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STS-51 SPACE SHUTTLE MISSION REPORT

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STS-51

SPACE SHUTTLE

MISSION REPORT

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INTRODUCTION

The STS-51 Space Shuttle Program Mission Report summarizes the Payloads as well as the Orbiter, External Tank (ET), Solid Rocket Booster (SRB), Redesigned Solid Rocket Motor (RSRM), and the Space Shuttle main engine (SSME) systems performance during the fifty-seventh flight of the Space Shuttle Program and seventeenth flight of the Orbiter vehicle Discovery (OV-103). In addition to the Orbiter, the flight vehicle consisted of an ET designated as ET-59; three SSME's which were designated as serial numbers 2031, 2034, and 2029 in positions 1, 2, and 3, respectively; and two SRB's which were designated BI-060. The lightweight RSRM's that were installed in each SRB were designated as 360W033A for the left SRB and 360L033B for the right SRB.

The STS-51 Space Shuttle Program Mission Report fulfills the Space Shuttle Program requirement as documented in NSTS 07700, Volume VIII, Appendix E. That document states that each major organizational element supporting the Program will report the results of their hardware evaluation and mission performance plus identify all related in-flight anomalies.

The primary objectives of this flight were to successfully deploy the Advanced Communication Technology Satellite/Transfer Orbit Stage (ACTS/TOS) payload and to perform the operations required to support the Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer - Shuttle Pallet Satellite (ORFEUS-SPAS) payload. Secondary objectives of this flight were to perform the operations of the IMAX Camera payload, the Limited Duration Space Environment Candidate Materials Exposure (LDCE) experiments, the Commercial Protein Crystal Growth (CPCG) experiment, the Chromosome and Plant Cell Division in Space experiment (CHROMEX), the High Resolution Shuttle Glow Spectroscopy-A (HRSGS-A) experiment, the Auroral Photography Experiment-B (APE-B), the Investigations into Polymer Membrane Processing (IPMP) payload, the Radiation Monitoring Equipment (RME-III) and the Air Force Maui Optical Alignment Site (AMOS) Calibration Test experiment.

The sequence of events for the STS-51 mission is shown in Table I, the official Orbiter and GFE Projects Problem Tracking List is shown in Table II, and the official MSFC In-flight Anomaly List is shown in Table III. In addition, the Integration and Payload in-flight anomalies are referenced in the applicable sections of the report. Appendix A lists the sources of data, both formal and informal, that were used in the preparation of this document. Appendix B provides the definition of acronyms and abbreviations used in this document. All times given in this report are in Greenwich mean time (G.m.t.) as well as mission elapsed time (MET).

The STS-51 mission was planned as a 9 + 1 day duration mission. The nominal duration was 9 days with an additional day being highly desirable. This additional day capability was to be determined in real-time based on consumables, with mission planning accommodating the longer duration wherever appropriate. Also, two additional contingency days existed in the planning.

In addition to presenting a summary of subsystem performance, this report also discusses the payload operations and results, as well as each in-flight anomaly that was assigned to each major element (Orbiter, SSME, ET, SRB, and RSRM).

Listed in the discussion of each anomaly in the applicable subsection of the report is the officially assigned tracking number as published by each respective Project Office in their respective Problem Tracking List.

The 5-person crew for this fifty-seventh flight of the Space Shuttle was Frank L. Culbertson, Capt., U. S. Navy, Commander; William F. Readdy, Civilian, Pilot; James H. Newman, Ph.D., Civilian, Mission Specialist 1; Daniel W. Bursch, Cdr., U. S. Navy, Mission Specialist 2; and Carl E. Walz, Lt. Col., U. S. Air Force, Mission Specialist 3; STS-51 was the second space flight for the Commander and the Pilot, and the first space flight for Mission Specialist 1, Mission Specialist 2, and Mission Specialist 3.

MISSION SUMMARY

The first launch attempt (July 17, 1993) of the STS-51 flight was scrubbed while in the T-20 minute hold because of an anomaly in the mobile launch platform (MLP). At approximately L-2 hours, the system B External Tank vent arm system (ETVAS)/holddown-post pyrotechnic initiator controllers (PICs) were armed without being commanded. Troubleshooting revealed a failure in a ground support equipment (GSE) 0.5-ampere solid-state switch card in the control panel assembly. The switch card was replaced and the circuits were retested with satisfactory results during the scrub turnaround. The launch was rescheduled for July 24, 1993.

The countdown for the July 24th launch attempt (second) proceeded in a nominal manner until T-20 seconds when the ground launch sequencer (GLS) detected an out-of-specification underspeed condition on the right-hand SRB thrust vector control (TVC) tilt hydraulic power unit (HPU); this was a violation of the Launch Commit Criteria (LCC). The specification requires the turbine speed to be between 66,200 and 77,800 rpm, and the speed at that point was 65,000 rpm. As a result, the GLS stopped the countdown at T-19 seconds. The HPU was replaced and successfully hot-fired. A tentative launch date of August 2, 1993, was planned. However, the debris field (Perseid meteoroid shower) of the Comet Swift-Tuttle was to pass near the Earth on August 11, 1993, and to remove the risk of possible damage to the Orbiter from this passage, the launch was rescheduled for August 12, 1993.

The third countdown proceeded nominally until T-5 minutes when a 2-minute 35-second hold occurred when the network signal processor (NSP) main synchronization lock between the Mission Control Center (MCC) and Merritt Island Launch Area (MILA) was lost for 1 second. Analysis showed that a multiplexer in the MCC was reset and this caused the loss of lock.

The countdown was reinitiated at T-5 minutes and continued until T-3 seconds when an on-pad abort occurred because of a miscompare in the turbine fuel flow meter for SSME 2. SSME 2 posted a major component failure approximately 0.6 second after SSME ignition; the cause of which was the failure of fuel flow meter channel A2 speed pickup coil sensor (loss of redundancy) to respond to the start transient. This condition caused a miscompare which violated the Launch Commit Criteria. The main engine controller uses the A and B flow rate measurement data for closed-loop thrust/mixture ratio control, and failure of the A or B measurements results in lockup of the preset engine mixture ratio. As a result of the failure, the engines were shut down and safing activities were initiated.

After replacement of all three SSME's and performance of other activities in support of the launch, a new launch date of September 10, 1993, was set. Analysis of the National Oceanic and Atmospheric Administration (NOAA)-I spacecraft ground checkout and the Mars Observer spacecraft loss pointed to the 2N3421 transistor as their failure mode. The launch was delayed two days to September 12 to verify that none of these transistors were used on the ACTS/TOS.

On the fourth launch attempt, the STS-51 Space Shuttle vehicle was launched from launch pad 39B at 255:11:45:00.006 G.m.t. (7:45 a.m. e.d.t. on September 12, 1993) as planned with no unscheduled holds. The launch azimuth for this mission was 90.0 degrees, which results in an orbital inclination of 28.45 degrees.

During ascent, the SSME 2 liquid hydrogen (LH_2) inlet pressure indication failed off-scale high at 255:11:49:55 G.m.t. (00:00:04:55 MET). Coincidentally, the flight critical aft 2 (FA2) multiplexer/demultiplexer (MDM) analog/digital converter built-in test equipment (BITE) bit was set. The BITE was a correct response of the MDM to an off-scale high input of the liquid helium inlet pressure. Postflight troubleshooting exonerated the FA2 MDM and identified the pressure transducer as the cause of the anomaly. Analysis and inspection of the transducer revealed that three of the gold wire leads were broken in the transducer because of thermal and vibration-related fatigue and the lack of proper stress relief.

A determination of vehicle performance was made using vehicle acceleration and preflight propulsion data. From these data, the average flight-derived engine specific impulse (Isp) determined for the time period between SRB separation and the start of 3g throttling was 452.3 seconds as compared to a main propulsion system (MPS) normal value of 452.79 seconds. This performance was considered nominal.

No orbital maneuvering subsystem (OMS) 1 maneuver was required. The OMS 2 maneuver was performed at 255:12:24:54.1 G.m.t. (00:39:54.1 MET). The maneuver was 145.2 seconds in duration and the differential velocity (ΔV) was 222 ft/sec. As a result, the Orbiter was placed in a 160.5 by 160.2 nmi. circular orbit.

Both payload bay doors (PLBDs) completed opening at 255:13:27:33 G.m.t. (00:01:42:33 MET).

The ACTS/TOS payload was successfully deployed at 255:21:13 G.m.t. (00:09:28 MET). The deployment was delayed one orbit because S-band forward link communications were lost for most of orbit 6 while the S-band was configured for operation in high frequency. When the payload interrogator (PI) was turned on, the PI and Tracking and Data Relay Satellite (TDRS) S-band frequencies were close enough that the Orbiter S-band forward link locked on to the PI rather than the TDRS. The crew performed the required malfunction procedure and when S-band low frequency was selected, communications were restored.

Reaction control subsystem (RCS) to left OMS interconnect operations were established at 255:16:08 G.m.t. (00:04:23 MET). Following the ACTS/TOS deployment, a 2 ft/sec RCS separation firing was performed at 255:21:13:55 G.m.t. (00:09:28:55 MET) using thrusters F1F and F2F. About 17 minutes later, a 28-second single-engine (right) OMS separation firing with a ΔV of 23.2 ft/sec was performed.

Payload signal processor (PSP) 1 dropped lock on payload data during orbit 20 at 256:17:05 G.m.t. (01:05:20 MET) for a period of 40 minutes. The PI power was cycled and configuration messages to the PSP were switched, but neither action was successful in recovering lock. PSP 1 power was cycled and configuration message 2 item entry was executed; this action restored lock on the payload data. At 259:18:02 G.m.t. (04:06:17 MET), the PI/PSP string 1 was switched to string 2. String 2 exhibited the same behavior as string 1. Initial indications are that the problem may be the result of an out-of-specification condition in the ORFEUS-SPAS transponder. A review of the ORFEUS-SPAS transponder specification data was made.

Video of the TOS Super*Zip separation system after the successful ejection of the ACTS/TOS revealed extensive damage to the expanding tube assembly and doublers on the Super*Zip ring. Debris consisting of metal with sharp edges as well as nonmetallic material was visible from the video. Over half of the expanding tube assembly was no longer restrained to the airborne support equipment (ASE). Payload personnel investigated the cause of this anomaly. The investigation revealed a commanded dual cord firing of the Super*Zip ring rather than the desired single cord firing. The primary concern was the potential for damage to Orbiter hardware during entry and landing. Analysis indicated that the payload bay liner/thermal blankets could withstand the impacts of the expanding tube assembly should it come free from the ASE during entry and landing. Therefore, no concern existed for Orbiter hardware as a result of this anomaly.

At 257:12:06 G.m.t. (02:00:21 MET), the procedures were initiated to reduce the crew cabin pressure to 10.2 psia in preparation for the planned extravehicular activity (EVA). Operations at 10.2 psia were satisfactory.

At 258:06:00 G.m.t. (02:18:15 MET) during flight day 4 post-sleep activities, approximately four tablespoons of water were found by the crew on humidity separator B, and the water was absorbed using towels. The humidity separator was checked again at approximately 258:18:50 G.m.t. (03:01:05 MET) during pre-sleep activities on flight day 4 and once again approximately four tablespoons of water were found, and it was absorbed with towels. The crew checked the humidity separator during post-sleep activities on flight day 5, and more water (3/4 cup) was found. The water was again absorbed using towels and the switch to humidity separator A was made at that time [259:05:16 G.m.t. (03:17:31 MET)]. No free water was found in the humidity separator area during the remainder of the mission. The postflight inspection revealed an accumulation of debris from the long period of service (fleet leader) without refurbishment.

A successful extravehicular activity (EVA) of 7 hours 5 minutes 27 seconds was completed. During the EVA, all planned activities were completed. The hand-warming procedure for the EVA crew person was performed with some warming being noted when the hand was about 8 inches from the light with residual heating being felt moments later. All hardware performed nominally except the port payload bay stowage assembly (PSA) sliding door which was difficult to close during the stowage operations at the end of the EVA. The crew was able to close the door by using a tool to lift the sliding door up (+Z direction) and clear the interference. The crew had opened and closed the door successfully earlier in the EVA with no problems. The postflight inspection showed that the problem was caused by the PSA sliding door moving underneath a modified closeout panel and jamming.

The Orbiter cabin repressurization to 14.7 psia was completed at 260:07:18 G.m.t. (04:19:33 MET). During the repressurization, the environmental control and life support system (ECLSS) oxygen supply system 1 valve was closed and reopened successfully at 260:07:01 G.m.t. (04:19:16 MET) as a part of a valve function test. This test was a functional verification of this valve which is not normally used during the flight. This verification was required because valves of similar design have failed to close on recent flights.

Development Test Objective (DTO) 700-6 - Global Positioning System (GPS) On-Orbit Demonstration - was completed allowing several opportunities for relative GPS operations with the ORFEUS-SPAS. Nominal performance was observed from both platforms. The crew reported that good GPS state vectors were computed during the flight day 3 sleep period. One floating point error occurred and this required the program to be restarted. Ground tests at Johnson Space Center (JSC) could not explain the cause for this error. In addition, simultaneous operation with the ORFEUS-SPAS and the GPS (DTO 700-6) occurred at 04:19:22:30 MET, 04:20:13:30 MET, 04:20:30:10 MET, and 04:20:44:00 MET. Video was available and the Orbiter GPS displays showed good comparison with the expected trajectories.

At 260:11:06:56.5 G.m.t. (04:23:21:56.5 MET), the right OMS engine was used to perform a 5.9 ft/sec firing in preparation for the SPAS rendezvous.

About 5 1/2 hours prior to the rendezvous, an RCS maneuver was performed to begin closing on the satellite. After two orbits, the Orbiter was trailing the ORFEUS-SPAS by 8 nmi., and the final rendezvous sequence was initiated with the terminal phase initiate maneuver at 262:09:38:35 G.m.t. (06:21:53:35 MET). During the closure, four midcourse corrections were made, and at a separation of approximately one mile, the Commander initiated manual control of the Orbiter for the final rendezvous maneuvers. At 262:11:49:11 G.m.t. (07:00:04:11 MET), the Orbiter rendezvous had been completed and the ORFEUS-SPAS was captured by the RMS.

The payload-bay mounted rendezvous radar TCS (Trajectory Control Sensor) (DTO 700-5) continuous mode was inoperative during rendezvous. Twelve manual calibrations of the continuous mode were performed and all failed. The pulse mode was operational and was used during rendezvous with the ORFEUS-SPAS. The pulse mode, which normally operates beyond 1000 feet, was used down to 30 feet with the continuous mode not operating. Later in the mission, the crew discussed some of the DTO 700-5 data from ORFEUS-SPAS rendezvous operations. The TCS acquired the target in pulse mode; however, the TCS range and range rate data did not match the data from the Ku-band radar or the hand-held laser.

The ORFEUS-SPAS was successfully berthed at 262:14:05:00 G.m.t. (07:02:20:00 MET). Prior to the berthing, the RMS was used to perform the Wake-Shield DTO and IMAX camera photo survey. When the RMS was being stowed for the day, the crew reported some difficulty in getting one ready-to-latch indication for one of the manipulator retention latches. The RMS was successfully latched once the ground controllers provided the joint angles recorded before the arm was last selected. This procedure has been used a number of times for RMS stowage on previous missions.

The data indicate that the Fuel Cell On Orbit Shutdown/Restart DTO (DTO 412) resulted in nominal fuel cell responses. Fuel cell 1 coolant and stack temperatures decreased as expected following the shutdown. Coolant pressure decreased to 49 psi and the stack temperature was 100°F two hours prior to the restart. Coolant pressure can drop to the electrolyte vapor pressure (<20 psia) before damage to the fuel cell could result; however, the reactant valves could have been reopened at any time to repressurize the fuel cell to 60 psia, should the coolant pressure have decreased significantly.

DTO 412 was completed at 263:14:14:00 G.m.t. (08:02:29:00 MET) when fuel cell 1 was restarted. The reactant valves opened instantaneously based on the panel indications, and telemetry also verified this response. Main busses A and B were untied about 19 minutes later, and the fuel cell operated satisfactorily for the remainder of the mission.

Auxiliary power unit (APU) 1 performance during the flight control system (FCS) checkout was nominal, with the APU running 4 minutes 28 seconds and consuming 18 lb of fuel. The maximum lubrication oil temperature achieved was 203°F; consequently, no water spray boiler (WSB) cooling was required.

