

STS-93 SPACE SHUTTLE MISSION REPORT

September 1999



**National Aeronautics and
Space Administration**

**Lyndon B. Johnson Space Center
Houston, Texas**

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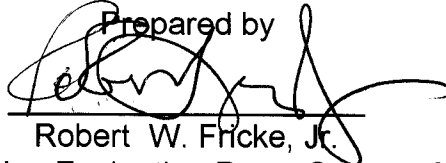
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STS-93

SPACE SHUTTLE

MISSION REPORT


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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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INTRODUCTION

The STS-93 Space Shuttle Program Mission Report presents a discussion of the Orbiter subsystem operation and the in-flight anomalies that were identified during the mission. The report also summarizes the mission activities and presents a summary of the External Tank (ET), Solid Rocket Booster (SRB), Reusable Solid Rocket Motor (RSRM), and Space Shuttle main engine (SSME) performance during this ninety-fifth mission of the Space Shuttle Program. STS-93 was the seventieth flight since the return to flight, and the twenty-sixth flight of the OV-102 (Columbia) Orbiter vehicle.

The flight vehicle consisted of the OV-102 Orbiter; an ET that was designated ET-99, which was the fifth super lightweight tank (SLWT); three Phase II SSMEs that were designated as serial numbers (S/N) 2012, 2031, and 2019 in positions 1, 2, and 3, respectively; and two SRBs that were designated BI-097. The two RSRMs were designated RSRM 69 with one installed in each SRB. The individual RSRMs were designated 360T069A for the left SRB, and 360T069B for the right SRB. For this mission, the vehicle was erected on Mobile Launch Platform (MLP) 1 and the launch was completed from launch pad 39B.

The primary objective of the STS-93 mission was to deploy the Advanced X-Ray Astrophysics Facility-Imaging (AXAF-I), which was renamed the Chandra X-Ray Observatory (CXO). Secondary objectives were to perform the operations of the Midcourse Space Experiment (MSX), Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX), Southwest Ultraviolet Imaging System (SWUIS), Gelation of Sols: Applied Microgravity Research (GOSAMR), Space Tissue Loss - B (STL-B), Lightweight Flexible Solar Array Hinge (LFSAH), Cell Culture Module (CCM), Shuttle Amateur Radio Experiment - II (SAREX-II), Plant Growth Investigations in Microgravity (PGIM), Commercial Generic Bioprocessing Apparatus (CGBA), Micro Electro-Mechanical Systems (MEMS), and the Biological Research in Canisters (BRIC).

The STS-93 mission was a planned 5 day plus 2-contingency-day mission during which items listed in the previous paragraph were to be performed. The two contingency days were available for bad weather avoidance for landing, or other Orbiter contingency operations. The STS-93 sequence of events is shown in Table I, and the Space Shuttle Vehicle Engineering Office (SSVEO) In-Flight Anomaly List is shown in Table II. Table III lists the Marshall Space Flight Center (MSFC) In-Flight Anomaly List. Appendix A lists the sources of data, both informal and formal, that were used in the preparation of this report. Appendix B provides the definitions of all acronyms and abbreviations used in this report. All times from liftoff to landing are given in Greenwich mean time (G.m.t.) and mission elapsed time (MET).

The five crewmembers of the STS-93 mission were Eileen M. Collins, Col., U. S. Air Force, Commander; Jeffrey S. Ashby, Capt. U. S. Navy, Pilot; Catherine G. Coleman, Ph.D., Lt. Col., U. S. Air Force, Mission Specialist 1; Steven A. Hawley, Ph.D., Civilian, Mission Specialist 2; and Michel Tognini, Col., French Air Force, Mission Specialist 3. STS-93 was the fifth Space Shuttle flight for Mission Specialist 2, the third Space Shuttle flight for the Commander, the second Space Shuttle flight for Mission Specialist 1, and the first Space Shuttle flight for the Pilot and Mission Specialist 3. This was the second space flight for Mission Specialist 3 as he spent two weeks on the Russian Mir Space Station in 1992.

MISSION SUMMARY

The STS-93 Space Shuttle vehicle was launched on an inclination of 28.45 degrees at 204:04:30:59.984 G.m.t. (12:31:00 a.m. e.d.t. on July 23, 1999) after a satisfactory countdown.

The initial launch attempt of the STS-93 vehicle, scheduled for 12:36 a.m. e.d.t. on July 20, 1999, was scrubbed when the hazardous gas sample reading from the Orbiter aft compartment at T-15 seconds indicated a hydrogen concentration of 640 ppm, which exceeded the Launch Commit Criteria (LCC) limit of 600 ppm. As a result of this occurrence, ignition of the three Space Shuttle main engines (SSMEs) was manually inhibited by the hazardous gas operator in the firing room.

The cause of the indicated increase in the aft compartment hydrogen concentration was determined to be a problem in the hazardous gas detection system. The subsequent investigation and fault tree analysis attributed the spike to an "ion-pump-burp", which is a known characteristic of mass spectrometers. Ion pumps are routinely replaced to reduce the frequency of this failure. This ion pump was well within the accepted service life, having been installed less than two weeks at the time of the occurrence. No Orbiter corrective actions were required and the launch was rescheduled for July 22, 1999. For subsequent launch attempts on this mission, mission management established a ground rule that if a similar event was seen on the prime machine, a corresponding level on the backup machine or a second data sample on the prime machine would be required to call a countdown hold.

The second STS-93 launch attempt was made for a launch at 12:28 a.m. e.d.t. on July 22, 1999, and was scrubbed because of unfavorable weather in the launch area. Lightning was present within the 20-mile LCC limit throughout the launch window. The launch was rescheduled for 12:24 a.m. e.d.t. on July 23, 1999.

During the countdown for the launch on July 23, 1999, a communications problem occurred that resulted in the loss of the forward link with the vehicle. The problem was corrected at the Merritt Island Launch Area (MILA) ground facility and communications were restored. As a result of this problem, the time of the planned launch was slipped seven minutes to 12:31 a.m. e.d.t. on July 23, 1999.

