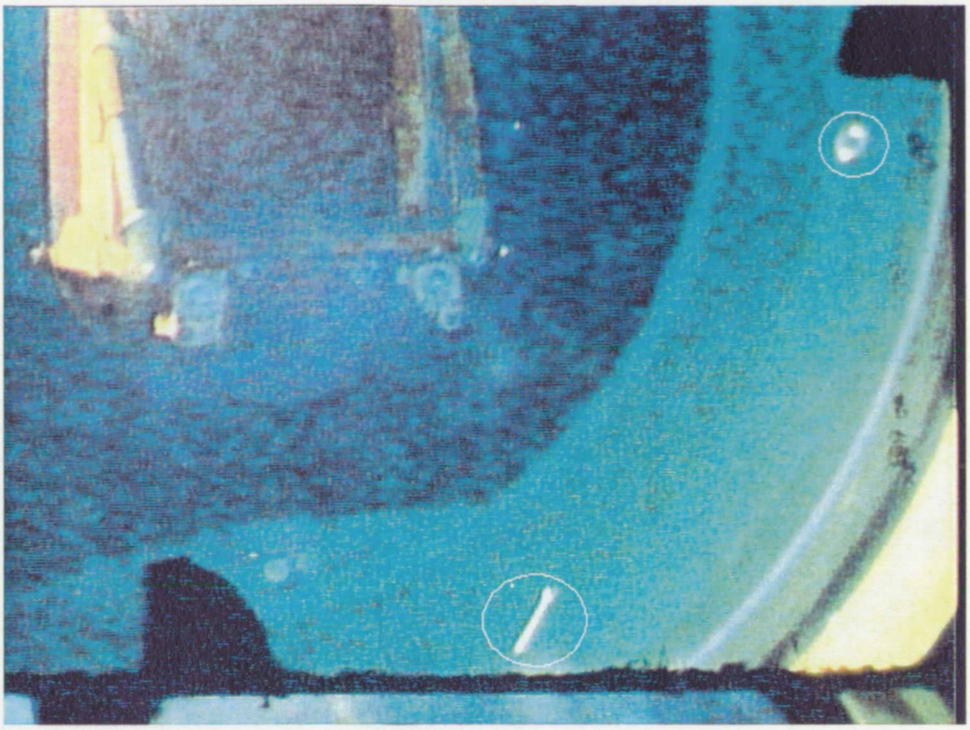

Figure 5

ET Separation Debris

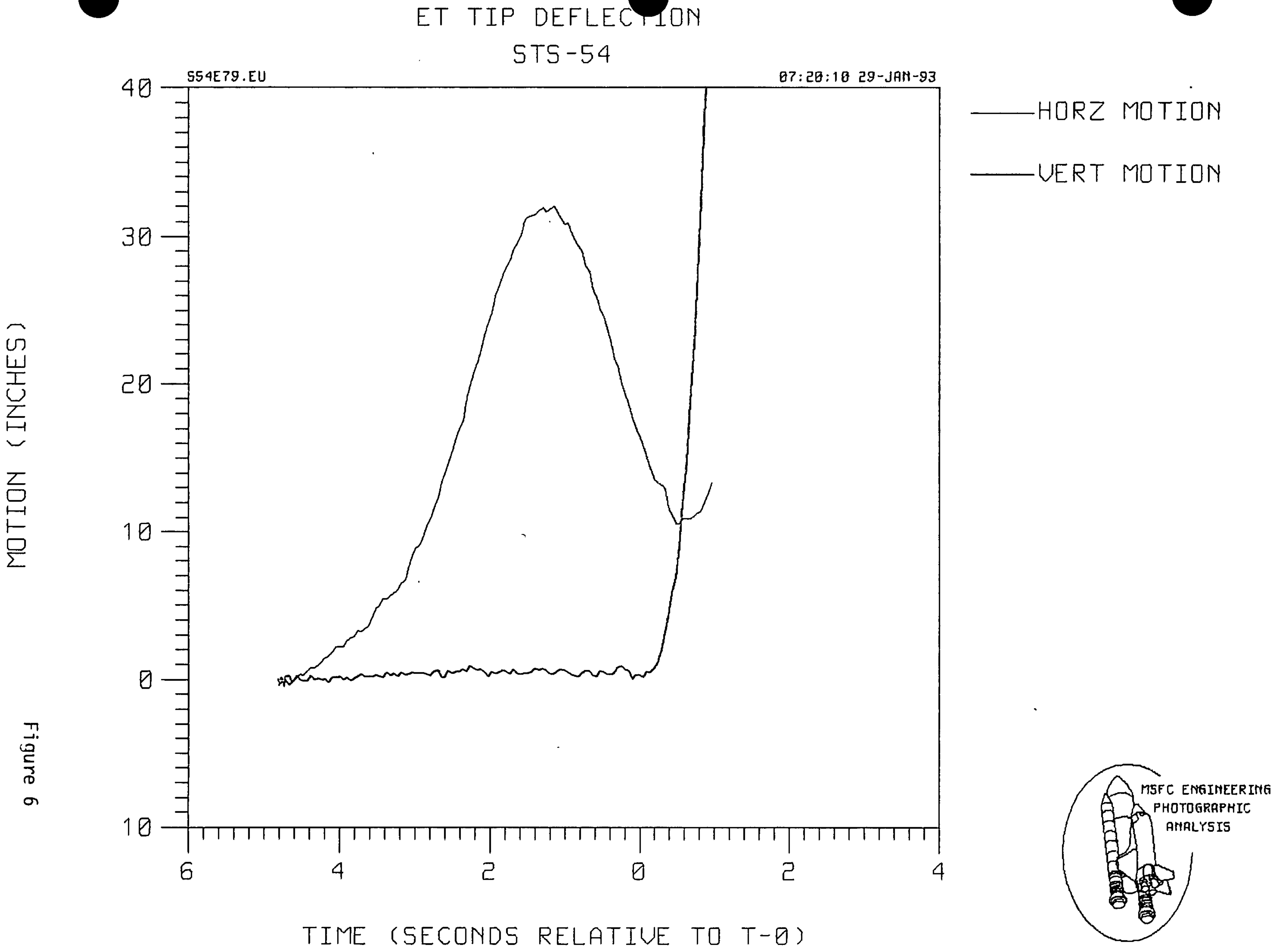
ET TIP DEFLECTION
STS-54
S54E79.EU
07:20:10 29-JAN-93
HORZ MOTION
VERT MOTION
MOTION (INCHES)
40
30
20
10
0
10
6
4
2
0
2
4
TIME (SECONDS RELATIVE TO T-0)
MSFC ENGINEERING
PHOTOGRAPHIC
ANALYSIS

Figure 6

## Appendix C. Rockwell Photographic Analysis Summary

Space Transportation Systems Division
Rockwell International Corporation
12214 Lakewood Boulevard
Downey, California 90241

Rockwell
International

February 24, 1993 In reply Refer to 93MA0600

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, Texas 77058

Attention: L. G. Williams (WA)

Contract NAS9-18500, System Integration, Transmittal of the Rockwell Engineering Photographic Analysis Report for the STS-54 Mission.

The System Integration Contractor hereby submits the Engineering Photographic Analysis Summary Report in accordance with the Space Shuttle Program Launch and Landing Photographic Engineering Evaluation Document (NSTS 08244).

Extensive photographic and video coverage was provided and has been evaluated to determine ground and flight performance. Cameras (cine and video) providing this coverage are located on the Launch Complex 39B, Fixed Service Structure (FSS), Mobile Launch Platform (MLP), various perimeter sites, and uprange and downrange tracking sites for the STS-54 launch conducted on January 13, 1993 at approximately 5:59 AM (PST) from the Kennedy Space Center (KSC ) and for the landing on January 19, 1993 at KSC (5:38 AM PST).

Rockwell received launch films from 82 cameras (58 cine, 24 video) and landing films from 22 cameras (14 cine, 8 video) to support the STS-54 photographic evaluation effort. One film, E-211 was not available due to camera malfunction.

All ground camera coverage for this mission including coverage on the MLP, FSS and tracking cameras were good.