The RCS hot-fire test was performed with some minor problems. RCS thruster L3L failed off on the first pulse, and the maximum chamber pressure recorded was 2.5 psia. This chamber pressure was indicative of either an oxidizer or fuel valve main stage failure. Temperature data indicate at least some propellant flow from both the oxidizer and fuel pilot stages. The thruster was deselected and placed in last priority.

The aft RCS thruster R1R chamber pressure indication prematurely stepped down from the nominal value of 155 psia and remained at 15 psia after the pulse was completed. To verify the health of the thruster, the thruster was fired again. Based on vehicle rate-data analysis, it performed nominally; however, the pressure transducer again showed off-nominal values. As a result, thruster R1R was deselected and placed in last priority. Neither thruster R1R nor L3L was used for the remainder of the mission.

The crew completed all stowage requirements and prepared the vehicle for entry and landing. The payload bay doors were closed and general purpose computers (GPCs) 1 and 2 were transitioned to OPS 3. However, during the redundant set expansion to include GPCs 3 and 4, GPC 3 failed to sync at 264:06:17 G.m.t. (08:18:32 MET). An initial program load (IPL) of GPC 3 was accomplished and the GPC was successfully brought into the redundant set. This GPC 3 failure-to-sync was initially thought to be explained by Operations (OPS) Note 42433; however, subsequent analysis removed this condition as a possible explanation. No explanation is currently known.

Two Kennedy Space Center (KSC) landing opportunities existed for the planned landing day; however, because of unacceptable forecast and observed weather at the Shuttle Landing Facility (SLF), both opportunities were waved off.
The second attempt to land was made on September 22, 1993, with payload bay door closure occurring at 265:04:23:12 G.m.t. (09:16:38:12 MET).

At 265:04:59 G.m.t. (09:17:14 MET), an "I/O ERR PL 2" message was annunciated by the BFS and MDM PF2 was bypassed. An input/output (I/O) reset was performed, but it was unsuccessful. A port mode was successful in recovering MDM PF2. This MDM, serial no. 0027, has experienced two sequence control unit (SCU) halts previously, and the signature seen in flight is consistent with the SCU halt failure mode. The SCU halt is a known condition believed to be caused by an internal timing problem in the MDMs self-check circuitry. The SCU halts have always been recovered with a power cycle. Under current philosophy, an MDM is removed only after three transient failures unless two failures occur within a six-month period, and that explains why the unit was not removed after the second failure.

The deorbit maneuver was performed at 265:06:55:30.1 G.m.t. (09:19:10:30.1 MET). The maneuver was approximately 137.4 seconds in duration and the ΔV was 251.3 ft/sec. Entry interface occurred at 265:07:24:40 G.m.t. (09:19:39:40 MET).

All three APUs were shutdown early after landing as a precaution because of burning exhaust plumes that were observed on the port side (APU 1 and 2 exhaust ducts) of the vertical stabilizer. Gas generator chamber pressures, turbine speeds, exhaust gas temperatures and pressures, injector tube temperatures, and all other APU parameters were nominal prior to and after the shutdown. Burning exhaust plumes have been noted on previous flights and are not considered abnormal; however, the plumes were more dramatic than normal because of the night landing.

Main landing gear touchdown occurred at the SLF on concrete runway 15 at 265:07:56:11 G.m.t. (09:20:11:11 MET) on September 22, 1993. The Orbiter drag chute was deployed satisfactorily at 265:07:56:15.6 G.m.t., and nose landing gear touchdown occurred 5 seconds after drag chute deployment. The drag chute was jettisoned at 265:07:56:42.5 G.m.t. with wheels stop occurring at 265:07:56:56 G.m.t. Preliminary indications are that the rollout was normal in all respects. The flight duration was 09 days 20 hours 11 minutes 11 seconds. All three APU's were powered down by 265:08:04:25.84 G.m.t. The crew completed the required postflight reconfigurations and departed the Orbiter landing area at 265:09:19 G.m.t.

PAYLOADS

The STS-51 mission was assigned 11 payloads. Three of these were located in the payload bay and the remaining eight were located in the crew module. During the flight, all payloads met or exceeded their mission objectives. The following paragraphs provide a description of each payload and the preliminary results, where available, of the payload activities.

ADVANCED COMMUNICATION TECHNOLOGY SATELLITE/TRANSFER ORBIT STAGE

The Advanced Communication Technology Satellite (ACTS) will provide, upon activation 12 weeks after launch, a flight test of high-risk advanced communications satellite technology. Using advanced antenna beams and advanced on-board switching and processing systems, ACTS will pioneer new initiatives in communications satellite technology.

The ACTS was deployed from the payload bay at approximately 255:21:13 G.m.t. (00:09:28 MET) during the seventh orbit of the STS-51 mission. The deployment was delayed one orbit because of the loss of Orbiter uplink communications. The Transfer Orbit Stage (TOS) injected the ACTS into a geosynchronous transfer orbit, and the burn was monitored by Apollo range instrumentation aircraft (ARIA) aircraft and the remote manipulator system (RMS) camera. The ACTS successfully separated from the TOS, and the satellite apogee kick motor injected ACTS into a geosynchronous orbit on September 15, 1993. From this orbit, the ACTS drifted to its final position at 100 degrees West longitude. The satellite thrusters were fired to place the ACTS into the geostationary orbit desired, at which time the ACTS was despun and was placed in a three-axis stabilized configuration. ACTS checkout activities were initiated, and these activities were in progress as this report was being written.

Approximately 60 experiments are planned to be performed with the ACTS, once the satellite completes the checkout phase.

Videos of the TOS Super*Zip separation system after the successful ejection of the ACTS/TOS revealed extensive damage to the expanding tube assembly and doublers on the Super*Zip ring. Debris consisting of metal with sharp edges as well as nonmetallic material was visible from the video. Over half of the expanding tube assembly was no longer restrained to the ASE. Payload personnel investigated the cause of this anomaly; findings were that the Super*Zip ring experienced a commanded dual cord firing rather than the desired single cord firing. This condition resulted from a payload wiring error in the drawings that resulted in the hardware being miswired. The primary concern was the potential for damage to Orbiter hardware during entry and landing. Analysis indicated that the payload bay liner/thermal blankets could withstand the impacts of the expanding tube assembly should it come free from the ASE during entry and landing. Therefore, no concern existed for Orbiter hardware as a result of this anomaly.

The postflight inspection of the Orbiter midbody and aft bulkhead revealed damage in bay 10 and aft of bay 10 in the payload bay as well as to the aft 1307 bulkhead. A total of 36 debris hits were found. The hits resulted in tears and/or residue on payload thermal blankets, three gouges or scratches to metal cable trays, and one penetration through the aft bulkhead. No visible damage to aft compartment equipment was caused by the bulkhead penetrant. None of the debris hits had any affect during the flight and all damage sites will be repaired during turnaround operations.

ORBITING AND RETRIEVABLE FAR AND EXTREME ULTRAVIOLET SPECTROMETER - SHUTTLE PALLET SATELLITE

The ORFEUS-SPAS mission was the first in a series of missions using the German-built ASTRO-SPAS science satellite. The ASTRO-SPAS spacecraft was designed to be launched, deployed, and retrieved by the Space Shuttle.

The RMS was used to successfully deploy the ORFEUS-SPAS at 256:15:05:59 G.m.t. (01:03:20:59 MET) on flight day 2 after a one orbit delay because of operational problems which delayed sending command files to the spacecraft. Once deployed, the ORFEUS-SPAS performed over 100 percent of the planned free-drift science operations. The data collected will require almost two years to evaluate; the time until the next mission of the ORFEUS-SPAS.

The one-meter diameter ORFEUS telescope with the Far Ultraviolet (FUV) Spectrograph (90-125 nm spectral range) and the Extreme Ultraviolet (EUV) Spectrograph (40-90 nm spectral range) were the main payloads, and these instruments investigated the very hot and very cold matter in the universe. These ranges of the electromagnetic spectrum are obscured by the Earth's atmosphere for ground-based observations. A secondary and highly complementary payload that was carried was the Interstellar Medium Absorption Profile Spectrograph (IMAPS). In addition, the Surface Effects Sample Monitor (SESAM) and the Remote IMAX Camera System (RICS) were also carried.

The ORFEUS-SPAS was retrieved and berthed in the payload bay at 262:14:05:44 G.m.t. (07:02:20:44 MET) on September 19, 1993, after 5 days 22 hours, 59 minutes and 45 seconds of exposure to the space environment. Some problems were noted during this exposure period; however, workarounds enabled all instruments to collect data.

LIMITED DURATION SPACE ENVIRONMENT CANDIDATE MATERIALS EXPOSURE

The primary objective of the LDCE experiment was to introduce developmental composite materials to a flux of atomic oxygen atoms in low-Earth orbit. The candidate materials, polymeric, coated polymeric, and light metallic composites, underwent extensive ground-based material performance testing prior to their flight on the Space Shuttle.

The LDCE consisted of two standard 5-ft^3 Getaway Special (GAS) canisters with motorized door assemblies that were located in the payload bay. The crew opened the doors as planned and closed the doors during entry preparations. Analysis of data will occur during the postflight period.

CHROMOSOMES AND PLANT CELL DIVISION IN SPACE EXPERIMENTS

STS-51 was the fourth flight of the CHROMEX-4 experiment which was located in a middeck locker in the crew module. All experiment hardware performed as expected. Three experiments were performed in conjunction with the CHROMEX-4. They were plant reproduction studies, plant cell development studies, and cell wall formation and gene expression studies. The CHROMEX-4 also provided an opportunity to evaluate a new nutrient support system.

The plants that were studied were mouse-ear cress (Arabidopsis thaliana) and a strain of wheat (Triticum aestivum). The entire plant structure was dissected by the investigators following landing and was preserved for study which is being performed at this writing.

RADIATION MONITORING EQUIPMENT-III

The RME-III measured ionizing radiation exposure to the crew within the Orbiter crew module. The RME-III measured gamma ray, electron, neutron and proton radiation; calculated the real-time exposure in RADS-tissue equivalent; and stored the data in a memory module for return to Earth for evaluation. RME-III was activated on flight day 1, and the equipment performed as expected.

A backup battery low message was seen on memory module 1, so the crew started with memory module 2. The crew changed the batteries on the extension day and extended RME-III operations through landing.

AIR FORCE MAUI OPTICAL SITE

The AMOS is a geophysical environmental study for testing ground-based optical sensors. The experiment also examined contamination/exhaust plume phenomena using the Space Shuttle as a calibration target. The planned firing of the RCS thrusters for the AMOS was performed as scheduled. The AMOS ground station was unable to acquire the Orbiter and unable to collect data because of the high atmospheric humidity present at the time of the RCS firing.

AURORA PHOTOGRAPHY EXPERIMENT-B

The objectives of the APE-B were to photograph the airglow aurora, auroral optical effects, the Shuttle glow phenomenon, and thruster emissions using various modes of photography. APE-B activities were initiated on flight day 6, and all but one of the requirements were met. The only requirement not met was to photograph Orbiter glow with thruster firings.

COMMERCIAL PROTEIN CRYSTAL GROWTH

The CPCG payload performed experiments which supplied information on the scientific methods and commercial potential for growing large high-quality protein crystals in microgravity. The Block II configuration of the CPCG consisted of one Commercial Refrigerator/Incubator Module (CR/IM) which contained four cylinder containers of the same diameter but different volumes. The CPCG payload was activated on flight day 1 and operated through landing. Over 100 percent of the operations requirements were met including two extra status checks.

HIGH RESOLUTION SHUTTLE GLOW SPECTROSCOPY

The HRSGS-A experiment provided high resolution spectra in the visible and near visible wavelength range of the Shuttle surface glow as observed on the Orbiter surfaces that faced the velocity vector. All requirements of this payload were fulfilled with no anomalies.

IMAX/REMOTE IMAX CAMERA SYSTEM

The IMAX payload was a 70mm motion picture camera system, with one camera used for filming the general Orbiter scene and the other attached to the ORFEUS-SPAS for taking remote pictures of the Orbiter and stars. The IMAX and supporting equipment operated very satisfactorily and the downlinks of photography showed some very spectacular pictures.

INVESTIGATION INTO POLYMER MEMBRANES PROCESSING

Two experimental units for the Investigation into Polymer Membranes Processing (IPMP) activity were used by the crew to flash evaporate mixed solvents in the absence of convection and thereby control the porosity of a polymer membrane. The IPMP was activated and deactivated as planned. Data analysis will occur during the postflight period.

VEHICLE PERFORMANCE

SOLID ROCKET BOOSTER/REDESIGNED SOLID ROCKET MOTOR

The countdown for the July 24th second launch attempt proceeded in a nominal manner until T-20 seconds when the GLS detected an out-of-specification underspeed condition on the right-hand SRB TVC tilt HPU (Flight Problem STS-51-B-01); this was a violation of the LCC. The specification requires the turbine speed to be between 66,200 and 77,800 rpm; however, the speed at that point was 65,000 rpm. As a result, the GLS stopped the countdown at T-20 seconds. The HPU was replaced and successfully hot-fired.

For the fourth launch attempt, power-up and operation of all case, igniter, and field joint heaters was accomplished routinely. All RSRM temperatures were maintained within acceptable limits throughout the countdown. For this flight, the high pressure heated ground purge in the SRB aft skirt was powered at T-15 minutes to inert the SRB aft skirt.

All of the field joint and igniter joint heaters operated satisfactorily during all launch attempts, and all joint temperatures were maintained within LCC limits. The aft skirt GN_2 purge performed its functions satisfactorily in removing all hazardous gases.

All SRB systems performed as expected during prelaunch testings and countdown. The SRB prelaunch countdown was normal, and no SRB or RSRM LCC or OMRSD violations occurred. The successful launch occurred on the fourth attempt. Event times were within the experience base.

Data indicate that the flight performance of both SRBs and RSRMs was well within the allowable performance envelope and was typical of the performance observed on previous flights. The RSRM propellant mean bulk temperature (PMBT) was 80°F at lift-off. The motor performance parameters for this flight were within specification limits as shown in the table on the following page. Minor pressure fluctuations were recorded on each motor. Data analysis shows that the magnitude of the pressure fluctuations on the left motor was 3.0 psi at 60.2 seconds, and the fluctuations for the right motor were 5.2 psi at 73.7 seconds. Both SRBs were successfully separated from the External Tank at 124.6 seconds MET.

The SRBs were recovered and returned to KSC for refurbishment and reuse. The postflight inspection revealed that the left-hand and right-hand aft skirts have Hypalon blistering over multiple areas of booster trowellable ablative (BTA) closeout (Flight Problem STS-51-B-02). This blistering condition is not a thermal concern; however, it is being evaluated to ensure it is not a debris concern for applications forward of the ET attachment ring.

EXTERNAL TANK

ET flight performance was excellent. All flight objectives and requirements associated with ET propellant loading and flight operations were satisfied. All ET electrical equipment and instrumentation performed satisfactorily. ET purge and heater operations were monitored and all performed properly. No ET LCC or OMRSD violations were identified.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 80°F		Right motor, 80°F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10^6 lbf-sec	65.42	65.56	65.54	65.43
I-60, 10^6 lbf-sec	174.47	175.24	174.75	174.88
I-AT, 10^6 lbf-sec	296.80	296.62	295.90	296.34
Vacuum Isp, lbf-sec/lbm	268.50	266.40	268.60	266.20
Burn rate, in/sec @ 60°F at 625 psia	0.3655	0.3671	0.3658	0.3669
Burn rate, in/sec @ 66°F at 625 psia	0.3706	0.3722	0.3711	0.3720
Event times, seconds				
Ignition interval[a]	0.232	N/A	0.232	N/A
Web time[a]	110.00	109.40	109.90	109.40
Separation cue, 50 psia	119.20	119.80	119.20	119.80
Action time	121.90	121.80	121.70	121.30
Separation command	124.70	124.50	124.70	124.50
PMBT, °F	80.00	80.00	80.00	80.00
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K), klbf-sec	2.80	2.80	2.80	2.70
Tailoff imbalance	Predicted		Actual	
Impulse differential,	N/A		554.4[b]	

Note:
[a] All times are referenced to ignition command time except where noted by the letter a. These items are referenced to lift-off time (Ignition interval).