Postlaunch data evaluation showed that approximately 5 seconds after SSME start and prior to liftoff, SSME 3 experienced a shift in performance that was the result of a 3.7 lb/sec hydrogen leak in the engine nozzle. Evidence of a hydrogen leak from SSME 3 nozzle was also observed in postlaunch photography. The leak was caused by the loss of a main injector liquid oxygen (LO₂) post-deactivation pin impacting the nozzle and rupturing three hydrogen cooling tubes. The hydrogen leak caused an off-nominal mixture ratio that resulted in low engine performance, which in turn caused a compensating increase in the flow of oxygen, and that in turn resulted in the low-level oxygen cutoff. The low-level oxygen cutoff of the three SSMEs resulted in a 16 ft/sec underspeed at main engine cutoff (MECO).

Approximately 5 seconds after the liftoff of the vehicle, an electrical short of approximately 0.5-second duration occurred on phase A of AC bus 1. Coincident with the short, the SSME 1 (center engine) digital computer unit (DCU) A was switched to DCU B and a channel B halt occurred on SSME 3 (right engine) DCU B. The loss of

DCU A on SSME 1 resulted in the loss of all data from that engine for the remainder of ascent. The disqualification of DCU B on SSME 3 resulted in its loss for control and red-line protection. However, all three SSMEs continued to operate satisfactorily for the remainder of ascent. Post ascent, the crew was asked to check the SSME controller circuit breakers on panel L4, and they reported that none had opened.

An extensive review of the Orbiter components that were being powered by AC bus 1 during the event was performed. This review showed that there were effects of the resulting AC bus 1 undervoltage caused by the short, but all of the Orbiter equipment operating at the time of the short operated nominally following the short. One of the effects seen was the high pH indication received by fuel cell 1 when the pH sensor performed a self test that was initiated by the undervoltage transient. A second was a momentary water (H₂O) loop light on caution and warning panel F7 that was caused by the effect of the undervoltage transient on the water coolant loop 2 signal conditioner. The data evaluation concluded that AC bus 1 was satisfactory for unrestricted use.

During flight day 3, the crew reported that the AC bus 1 phase A circuit breaker for SSME 1 controller A was actually open and transmitted photographs of the circuit breaker to the ground. Earlier in the mission, the crew had indicated that the circuit breaker was closed; however, a closer inspection of the circuit breaker showed that this initial report was in error. With these data, the source of the short was isolated to a point downstream of the circuit breaker, either in the Orbiter aft compartment wiring or the SSME 1 controller/wiring. The AC 1 phase B and C circuit breakers for SSME 1 controller A were opened for entry to protect against an inadvertent powering of the controller. Postflight troubleshooting isolated the cause of the short to a damaged wire in the Orbiter port wire tray at the midbody bay 11/12. A more complete discussion of this anomaly is contained in the Electrical Power Distribution and Control Subsystem section of this report.

During ascent, the flash evaporator system (FES) high-load inboard-duct temperature dropped to 124 °F at 204:04:46 G.m.t. (approximately 15 minutes MET). The temperature normally remains above 190 °F with only one heater activated. Throughout the occurrence, the evaporator outlet temperatures were stable. The FES performed nominally during entry. The high-load FES on OV-102 has a history of water carryover resulting in off-nominal FES duct temperatures. This unit will be removed from the vehicle during postflight operations and returned to the vendor for refurbishment.

At 204:05:03:15 G.m.t. (00:00:32:15 MET), the backup flight system (BFS) annunciated a cathode ray tube (CRT) BITE 3 message. The BFS was polling the display electronics unit (DEU) at the time, with the BFS/CRT select switch in the 3+1 position. The BITE status words indicated a DEU central processing unit (CPU) memory parity error. The crew performed the malfunction procedure and verified the memory parity error. CRT 3 was recovered and remained selected and powered for the remainder of the mission. All of the CRTs and DEUs will be removed from OV-102 prior to ferrying the vehicle to Palmdale for Orbiter Maintenance Down Period (OMDP), where the multifunction electronic display system (MEDS) upgrade will be installed.

The orbital maneuvering subsystem (OMS) -1 maneuver was not required. The OMS-2 maneuver was performed at 204:05:12:06.97 G.m.t. [00:00:41:06.98 MET). The maneuver was 135.8 seconds in duration and a differential velocity (ΔV) of 201.3 ft/sec was imparted to the vehicle. The resulting orbit was 144.7 by 153.7 nmi.

The payload bay doors were opened at 204:06:08:35 G.m.t. (00:01:37:35 MET). Dual motor times were recorded during the opening operations.

The Ku-Band antenna was deployed at 204:12:16:00 G.m.t. (00:07:45:00 MET) and the initial self-test failed due to a known and expected condition. After the initialization was complete, the system was switched to the communications mode, and the antenna operated nominally throughout the flight.

The Chandra X-Ray Observatory (CXO) was successfully deployed at 204:11:47:01 G.m.t. (00:07:16:01 MET). At 204:11:48:25 G.m.t. (00:07:17:25 MET), an Orbiter -X-axis maneuver was initiated to separate from Chandra. This was accomplished with two firings of reaction control subsystem (RCS) thrusters F2F and F3F. The first pulse was 0.54-second in duration, and the second was 6.7 seconds in duration. This separation firing was performed nominally with no requirement for an additional trim firing. At 204:12:02:25 G.m.t. (00:07:31:25 MET), additional separation from the CXO was accomplished with a 34.0-second firing of the left OMS engine. The resultant orbit was 153 by 163 nmi. The maneuver delivered a ΔV of 34.5 ft/sec to the vehicle.

Throughout the mission, there were many RCS and OMS firings performed in support of the Midcourse Space Experiment (MSX) and Shuttle Ionospheric Modification with Pulsed Local Exhaust (SIMPLEX) payloads, the Development Test Objective (DTO) 260 fly-cast maneuver, and orbital adjustments. RCS and OMS performance during each of these firings was nominal. Details of these firings are tabulated in the Reaction Control Subsystem and Orbital Maneuvering Subsystem sections of this report.

At 205:04:31 G.m.t. (01:00:00 MET), pressure control system (PCS) 1 oxygen flow sensor failed to indicate flow during several periods when oxygen flow was selected. However, this sensor did indicate flow earlier in the mission (between 6 and 10 hours MET) and briefly indicated flow at approximately 208:14:07 G.m.t. (04:09:36 MET). During postflight troubleshooting, flow was being indicated.