Overall, the films showed STS-54 to be a clean flight. Several pieces of ice from the ET/ORB umbilicals were shaken loose at SSME ignition, but no damage to the Orbiter Thermal Protection System (TPS) was apparent. The usual condensation and water vapors were seen at the ET aft dome and the SRB stiffener rings and dissipated after the completion of the roll maneuver. Vapor was observed in the vicinity of the rudder/speed brake at liftoff. Charring of the ET aft dome and recirculation and brightening of the SRB plumes were visible and normal. Booster Separation Motor (BSM) firing and SRB separation also appeared to be normal.



(Packing Sheet No. DM93-08893)

Nominal performance was seen for the MLP and FSS hardware. FSS deluge water was activated prior to SSME ignition and the MLP rainbirds were activated at approximately 1 second Mission Elapsed Time (MET), as is normal. All blast deflection shields closed prior to direct SRB exhaust plume impingement. Both TSM umbilicals released and retracted as designed. The ET GH2 vent line carrier dropped normally and latched securely with no rebound. No anomalies were identified with the ET/ORB LH2 umbilical hydrogen dispersal system hardware.

STS-54 was the thirteenth flight with the optimized attach link in the SRB holddown support post Debris Containment Systems (DCS's). The link is designed to increase the plunger velocity and seating accuracy, while leaving the holddown bolt ejection velocity unchanged. This prevents frangible nut fragments and/or NSI cartridges from falling from the DCS, while not increasing the probability of a holddown bolt hang-up. However, during the review of the holddown post films for this mission, a piece of (dark) debris was observed originating from the DCS area at liftoff.

Significant events that were observed were the green streaks in the SSME #1 plume just prior to liftoff and the three debris objects seen in the film from the LH2 ET/ORB umbilical 16mm camera shortly after ET separation. These events and other events noted by the Rockwell film/video users during the review and analysis of the STS-54 photographic items are summarized in the following comments. These events are not considered to be a constraint to next flight.

<u>COMMENTS</u>

1. Green streaks or flashes were noted in the SSME #1 plume just prior to liftoff on cameras E-2, E-3, E-19, E-52 and E-76. The streaks were seen at GMT 13:59: 26.913, 13:59:27.592, 13:59:27.941 and 13:59:27.970 and may be copper debris contamination. Post landing inspection of the Main Combustion Chamber by Rocketdyne did not reveal the source and cause of the green streaks. Rocketdyne will investigate further, after the engine is removed the second week of February. No follow-up photographic analysis has been requested.

2. During the screening of the DTO-312, 16mm camera film, three debris objects were noted in the LH2 ET/ORB umbilical camera (5mm lens) field of view shortly after ET separation. The objects noted were; 1) a small metallic appearing cylindrical or washer shaped object with a hole in the center (frames 7354-7547), 2) a small metallic appearing rod or pin shaped object with a possible hole or opening at one end (frames 7431-7809), and 3) a small appearing flexible strap or tape like object (frames 7907-8094). No positive identification of these objects as flight hardware has been made. Review of the film and selected frame enlargements continue at RI/Downey, JSC and KSC in an effort to identify the debris objects and resolve this in-flight anomaly.

3. On camera E-12, a dark piece of debris was seen near the DCS area of holddown post M-5 at liftoff. This debris did not appear to strike the vehicle. No further analysis is planned.

4. On cameras KTV-7B, ET-207, ET-213, E-15, E-25, E-26, E-30, E-34, E-35, E-36, E-40, E-41, E-50, E-54 and E-59, a large cloud of vapor was seen moving north from the base of the SLV at liftoff. This is believed to be a manifestation of shock waves typically seen at launch. Due to existing temperature (72° F) and dew point (69°F) conditions, a large condensation cloud showing the pulsing characteristics of pressure waves was generated at liftoff. This event is similar to the condensation which forms around the vehicle on some launches as it travels through a moisture layer in the atmosphere. Before reaching these conclusions the image analysis teams at JSC, MSFC and KSC consulted with each other and corroborated on the conclusions. A statement was then given to the Public Affairs Office at JSC in regard to an inquiry concerning this vapor cloud.

   Rockwell concurs with this conclusion and no follow-up action is planned.