There was no evidence of unacceptable acreage ice formation at any time during the loading for launch. Typical ice/frost formations were observed on the ET during each countdown. Normal quantities of ice or frost were present on the liquid oxygen (LO_2) and LH_2 feedlines and on the pressurization line brackets, and some frost or ice was present on the LH_2 protuberance air load (PAL) ramps. These observations were acceptable per NSTS-08303.

A new intertank heater control gain setting and a reduced initial-temperature control set point were implemented during loading operations for this flight. As a result, the wide oscillations in heater outlet temperature observed on previous leadings were reduced as well as the peak heater outlet temperature. The net gains from these changes are a smoother temperature performance for the purge system and more margin for the intertank purge maximum temperature limit.

The ET pressurization system functioned properly throughout engine start and flight. The minimum LO_2 ullage pressure experienced during the period of the ullage pressure slump was 13.1 psid.

Post separation photographs of the ET revealed five divots in or adjacent to the intertank-to-LH_2-tank-flange closeout, one approximately 8-inch diameter divot in the -Y longeron closeout, and an area of foam missing from the +Y thrust strut flange closeout. All of these divots were typical of observed conditions from previous flights.

The postflight predicted impact point for the ET was 47 nmi uprange of the preflight prediction and within the expected footprint.

SPACE SHUTTLE MAIN ENGINE

The countdown for the August 12, 1993, launch was reinitiated at T-5 minutes and continued until T-3 seconds when an on-pad abort occurred because of a miscompare in the turbine fuel flow meter for SSME 2. SSME 2 posted a major component failure approximately 0.6 second after ignition, the cause of which was the failure of fuel flow meter channel A2 speed pickup coil sensor (loss of redundancy) to respond to the start transient (Flight Problem STS-51-E-3). This condition caused a miscompare which violated the Launch Commit Criteria. The main engine controller uses the A and B flow rate measurement data for closed-loop thrust/mixture ratio control, and failure of the A or B measurements results in lockup of the preset engine mixture ratio. As a result of the failure, the engines were shut down and safing activities were initiated. During the abort, engine performance during the start and shutdown was acceptable, with engine run durations of 1.5 seconds (SSME-2), 2.8 seconds (SSME-3), and 3.84 seconds (SSME-1). As a result of engine operation, the three SSMEs were replaced prior to the launch.

For the flight on September 12, all tanking and prelaunch preparations were met, and all LCC, ignition confirm limits, and mainstage redline margins were satisfactory. All start and shutdown transient requirements were met. All SSME parameters were nominal and as predicted during start, mainstage, and shutdown. Based on trajectory data, the Isp was 452.30 seconds.

Preliminary flight data indicate that SSME performance during mainstage, throttling, shutdown, and propellant dump operations was normal. High pressure oxidizer turbopump (HPOTP) and high pressure fuel turbopump (HPFTP) temperatures appeared to be well within specification throughout engine operation. Space Shuttle main engine cutoff (MECO) occurred 509.53 seconds after lift-off.

A control system measurement (transducer) operated erratically on SSME 1 (engine 2031) and led to the disqualification of the transducer approximately 18 seconds after lift-off (Flight Problem STS-51-E-1). This measurement was the low pressure fuel turbine channel B turbine discharge temperature, which is used in the engine mixture ratio control. Normal operation continued using the channel A turbine discharge temperature measurement.

A redline monitor measurement (transducer) failed on SSME 2 (engine 2034) at approximately 412.5 seconds after lift-off (Flight Problem STS-51-E-2). The measurement was the high pressure fuel turbine channel B turbine discharge temperature. The channel A turbine discharge temperature measurement and other engine measurements confirmed that the engine operation was normal.

During mainstage operations, the SSME-1 (E2031) main fuel valve skin temperature channel A failed high at engine start plus 210 seconds. This sensor is used prestart to verify no main fuel valve leakage, and failures of this sensor have occurred during mainstage on previous flights. Sensor replacement is considered normal maintenance.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle range safety system (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS safe and arm (S&A) devices were armed and system inhibits turned off at the appropriate times. All SRSS measurements indicated that the system operated as expected throughout the countdown and flight.

As planned, the SRB S&A devices were safed, and SRB system power was turned off prior to SRB separation. The ET system remained active until ET separation from the Orbiter.

ORBITER SUBSYSTEMS

Main Propulsion System

The overall performance of the MPS was as expected. LO_2 and LH_2 loading was performed as planned during each launch attempt with no stop-flows or reverts. There were no OMRSD or LCC violations.

Based on an analysis of loading system data, the LH_2 load at the end of replenish was 231,850 lbm, Compared to the inventory (predicted) load of 231,853 lbm, this assessment yields a difference of -0.001 percent, which is well within the required loading accuracy.

Based on an analysis of loading system data, the LO_2 load at the end of replenish was 1,388,469 lbm. Compared to the inventory (predicted) load of 1,387,469 lbm, this assessment yields a difference of +0.05 percent, which is well within the required loading accuracy.

Throughout the period of preflight operations for the launch, no significant hazardous gas concentrations were detected. The maximum hydrogen concentration level in the Orbiter aft compartment (which occurred shortly after the start of the LH_2 recirculation pumps) was approximately 111 ppm (corrected), which compares favorably with previous data for this vehicle. The hazardous gas concentrations during the three previous launch attempts were also well within the experience base.

Ascent MPS performance appeared to be completely normal. Data indicate that the LO_2 and LH_2 pressurization systems performed as planned with the minimum LO_2 ullage pressure slump experienced being 12.5 psid. This is a historical low value for the slump, and it appears to have been an accumulation of conditions.

The most notable condition was that only one prepress helium burst occurred after engine ignition; whereas two bursts are normally the case. However, no requirements were violated. In addition, all SSME inlet net positive suction pressure (NPSP) requirements were met throughout the flight.

During ascent, the SSME 2 LH2 inlet pressure indication failed off-scale high to a value of 204 psia at 255:11:49:55 G.m.t. (00:00:04:55 MET) (Flight Problem STS-51-V-01). This measurement is used primarily for monitoring of hydrogen quality during loading. Troubleshooting at KSC isolated the failure to the transducer, and the transducer has been replaced. Inspection and analysis revealed three broken wires (gold). The condition was caused by thermal and vibration-related fatigue. Newly manufactured transducers will incorporate a design change to provide adequate stress relief.

MPS performance during entry was nominal. During the MPS reconfiguration for entry at 265:06:28 G.m.t. (09:18:43 MET), the crew reported that the panel F7 center SSME gaseous helium regulator pressure off-flag was set (Flight Problem STS-51-V-11). The meter should have been displaying the center A regulator pressure. The meter switch was cycled numerous times by the Pilot, but to no avail. All other indications on the meter were nominal and this condition did not affect entry operations. The telemetry data were nominal and the meter performed nominally after landing. The postlanding discussion with the Pilot revealed that the meter began working properly after the deorbit maneuver. Postflight troubleshooting has failed to repeat the failure, and the meter has been removed for further testing. Postflight troubleshooting could not reproduce the anomaly, and the meter was acceptance tested and returned to the vehicle.

The gaseous oxygen fixed orifice pressurization system performed as predicted. The GH_2 pressurization system also performed nominally. Evaluation of the flow control valve data revealed no problems. Helium consumption by the MPS was 58.4 lb, which is within the flight history of this vehicle.

Reaction Control Subsystem

The RCS performed nominally during the STS-51 mission. Propellant consumption from the RCS tanks totaled 5028.4 lbm. Also, the RCS was interconnected to the left OMS and right OMS during a major portion of the mission and 1752.1 lbm (13.53 percent) of the OMS propellants were used by the RCS. Seventeen major RCS firings were completed on-orbit in support of the activities supporting the separation and rendezvous with the ORFEUS-SPAS satellite. Over 30 ft/sec in velocity changes were made with these firings.

Throughout the mission when operating on the primary RCS thrusters, low chamber pressure was observed on RCS thrusters F4D and F3U several times. The low chamber pressure occurred only on the 80-msec duration firings; however, not all F4D 80ms firings had low chamber pressure. The chamber pressure was normal on longer duration firings. The low chamber pressure values were in the range of 50 to 120 psia, with normal chamber pressure being 150 psia. A number of occurrences have also been noted on the F4D thruster in the STS-53, STS-56 and STS-42 data. Low chamber-pressure levels had no adverse impact on the mission.

During the RCS hot fire, RCS thruster L3L failed off on the first pulse, and the maximum chamber pressure recorded was 2.5 psia (Flight Problem STS-51-V-05).

Past failure history indicates that this chamber pressure was indicative of an oxidizer valve main-stage failure. Temperature data indicate that at least some propellant did flow from both the oxidizer and fuel pilot stages. The thruster was deselected and placed in last priority. The L3L thruster was replaced and sent to White Sands Test Facility (WSTF) for testing and failure analysis.

Also during the RCS hot fire, the aft RCS thruster R1R chamber pressure indication prematurely stepped down from the nominal value of 155 psia and remained at 15 psia after the pulse was completed (Flight Problem STS-51-V-04). To verify the health of the thruster, the thruster was fired again. Based on vehicle rate data analysis, it performed nominally; however, the pressure transducer again showed off-nominal values. As a result, thruster R1R was deselected and placed in last priority. The R1R thruster chamber pressure transducer tracked with the other thrusters as the ambient pressure increased during entry, with thruster R1R indicating 30 psia after landing. Neither thruster L3L or R1R were used again during the mission. Thruster R1R was removed and sent to the vendor for troubleshooting and failure analysis.

Orbital Maneuvering Subsystem

The OMS performed six maneuvers very satisfactorily during the mission. Total firing time for the left engine was 307.8 seconds, and 317.9 seconds for the right engine. Propellant consumption including that used by the RCS during interconnect operations was 16,590 lbm. The following table provides details of each OMS firing.

OMS firing	Engine used	Time, G.m.t./MET	Firing duration, sec	ΔV ft/sec
2	Both	255:12:24:53.7 G.m.t. 00:00:39:53.7 MET	145.2	222.0
3	Right	255:21:30:29.3 G.m.t. 00:09:45:29.3 MET	27.7	23.2
4	Left	256:09:23:01.5 G.m.t. 00:21:38:01.5 MET	45.7	39.8
5	Left	260:06:32:44.7 G.m.t. 04:18:47:44.7 MET	6.6	5.9
6	Right	260:11:06:56.5 G.m.t. 04:23:21:56.5 MET	6.5	5.9
Deorbit	Both	265:06:55:30.1 G.m.t. 09:19:10:30.1 MET	136.9	251.1

The fuel total quantity aft probe in the left OMS fuel tank failed during the deorbit maneuver. The aft quantity read full well into the deorbit maneuver when it should have been dropping; then approximately 83 seconds into the maneuver, the level started dropping at an exaggerated but constant rate until the end of the maneuver when it read approximately 8-percent high.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performed nominally in meeting all requirements. A total of 2239 lb of oxygen and 282 lb of hydrogen were supplied to the fuel cells for power generation. In addition, 63 lb of oxygen was supplied to the crew for breathing purposes. Cryogenics remaining at touchdown would have provided for a mission extension of 60 hours at the average power level of 13.8 kW.

When the reactant valves were closed to initiate the fuel cell 1 shutdown DTO at 262:14:18:28.8 G.m.t. (07:02:33:28.8 MET), the fuel cell 1 oxygen reactant valve position talkback indicated closed immediately upon command. However, the hydrogen reactant valve position talkback was reported to have indicated closed after a delay of 4 seconds (Flight Problem STS-51-V-12). Data review of the valve position indicators showed that the oxygen and hydrogen valves closed simultaneously at 262:14:18:29.1 G.m.t. (07:02:33:29.1 MET) 0.3 second after the switch was thrown. Review of the essential bus 1BC data showed that the reactant valve switch was held in the closed position for 5.0 seconds. The response of the indicator suggests that the talkback was sluggish and this exonerated the fuel cell hydrogen reactant valve. Postflight troubleshooting could not reproduce the anomaly, and indicator performance will be monitored on future flights.

The oxygen in tank 4 was used down to 5.5 percent when the heater temperature reached 240°F. The hydrogen in tank 4 was used to below the defined residual quantity of 2.5 percent to a level of 2.0 percent. Use of the tank set 4 to depletion prior to using tank set 3 is now a standard mode of operation as defined in the Flight rules.

The ECLSS primary supply valve was successfully cycled closed and then reopened during the cabin repressurization following the EVA. The cycling of this valve was performed to verify that the valve would cycle under cryogenic conditions. Also, in this case, the cycling negated the need to remove the oxygen manifold 1 valve panel since all the valves were cycled successfully on this flight. Failure analysis of a valve of this type from a previous mission revealed that the failure only occurs while operating under cryogenic conditions and not at ambient conditions. Any valve of this type on an Orbiter that has not been cycled at cryogenic temperatures will be removed and tested at those temperatures.

Fuel Cell Powerplant Subsystem

The fuel cells performed in a very satisfactory manner and generated 3249 kWh of electricity. The fuel cells consumed 282 lb of hydrogen and 2239 lb of oxygen, which in turn produced 2521 lb of water. The average Orbiter electrical power level was 13.8 kW at an average load of 450 amperes.

During the countdown for the August 12, 1993 (the third launch attempt), the fuel cell 3 hydrogen flowmeter identified two spikes during the final purge before the planned launch. The first spike was 0.2 lbm/hr above nominal for 0.2 second, and the second spike was 0.5 lbm/hr above nominal for 1.0 second.

No changes in hydrogen or oxygen flow or fuel cell coolant pressure were noted in conjunction with the spikes. Likewise, no current spikes were noted. This condition did not occur during the flight.

The fuel cell 2 oxygen flow meter was failed off-scale low during the countdown and initial 78 minutes of the flight. However, the fuel cell 2 oxygen flow meter began working properly 78 minutes after launch and continued to operate properly for the remainder of the mission. Shortly after fuel cell shutdown after landing, the flow meter again failed to off-scale low. This condition did not impact flight operations.

Six fuel cell purges were performed at approximately 21, 113, 158, 195, 207, and 230 hours mission elapsed time. During the 92-hour interval between the first and second purges, the fuel cell voltage decays ranged between 0.15 and 0.2 volt. The actual fuel cell voltages at the end of the mission were 0.1 volt below predicted for fuel cell 1, as predicted for fuel cell 2, and 0.05 volt below predicted for fuel cell 3.

The data indicate that the Fuel Cell On-Orbit Shutdown/Restart DTO (DTO 412) resulted in nominal fuel cell performance. Fuel cell 1 coolant and stack temperatures decreased as expected following the shutdown. Coolant pressure decreased to 49 psi and the stack temperature was 100°F two hours prior to the restart. Coolant pressure can drop to the electrolyte vapor pressure (<20 psia) before damage to the fuel cell could result; however, the reactant valves can be reopened at any time to repressurize the fuel cell to 60 psia, if the coolant pressure had decreased significantly.

DTO 412 was completed at 263:14:14:00 G.m.t. (08:02:29:00 MET) when fuel cell 1 was restarted. The reactant valves opened instantaneously based on the panel indications, and telemetry confirmed this response. Main busses A and B were untied about 19 minutes later, and the fuel cell operated satisfactorily for the remainder of the mission.

Auxiliary Power Unit Subsystem

The APU subsystem performed nominally in meeting all requirements during the two scrubs and the flight. The table on the following page shows the run times and fuel consumption for each APU.

Following ascent, APUs 1A, 2A, and 3A tank/fuel/H_2O heaters were switched on about 30 minutes early (20 minutes after APU shutdown) when the fuel test line temperature 1 reached 50°F, and thereby a fault detection annunciator (FDA) alarm at 48°F was avoided. Early activation of these heaters is a common occurrence, and consideration is being given to lowering the FDA alarm level to alleviate the necessity of early heater activation.

At approximately 265:07:22 G.m.t. (09:19:37 MET), the APU 3 bearing temperature 2 failed off-scale high (Flight Problem STS-51-V-08). The measurement failed rapidly and this is indicative of an open circuit in the sensor. Other indications of the APU 3 temperatures were nominal, and as a result, this failure had no effect on entry. Postflight troubleshooting verified that the APU 3 gearbox bearing transducer had failed, and a new transducer was installed and verified.