Several times during the mission, the crew experienced tape jamming problems on the Canon L1 camcorder. They also had problems recording and reported later in the mission that the viewfinder display was blank during use. The crew used gray tape to identify the camcorder and the problems they experienced with it. The unit was returned to Houston for failure analysis.

Throughout the mission following firings of RCS primary thruster F2D, the fuel injector temperature dropped, indicating a small volume leak from the fuel valve. The temperature remained above the redundancy management (RM) leak detection limit of 20 °F for the fuel injector temperature. This performance did not impact the mission, and the thruster was used as planned. All of the primary RCS thrusters will be removed from the vehicle and sent to the White Sands Test Facility (WSTF) for OMDP processing.

The flight control system (FCS) checkout was performed using auxiliary power unit (APU) 1 at 208:01:27:06 G.m.t. (03:20:56:06 MET). The data showed performance was nominal. The checkout lasted for 5 minutes 49 seconds and 18 lb of fuel were consumed. Because of the short run-time of the APU, water spray boiler (WSB) 1 cooling was not required as the APU 1 lubrication oil temperature only reached 219 °F.

The RCS hot-fire began at 208:02:19:07 G.m.t. (03:21:48:07 MET) and was completed by 208:02:24:41 G.m.t. (03:21:53:41 MET). Sixteen thrusters were fired for the first time during the hot-fire. Also during the hot-fire, the primary thruster F2D fuel-injector temperature exhibited the same dribbling signature seen throughout the mission. The fuel injector temperature dropped to 29 °F. As stated previously, the RM deselection limit is 20 °F.

Ku-band antenna stowage was accomplished at about 208:07:05 G.m.t. (04:02:34 MET) with dual motor run times.

During deorbit preparations at 209:01:55 G.m.t. (04:21:24 MET), the right vent door 3 close 1 microswitch initially responded correctly. Approximately 5 seconds later, the microswitch transferred off where it remained for approximately one minute 30 seconds. Following that period, the microswitch transferred back on and remained in that position. Data indicate that the door closed in dual motor time. The door was actuated two other times during the mission and its performance was nominal. Postflight troubleshooting failed to duplicate the anomaly.

The payload bay doors were closed and latched for landing at 208:23:40:36 G.m.t. (04:19:09:36 MET). The dual-engine deorbit maneuver for the first landing opportunity at the Kennedy Space Center (KSC) Shuttle Landing Facility (SLF) was performed on orbit 79 at 209:02:19:00.1 G.m.t. (04:21:49:00.1 MET). The maneuver was 133.6 seconds in duration with a ΔV of 134.4 ft/sec.

Entry interface occurred at 209:02:48:47.7 G.m.t. (04:22:17:47.7 MET). Entry was completed satisfactorily, and main landing gear touchdown occurred on SLF concrete runway 33 at 209:03:20:36 G.m.t. (04:22:49:37 MET) on July 27, 1999. The nose gear touchdown occurred at 209:03:20:43.8 G.m.t. The drag chute was deployed at 209:03:20:48 G.m.t. and jettisoned at 209:03:21:08 G.m.t. Wheels stop occurred at 209:03:21:22 G.m.t. The rollout was normal in all respects. The flight duration was 4 days 22 hours 49 minutes 36 seconds. The APUs were shut down 16 minutes 3 seconds after landing.

PAYLOADS AND EXPERIMENTS

CARGO BAY PAYLOAD

The Chandra X-Ray Observatory (CXO), a National Aeronautics and Space Administration (NASA) payload, is the world's most powerful X-Ray telescope, and it was the primary payload on the STS-93 mission. The in-bay activation and checkout of the CXO power, communications and data management systems were successful, and the onboard computers were loaded and started. No system anomalies were noted.

The CXO and inertial upper stage (IUS) were successfully deployed at 204:11:47:01 G.m.t. (00:07:16:01 MET). The two-minute duration IUS first-stage firing was performed as planned about one hour after the deployment. Following a two-minute coast period, the first stage of the IUS was separated and the second stage fired for two-minutes. A nominal orbit of 327 km by 72,067 km was achieved by the two IUS firings.

The IUS second stage was separated and the first firing of the Integral Propulsion System (IPS) was performed. The resultant orbit was a nominal 1191.9 km by 72,067.5 km. The second IPS firing raised the perigee to 3400 km. A total of five firings of the IPS were made to reach the desired orbital conditions.

As this report was being finalized, all of the CXO maneuvers as well as the activation of the CXO were successfully completed. The initial data from the first observation was received at the ground stations, and the initial evaluation of that data indicated very satisfactory operation.

MIDDECK PAYLOADS

Light Weight Flexible Solar Array Hinge Experiment.- All six of the Light Weight Flexible Solar Array Hinges (LFSAH) were deployed during the course of the mission. The crew reported that all hinge operations were nominal, with no anomalies noted. All of the planned mission objectives were accomplished for a 100-percent success rate.

Midcourse Space Experiment.- A total of three firings of the orbital maneuvering subsystem (OMS) were made in support of the Midcourse Space Experiment (MSX). The results were not available when this report was written as analysis of the data requires several weeks to determine if the ion beams from the OMS engines produced the predicted effects. No vehicle anomalies were reported and the Principal Investigator reported that 100 percent of the payload objectives were accomplished.

Shuttle Amateur Radio Experiment - II.- The twenty-fifth flight of the Shuttle Amateur Radio Experiment (SAREX-II) was very successful with 100-percent of the school contacts (5) and 100-percent of the personal contacts (5) completed. In addition, random voice contacts were made during the crew free-time, and the Pilot made contact with the Russian Mir Space Station as well as a radio station in Colorado.

The crew reported on several occasions that the digital signal processor (DSP) unit was not performing nominally as it was losing the audio signal. Initially it was thought that a low-power condition could be contributing to the problem, but the problems were also

present with the supplementary battery pack. An evaluation is being conducted to determine the cause of the problem.