5. Orange vapor (possibly free burning hydrogen) was seen beneath the body flap at SSME ignition on cameras OTV-163, E-2, E-18, E-30 and E-36. This vapor appears to be similar to the vapor noted on previous missions. It is not an issue and no follow-up action is planned.

6. On cameras OTV-170, E-2, E-3 and E-19 and orange flash was noted in the SSME #1 plume prior to liftoff. Orange flashes have been seen on previous missions. No follow-up action is planned.

7. On camera E-8, a piece of tape debris was ejected out of the SRB exhaust hole at liftoff. This debris did not appear to strike the vehicle. No follow-up action is planned.

8. On cameras OTV-170, E-4, E-5, E-6, E-34, E-35, E-41, E-52, E-54, E-76, E-212 and E-213, multiple pieces of light colored debris were seen falling aft of the vehicle at liftoff. This debris is similar to that seen on previous missions. No follow-up action is planned.

9. Multiple pieces of light-colored debris (probably ice) were seen falling along the underside of the body flap and into the SSME plume at liftoff on cameras E-31 and E-33. This debris did not appear to contact the vehicle. No follow-up action is planned.

10. The following events have been reported on previous missions and observed on STS-54. These are not of major concern, but are documented here for information only.
    - Ice debris falling from the ET/Orbiter Umbilical disconnect area.
    - Debris (Pad, insta-foam, water trough) in the holddown post areas and MLP.

- Butcher paper falling from the RCS.
- Recirculation or expansion of burning gases at the aft end of the SLV prior to SRB separation.
- Slight TPS erosion on the base heat shield during SSME start-up.
- Twang Motion
- Body flap motion during the maximum dynamic pressure (MAX-Q) region which appeared to have an amplitude and frequency similar to those of previous missions.
- Linear optical distortion, possibly caused by shock waves or ambient meteorological conditions near the vehicle, during ascent
- Slag in SRB plume after separation.
- Condensation around the SLV during ascent.
- Vapor from the SRB stiffener rings after liftoff.
- Fore-and-aft movement of the Orbiter base heat shield in the centerline area between the SSME cluster at engine start-up.

11. Cameras E33 and E41 - OMRSD File IX Vol. 5, Requirement No. DV08P.010 requires an analysis of launch pad film data to verify that the initial ascent clearance separation between the left SRB outer mold line and the falling ET vent umbilical structure does not violate the acceptable margin of safety.

    A qualitative assessment has been conducted and positive clearances between the left SRB and the ET vent umbilical have been verified. The films showed nominal launch pad hardware performance, and no anomalies were observed for the SRB body trajectory.

12. Cameras E7-16 and E27-28 - OMRSD File IX Vol. 5, Requirement No. DV08P.020 requires an analysis of film data of SRM nozzle during liftoff to verify nozzle to holddown post drift clearance.

    A qualitative assessment of the launch films has been completed. No anomalies were observed for the SRM nozzle trajectory and positive clearances between the SRB nozzles ad the holddown posts were verified.

13. The landing of STS-54 occurred on runway 33 at the KSC Shuttle landing facility. Good video and film coverage were obtained and no anomalous events were and no hardware anomalies were observed. The drag chute appeared to make an excursion to the right about 5 degrees as noted on previous flights.

This letter is of particular interest to W. J. Gaylor (VF2) and J. M. Stearns (WE3) at JSC. The Integration Contractor contact is R. Ramon at (310) 922-3679.

**ROCKWELL INTERNATIONAL**
Space Systems Division

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A Debris/Ice/TPS assessment and integrated photographic analysis was conducted for Shuttle Mission STS-54. Debris inspections of the flight elements and launch pad were performed before and after launch. Ice/frost conditions on the External Tank were assessed by the use of computer programs, nomographs, and infrared scanner data during cryogenic loading of the vehicle followed by on-pad visual inspection. High speed photography was analyzed after launch to identify ice/debris sources and evaluate potential vehicle damage and/or in-flight anomalies. This report documents the debris/ice/TPS conditions and integrated photographic analysis of Shuttle Mission STS-54, and the resulting effect on the Space Shuttle Program.

**14. SUBJECT TERMS**

STS-54 Ice Frost Debris
Thermal Protection System (TPS) Photographic Analysis

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