All three APUs were shutdown early after landing as a precaution because of burning exhaust plumes that were observed on the port side of the vertical stabilizer (APU 1 and 2 exhaust ducts). Gas generator chamber pressures, turbine speeds, exhaust gas temperatures and pressures, injector tube temperatures, and all other APU parameters were nominal prior to and after the

Flight Phase	APU 1 (S/N 405)		APU 2 (S/N 406)		APU 3 (S/N 404)	
	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb	Time, min:sec	Fuel consumption, lb
July 24 Scrub	05:08	18	05:12	16	05:15	18
Aug. 12 Scrub	05:38	20	05:37	18	05:37	19
Ascent	22:15	69	22:27	66	22:00	56
FCS checkout	4:28	18				
Entry[a]	50:49	111	72:12	138	52:38	105
Total[a,b]	77:32	198	94:39	204	74:38	161

Notes:
[a] APU's 1 and 2 ran for 6 minutes, 39 seconds after landing (touchdown), and IAPU 3 ran for 8 minutes, 19 seconds after landing.
[b] Totals include ascent, FCS checkout, and entry.

shutdown. Burning exhaust plumes have been noted on previous flights and are not considered abnormal; however, the plumes were more dramatic than normal because of the night landing.

The ignition temperature of the APU hydrazine exhaust gas mixtures of 8 percent hydrogen, 28 percent ammonia, and 64 percent nitrogen in a sea level environment is 1075°F, and exhaust gas temperatures for all three APUs were near this value at the landing time. The windward APU operational flight rule indicates that the allowable APU postlanding running time for a crosswind (Y component) of less than 5 knots with a burning plume is greater than 60 minutes.

Postflight inspection of the Orbiter TPS near the exhaust duct outlets and on the vertical tail showed the area to be normal; the inside of the exhaust ducts near the outlet was normal, and the condition of the APUs and exhaust ducts in the aft compartment was nominal.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/water spray boiler subsystem performed nominally. WSB 1 was configured to operate on B controller for ascent because of anomalous ac current signatures that were emanating from the A controller during previous prelaunch operations.

WSB 1 experienced a momentary freeze-up during ascent and the lubrication (lube) oil temperature reached 280°F prior to the start of spray cooling. This was followed by a momentary period of over-cooling during which the oil temperature reached 221°F because of a delay in the controller changing from high spray rate to normal spray rate as the controller tried to compensate for the initial over-temperature condition.

Approximately a 10-inch segment of the hydraulic systems 1 and 3 circulation pump unheated inlet lines was exposed to a more severe local thermal environment because a portion of a thermal blanket became detached from the aft bulkhead. Thermal analysis indicated that the systems 1 and 3 circulation pump hydraulic fluid inlet temperature could drop below the Shuttle Operational Data Book (SODB) lower limit of 20°F. As a result, circulation pumps 1 and 3 were operated for 2 minutes to heat the fluid in these lines.

WSB 2 system 2 had two minor instances of over-cooling of the APU lube oil return during entry. The first over-cooling (253°F to 233°F) that occurred at 265:07:30 G.m.t. (09:19:30 MET), and the second (253°F to 237°F) occurred at 265:07:50 G.m.t. (09:19:50 MET). Both of these instances occurred after steady-state spray cooling had commenced. Neither instance had any impact on the flight.

Electrical Power Distribution and Control Subsystem

The electrical power distribution and control (EPD&C) subsystem performance was satisfactory throughout the mission with no problems or anomalies identified. All data analyzed showed nominal voltage and current signatures, and no specified limits were exceeded.

Environmental Control and Life Support System

Overall performance of the ECLSS was satisfactory.

The active thermal control subsystem (ATCS) performance was nominal except for the flash evaporator system (FES) shutdown during ascent. The shutdown was attributed to excessive water in the FES core from the water deluge system and the unique midpoint sensor on this Orbiter (OV-103). The water deluge system had been used during the on-pad abort that occurred 1 month before launch.

The FES was restarted and it performed nominally throughout the remainder of the flight. STS-51 was the first operation of ammonia boiler system A secondary controller since it was installed during the Orbiter Maintenance Down Period (OMDP) in 1992. The system A secondary controller maintained a nominal 34.5°F during its 18 minutes of operation. System B was also used for 10 minutes postlanding until ground cooling was connected.

The supply water and waste water systems performed satisfactorily throughout the mission. Supply water was managed through the use of the overboard dump system and the FES. One supply water dump was performed simultaneously with the second waste water dump. The average supply water dump rate was 1.48 percent/minute (2.44 lb/minute). The supply water dump line temperature was maintained between 64°F and 95°F throughout the mission with the operation of the line heater.

Waste water was gathered at the predicted rate. Three waste water dumps were performed at an average rate of 1.8 percent/minute (2.97 lb/minute). The waste water dump line temperature was maintained between 56°F and 86°F, while the vacuum vent line temperature was between 59°F and 84°F.

Data indicate that internal leakage was occurring through the supply water dump valve following the simultaneous water dump discussed previously. Data from STS-53, STS-48, STS-44, and STS-56 have confirmed that this "burping" phenomenon occurred on those missions, and it also is suspected to have occurred on previous flights of OV-103 and OV-104. This phenomenon did not impact mission operations.

The waste collection system performed normally throughout the mission.

The atmospheric revitalization system (ARS) performance was nominal with the exception of the slight water carry-over from humidity separator B that was reported by the crew. At approximately 258:06:00 G.m.t. (02:18:15 MET) during flight day 4 post-sleep activities, about four tablespoons of water were found by the crew on humidity separator B (Flight Problem STS-51-V-03), and the water was absorbed using towels. The humidity separator was checked again at approximately 258:18:50 G.m.t. (03:01:05 MET) during pre-sleep activities on flight day 4 and once again about four tablespoons of water were found and it was absorbed with towels. The crew checked the humidity separator during post-sleep activities on flight day 5, and water (3/4 cup) was found. The water was again absorbed using towels and the switch to humidity separator A was performed at that time [259:05:16 G.m.t. (03:17:31 MET)]. No free water was found in the humidity separator area during the remainder of the mission. The humidity separator was removed and during refurbishment, a buildup of debris was found on the pitot tube. The humidity separator was refurbished and placed back into service.

Pressure control system 1 and 2 operated satisfactorily throughout the mission. Cabin pressure was reduced to 10.2 psia at 257:12:32 G.m.t. (02:00:57 MET) in preparation for the planned EVA. The Orbiter cabin repressurization to 14.7 psia was completed at 260:07:18 G.m.t. (04:19:33 MET). During the repressurization, the ECLSS oxygen supply system 1 valve was closed and reopened successfully at 260:07:01 G.m.t. (04:19:16 MET) to functionally verify the valve (See the PRSD subsystem section for a more detailed discussion.)

Smoke Detection and Fire Suppression Subsystems

All smoke detection parameters remained within normal limits throughout the mission, indicating nominal performance. The use of the fire suppression system was not required.

Airlock Support System

All airlock support system hardware performed normally throughout the mission. The airlock was depressed at 259:08:18 G.m.t. (03:20:33 MET) for the scheduled EVA, and the airlock was repressed at 259:15:37 G.m.t. (04:03:52 MET).

Avionics and Software Subsystems

The avionics and software subsystems performed acceptably throughout the mission, and all requirements placed on the subsystems were met.

The integrated guidance, navigation and control (GN&C) performed normally in support of the ACTS/TOS deployment, the ORFEUS-SPAS deployment, and the ORFEUS-SPAS rendezvous and retrieval. Data analysis indicates that all aspects of the rendezvous went as expected. However, a number of interesting points were noted in the rendezvous sequence.

a. The radar was able to lock on the target earlier than expected (range of 150,000 feet). The lock-on was solid; consequently, the crew switched to radar angles instead of using star tracker angles. The lock was subsequently lost, and the star tracker angles were again used satisfactorily.

b. During the intermediate targeting of the initial rendezvous maneuver (NCC), the crew performed at T1 compute without a target ID. As a result, the targeting solution did not change from the preliminary solution. The maneuver was retargeted using a target ID of 9 and a satisfactory solution was obtained.

c. The performance of the navigation filter was monitored very closely during star tracker passes because of the performance observed on STS-57. Data analysis indicates that the targeting error seen during STS-57 was not seen on this flight.

The flight control system performance was nominal during the FCS checkout as well as during the rest of the mission. No flight control system problems have been identified from the data.

The inertial measurement unit (IMU) performance and the star tracker performance during the mission were satisfactory with no anomalies or problems identified.

During ascent, the SSME 2 LH_2 inlet pressure indication failed off-scale high at 255:11:49:55 G.m.t. (00:00:04:55 MET). Coincidentally, the FA2 MDM analog/digital converter BITE bit was set. After landing, the dedicated signal conditioner (DSC) was powered off in an effort to isolate the problem. The BITE indication ceased, exonerating the MDM. Troubleshooting at KSC has isolated the failure to the transducer.

A display electronics unit (DEU) memory parity error bit was set in the software status word when the crew powered up the CRT 1 at 260:02:12:35.04 G.m.t. (04:14:27:35.04 MET). This particular bite is a critical BITE, meaning that the GPC bypasses the DEU and issues an "Input/Output Error CRT" message. This caused a big "X" and "Poll Fail" message to appear on the CRT. A possible explanation is that the DEU experienced a "short store complete", which may occur when -0109 and -0108 DEUs are powered off. All four CRT's on this vehicle are susceptible to this problem (slots 1-3 DEUs are -0109 units, and slot 4 DEU is -0108 unit). The DEU power was cycled and reassigned successfully. An IPL was performed to ensure that no hidden corruptions remained in the DEU 1 memory. There was no risk to continued use of the DEU, and the DEU was used without further problems for the remainder of the mission.

The payload bay doors were closed in preparation for the first entry opportunity on the planned landing day, and GPCs 1 and 2 were transitioned to OPS 3. However, during the redundant set expansion to include GPCs 3 and 4, GPC 3 failed to sync at 264:06:17 G.m.t. (08:18:32 MET) (Flight Problem STS-51-I-01). An IPL of GPC 3 was accomplished and the GPC was successfully brought into the redundant set, and the GPC performed nominally for the rest of the flight. This GPC 3 failure-to-sync was initially thought to be explained by Operations (OPS) Note 42433; however, subsequent analysis removed this condition as a possible explanation. No explanation is currently known.

During deorbit preparations for the second landing attempt, at 265:04:59 G.m.t., the backup flight control system (BFS) bypassed the payload forward 2 (PF2) multiplexer/demultiplexer (MDM) (Flight Problem STS-51-V-07). An input/output (I/O) error fault summary message was annunciated. An I/O reset, performed by the crew, was unsuccessful. A port mode to secondary ports recovered the MDM. This configuration on secondary ports was maintained for the remainder of the flight without further problems. This MDM, serial no. 0027, has experienced two sequence control unit (SCU) halts previously, and the signature seen in flight is consistent with the SCU halt failure mode. The SCU halt is a known condition believed to be caused by an internal timing problem in the MDMs self-check circuitry. The SCU halts have always been recovered with a power cycle. Under current philosophy, an MDM is removed only after three transient failures unless two failures occur within a six-month period, and that explains why the unit was not removed after the second failure.

Displays and Controls Subsystem

The displays and controls (D&C) subsystem performed acceptably; however, some problems were noted and are discussed in the following paragraphs.

The crew reported at 262:12:13 G.m.t. (07:00:28 MET) that the mid-starboard payload bay floodlight was flickering and did not come up to full brightness (Flight Problem STS-51-V-06). The light was turned off. Amperage data from the mid main C bus shows small spikes indicative of arcing or flickering within the light. The mid-starboard floodlight was powered off and not used for the remainder of the flight. The floodlight was removed for testing which showed that the nitrogen back-fill in the floodlight had been lost. A design change to prevent recurrences of this anomaly is in work.

The crew reported that the off flag was in view on the MPS center helium regulator meter on panel F7 during deorbit preparations (Flight Problem STS-51-V-11). Discussions with the crew revealed that the off flag was in view for about 1 hour and disappeared at approximately entry interface. Postflight troubleshooting could not reproduce this anomaly. The meter was acceptance tested and reinstalled in the vehicle.

When the reactant valves were closed to initiate the fuel cell 1 shutdown DTO at 262:14:18:28.8 G.m.t. (07:02:33:28.8 MET), the fuel cell 1 oxygen reactant valve position talkback indicated closed immediately upon command. However, the hydrogen reactant valve position talkback was reported to have indicated closed after a delay of 4 seconds. Data review of the valve position indicators showed that the oxygen and hydrogen valves closed simultaneously at 262:14:18:29.1 G.m.t. (07:02:33:29.1 MET) 0.3 second after the switch was thrown. Review of the essential bus 1BC data showed that the reactant valve switch was held in the closed position for 5.0 seconds. The response of the indicator suggests that the talkback was sluggish. Postflight ground tests of the indicator could not reproduce the anomaly.

Communications and Tracking Subsystem

During prelaunch activities for the fourth launch attempt, the Shuttle Training Aircraft (STA) reported loss or intermittent operation of the microwave scanning beam landing system (MSBLS) on KSC runway 15 approach. Initially it was believed that dew on the ground station radomes was the source of the anomaly;

however, later testing exonerated dew on the radomes. The cause of the problem is currently unknown. Runway checks on landing minus one day showed satisfactory MSBLS operation.

The Ku-band system performed nominally in all modes of operation. The S-band performed acceptably with some problems noted and these are discussed in the following paragraphs.

The ACTS/TOS deployment was delayed one orbit because S-band PM forward link communications were lost for most of orbit 6 while configured for operation in high frequency. When the PI was turned on, the PI and TDRS S-band frequencies were close enough that the Orbiter S-band forward link locked on to the PI rather than the TDRS. The crew performed the required malfunction procedure, and when S-band low frequency was selected, communications were restored. The flight attitude caused the TDRS look angles to cut across the midsection of the Orbiter and avoid the nose and tail regions. As a result, some losses of communications occurred.

During ORFEUS-SPAS operations at 256:12:56 G.m.t. (01:01:11 MET), the crew noticed that the Orbiter S-band forward communications link dropped momentarily when the extravehicular mobility unit (EMU) television transmitter on the SPAS was turned on. The evaluation shows that when the EMU TV transmitter was turned on, the carrier swept through the TDRS high frequency of 2106 MHz and the SPAS telemetry frequency of 2225 MHz and then stopped at 2250 MHz. Because of the EMU start-up behavior, the Orbiter S-band phase modulation (PM) and PI receivers experienced momentary interference. After the EMU transmitter swept through the PM and PI receiver frequencies, the PM and PI locked up again on their respective frequencies without any crew or ground intervention.

The PI worked acceptably out to at least 53 nmi. The bit synchronizer occasionally had problems maintaining bit sync lock during reacquisitions. Payload signal processor (PSP) 1 dropped lock on payload data during orbit 20 at 256:17:05 G.m.t. (01:05:20 MET) for a period of 40 minutes. The PI power was cycled and configuration messages to the PSP were switched, but neither action was successful in recovering lock. PSP 1 power was cycled and configuration message 2 item entry was executed; this action restored lock on the payload data. At 259:18:02 G.m.t. (04:06:17 MET), the PI/PSP string 1 was switched to string 2. String 2 exhibited the same behavior as string 1. Initial indications are that the problem may exist because of an out-of-specification condition in the ORFEUS-SPAS transponder (Flight Problem STS-51-P-02).

The CCTV provided satisfactory video throughout the mission; however, some camera problems were noted. CCTV camera C exhibited defocusing problems when operating with low-light level scenes. Also, camera B had spots on the lens.

The crew reported intermittent lines and weak images on CCTV monitor 2 (Flight Problem STS-51-V-09). A special test was run on monitors 1 and 2; however, the procedure tested both monitors per the wrong configuration. Adequate time was not available to rerun the procedure. Monitor 2 was removed from the vehicle and sent to the vendor for testing and failure analysis.

Direct downlink of television from the SPAS EMU TV camera to the ground stations provided excellent color images. The images were recorded by the video tape recorder onboard the Orbiter. When the camcorder recordings were played back, the images should have been in color but were in black and white on the onboard monitors and on the ground (Flight Problem STS-51-V-10). The degraded color burst signal resulted from a stack-up of attenuation in the video processing portion of the EMU TV receiver/video processor and the camcorder. Corrective action requires modification of the camcorder and the receiver video processing circuitry designs and adjustments to the camcorder sensitivity circuitry.