Shuttle Ionospheric Modification with Pulsed Local Exhaust Experiment.- Six firings of the OMS and reaction control subsystem (RCS) thrusters were made in support of the Shuttle Ionospheric Modification with Pulsed Local Exhaust Experiment (SIMPLEX). The Principal Investigator reported that good data were received from all engine firings; however, the results of the refined data analysis will not be available for this report. All planned in-flight SIMPLEX objectives were accomplished for a 100-percent success rate.

Southwest Ultraviolet Imaging System.- Observations were made for the Southwest Ultraviolet Imaging System (SWUIS) payload on three flight days. Data were taken on Venus, the Vulcanoid search fields, the Moon, the Jupiter system, the comet Lee as well as two calibration targets. From all indications, the SWUIS operated nominally. The crew completed all the planned astronomical observations, pointings, and also accomplished the highly desired test of the SWUIS camera science mode.

Based on crew comments and the sparse but valuable Ku-Band downlinked video of the observations, many of the observations appeared to be successful; however, some were out of focus. Based on the initial analysis, between 50 and 70 percent of the planned objectives were accomplished. The principal investigator also reported that the lunar images contain some exciting scientific surprises. No in-flight anomalies were experienced with this payload.

Biological Research in Canisters.- The Biological Research in Canisters (BRIC) payload accomplishments exceeded preplanned objectives. All preplanned objectives for both units were accomplished plus re-planning some activities increased the overall accomplishments. No anomalies occurred that impacted overall payload mission success or contributed to any loss of science. The overall success rate for this payload is 110 percent.

Cell Culture Module.- All operations of the Cell Culture Module (CCM) experiment proceeded nominally, and 100 percent of the mission objectives were completed. Crew interaction with the module involved a switch throw for activation, daily status checks and a switch throw to deactivate the module.

Commercial Generic Bioprocessing Apparatus.- Three experiments were flown as the components of the Commercial Generic Bioprocessing Apparatus (CGBA).

Tissue Experiment: All status checks were completed on the Tissue Experiment locker. The only problem during the mission was that power was inadvertently shut off to the payload for an unknown period of time. The un-powered duration will be determined during postflight operations from time-stamp data stored in the payload computer, and the impact to the overall success of the experiment will be assessed. One experiment depended on power to pulse the sample container syringes, and these data will now differ from the simultaneous ground controls. Commercial biotechnological sample processing did occur on-orbit as planned.

Ladybug Experiment: All status checks for this locker were nominal. Activation was successful. This locker was on a shared Y-cable with the Tissue Experiment and also

experienced an unknown period of the power being shut off. The impact of this condition is unknown but it is not likely to be significant for this locker. Excellent quality as well as ample quantity, video images were obtained of the ladybugs, aphids, wheat plants, caterpillars butterflies and sweet potatoes. The data were posted in near real-time on the Internet for analysis by students in grades Kindergarten through 12 throughout the United States and Chile. Video operations for this locker were a great success with all objectives met.

National Institutes of Health-B Experiment: An anomaly occurred when the experiment was installed in the Orbiter prior to flight as the experiment could not be powered. As a result, an in-flight maintenance (IFM) procedure was performed that bypassed the suspect circuit in the payload and allowed partial operation. The Principal Investigator's initial evaluation suggested that the IFM may have salvaged 20 percent of the original science objectives and will produce 67-percent usable sample material. If the IFM had not been performed, the science loss would have been 100 percent.

Gelation of Sols: Applied Microgravity Research.- The Gelation of Sols: Applied Microgravity Research (GOSAMR) experiment was activated as planned of flight day 2 and operated satisfactorily throughout the mission. The crew interaction consisted of a switch throw to activate the experiment, and all preplanned objectives were accomplished. Mission success is expected to be 100 percent.

Micro Electro-Mechanical Systems.- The Micro Electro-Mechanical Systems (MEMS) operated nominally, with the possible exception of the thermal control device (TCD). No in-flight maintenance (IFM) can be performed on the unit while on-orbit. Despite the potential loss of the TCD, the Principal Investigator reported that 100-percent of the planned mission objectives were accomplished.

Plant Growth Investigations in Microgravity.- The Plant Growth Investigations in Microgravity (PGIM) experiment data from the plant growth facility (PGF) showed that the plant growth chamber temperatures, humidity, and lighting were nominal. All preplanned objectives were accomplished.

On flight day 2, the crew reported that the fluorescent light module (FLM) in the plant growth facility had been off since flight day 1. An IFM was performed to provide cooling and normal operations were resumed. This same IFM had been successfully performed on STS-87. Postflight analysis of the plants will determine the impact on science; however, overall mission success was reported as 110 percent. This increase above 100-percent resulted from the performance and downlink of plant photographs.

Space Tissue Loss.- The Space Tissue Loss (STL-B) payload initially had a problem, as noted during the first video downlink, with the focus of the video camera. The video camera was refocused and provided good coverage.

The experiment also experienced problems with the automatic focus of the microscopy camera on the spores. Manual operations of the camera provided some improvement in the focus. Downlinked data showed that the focal plane in automatic mode was not penetrating deep enough. A workaround was provided that required the camera to be re-zeroed at the appropriate focal plane. Initially, following this change in operations, the automatic mode appeared to operate properly.

Upon viewing the real-time video downlink of the experiment at 208:02:42 G.m.t. (03:22:11 MET), the crew was requested to perform the manual re-zero focus operations one last time. The unit appeared to hold focus for only one of the three chambers being studied. Postflight analysis of the video recorded onboard as well as the experiment lockers will be required to determine the effects of the camera focus problem.

LAUNCH SCRUBS

FIRST LAUNCH SCRUB - JULY 20, 1999

The first launch attempt was scrubbed when the primary mass spectrometer reading for the aft compartment hydrogen concentration spiked to 640 ppm at T-15 seconds. The system engineer called a hold based on this data. Since the SSME hydrogen burn-off igniters had been fired, the hold became a launch scrub. The subsequent investigation and fault-tree analysis attributed the spike to an "ion-pump-burp", which is a known characteristic of mass spectrometers. Ion pumps are routinely replaced to reduce the frequency of this failure. This ion pump was well within the accepted service life, having been installed less than two weeks at the time of the occurrence. It was determined that no hardware changes were required prior to the next launch attempt. For subsequent launch attempts on this mission, mission management established a ground rule that if a similar event was seen on the prime machine, a corresponding level on the backup machine or a second data sample on the prime machine would be required to call a countdown hold.

SECOND LAUNCH SCRUB - JULY 22, 1999

The second launch attempt was scrubbed because of unfavorable launch site weather (thunderstorms and lightning within 20 nmi.). The scrub was declared during the T-5 minute hold at approximately 203:05:18 G.m.t. (12:05:18 a.m. e.d.t.).

VEHICLE PERFORMANCE

Two anomalies were identified in the Marshall Space Flight Center (MSFC) elements and one Orbiter in-flight anomaly was identified in the Johnson Space Center (JSC) element. These anomalies did not impact the successful completion of the mission. The overall performance of the subsystems of the various elements are discussed in this section of the report. Two launch scrubs occurred prior to the launch of this flight. These are discussed in the previous section of this report entitled Launch Scrubs.

SOLID ROCKET BOOSTERS

All Solid Rocket Booster (SRB) subsystems performed satisfactorily during the prelaunch testing and countdown. The overall flight performance of the SRBs was satisfactory, except for the measurement anomaly discussed in the following paragraph. No SRB Launch Commit Criteria (LCC) or Operations and Maintenance Requirements Document (OMRSD) violations occurred.

An in-flight anomaly (Flight Problem STS-93-B-01) was experienced in the right-hand SRB thrust vector controller tilt system hydraulic pressure measurement, which became erratic twice during ascent. Assessment of the other measurements parameters associated with the tilt system showed that the erratic data were caused by a failure within the measurement system and was not a hydraulic system failure. All other SRB systems performed as expected.

STS-93 was the third flight of the External Tank (ET) thermal protection system (TPS) observation cameras, which were flown to obtain photography of TPS loss from ET thrust panel areas. The cameras, which were flown on both SRBs this flight, functioned as designed by providing continuous visual coverage of the ET thrust panel areas from liftoff through SRB separation.

This flight was also the third flight on which all of the main parachutes (eight links per main parachute) were equipped with sea water activated release (SWAR) links. A total of 46 of the 48 SWARs operated properly. The cause of the failure of two of the SWARs to activate after water impact is under investigation.

Both SRBs were recovered and returned to Kennedy Space Center (KSC) for inspection, cleaning and refurbishment. All recovery systems operated as planned. The inspection of the retrieved SRBs was completed, and the SRBs were found to be in excellent condition. All damage noted was minimal and considered typical of that observed following previous launches.

REUSABLE SOLID ROCKET MOTORS

The Reusable Solid Rocket Motors (RSRMs) performed satisfactorily with no in-flight anomalies noted in the data. Also, no LCC violations occurred during the countdown. The propulsion performance data are shown in the table on the following page.

Flight data indicate that the performance of the RSRMs was well within the allowable performance envelopes and was typical of the performance observed on previous flights. The RSRM propellant mean bulk temperature (PMBT) was a nominal 80 °F at

liftoff. The maximum trace-shape variation of pressure versus time during the 62- to 80-second time frame was calculated to be 0.83 percent at 80 seconds for the left motor, and 0.78 percent at 74 seconds for the right motor. Both of these values are within the 3.2 percent allowable limits.

RSRM PROPULSION PERFORMANCE

Parameter	Left motor, 80 °F		Right motor, 80 °F	
	Predicted	Actual	Predicted	Actual
Impulse gates				
I-20, 10 ⁶ lbf-sec	65.97	65.73	66.04	65.91
I-60, 10 ⁶ lbf-sec	175.73	175.64	175.88	176.13
I-AT, 10 ⁶ lbf-sec	297.00	296.63	297.10	297.14
Vacuum Isp, lbf-sec/lbm	268.6	268.3	268.6	268.7
Burn rate, in/sec @ 60 °F at 625 psia	0.3672	0.3679	0.3673	0.3679
Event times, seconds ^a				
Ignition interval	0.232	N/A	0.232	N/A
Web time ^b	109.2	108.7	109.1	108.6
50 psia cue time	118.9	118.7	118.9	118.8
Action time ^b	121.0	121.0	120.9	120.8
Separation command	123.8		123.8	
PMBT, °F	80	80	80	80
Maximum ignition rise rate, psia/10 ms	90.4	N/A	90.4	N/A
Decay time, seconds (59.4 psia to 85 K)	2.8	3.1	2.8	2.9
Tailoff Imbalance Impulse differential, Klbf-sec	Predicted N/A		Actual 228.2	

Impulse Imbalance = Integral of the absolute value of the left motor thrust minus right motor thrust from web time to action time.

^a All times are referenced to ignition command time except where noted by a ^b

^b Referenced to liftoff time (ignition interval).

During the ordnance installation operations, the first cycle time of the right-hand safe and arm (S&A) device exceeded the OMRSD requirement of 2.0 seconds by 0.33 second. The remaining cycles met the OMRSD requirement of 0.82-second safe-to-arm time. A special 10-cycle test was performed on the device and the maximum cycle time was less than one second which is well below the OMRSD limit. The cause of the slow first cycle time was not determined.

The power-up of the igniter and field joint heaters was accomplished routinely. The field-joint heaters operated for 11 hours 58 minutes during the launch countdown. Power was applied to the heating elements an average of 21-percent of the time during the LCC time frame to maintain the joints within the nominal operating temperature range. Igniter joint heaters operated for 11 hours 47 minutes during the countdown. Power was applied to the heating elements an average of 28-percent of the time to maintain nominal igniter joint temperatures.

The aft skirt purge operated prior to and during the LCC time frame for a total of 6 hours 3 minutes during the countdown. It was not necessary to activate the aft skirt

purge during the LCC time frame of the successful countdown to maintain the nozzle/case joint temperatures above the minimum LCC temperature. The calculated flex bearing mean bulk temperature was a nominal 81 °F.