During receipt of the morning mail at 259:03:58 G.m.t. (03:16:13 MET), the crew reported that the thermal impulse printer system (TIPS) would not perform any requested commands. Initial checks were made of the paper supply and it was not exhausted. The TIPS hang-up problem has been attributed to a previously experienced, but unexplained software problem that occurs randomly. This condition occurred several times and was cleared each time by cycling power to the TIPS.

The morning mail on flight day 10 had corrupted uplink messages. The JSC Electronic Systems Test Laboratory (ESTL) performed troubleshooting support and was able to determine that the problem was in the ground hardware and software and not in the Orbiter hardware.

Several times during the mission, the ground controllers had difficulty uplinking files to the portable auxiliary data modem (PADM) using the Z-modem protocol. In most of these instances, the X-modem protocol was successful. The crew stated during the debriefings that only one of the two modems onboard the Orbiter was used. Testing of this modem will be performed during postflight turnaround activities.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed nominally. During the payload bay door opening activities, the "port door close 2" indication was lost when the forward/aft bulkhead door was unlatching at 255:13:22 G.m.t. (00:01:37 MET). The loss of this indication terminated the automatic mode opening of the port PLBD approximately 14 seconds after initiation of bulkhead latch actuator movement to unlatch. This required that the door opening operation be completed in the manual mode. A visual inspection of the port PLBD using the RMS TV camera showed no anomalies with the aft bulkhead seals or latch mechanism. The aft end of the port PLBD may have moved slightly open when the bulkhead latches were being released, resulting in an open indication. Subsequent door operations were nominal. Switch module rigging was inspected after the flight and an adjustment was made.

The main landing gear inboard tires showed tread wear from the landing on the SLF runway. The landing and braking data are presented in the table on the following page.

All structural hardware performed nominally except the port payload bay stowage assembly sliding door which was difficult to close during the stowage operations at the end of the EVA (Flight Problem STS-51-V-02). The crew was able to close the door by using a tool to lift the sliding door up (+Z direction) and clear the interference. The crew had opened and closed the door successfully earlier in the EVA with no problems. The door operates within a totally enclosed track system and moves on six Teflon rollers (three on each side) and two steel rollers (one on each side) that are captured within the track. The postflight inspection revealed that the problem was caused by the PSA sliding door moving underneath a modified closeout panel and jamming.

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2099	194.6	~1.5	n/a
Nose gear touchdown	6539	140.4	n/a	3.32

Braking initiation speed	110. knots (keas)
Brake-on time	28.5 seconds (sustained)
Rollout distance	8,276 feet
Rollout time	50.1 seconds
Runway	15 (concrete) at KSC
Orbiter weight at landing	207,006 lb (landing estimate)

Brake sensor location	Peak pressure, psia	Brake assembly	Energy, million ft-lb
Left-hand inboard 1	1150	Left-hand outboard	17.37
Left-hand inboard 3	1097	Left-hand inboard	19.94
Left-hand outboard 2	1071	Right-hand inboard	18.13
Left-hand outboard 4	1031	Right-hand outboard	15.01
Right-hand inboard 1	938		
Right-hand inboard 3	1031		
Right-hand outboard 2	859		
Right-hand outboard 4	872		

The postflight inspection of the Orbiter midbody and aft bulkhead revealed damage in bay 10 and aft of bay 10 in the payload bay as well as to the aft 1307 bulkhead. A total of 36 debris hits was found. The hits resulted in tears and/or residue on payload thermal blankets, three gouges or scratches to metal cable trays, and one penetration through the aft bulkhead. No visible damage to aft compartment equipment was caused by the bulkhead penetrant. None of the debris hits had any effect during the flight and all damage sites will be repaired during turnaround operations.

Aerodynamics, Heating, and Thermal Interfaces

The ascent and entry aerodynamics were nominal with no problems or anomalies noted. Video data show that the drag chute experienced a nominal deployment. The parachute was a five-ribbon out, 100-percent disreef configuration parachute.

The aerodynamic and plume heating was nominal as well as the entry heating, and no problems or anomalies have been identified.

The prelaunch thermal interface temperatures were all within design limits, and the Orbiter/SSME hydraulic interface temperatures remained within Interface Control Drawing (ICD) limits for all mission phases.

Thermal Control Subsystem

The performance of the Orbiter thermal control subsystem was nominal during all phases of the mission, and all Orbiter subsystem temperatures were maintained within acceptable limits.

One aft bulkhead (X_o=1307) thermal blanket on the port side of the vehicle became partially detached (approximate location Y_o = 0.25, Z_o = 490) exposing a portion of the aft bulkhead behind which the hydraulic circulation pump 1 and 3 inlet lines were located. Because of the detached blanket, circulation pumps 1 and 3 were manually operated for 2 minutes to preclude exceeding the 20°F lower limit for the fluid inlet.

Data were obtained on the fuel cell 1 shutdown and restart on-orbit DTO. Fuel cell component temperature decay rate data were obtained over the 24-hour period of the shutdown.

Aerothermodynamics

The acreage heating was nominal with structural temperatures within limits during entry. Likewise, the structural temperature rise rates were within the experience base. The TPS damage from heating during entry was nominal.

Thermal Protection Subsystem

The thermal protection subsystem (TPS) performed satisfactorily throughout the mission based on structural temperature response data, which indicates average entry heating. The overall boundary layer transition from laminar flow to turbulent flow occurred at 1240 seconds after entry interface on the forward center-line of the vehicle, and at 1160 seconds after entry interface on the aft center-line of the vehicle. Based on the data evaluated, the transition was asymmetrical from right to left on the vehicle. Transition occurred at 1160 seconds on the starboard side and 1225 seconds on the port side.

The TPS showed debris impact damage at 154 sites of which 18 had a major dimension of one inch or greater. A comparison of the damage on this flight with previous flights indicates that the total number of damage sites was slightly greater than average while the number of major damage sites (one inch or greater) was less than average. No tile replacements were identified as being necessary because of impact damage.

The lower surface had a total of 100 damage sites and all 18 of the major damage sites (one inch or greater) were located on the lower surface. The distribution of damage sites on the lower surface does not suggest a single source of ascent debris, but rather indicates a shedding of ice and TPS debris from random sources. The largest damage site on the lower surface (right-hand inboard elevon) measured 3.75 inches by 0.50 inch by 0.25 inch. Twenty-nine sites immediately aft of the LH_2 ET/Orbiter umbilical door may be indicative of higher density materials, such as ice, striking the TPS. No TPS damage was attributed to material from the wheels, tires, or brakes.

The primary nose landing gear door thermal barrier (T/B) was in good condition, and nose landing gear door tile damage was minor. Some minor protrusion of gap fillers was also noted in the forward area of the lower surface.

The main landing gear door T/Bs and tiles were in good condition. No anomalies were noted on the reinforced carbon carbon (RCC) nose cap. The left-hand RCC panel 9 coating was degraded, and right-hand RCC panels 9 and 12 were streaked or marked. Some erosion was evident along the port outboard elevon ablator tile radius outer mold line; however, these tiles will be replaced with a new design during the upcoming turnaround flow.

The three ET/Orbiter separation devices functioned properly, and all associated retention shutters were closed properly. No debris was found on the runway below the ET/Orbiter umbilical cavities.

The ET door T/Bs and tiles were in good condition. There was minor tile impact peppering inboard and aft of the port ET door. No tiles were damaged due to drag chute deployment.

Orbiter windows 3 and 4 were moderately hazed, and windows 2 and 5 exhibited light hazing. Streaks were present on windows 2, 3, and 4. Surface wipes were taken from each window for laboratory analysis.

Tile damage on the base heat shield was less than average although one tile between SSME 2 and 3 had a large damage site. One dome-mounted heat shield (DMHS) closeout blanket sacrificial panel that was located at the 9:00 o'clock position was torn/frayed, but no material was missing. The other DMHS blankets were in excellent condition. Tiles on the vertical stabilizer "stinger" and around the drag chute door were intact and undamaged.

An inspection of the area around the APU exhaust ports and the base of the vertical stabilizer revealed no obvious anomalies (TPS damage, loss of material, signs of burning or melting, scorch marks, etc.).

The Shuttle thermal imager was used to measure the surface temperatures of several areas on the vehicle. Nine minutes after landing, the Orbiter nose cap RCC was 206°F. Forty-two minutes after landing, the right-hand wing leading edge RCC panel 9 was 108°F, and RCC panel 17 was 107°F.

REMOTE MANIPULATOR SYSTEM

The RMS performed satisfactorily in deploying and retrieving the ORFEUS-SPAS, which were the primary RMS objectives. The RMS also exhibited nominal operation when used to perform several payload bay surveys with the end effector CCTV camera. No RMS anomalies were noted during the mission operations.

After orbital insertion, the RMS was initialized with the rollout of the manipulator positioning mechanism (MPM), the release of the shoulder brace and configuration of the arm into GPC temperature-monitoring mode. Approximately one hour later, the manipulator retention latches (MRLs) were opened, and the arm was uncradled to perform the on-orbit RMS checkout. All performance signatures were nominal. At the end of the checkout, the crew performed the first of a number of preplanned end effector (EE) camera surveys of the payload bay. These CCTV surveys have become a normal part of RMS mission esign during which the crew is provided an opportunity to become familiarized with the on-orbit performance of the RMS. During the survey, the crew reported that the forward (elbow joint) MRL thermal blanket appeared to be loose; however, the downlinked video view showed nothing abnormal. The arm was cradled and latched after the survey.

Approximately 4 1/2 hours later, after the nominal deployment of the ACTS/TOS from the payload bay, the arm was again selected and uncradled to perform a preplanned ACTS solid rocket motor (SRM) burn monitor with the EE CCTV camera. After completion of the monitoring, the arm was again stowed.

At approximately 256:08:45 G.m.t. (00:21:00 MET), the RMS was powered and uncradled to deploy the ORFEUS-SPAS. The payload was grappled and unberthed and the ORFEUS-SPAS was activated with signals transferred through the RMS special purpose end effector (SPEE) connector and the payload's electrical flight grapple fixture. The ORFEUS-SPAS was released at 256:15:05:59 G.m.t. (01:03:20:59 MET). After the satellite was released, an unplanned SPEE CCTV survey of the ACTS ASE was performed because of concern for jagged metal edges left on the ASE when the pyrotechnics fired to release the ACTS/TOS satellite. The RMS had been powered up for approximately 7 1/2 hours when it was again cradled and latched.

The continuing concern about the jagged edges on the ACTS/TOS airborne support equipment lead to a second unscheduled payload bay survey at 257:09:54 G.m.t. (01:22:09 MET). When the arm was selected it was noticed that the wrist roll range (WRR) was not at its expected value. The RMS wrist roll can travel a total of 900 degrees, but the joint's position encoder can only read values from 0 to 360 degrees. The WRR value is maintained in software as an integer value from 1 to 6, identifying in which of six possible 180-degree arc segments the wrist joint resides. The analysis of the data after the ORFEUS-SPAS deployment showed that the WRR jumped in value from 4 to 5 at the instant the RMS was deselected. Data irregularities when the arm is deselected are a common occurrence, and this condition was investigated after a systems management (SM) fault message was annunciated on STS-57. A low downlist data rate of RMS parameters prevents an accurate statistical sampling, and the analysis of past flight data showing that data irregularities can be expected a minimum of 43 percent of times when the arm is deselected. These data irregularities are not always manifested with visible signatures, but in this case the wrist roll encoder data jumped to a value recognized by the WRR software algorithm as a request for a step increase in the WRR value. This same event occurred on STS-61B and the WRR was reset by the crew to the correct value as it was on this mission. This condition did not impact mission operations in any manner. The unplanned CCTV survey of the ACTS/TOS ASE was completed and the arm was cradled and latched approximately 6 hours after the system was powered up.

The planned EVA required the arm to be maneuvered out of the way of crewmembers working on the port longeron. As a result, the arm was placed in the pre-cradle position during the period of the EVA.

At approximately 262:07:15 G.m.t. (06:19:30 MET), the arm was uncradled for the ORFEUS-SPAS retrieval. Prior to the capture, another payload bay survey was performed after which the arm was moved to the poise-for-capture configuration at 262:11:15 G.m.t. (06:23:30 MET). The ORFEUS-SPAS was captured at 262:11:49:11 G.m.t. (07:00:03:11 MET) and berthed at 262:14:05:44 G.m.t. (07::02:20:44 MET). Prior to the berthing, the RMS/SPAS performed an ORFEUS-SPAS mounted IMAX camera survey of the Orbiter and was also used in a DTO developed during the STS-51 mission that measured the amount of Orbiter free-drift roll caused by an RMS/payload maneuver planned for STS-60 (Wake Shield Facility). Data from this DTO will be used to verify ground-based mission simulations.

During the cradling of the arm following the berthing, the crew experienced difficulty in getting the aft MRL ready-to-latch indication. The RMS was successfully latched once the ground controllers provided the joint angles recorded before the arm was last selected. This procedure has been used on a number of flights for RMS stowage.

The final RMS activity began with uncradling at 263:04:45 G.m.t. (07:17:00 MET). A preplanned payload bay survey was performed to evaluate the proposed new foot-hold for the RMS operator. The evaluation was performed under DTO 668, Advanced Lower Body Restraint Test (ALBERT). At the end of the ALBERT evaluation, the arm was cradled and latched and the MPM's were rolled in at approximately 263:05:25 G.m.t. (07:17:40 MET). No RMS activities were planned or conducted during the remainder of the mission.

EXTRAVEHICULAR ACTIVITY

SUMMARY

The extravehicular activity (EVA) was performed as a part of DTO 1210 - EVA Operations Procedures/Training, and DTO 671 - EVA Hardware for Future Scheduled EVA Missions (tests 3, 4, 6 and 7). This EVA was the third of three performed to study the differences in task performance on the ground during training and on-orbit in a systematic manner. The main objectives of the EVA were as follows:

a. DTO 1210 - EVA Operations Procedures/Training
    1. Restraint for High-Torque
    2. Restraint for Low-Torque
    3. Large Orbital Replacement Unit Mass Handling/Semi-Rigid Tether Evaluation
    4. Portable Foot Restraint PFR Evaluation
    5. Unemcumbered and Encumbered Translation
    6. Space Station Large Tool Handling
    7. PFR Ingress/Egress Without Structural Handholds

b. DTO 671 - EVA Hardware for Future Scheduled EVA Missions
    1. Test 3: High Torque Free Float and Restrained Evaluations
    2. Test 4: PFR Operations Evaluations
    3. Test 6: Improved Tether Operations Evaluations
    4. Test 7: Contamination Data Collection

EVA tasks and activities necessary to satisfy the objectives were accomplished during the EVA on September 16, 1993. The data gained from the real-time and post-EVA evaluations are being evaluated, and the data will be used to refine future EVA procedures both for Space Shuttle and the Space Station programs. No in-flight anomalies were identified from the data analysis and debriefings.

The DTO 1210 EVA activities were completed nominally. At the end of the EVA while stowing the EVA tools, the EV crew members encountered difficulty in closing the doors on the port-side PSA. The PSA doors were successfully closed using two improvised pry bars. The crew members reentered the airlock and completed the 7-hour, 5-minute, 27-second EVA satisfactorily.

INITIAL IN-FLIGHT PREPARATIONS

In preparation for the planned EVA, the Orbiter crew module pressure was reduced to 10.2 psia on flight day 2. The EMU equipment preparation and checkout began on flight day 4 at 258:08:36 G.m.t. (02:20:51 MET) and required 1 hour 17 minutes to complete. During the secondary oxygen pack (SOP) checkout, the SOP pressures were read to the ground controllers, and the pressure in EMU 2 was 5,880 psia compared with the 6,090 psia in EMU 1; however, the pressure was within the 6,000 $\pm$ 200 psia normal-use specification.

On flight day 5 the two extravehicular (EV) crewmembers donned the EMUs, completed the necessary leak check, 8-minute nitrogen purge, and the 40-minute prebreathe period. Preparations for the EVA began 30 minutes ahead of schedule the morning of flight day 5. This lead was maintained throughout the EVA preparation period. Both crewmembers completed donning their suits using the standard procedures in the EVA checklist. The crewmembers began their 40-minute prebreathe period at 259:07:38:00 G.m.t. (03:19:53:00 MET), which was 27 minutes early.