EXTERNAL TANK

All External Tank (ET) subsystems performed satisfactorily and all flight objectives were satisfied. No in-flight anomalies were noted in the data review, and no LCC or OMRSD violations occurred during the countdown. All ET electrical equipment and instrumentation operated satisfactorily. Purge and heater operations were performed properly. STS-93 was the fifth flight of the Super Lightweight Tank (SLWT) and the second flight of the modified hazardous gas detection system (HGDS). No significant oxygen or hydrogen leakage concentrations were detected in the intertank.

Two cracks were observed in the intertank TPS foam insulation; one on the second stringer valley in the -Y+Z quadrant and about 16 to 18 inches long, and one on the second stringer valley in the -Y-Z quadrant and about 10 to 11 inches long. Both of these cracks were typical of those observed on previous missions and were acceptable per NSTS 08303. However, a crack that was approximately 6 inches long was observed on the +Y longeron on the -Z bondline-to-acreage TPS. Sixty percent of this crack exhibited offset, making it unacceptable based on NSTS 08303. The crack was dispositioned to be flown as is.

No evidence of ice or frost on the acreage areas was evident. Normal quantities of ice or frost were present on the liquid oxygen (LO₂) and liquid hydrogen (LH₂) feedlines, the pressurization line brackets, and along the LH₂ protuberance air load (PAL) ramps. All of these observations were acceptable per NSTS 08303.

The pressurization system functioned properly throughout engine start and flight. The minimum LO₂ ullage pressure experienced during the ullage pressure slump was 13.6 psid.

ET separation was confirmed at the expected time followed by entry and breakup, within the predicted footprint. The postflight predicted ET intact impact point was approximately 491 nmi. uprange from the preflight prediction. The larger-than-normal difference between the predicted and actual intact impact point was the result of the low-level oxygen cutoff at main engine cutoff (MECO).

SPACE SHUTTLE MAIN ENGINES

The Space Shuttle main engine (SSME) performance was nominal except for SSME 3. Review and analysis of the postlaunch photography from ground-based cameras revealed a streak, indicative of a hydrogen leak from SSME 3. A discussion of this anomaly is presented in the following paragraph of this section.

Approximately 5 seconds after engine start and prior to liftoff, SSME 3 experienced a shift in performance that was the result of a 3.7 lb/sec hydrogen leak in the engine nozzle (Flight Problem STS-93-E-01). The hydrogen leak from the SSME 3 nozzle was also observed in postlaunch photography. The leak was caused by the loss of a main injector LO₂ post-deactivation pin impacting the nozzle and rupturing three hydrogen cooling tubes. The hydrogen leak caused an off-nominal mixture ratio that resulted in low engine performance, which in turn caused a compensating increase in the flow of

oxygen, and that in turn resulted in the low-level oxygen cutoff. The low-level oxygen cutoff of the three SSMEs resulted in a 16 ft/sec underspeed at main engine cutoff (MECO).

Approximately 5 seconds after the liftoff of the vehicle, an electrical short of approximately 0.5-second duration occurred on phase A of AC bus 1. Coincident with the short, the SSME 1 (center engine) digital computer unit (DCU) A was switched to DCU B and a channel B halt occurred on SSME 3 (right engine) DCU B. The loss of DCU A on SSME 1 resulted in the loss of all data from that engine for the remainder of ascent. The disqualification of DCU B on SSME 3 resulted in its loss for control and red-line protection. However, all three SSMEs continued to operate satisfactorily for the remainder of ascent.

During flight day 3, the crew reported that the AC bus 1 phase A circuit breaker for SSME 1 controller A was open and transmitted photographs of the circuit breaker to the ground. The AC 1 phase B and C circuit breakers for SSME 1 controller A were opened for entry to protect against an inadvertent powering of the controller. During the postflight inspection, the cause of the short was isolated to a wire in a cable tray in the aft portion of the Orbiter. As a result of the loss of data from SSME 1, the engine required a confidence hot-fire to be performed at John C. Stennis Space Flight Center to clear all of the hardware on the engine for continued flight service.

SHUTTLE RANGE SAFETY SYSTEM

The Shuttle Range Safety System (SRSS) closed-loop testing was completed as scheduled during the launch countdown. All SRSS S&A devices were armed and system inhibits turned off at the appropriate times. As planned, the SRB S&A devices were safed and SRB system power was turned off prior to SRB separation. The SRSS operated nominally throughout the countdown and flight.

ORBITER SUBSYSTEM PERFORMANCE

Main Propulsion Subsystem

The overall in-flight performance of the main propulsion subsystem (MPS) was nominal. No LCC or OMRSD violations occurred during the countdown. The ascent MPS performance was nominal in all aspects with no in-flight anomalies noted.

The initial launch attempt of the STS-93 vehicle, scheduled for 12:36 a.m. e.d.t. on July 20, 1999, was scrubbed when the hazardous gas measurement reading from the Orbiter aft compartment at T-15 seconds indicated a spike in the hydrogen concentration from 120 ppm to 640 ppm, which exceeded the LCC limit of 600 ppm. A hold in the countdown was called, and ignition of the three SSMEs was inhibited. The next data sample at T-8 seconds showed a nominal reading in the aft compartment of approximately 120 ppm. As a result of the scrub, detanking of the External Tank was performed.

The cause of the indicated increase in the aft compartment hydrogen concentration was a "burp" in the hazardous gas detection system ion pump. The mixing model analysis of the aft compartment indicated that an actual hydrogen leak of the magnitude recorded by the prime machine would require approximately 70 seconds to

dissipate. No Orbiter corrective actions were required, and the launch was rescheduled for July 22, 1999. For subsequent launch attempts on this mission, mission management established a ground rule that if a similar event was seen on the prime machine, a corresponding level on the backup machine or a second data sample on the prime machine would be required to call a countdown hold.

During the LH₂ drain following the first launch scrub, the aft Helium concentration exhibited a cyclical frequency that matched the LH₂ prepressurization pulses with a peak-to-trough magnitude of approximately 1200 ppm. A change in the indicated aft fuselage Helium concentration in response to small hydrogen system pressure cycles is indicative of a soft-seal leak. The most likely source of the leakage was the LH₂ time-zero (T-0) umbilical carrier plate cavity. This cavity is purged with Helium and leakage of the aft fuselage hazardous gas detection line T-0 quick disconnect interface seal in this cavity would give the appearance of a Helium leak in the aft fuselage. The seal is subjected to mechanical and thermal loads that are believed to cause enough deflection to result in the leak signature observed. This signature has been seen on previous detanking operations and is an acceptable condition.