EVA ACTIVITIES

Depressurization for the EVA began at 259:08:18:20 G.m.t. (03:20:33:20 MET) and was completed 11 minutes later when the hatch was opened. The EVA crewmembers egressed the hatch at 259:08:39:42 G.m.t. (03:20:54:42 MET). The first DTO task performed was the translation exercise. As a part of this exercise, the EV1 crewmember (Walz) examined the debris left over from the ACTS/TOS pyrotechnic malfunction. The EV1 crewmember confirmed the ground opinion that the TOS ASE Super*Zip ring metal debris appeared stable enough for landing, being securely held down in two places. The excess material appeared to be at least 6 inches away from the Orbiter sill, and the payload bay door hinges were undamaged. Based on these observations, it was deemed more prudent to leave the debris alone rather than risk damage to the space suit from the sharp metal edges on the containment tube, frangible doubler and other broken hardware. After these translations, both crewmembers translated to the payload bay stowage assembly (PSA). The crew described these translations as being very important to space adaptation. The ground simulation in the Weightless Environment Training Facility (WETF) was deemed to be more difficult than the actual experience.

The EV1 crewmember then began to prepare for the restraint-for-high-torque evaluation at the starboard-bay 6 bolt/probe work site. At this point in the activities, a low battery power warning in the power tool was noted, and it required the EV2 (Newman) crewmember, who was also ahead of the timeline, to return to the airlock for a new battery. During this activity, comments from

EV1 included the observation that the mini-workstation (MWS) provided very little restraint for the torque operations. The next scheduled activity for EV2 was the encumbered/unemcumbered translations, which were expected to require about one hour to complete. A minor problem during this portion of the EVA was that the left waist-tether disconnected from the semi-rigid tether (SRT). About 45 minutes into the EVA and beginning at 259:09:16 G.m.t. (03:21:31 MET), EV2 also performed the glove warming evaluation by holding his hands first 12 inches and then 8 inches away from the payload bay lights. He described a slow warming effect at 8 inches with some residual. The next task for EV2 was the Hubble Space Telescope (HST) portable foot restrain (PFR) evaluation. During this activity, EV2 reported that it was more difficult to egress the PFR than it was during training, and it was also harder to perform the heel motion.

By the time EV2 had completed the PFR evaluation, EV1 had finished the second part of the high-torque evaluation using the torque multiplier on the passive latch worksite in starboard bay 6, as well as the evaluation of the two-tether concepts - the radial-hook tether and the swivel-hook tether. Of the two concepts, the radial hook was the preferred tether. The last hour prior to payload bay cleanup was used by EV1 to perform a PFR comparison evaluation, and for EV2 to perform the restraint-for-low-torque evaluation at the same starboard 6 bolt/probe work site used by EV1 when performing the high torque evaluation. All of these DTO activities were accomplished well within the time allowed. As a result of the crew consistently staying ahead of the timeline, additional activities were added at the end of the EVA. EV1 was allowed to perform an additional PFR evaluation, and EV2 performed an additional tether-concept evaluation.

During the payload bay cleanup, the port PSA door jammed open. Although it required 45 minutes, the crew was able to close the door by lifting it up to clear the interference by using a tool as a lever (Flight Problem STS-51-V-02). This door had been opened and closed earlier in the EVA with no problem. The only other problem encountered with the EVA support equipment was the disconnecting of the MWS end effector from the retracting tether's 2-inch french hook. No lock was provided on this french hook to preclude inadvertent release of tethered items.

The EVA crew returned to the airlock, and the third EVA of 1993 ended with an official time of 7 hours 5 minutes 27 seconds.

After performing each of their tasks, both crewmembers answered a standard set of questions. The purpose of these questions was to obtain from the crewmembers their instantaneous impression of the relative weight of various factors such as lighting, position, visibility, training correlation, technique, hand fatigue, suit stiffness, etc., on his ability to perform a particular task on-orbit. The data from these questions are being analyzed, and a final report will be published after completion of the analysis.

Following the flight, a debriefing of the EVA crewmembers was held to gain more detailed information on the EVA operations. The crew stated that no difficulty was experienced with display and control module (DCM) controls, specifically the oxygen actuator. The suit fit and comfort responses were standard, and visibility limitations on-orbit were on a par with those in the Weightless Environment Training Facility (WETF). There was no noticeable effect on task performance from the suit stiffness; however, the suit stiffness was most noticeable in the lower torso assembly. Anticipation of thermal changes by pre-adjusting the temperature control valve worked well. The allowance for zero-g spine growth was adequate. Lighting from the helmet and payload bay lights was also adequate for task performance.

The crew was asked to comment on the value of the 11-foot and environmental test article (ETA) vacuum chamber runs. The crew responded that both chamber runs were beneficial, and they gained an understanding of the suit in the 11-foot chamber, while the ETA was valuable for the airlock exposure. The chamber runs were highly endorsed for first-time EVA crew members.

FLIGHT CREW EQUIPMENT/GOVERNMENT FURNISHED EQUIPMENT

The flight crew equipment performance was satisfactory. One problem was noted that is discussed in the following paragraph.

At 262:05:30 G.m.t. (06:17:45 MET), the crew downlinked video of the ALBERT (DTO-688) operations from the flight deck. The video showed that the pin that held the locking gear in place on the slip clutch joint of the ALBERT had failed. The crew reported that the pin had sheared off after the device had been used for an undetermined period of time. The crew had fixed the ALBERT device by attaching "vise grips" and tape to the slip clutch joint; the device appeared to be working satisfactorily when observed on the video. The crew used the ALBERT hardware during the ORFEUS-SPAS capture/berthing operations and again during the RMS payload bay survey. In spite of the sheared pin, the ALBERT performed acceptably in providing a stable platform from which to operate the RMS.

INTEGRATION

All integration hardware supported the completion of all related objectives with no problems noted.

DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES

A total of 19 DTO's and 13 detailed supplementary objectives (DSO's) were assigned to the STS-51 mission. A discussion of the results of each DTO and DSO is contained in the following paragraphs.

DEVELOPMENT TEST OBJECTIVES

DTO 301D - Ascent Structural Capability Evaluation - Data for this DTO were recorded on the modular auxiliary data system (MADS) recorder. The data were recovered after landing and given to the DTO sponsor for evaluation and reporting.

DTO 305D - Ascent Compartment Venting Evaluation - Data for this DTO were recorded on the MADS recorder. The data were recovered after landing and have been given to the DTO sponsor for evaluation. The initial evaluation of 12 differential and 18 absolute pressure transducers has been completed. In general the flight data shows profiles similar to data obtained from previous OV-103 flights. Detailed analysis of the data were in progress as this report is being written.

DTO 306D - Descent Compartment Venting Evaluation - Data for this DTO were recorded on the MADS recorder. The data were recovered after landing and have been given to the DTO sponsor for evaluation and reporting.

DTO 307D - Entry Structural Capability - Data for this DTO were recorded on the MADS recorder. The data were recovered after landing and given to the DTO sponsor. A preliminary assessment of the data shows no anomalies or any obvious venting characteristics. Detailed analysis of the data were in progress and this report was being written.

DTO 308D - Payload Bay Acoustic Evaluation - Data for this DTO were recorded on the MADS recorder. The data were recovered after landing and have been given to the DTO sponsor for evaluation and reporting.

DTO 312 - ET TPS Performance (Method 1 and 3) - This DTO was accomplished during the Orbiter/External Tank separation maneuvers using a hand-held Nikon camera with a 300 mm lens and a 2x extender. A total of 37 excellent quality frames of the ET were acquired by the astronauts using the Nikon camera. All sides of the ET were photographed, and several small divots were visible but the ET in general appeared in good condition. The first picture was taken approximately 16 minutes into the flight and the last was taken about 25 minutes into the flight. In addition, the L1 camcorder was used to video-tape the ET.

DTO 319D - Orbiter/Payload Acceleration and Acoustics Environment Data - These data were recorded on the MADS recorder. The data were recovered after landing and have been given to the DTO sponsor for evaluation and reporting.

DTO 412 - Fuel Cell On-Orbit Shutdown/Restart - The goals of the DTO were met with the shutdown of the fuel cell no. 1 on flight day 8. The fuel cell was shut down for a period of 24 hours and was restarted as planned with no problems encountered.

The shutdown procedure began by bus tying main busses A and B, and then removing fuel cell 1 from the essential bus 1BC and main bus A. The fuel cell was then shut down at 262:14:18:00 G.m.t (07:02:33:00 MET), and the reactant valves were closed to protect against a possible crossover failure.

When the fuel cell was disconnected from the main bus, the coolant pressure immediately increased from 58.4 psia to 60.4 psia. Over the next four hours, the pressure increased 1 psia, after which the pressure began to decay. Over the next 20 hours, the pressure decayed at a steady rate of 0.7 psi/hr to 47.5 psia. The coolant pressure fault detection annunciator (FDA) lower limit of 55 psia was first lowered to 50 psia and then to 45 psia to avoid nuisance alarms. Coolant pressure would have to drop to the electrolyte vapor pressure (20 psia) before any damage would occur to the fuel cell, and the reactant supply valves could be opened causing an immediate pressure increase to 60 psia, if required.

The on-orbit restart procedure began by placing the purge heaters to manual "on" and then opening the reactant valves, at which time the coolant pressure increased to 60.3 psia. The start command was issued at 263:14:19:01 G.m.t. (08:02:34:01 MET). The stack exit temperature reading was 99°F at the restart, but the temperature jumped to 134°F after the coolant pump was started, indicating that the stack was still 35°F warmer than the accessory section. The cell performance monitor (CPM) reading for substack 3 increased 200 mV during the shutdown; however, after start-up the readings returned to just slightly higher than observed before the shutdown. After the ready-for-load indication was received, the fuel cell was reconnected to the main and essential busses, the main busses were untied, and normal fuel cell operation continued.

DTO 414 - APU Shutdown Test - The APU shutdown test was conducted on STS-51 to determine why an anomalous supply pressure hang-up of about 40 seconds was observed when APU 3 was shut down early during ascent on STS-54. The DTO was performed with the same shutdown sequence at STS-54 (3-1-2) with at least 5 seconds between individual APU shutdowns. Although the APU shutdown sequence was not performed in the order requested, no anomalous behavior was noted. This DTO will continue to be performed on future flights.

DTO 521 - Orbiter Drag Chute System (Special test condition: Post derotation (nose in air) deployment with five ribbons removed from the chute) - This DTO was accomplished as planned and no anomalies were noted.

DTO 656 - Payload General Support Computer Single Event Upset Monitoring - This DTO using the payload general support computer (PGSC) was performed and the data will be evaluated during the postflight period.

DTO 660 - Thermal Impulse Printer System Demonstration - The DTO to operate the TIPS was completed with satisfactory performance of the TIPS. However, during receipt of the morning mail at 259:03:58 G.m.t. (03:16:13 MET), the crew reported that the TIPS would not perform any requested commands. Initial checks were made of the paper supply and it was not exhausted. The TIPS hang-up problem has been attributed to a previously experienced, but unexplained, software problem that occurs randomly. The condition was cleared each time by cycling power to the TIPS.

DTO 668 - Advanced Lower Body Restraint Test - The ALBERT was performed by the crew during the ORFEUS-SPAS deployment and retrieval operations and during Earth observations.

At 262:05:30 G.m.t. (06:17:45 MET), the crew downlinked video of the ALBERT operations from the flight deck. The video showed that the pin that held the locking gear in place on the slip clutch joint of ALBERT had failed. The crew reported that the pin had sheared off after the device had been used for an undetermined period of time. The crew had fixed the ALBERT device by attaching "vise grips" and tape to the slip clutch joint; the device appeared to be working satisfactorily when observed on the video. The crew used the ALBERT hardware during the ORFEUS-SPAS capture/berthing operations and again during the RMS payload bay survey.

DTO 671 - EVA Hardware for Future Scheduled EVA Missions (Test 3, 4, 6, and 7) - This DTO was performed on flight day 5 during the 7-hour EVA. During the EVA, all of the DTO 671 objectives were met, and the various EVA tools all operated successfully. The only tool-related anomaly that occurred during the EVA was a low battery voltage indication on the Goddard power ratchet tool (PRT). The battery was changed out and a postflight inspection will be performed to determine the cause of the discharge. Based on the overall performance of the tool, the PRT should function nominally during the upcoming Hubble Space Telescope mission.

DTO 779 - STS Orbiter Attitude Control Translational Thrusting - Data were gathered during four sleep periods, and these data will be analyzed during the postflight operations.

DTO 700-2 - Laser Range and Range Rate Device - The Laser Range and Range Rate Device was used extensively during the ORFEUS-SPAS retrieval, and the device performed well. Performance was very good when compared to Ku-band radar and even better than the Ku-band radar when within 150 ft. From a range of 100-feet to the completion of the rendezvous, this device was used exclusively.

DTO 700-5 - Payload Bay Mounted Rendezvous Laser TCS - The payload-bay mounted rendezvous laser TCS continuous mode was inoperative. Twelve manual calibrations of the continuous mode were performed and all failed. The pulse mode was operational and was used during rendezvous with the ORFEUS-SPAS. The pulse mode, which normally operates beyond 1000 feet, can be used down to 30 feet with the continuous mode not operating. Later in the mission, the crew discussed some of the DTO 700-5 data from ORFEUS-SPAS rendezvous operations. The TCS acquired the target in pulse mode; however, the TCS range and range rate data did not match the data from the Ku-band radar or the hand-held laser.

DTO 700-6 - Global Positioning System On-Orbit Demonstration - The GPS was successful in meeting all objectives in demonstrating real-time absolute and relative global positioning in an orbital dynamic environment as well as collecting data for postflight evaluation. Numerous periods of simultaneous Shuttle Pallet Satellite (SPAS) and Orbiter GPS data collection occurred, providing an adequate data base for postflight evaluation. Nominal performance was observed from both platforms. The crew reported that good GPS state vectors were computed during the flight day 3 sleep period. One floating point error occurred and this required the program to be restarted. Ground tests at JSC could not explain the cause for this error. Video was available and the Orbiter GPS displays showed good comparison with the expected trajectories. The preliminary evaluation has determined that the receiver's signal processing should be modified to provide addition resistance to jamming caused by the PGSC.

DTO 700-7 - Orbiter Data for Real-Time Navigation Evaluation - The Orbiter data for real-time navigation evaluation performed throughout the entire mission and everything planned was accomplished both onboard and on the ground. Both systems successfully provided Orbiter data to hardware for two other DTO's.

DTO 805 - Crosswind Landing Performance - The crosswind landing performance DTO was not accomplished because crosswinds were not high enough to satisfy the DTO requirement.

DTO 1210 - EVA Operations Procedures/Training - The EVA Operations Procedures/Training was accomplished with all objectives successfully completed. The combination of this DTO and DTO 671 showed no significant issues that would impact STS-61. Mass handling and tool management were evaluated. Encumbered tasks were completed. One portion of mass handling was not completed as a result of the transfer orbit stage (TOS) tool not fitting the MWS. The TOS tool had a bayonet that seemed to not fit. This tool was fit-checked prior to flight using a go/no go gauge. It appears that the gauge may be incorrect, and this is being investigated. The lessons learned from this flight are being detailed to benefit future operations.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 476 - In-Flight Aerobic Exercise (Cycle Ergometer) - Good reports of exercise sessions by the crew were received. No problems were reported and the detailed supplementary objective (DSO) is considered 100-percent successful. The setup as well as the stowage of the ergometer was successful, and no hardware problems were reported by the crew.

DSO 485 - Inter Mars Tissue Equivalent Proportional Counter - Data were collected for this DSO, and the data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 487 - Immunological Assessment of Crewmembers - Data were collected for this DSO, and the data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 603 - Orthostatic Function During Entry, Landing, and Egress (603B Schedule) - Data were collected for this DSO, and the data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 604 - Visual-Vestibular Integration as a Function of Adaptation (Investigation OI-1 and OI-3) - This DSO was performed on flight day 2 and 8. Data collection was performed. The percentage of successful data collection will be determined from postflight analysis. A lens in the goggles failed to stay completely opaque; a second lens was tried with the same result. The eyes-open protocol was assumed to be 100-percent successful; however, the vision occluded protocol is in question. Data were also collected throughout entry and landing until wheel stop.

DSO 605 - Postural Equilibrium Control During Landing/Egress - Data were collected for this DSO, and the data were given to the sponsor for evaluation. The results will be published in separate documentation.

DSO 617 - Evaluation of Functional Skeletal Muscle Performance Following Space Flight - Data were collected for this DTO, and the data have been given to the sponsor for evaluation. The results of the evaluation will be published in separate documentation.