No significant hazardous gas concentrations were detected prior to liftoff. The maximum hydrogen concentration level in the Orbiter aft compartment was 100 ppm. This level compares favorably with previous launch countdown data from this Orbiter.

Approximately 5 seconds after the liftoff of the vehicle, an electrical short of approximately 0.5-second duration occurred on AC bus 1. Coincident with the short, the SSME 1 (center engine) controller (DCU) A and the SSME 3 (right engine) controller (DCU) B were disqualified. Data evaluation indicated that the short had occurred on phase A of AC bus 1. Postflight troubleshooting isolated the cause of the short to a damaged wire in the Orbiter port wire tray at the midbody bay 11/12. A more complete discussion of this anomaly is contained in the Electrical Power Distribution and Control Subsystem section of this report.

Also during ascent, there was a low-level oxygen cutoff of the three SSMEs, resulting in a 16 ft/sec underspeed at MECO. During the SSME start sequence, photography and video showed a flash in the SSME 3 nozzle that began approximately 5 seconds after SSME start. Following the flash, a change in the oxidizer preburner oxidizer valve (OPOV) position and the fuel and oxidizer turbine temperatures occurred, all of which are an indication of a hydrogen leak. These off-nominal conditions existed throughout ascent. The hydrogen leak caused the main combustion chamber (MCC) pressure to fall below the target value. The controller compensated by increasing the LO₂ flow to increase MCC pressure back to the targeted value. This increased LO₂ flow caused the low-level oxygen cutoff. The postflight inspection revealed a hole in three of the hydrogen tubes inside the engine nozzle. Further evaluation and analysis revealed that a main injector LO₂ post deactivation pin (no. 32 on row 13) was missing. The leak was caused by the pin being ejected during SSME start and impacting the nozzle, rupturing three hydrogen cooling tubes.

The overall gaseous hydrogen (GH₂) system in-flight performance was nominal. All three flow control valves performed nominally. Likewise, the gaseous oxygen (GO₂) fixed orifice pressurization system performed as predicted. Because of the AC bus 1 phase A short, the SSME 1 data were lost five seconds after liftoff.

An evaluation of vehicle performance was made using vehicle acceleration and preflight propulsion prediction data. The average flight-derived engine specific impulse (I_{sp}) was 451.3 seconds as compared to an MPS tag value of 452.21 seconds at 104-percent throttle setting. This 0.9-second lower than predicted I_{sp} is even more significant when compared to demonstrated in-flight "higher-than-predicted" values on the order of 0.7-second for phase II engines.

Reaction Control Subsystem

The reaction control subsystem (RCS) performed satisfactorily throughout the mission, and no in-flight anomalies occurred within the subsystem. A total of 4639.2 lbm of RCS propellants were consumed, and no orbital maneuvering subsystem (OMS) interconnect operations were performed. The vernier thrusters had 16,080 firings and the firing time was 10916.08 seconds. The primary thrusters had 2708 firings and a total firing time of 1142.64 seconds. The following table provides pertinent data about the significant RCS maneuvers.

RCS MANEUVERS

RCS maneuver	Ignition time, day:hr:min:sec	Differential velocity, ft/sec	Firing Time, seconds	Orbit, nmi.
Separation 1 and 2	204:11:48:25 G.m.t. 00:07:17:25 MET	-	0.54 and 6.7	-
Flycast no. 1 +X 1, 2 and 3	205:03:14:00 G.m.t. 00:22:43:00 MET	3.1	1.64, 8.92, and 1.64	153.3 by 152.8
MSX -X Translation	205:10:29:54 G.m.t. 01:05:58:54 MET	-	9.9	-
MSX +X Translation	205:10:30:14 G.m.t. 01:05:59:14 MET	-	9.9	-
MSX +X Translation	206:10:32:36 G.m.t. 02:06:01:36 MET	-	9.8	159.2 by 145.8
MSX Part II -X Translation	207:10:34:36 G.m.t. 03:06:03:36 MET	-	9.5	-
Post OMS-9I +X Translation	207:10:34:59 G.m.t. 03:06:03:59 MET	-	8.0	-
Flycast no. 2 +X 1, 2 and 3	208:03:08:02 G.m.t. 03:22:37:02 MET	4.8	1.68, 15.81 and 1.64	160.2 by 145.9
Forward RCS Orbit Adjust	208:09:21:52 G.m.t. 04:04:50:52 MET	19.3	69.6	151.1 by 138.6

Twenty-two of the RCS thrusters experienced temperature drops of up to 15 °F during the first three minutes of the flight at the oxidizer or fuel temperature sensors without corresponding thruster firings. The temperature drops were attributed to moisture evaporation during ascent. This condition did not impact mission operations.

Throughout the mission following firings of RCS primary thruster F2D, the fuel injector temperature dropped, indicating a small volume leak from the fuel valve. The

temperature remained above the redundancy management (RM) leak detection limit of 20 °F for the fuel injector temperature. This performance did not impact the mission, and the thruster was used as planned. All of the primary RCS thrusters will be removed from the vehicle and sent to the White Sands Test Facility (WSTF) for Orbiter Maintenance Down Period (OMDP) processing.

When the Midcourse Space Experiment (MSX) maneuvers were performed, the two maneuvers were separated by a 10-second coast period. Discussions concerning the MSX are contained in the Payloads and Experiments section of this report.

The RCS hot-fire began at 208:02:19:07 G.m.t. (03:21:49:07 MET) and was completed by 208:02:24:41 G.m.t. (03:21:54:41 MET). Sixteen thrusters were fired for the first time during the hot-fire. Also during the hot-fire, the primary thruster F2D fuel-injector temperature exhibited the same dribbling signature seen throughout the mission. The fuel injector temperature dropped to 29 °F. As stated previously, the RM deselection limit is 20 °F.