DSO 622 - Gastrointestinal Function During Extended Duration Space Flight - This DSO was accomplished with 100 percent of the urine and saliva samples collected. Breath sampling was discontinued due to a question about the sampling bag and desiccant. Initial estimates are that 50 percent of the overall DSO was accomplished.

DSO 625 - Measurement of Blood Volumes Before and After Space Flight - Data were collected for this DSO, and the data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 626 - Cardiovascular and Cerebrovascular Responses to Standing Before and After Space Flight - Data were collected for this DSO, and the data have been given to the sponsor for evaluation. The results of that evaluation will be published in separate documentation.

DSO 901 - Documentary Television - Video taken during the normal course of the mission has been given to the sponsor for evaluation and reporting.

DSO 902 - Documentary Motion Picture Photography - Film taken during the normal course of the mission has been given to the sponsor for evaluation and reporting.

DSO 903 - Documentary Still Photography - Still photographic film taken during the normal course of the mission has been given to the DSO sponsor for evaluation and report.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHIC AND VIDEO DATA ANALYSIS

No films or video were reviewed from the first two launch attempts. For the third launch attempt, which was aborted at T-3 seconds, five videos of the abort were reviewed as well as 18 launch pad films. The review of these films showed orange vapors (probably free burning hydrogen) below the SSMEs after the startup of the hydrogen igniters. After the shutdown of the SSMEs, orange vapors were noted beneath the SSMEs near the base heat shield and extending forward along the left OMS pod and forward of the vertical stabilizer. Orange flames were also seen along the LH_2 T-0 umbilical disconnect tubing. The paper covering the aft RCS ports was observed to ignite in flames. The results of this film review were presented to management.

On launch day, 24 videos were screened, and following launch day, 55 films were reviewed. No potential anomalies were noted.

ON-ORBIT PHOTOGRAPHIC AND VIDEO DATA ANALYSIS

Downlinked videos documenting the damage to the ACTS/TOS deployment structure were reviewed. Views of the actual deployment sequence and subsequent views of the damaged area were obtained from payload bay cameras A, B, C, and D; RMS elbow and end effector cameras; and the in-cabin hand-held camera. The detailed video analysis showed that the Super*Zip was only attached to the cradle at the detonation boxes located at the 12 o'clock position. The distance between the aft cradle and the base of the cradle was determined to be 8.1 inches. Analysis of the motion induced in the Super*Zip after an RCS firing was shown to have a peak-to-peak magnitude of 4.4 inches with a frequency of 0.30 Hertz.

LANDING PHOTOGRAPHIC AND VIDEO DATA ANALYSIS

On landing day, 12 videos were screened with four of these views being from infrared cameras. In addition, eight films of landing were also reviewed. The ignited APU 1 or 2 exhaust was noted in the films; however, postflight inspections have not revealed any damage in the area of the ignited exhaust. A comparison of the venting on this mission with seven previous night landings showed that the venting on those missions could only be seen on the infrared film. A more complete discussion of this condition is contained in the Auxiliary Power Unit section of this report.

TABLE I.- STS-51 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
	ON-PAD ABORT - AUGUST 12,1993	
APU activation	APU-1 GG chamber pressure	224:13:07:42.66
	APU-2 GG chamber pressure	224:13:07:43.70
	APU-3 GG chamber pressure	224:13:07:44.50
SRB HPU activation[a]	LH HPU system A start command	224:13:12:07.
	LH HPU system B start command	224:13:12: .
	RH HPU system A start command	224:13:12:08.
	RH HPU system B start command	224:13:12: .
Main propulsion system start[a]	Engine 3 start command accepted	224:13:12:28.5
	Engine 2 start command accepted	224:13:12:28.6
	Engine 1 start command accepted	224:13:12:28.7
Main propulsion system stop	Engine 2 shutdown	224:13:12:30.071
	Engine 3 shutdown	224:13:12:31.271
	Engine 1 shutdown	224:13:12:32.545
APU deactivation	APU-1 GG chamber pressure	224:13:13:18.39
	APU-2 GG chamber pressure	224:13:13:21.15
	APU-3 GG chamber pressure	224:13:12:22.08
	LAUNCH - SEPTEMBER 10, 1993	
APU activation	APU-1 GG chamber pressure	255:11:40:07.91
	APU-2 GG chamber pressure	255:11:40:08.58
	APU-3 GG chamber pressure	255:11:40:09.26
SRB HPU activation[a]	LH HPU system A start command	255:11:44:32.737
	LH HPU system B start command	255:11:44:32.737
	RH HPU system A start command	255:11:44:32.897
	RH HPU system B start command	255:11:44:32.897
Main propulsion system start[a]	Engine 3 start command accepted	255:11:44:53.452
	Engine 2 start command accepted	255:11:44:53.571
	Engine 1 start command accepted	255:11:44:53.693
SRB ignition command (lift-off)	SRB ignition command to SRB	255:11:45:00.006
Throttle up to 104 percent thrust[a]	Engine 3 command accepted	255:11:45:04.012
	Engine 2 command accepted	255:11:45:04.012
	Engine 1 command accepted	255:11:45:04.014
Throttle down to 69 percent thrust[a]	Engine 3 command accepted	255:11:45:28.492
	Engine 2 command accepted	255:11:45:28.492
	Engine 1 command accepted	255:11:45:28.494
Throttle up to 104 percent thrust[a]	Engine 3 command accepted	255:11:45:53.772
	Engine 1 command accepted	255:11:45:53.773
	Engine 2 command accepted	255:11:45:53.775
Maximum dynamic pressure (q)	Derived ascent dynamic pressure	255:11:46:03
Both SRM's chamber pressure at 50 psi[a]	RH SRM chamber pressure mid-range select	255:11:46:59.367
	LH SRM chamber pressure mid-range select	255:11:46:59.727

[a]MSFC supplied data

TABLE I.- STS-51 SEQUENCE OF EVENTS (Continued)

Event	Description	Actual time, G.m.t.
End SRM action[a]	RH SRM chamber pressure mid-range select	255:11:47:01.537
	LH SRM chamber pressure mid-range select	255:11:47:01.817
SRB separation command	SRB separation command flag	255:11:47:05
SRB physical separation[a]	LH rate APU A turbine speed LOS	255:11:47:04.687
	RH rate APU A turbine speed LOS	255:11:47:04.687
3g acceleration	Total load factor	255:11:52:33.2
Throttle down for 3g acceleration[a]	Engine 3 command accepted	255:11:52:33.298
	Engine 1 command accepted	255:11:52:33.301
	Engine 2 command accepted	255:11:52:33.303
Throttle down to 67 percent thrust[a]	Engine 3 command accepted	255:11:53:23.218
	Engine 1 command accepted	255:11:53:23.222
	Engine 2 command accepted	255:11:53:23.224
Engine Shutdown[a]	Engine 3 command accept	255:11:53:29.538
	Engine 1 command accept	255:11:53:29.542
	Engine 2 command accept	255:11:53:29.544
MECO	Command flag	255:11:53:30
	Confirm flag	255:11:53:31
ET separation	ET separation command flag	255:11:53:49
OMS-1 ignition	Left engine bi-prop valve position	Not performed - direct insertion trajectory flown
	Right engine bi-prop valve position	
OMS-1 cutoff	Left engine bi-prop valve position	
	Right engine bi-prop valve position	
APU deactivation	APU-3 GG chamber pressure	255:12:02:08.99
	APU-1 GG chamber pressure	255:12:02:22.56
	APU-2 GG chamber pressure	255:12:02:35.61
OMS-2 ignition	Left engine bi-prop valve position	255:12:24:54.1
	Right engine bi-prop valve position	255:12:24:54.1
OMS-2 cutoff	Left engine bi-prop valve position	255:12:27:19.6
	Right engine bi-prop valve position	255:12:27:19.6
Payload bay door open	PLBD right open 1	255:13:21:55
	PLBD left open 1	255:13:27:33
ACTS/TOS deploy	Voice call	255:21:13
OMS-3 ignition	Right engine bi-prop valve position	255:21:30:29.3
	Left engine bi-prop valve position	Not applicable

[a]MSFC supplied data

TABLE I.- STS-51 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
OMS-3 cutoff	Right engine bi-prop valve position	255:21:30:57.3
	Left engine bi-prop valve position	Not applicable
OMS-4 ignition	Right engine bi-prop valve position	Not applicable
	Left engine bi-prop valve position	256:09:23:29.3
OMS-4 cutoff	Right engine bi-prop valve position	Not applicable
	Left engine bi-prop valve position	256:09:23:47.2
ORFEUS-SPAS grapple	Payload capture flag	256:09:54:18
ORFEUS-SPAS unberthing	Payload latch 1A released indication	256:12:44:07
ORFEUS-SPAS release	Payload capture flag	256:15:05:59
Cabin depressurization	Cabin pressure	257:13:05:03
Airlock depressurization	Airlock differential pressure 1	259:08:29:45
Airlock repressurization	Airlock differential pressure 1	259:15:41:56
OMS-5 ignition	Left engine bi-prop valve position	260:06:32:44.7
	Right engine bi-prop valve position	Not applicable
OMS-5 cutoff	Left engine bi-prop valve position	260:06:32:51.7
	Right engine bi-prop valve position	Not applicable
Cabin repressurization	Cabin pressure	260:07:04:03
OMS-6 ignition	Left engine bi-prop valve position	Not applicable
	Right engine bi-prop valve position	260:11:06:56.5
OMS-6 cutoff	Left engine bi-prop valve position	Not applicable
	Right engine bi-prop valve position	260:11:07:03.5
ORFEUS-SPAS capture	Payload capture flag	262:11:49:11
ORFEUS-SPAS berthing	Payload latch 1A latched indication	262:14:05:44
Fuel cell 1 shutdown	Fuel cell no. 1 ready	262:14:17:59
Flight control system checkout		
APU start	APU-1 GG chamber pressure	263:05:49:34.69
APU stop	APU-1 GG chamber pressure	263:05:54:02.99

TABLE I.- STS-51 SEQUENCE OF EVENTS (Concluded)

Event	Description	Actual time, G.m.t.
Fuel cell 1 power-up	Fuel cell powerplant 1 O_2 reactant valve open	263:14:16:39
Payload bay door 1 close	PLBD left close 1	264:05:55:58
	PLBD right close 1	264:05:57:57
Payload bay door 2 open	PLBD right open 1 - BFS	264:09:45:06
	PLBD left open 1 - BFS	264:09:46:25
Payload bay door 2 close	PLBD left close 1	265:04:23:12
	PLBD right close 1	265:04:23:12
APU activation for entry	APU-2 GG chamber pressure	265:06:50:32.81
	APU-3 GG chamber pressure	265:07:11:48.45
	APU-1 GG chamber pressure	265:07:11:54.95
Deorbit maneuver ignition	Left engine bi-prop valve position	265:06:55:30.1
	Right engine bi-prop valve position	265:06:55:30.3
Deorbit maneuver cutoff	Left engine bi-prop valve position	265:06:57:47.7
	Right engine bi-prop valve position	265:06:57:47.7
Entry interface (400K)	Current orbital altitude above reference ellipsoid	265:07:24:40
Blackout ends	Data locked at high sample rate	No blackout
Terminal area energy management	Major mode change (305)	265:07:49:30
Main landing gear contact	LH MLG tire pressure	265:07:56:06
	RH MLG tire pressure	265:07:56:06
Main landing gear weight on wheels	LH MLG weight on wheels	265:07:56:11
	RH MLG weight on wheels	265:07:56:11
Drag chute deploy	Drag chute deploy 1 CP Volts	265:07:56:15.6
Nose landing gear contact	NLG tire pressure	265:07:56:21
Nose landing gear weight on wheels	NLG WT on Wheels -1	265:07:56:21
Drag chute jettison	Drag chute jettison 1 CP Volts	265:07:56:42.5
Wheels stop	Velocity with respect to runway	265:07:56:56
APU deactivation	APU-1 GG chamber pressure	265:08:02:43.88
	APU-2 GG chamber pressure	265:08:02:44.95
	APU-3 GG chamber pressure	265:08:04:25.84

TABLE II.- STS-51 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-51-V-01	Engine 2 LH_2 Inlet Pressure Failure/FA2 MDM Analog Input BITE	255:11:49 G.m.t. IM 51RF09 IPR 60V-0004	An FA2 MDM analog input BITE bit was set, indicating a problem with FA2 card 14 channel 16. Simultaneously, the engine 2 LH_2 inlet pressure (V41P1200C) which came through channel 16 failed off-scale high. KSC: Troubleshooting determined that the transducer failed. The The MDM (FA2), the dedicated signal conditioner, and wiring were exonerated. Transducer has been replaced and tested successfully.
STS-51-V-02	Port PSA Sliding Door Failure to Close	259:14:16 G.m.t. IM 51RF02 PR CM-3-18-0296	The crew was unable to close the port provision stowage assembly (PSA) sliding door under normal operation during the EVA. The crew closed the sliding door by using a tool to lift it up (-Z direction) to clear the interference with the flipper door hinge. The crew opened and closed the sliding door successfully earlier during the EVA on this mission. KSC: Troubleshooting was performed on October 1.
STS-51-V-03	Humidity Separator B Water Carryover	259:15:10 G.m.t. IM 51RF03 PR ECL-3-18-0966	The crew found approximately 4 tablespoons of water on the outlet screen of humidity separator B during both the post-sleep and pre-sleep checks on flight day 4. Each time the crew soaked up the water. During pre-sleep activities on flight day 5, about 3/4 cup of water was found on the side of the humidity separator controller. The crew soaked up the water and switched to humidity separator A. KSC: Replace humidity separator B.
STS-51-V-04	Aft RCS Thruster R1R Pressure Transducer Abnormality	263:06:50 G.m.t. IM 51RF04 PR RP03-19-0614	During the RCS hotfire, the chamber pressure indication for aft RCS thruster R1R prematurely stepped down from the nominal chamber pressure and remained at 15 psia after the pulse. The thruster was rehot-fired and the chamber pressure was 48-49 psia. The pressure transducer is either failed or biased. KSC: Troubleshoot the wiring and signal conditioner. If nothing is found, the thruster will be replaced.
STS-51-V-05	Aft RCS Thruster L3L Fail-Off	263:06:50 G.m.t. IM 51RF05 PR LP01-21-0594	Aft RCS thruster L3L failed-off when it was commanded during RCS hotfire. The chamber pressure reached only 2.5 psia which is indicative of failure of either the oxidizer or fuel valve main stage. Temperature data indicate at least some pilot stage flow through both oxidizer and fuel valves. Thruster was deselected. KSC: Remove and replace the thruster.
STS-51-V-06	Mid Starboard Payload Bay Floodlight Failure Level III Closure	262:12:13 G.m.t. IM 51RF06 IPR 60V-0010	Crew reported that the mid starboard payload bay floodlight was flickering and did not come on full bright. The light was turned off. On the mid MNC amperes, small spikes were seen which would relate to arcing and flickering. KSC: Troubleshooting has determined a bad floodlight with evidence of arcing. Floodlight was replaced.

TABLE II.- STS-51 PROBLEM TRACKING LIST

Number	Title	Reference	Comments
STS-51-V-07	MDM PF2 I/O Error	265:04:59 G.m.t. IM 51RF07 IPR 60V-0009	The Backup Flight System (BFS) general purpose computer (GPC), GPC 5, bypassed the PF2 MDM (S/N 27). The BFS annunciated an I/O error fault message. An I/O reset was unsuccessful and another I/O error fault message was received. The port mode to the secondary port was successful. Postflight, the MDM was power cycled and the I/O problem cleared. KSC: The MDM was replaced.
STS-51-V-08	APU 3 Bearing Temperature 2 Failed Off-Scale High	265:07:22 G.m.t. IM 51RF08 IPR 60V-0008	During entry, 11 minutes after APU 3 was started, the bearing temperature 2 (V46T0362A) measurement went off-scale high. The rapid failure is indicative of an open circuit in the sensor. KSC: The sensor will be checked out and replaced, if required.
STS-51-V-09	Lines and Weak Image on Monitors 1 and 2 Level III Closure	258:18:46 G.m.t. IPR 60V-0012	Crew reported that monitor 1 and 2 contained horizontal lines, scrolling, and bands across the center of the picture. Flight day 10 test was inconclusive in resolving the reported problem. KSC: Troubleshoot monitors on the vehicle.
STS-51-V-10	Orbiter Processed Degraded Color Burst from SPAS EMU RF Video Signal Level III Closure	257:09:00 G.m.t. IPR 60V-0013	During SPAS/EMU-TV operations, the crew recorded EMU-TV video on the TEAC VCR. When the video was played back, it was in black and white both onboard and on the ground. The video should have been in color. The connection between the TEAC and the CCTV monitor is through a video interface unit (VIU) located in the TEAC housing. The problem could be a faulty VIU. While investigating this anomaly, NGT-TV reported a diminished color burst signal. This problem stems from a degraded color burst directly from the SPAS that indicates the EMU-TV receiver to be a possible cause. KSC: Troubleshoot on the vehicle.
STS-51-V-11	MPS Center Engine GHe Regulator Pressure Meter OFF Flag Set	265:06:30 G.m.t. IPR 60V-0014	During the TIG minus 25 minute procedures, the crew reported that the MPS center engine gaseous helium regulator meter on panel F7 had its off flag in view when data indicated that the meter should have been operational. KSC: Troubleshooting isolate the problem to either the wiring to the meter (M4 on panel F7) or the meter itself. Troubleshooting has not reproduced the problem. Wiring to the meter has been verified and also the meter resistance has been verified. This meter was replaced prior to STS-51.
STS-51-V-12	Fuel Cell 1 H_2 Reactant Valve Talkback Sluggish Level III Closure	252:14:18 G.m.t. IPR 60V-0018	The crew reported that the H_2 reactant valve position talkback indicated closed after a delay of 4 seconds. Data review of the valve position indicators (VPI) show that the H_2 valves closed 0.3 second after the switch was thrown. KSC: Troubleshooting has not repeated the problem. The valve switch was cycled three times with instantaneous talkback response.

TABLE III.- MSFC ELEMENTS STS-51 PROBLEM TRACKING LIST

Problem/Title	Element	Description	Comments/Status
STS-51-B-01 Right SRB TVC (Tilt) APU Turbine Under-Speed	Solid Rocket Booster (USBI) Auxiliary Power Unit (Tilt)	During the countdown of the unsuccessful STS-51 launch attempt on July 24, 1993, the right SRB TVC APU (tilt) turbine experienced an underspeed redline violation at T-20 seconds	The turbine redline violation resulted in a launch pad abort. USBI, MSFC, and KSC assembled an anomaly resolution team that identified three areas to examine as candidates causing the shutdown. The targeted areas were: 1) hydraulic system; 2) electrical/electronics system; and 3) fuel system. After evaluation of all data, it was determined that the APU was the most probable cause. The APU was removed and sent to the vendor where, upon receipt, the unit was hot-fired. The APU was disassembled, and all components checkout out successfully except the fuel pump. The fuel pump exhibited degraded output flow; however, the slight degradation would not account for the underspeed condition observed during countdown. The most probable cause of the APU underspeed is believed to be particulate contamination in the fuel pump start bypass valve. This condition results in reduced fuel flow to the gas generator, causing sped reduction of the turbine. In addition, three points substantiate this conclusion: (1) Similar previous occurrences have been observed on both the SRB and Orbiter programs; (2) Particles as small as 0.004 inch on the poppet seat of the start bypass valve are sufficient to cause the anomaly; and (3) A low spring force makes this valve susceptible to trapped contamination. The failure effects of a turbine underspeed during the countdown result in a launch abort up to the T-0 time frame. If this condition occurs during flight and is sufficient to cause the hydraulic pressure to drop below 2,200 psi (lower limit), the redundant system will crossover and supply hydraulic pressure through the servoactuator switching/bypass valve. This action satisfies all mission requirements for success and safety.
STS-51-B-02 Aft Skirt Blistering of Hypalon over BTA on Left and Right SRBs	Solid Rocket Booster (USBI) Aft Skirts	During postflight inspections of both the left and right aft skirts, blistering of the hypalon was observed over multiple areas of the BTA closeout material	Although blistering of this area is not an uncommon occurrence, the booster trowellable ablator (BTA) is a recent modification to the TPS flight configuration. The BTA closeout material has only flown for four flights, and its application has been limited to the aft skirt regions through BI-063. The investigation is evaluating the cause of the blistering and will recommend appropriate corrective actions. The concern for this type of anomaly is the hypalon as a debris source. No correlation can be made at present between the hypalon blistering and the new BTA material, especially since this condition has been randomly observed on current/previous TPS configurations. The current TPS configurations limit BTA to the aft skirts only (next three missions: STS-58; STS-61; and STS-60). Therefore, no hypalon debris or flight safety concerns exist. Effective STS-6[illegible] (BI-064), BTA is scheduled for flight on the forward assemblies of the SRBs. The potential of hypalon debris from the forward areas is being evaluated, and the results will be reported when available.

TABLE III.- MSFC ELEMENTS STS-51 PROBLEM TRACKING LIST

Problem/Title	Element	Description	Comments/Status
STS-51-E-01 SSME-1 LPFTP Discharge Temperature Sensor Disqualification	Space Shuttle main engine (RKDN)	During ascent of STS-51, the SSME-1 (E2031) LPFTP discharge temperature (channel B) exhibited negative spiking, beginning at 11 seconds after engine start	A failure identification (FID) was posted by the main engine controller 24.8 seconds after ignition, thereby disqualifying the channel B output. The temperature sensor is identified as P/N RES7002-241, S/N 18954. This sensor has experienced 13 starts and 6,809 seconds, including this ninth flights. The observed condition could have resulted from a problem in either the sensor, harness, or controller. The sensor is the most likely cause and will be returned to the vendor for failure analysis. The temperature measurement has two channels, A and B, which are averaged and used to calculate fuel density for the mixture ratio control loop during ascent. Before engine start, the LPFTP discharge temperature is used to verify proper engine conditioning for the engine start command. A single channel failure before engine start results in a Major Component Failure (MCF) and subsequent launch scrub. A single channel failure before SRB ignition results in a report-only FID (no MCF). Failure of both channels during ascent results in the mixture ratio loop using a fixed value for fuel density.
STS-51-E-02 SSME-2 HPFTP Discharge Temperature Sensor Disqualification	Space Shuttle main engine (RKDN)	During the STS-51 flight, SSME-2 (E2034) HPFTP discharge temperature sensor (channel B) failed high and was disqualified 412.05 seconds after engine start	The failure cause could be in the sensor, harness, or controller. The measurement briefly recovered during engine shutdown, which is indicative of an "open wire" scenario of the element sensor. The failure is suspected to be a brittle wire failure, similar to three prior ground test failures of the RE7013 transducer (UCRs A026624, A25889, and A032223). It had experienced seven starts and 2,045 seconds, including three flights and one FRF. If confirmed, this will be the fourth failure of the RE7013-01 hot gas temperature sensors with this being the first in the flight program. STS-58 (next flight) is configured with P/N RES7004-91 transducers in the turbine discharge locations. This configuration transducer has demonstrated a higher reliability than the P/N RE7013-01 transducers. In addition, a vendor request replaced the RE7013 parts on E2033 for STS-61. Using the -91 transducers, the probability of an on-pad abort is one in 1,189 flights, and the probability of an erroneous engine shutdown during a flight is one in 8,719 flights.
STS-51-E-03 SSME-2 Fuel Flow Sensor Anomaly on Channel A2	Space Shuttle main engine (RKDN)	During the STS-51 launch attempt on August 12, 1993, channel A2 of SSME-2 (E2033) fuel flow sensor failed the 1,800 1,800 gpm intrachannel limit 1.34 seconds after engine start	A failure identification (FID) was posted by the main engine controller and the engine commanded to shutdown at engine start + 1.5 seconds, due to lack of critical sensor redundancy prior to SRB ignition. Channel A2 of the fuel flow sensor never responded (remained constant) during the engine start transient phase. After the pad abort, a troubleshooting plan was developed. The normal sensor checkout moduel performed by the controller was completed three times without an indication of failure. A harness wiggle check was performed, and there were no indications of an anomaly. The sensor was removed, and circuit resistances were found to be nominal for both coils (A1 and A2). The sensor was removed and no damage was noticeable from visual examination. The sensor checkout was performed without a fuel flow sensor, and a failure was indicated; therefore, the controller was verified to be able to detect a failure of the fuel flow coil. The sensor was sent to the supplier for failure analysis testing.

TABLE III.- MSFC ELEMENTS STS-51 PROBLEM TRACKING LIST

Problem/Title	Element	Description	Comments/Status
			The part was examined, and no damage was noted. Room temperature electrical tests revealed no problems with the sensor. The next test was "isolation resistance" where the resistance between two coils was measured in liquid nitrogen. The liquid nitrogen exposure was performed with a controlled thermal gradient as used in the workmanship screening thermal cycle. The sensor passed, however, it was noted that coil 2 was open when submerged in liquid nitrogen. The sensor was examined using high magnification real-time X-ray, and no obvious abnormalities were noted. A controlled thermal cycle was performed using an insulated chamber which used cold nitrogen entering in spurts to control the temperature. The flow sensor had a thermocouple attached to the coil side, and the coil resistance was monitored on both elements of the flow sensor. The open circuit was duplicated several times as the temperature went below 57°F. Capacitance checks were performed with the open coil to find that pin 3 was the lead most associated with the open. Teardown was initiated by machining off the housing over the coil assembly. Upon peeling back the sheath, an axial crack was noticed from the flange end to the coil tip end and it was photographically documented. The part was subjected to additional real-time X-ray; however, no anomaly could be found. Electrical checks found that the circuit was now open at room temperature. The entire sensor was viewed in the scanning electron microscope (SEM). High magnification examination found that the crack had propogated along voids or air bubbles in the epoxy molding. It appeared the largest crack width was at the lead wire location, as the lead wire insulation leading to pin 3 was slightly exposed. The potting material was etched off with a chemical solution. A break was noticed on the coil wire of pin 3, one revolution from the braze joint with the lead wire. Proper strain relief was employed for the coil wire. The break was outboard of the outside diameter of the mold. The fracture surfaces were examined, and necking was confirmed in the area of the break by the SEM indicating that the coil wire experienced ductile overload. Necking was noticed along the coil wire in the area of the fracture. This is similar to previous failure analysis reports for the fuel flow transducer. Revision 6 to the operational instrumentation version of software for the SSME controller implements a change as a recurrence control. The change removed the logic which treats fuel flow sensor outputs in pairs in favor of treating the four outputs per engine as individual channels. This change has been incorporated in the next version of the software. The change also retains the fail-operate/fail safe capability, and allows liftoff to occur with a single sensor failed. The probability of an on-pad launch abort has been significantly reduced with this change. Additionally, a redesign of the fuel flow sensor is under consideration. The flow sensor is external to the engine, and a worst case failure would not result in a criticality I effect.

DOCUMENT SOURCES

In an attempt to define the official as well as the unofficial sources of data for this mission report, the following list is provided.

1. Flight Requirements Document
2. Public Affairs Press Kit
3. Customer Support Room Daily Reports
4. MER Daily Reports
5. MER Mission Summary Report
6. MER Quick Look Report
7. MER Problem Tracking List
8. MER Event Times
9. Subsystem Manager Reports/Inputs
10. MOD Systems Anomaly List
11. MSFC Flash Report
12. MSFC Event Times
13. MSFC Interim Report
14. Crew Debriefing comments
15. Shuttle Operational Data Book

ACRONYMS AND ABBREVIATIONS

The following is a list of the acronyms and abbreviations and their definitions as these items are used in this document.

ACTS/TOS	Advanced Communication Technology Satellite/Transfer Orbit Stage
ALBERT	Advanced Lower Body Extremities Restraint
AMOS	Air Force Maui Optical Site Calibration Test
APE-B	Auroral Photography Experiment-B
APU	auxiliary power unit
ARIA	Apollo Range Instrumentation Aircraft
ARS	atmospheric revitalization system
ASE	airborne support equipment
ATCS	Active thermal control system
BFS	backup flight system
BITE	built-in test equipment
BTA	booster trowellable ablator
CCTV	closed circuit television
CHROMEX	Chromosome and Plant Cell Division in Space
CPCG	Commercial Protein Crystal Growth
CR/IM	commercial refrigerator/incubator module
CRT	cathode ray tube
D&C	displays and controls
DCM	display and control module
DEU	display electronics unit
DMHS	dome-mounted heat shield
DSC	dedicated signal conditioner
DSO	Detailed Supplementary Objective
DTO	Development Test Objective
ΔV	differential velocity
ECLSS	Environmental Control and Life Support System
EE	end effector
EMU	extravehicular mobility unit
EPDC	electrical power distribution and control subsystem
ESTL	Electronic Systems Test Laboratory
ET	External Tank
ETVAS	External Tank vent arm system
EUV	extreme ultraviolet
EV	extravehicular
EV1	extravehicular 1 (Walz)
EV2	extravehicular 2 (Neuman)
EVA	extravehicular activity
FA2	flight critical aft 2
FCS	flight control system
FDA	fault detection and annunciation
FES	flash evaporator system
FUV	far ultraviolet
GAS	getaway special
GFE	Government furnished equipment
GLS	ground launch sequencer
G.m.t.	Greenwich mean time

GN&C	guidance, navigation and control
GPC	general purpose computer
GPS	Global Positioning System
GSE	ground support equipment
HPFTP	high pressure fuel turbopump
HPOTP	high pressure oxidizer turbopump
HPU	hydraulic power unit
HRSGS-A	High Resolution Shuttle Glow Spectroscopy-A
HST	Hubble Space Telescope
IAPU	improved auxiliary power unit
ICD	Interface Control Document
IFM	in-flight maintenance
IMU	inertial measurement unit
I/O	input/output
IMAPS	Interstellar Medium Absorption Profile Spectrograph
IPL	initial program load
IPMP	Investigations into Polymer Membrane Processing
Isp	specific impulse
JSC	Johnson Space Center
keas	knots estimated air speed
KSC	.nnedy Space Center
kWh	kilowatt hours
LCC	Launch Commit Criteria
LDCE	Limited Duration Space Environment Candidate Materials Exposure
LESC	Lockheed Engineering and Sciences Company
LH_2	liquid hydrogen
LO_2	liquid oxygen
MADS	modular auxiliary data system
MCC	Mission Control Center
MDM	multiplexer/demultiplexer
MECO	main engine cutoff
MET	mission elapsed time
MILA	Merritt Island launch area
MLGD	main landing gear door
MLP	mobile launch platform
MPM	manipulator positioning mechanism
MPS	main propulsion system
MRL	manipulator retention latches
MSBLS	microwave scanning beam landing system
MSFC	George C. Marshall Space Flight Center
MWS	miniwork station
NCC	nominal correction (maneuver)
NLGD	nose landing gear door
NOAA	National Oceanic and Atmospheric Administration
NPSP	net positive suction pressure
NSP	network signal processor
OMDP	Orbiter maintenance down period
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPS	Operations
ORFEUS-SPAS	Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer -Shuttle Pallet Satellite

PADM	portable audio data modem
PAL	protuberance air load
PF2	payload forward 2
PGSC	payload general support computer
PI	payload interrogator
PIC	pyrotechnic initiator controller
PLBD	payload bay door
PM	phase modulation
PMBT	propellant mean bulk temperature
PRSD	power reactant storage and distribution
PRT	power ratchet tool
PSA	payload bay stowage assembly
PSP	payload signal processor
RCC	reusable carbon carbon
RCS	reaction control subsystem
RICS	Remote IMAX Camera System
RME-III	Radiation Monitoring Equipment-III
RMS	remote manipulator system
rpm	revolutions per minute
RSRM	Redesigned Solid Rocket Motor
S&A	safe and arm
SCU	sequence control unit
SCU	service and cooling unit
SESAM	Surface Effects Sample Monitor
SLF	Shuttle Landing Facility
SM	systems management
SODB	Shuttle Operational Data Book
SPEE	Special Purpose End Effector
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SRSS	Shuttle Range Safety System
SSME	Space Shuttle main engine
STA	Shuttle training aircraft
STS	Space Transportation System
T/B	thermal barrier
TCS	Trajectory Control Sensor
TCS	thermal control system
TDRS	Tracking and Data Relay Satellite
TIPS	Thermal Impulse Printer System
TPS	thermal protection subsystem
TVC	thrust vector control
USAF	U. S. Air Force
WETF	Weightless Environment Training Facility
WRR	wrist roll range
WSB	water spray boiler