Orbital Maneuvering Subsystem

The OMS performed satisfactorily throughout the flight. No in-flight anomalies occurred in the subsystem. A total of 12,982 lbm of OMS propellants (8128 lbm of oxidizer and 4854 lbm of fuel) were consumed by the OMS, and no propellants were used by the RCS as no interconnect operations occurred. The table on the following page provides data concerning each of the OMS maneuvers.

As has been observed on most of the previous flights of the right OMS engine (S/N 116), there was a slight external leak of the gaseous nitrogen (GN₂) low pressure system (approximately 38 scch) throughout the mission. Troubleshooting in the past has been unable to isolate the source of the leak, which only manifests itself in flight. Since there were numerous OMS firings during the mission, there were only two occasions where the GN₂ accumulator had to be manually repressurized. The total GN₂ lost during the mission was the equivalent of one engine firing, including purge, or about 200 psi of GN₂ from the GN₂ tank. This engine is going to the WSTF for refurbishment, and the source of the leak will again be investigated.

Power Reactant Storage and Distribution Subsystem

The power reactant storage and distribution (PRSD) subsystem performed satisfactorily throughout the STS-93 mission with no anomalies identified from the data. There were no LCC violations noted during the prelaunch operations. The PRSD subsystem supplied the fuel cells with 1053 lbm of oxygen and 133 lbm of hydrogen for the production of electrical energy. The Orbiter landed with 854 lbm of oxygen and 125 lbm of hydrogen remaining in the system. A 76-hour mission extension was possible at the average power level with the reactants remaining at landing.

The fuel cell 2 oxygen reactant valve failed to close during the postlanding fuel cell shutdown and inerting operations. The valve failed to respond to two close commands from the Launch Processing System (LPS), and also failed to close when the cabin panel switch was held closed for 96 seconds. The valve did close immediately when the redundant closure circuit was energized. Troubleshooting will be performed to determine the cause of the failure to close. The valve panel that this valve is installed

OMS MANEUVERS

OMS Maneuvers	Engine Configuration	Ignition Time, day:hr:min:sec	Firing time, seconds	Differential Velocity, ft/sec	Orbit, nmi.
OMS-1		Not required			
OMS-2	Dual-engine	204:05:12:06 G.m.t. 00:00:41:06 MET	135.8	201.3	144.7 by 153.7
OMS-3	Left-engine	204:12:02:25 G.m.t. 00:07:31:25 MET	34.0	34.5	153 by 163
OMS-4	Right-engine	205:01:42:05 G.m.t. 00:21:11:05 MET	15.4	14.7	153 by 155
OMS-5	Left-engine	205:07:09:35 G.m.t. 01:02:38:35 MET	10.2	8.8	147.9 by 153.5
OMS-6 SIMPLEX	Dual-engine	205:11:05:56 G.m.t. 01:06:34:56 MET	5.0	3.77	148.0 by 158.2
OMS-7	Left-engine	206:05:49:01 G.m.t. 02:01:18:01 MET	9.8	9.1	142.8 by 157.4
OMS-8	Right-engine	206:07:09:31 G.m.t. 02:02:38:31 MET	10.0	8.9	147.0 by 158.2
OMS-9 MSX	Left-engine	206:10:32:16 G.m.t. 02:06:01:16 MET	10.0	9.0	147.0 by 158.2
OMS-10	Right-engine	207:07:09:34 G.m.t. 03:02:38:34 MET	9.8	8.6	141.7 by 157.7
OMS-11 MSX	Right-engine	207:10:34:15 G.m.t. 03:06:03:15 MET	9.8	8.8	144.3 by 159.6
OMS-12	Right-engine	208:04:48:59 G.m.t. 04:00:17:59 MET	10.0	8.8	-
Deorbit	Dual-engine	209:02:19:00 G.m.t. 04:21:48:00 MET	133.6	134.4	-

on, along with the other three control valve panels, will be removed and each of the solenoid valves will be subjected to the thermal screening procedure at the NASA Shuttle Logistics Depot (NSLD).

Fuel Cell Powerplant Subsystem

The fuel cell powerplant (FCP) subsystem performed satisfactorily during the mission, and no in-flight anomalies were identified from the data evaluation. The average electrical power level and load was 12.9 kW and 421 amperes. The fuel cells produced 1186 lbm of potable water and 1528 kWh of electrical energy from 1053 lbm of oxygen and 133 lbm of hydrogen. Two purges were performed, one at approximately 20 hours MET and the second at 111 hours MET. The actual fuel cell voltages at the end of the mission were 0.20 Vdc above the predicted for fuel cell 1, 0.10 Vdc above predicted for fuel cell 2, and 0.15 Vdc above predicted for fuel cell 3.

Approximately 5 seconds after the liftoff of the vehicle, an electrical short of approximately 0.5-second duration occurred on AC bus 1. An extensive review of the Orbiter components showed that there were effects of the resulting AC bus 1 undervoltage caused by the short, but all of the Orbiter equipment operating at the time

of the short operated nominally following the short. One of the effects seen was the high pH indication received by fuel cell 1 when the sensor performed a self test that was initiated by the undervoltage transient. The sensor indicated high pH for 32 seconds. The data evaluation also revealed a step increase in the current on each fuel cell (73-ampere total increase) for 0.42 second. The fuel cell 1 coolant pump and hydrogen pump, which are also powered by the AC 1 bus, were not affected.

The data evaluation concluded that AC bus 1 was satisfactory for unrestricted use. A more complete discussion of this anomaly is found in the Electrical Power Distribution and Control Subsystem section of this report.

Auxiliary Power Unit Subsystem

The auxiliary power unit (APU) subsystem performed satisfactorily throughout the mission, and no in-flight anomalies were identified from the data. The following table shows the APUs by serial number and their run times and propellant consumption during the mission.

APU RUN TIMES AND FUEL CONSUMPTION

Flight phase	APU 1 (S/N 208)		APU 2 (S/N 410)		APU 3 (S/N 311)	
	(a) (b) Time, min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb	(a) Time, min:sec	Fuel consumption, lb
Ascent	20:27	53	20:39	56	20:44	57
FCS checkout	05:49	18				
Entry ^a	59:54	121	82:17	168	60:11	125
Total	86:10	192	102:56	224	80:55	182

^a APUs were shut down 16 minutes 3 seconds after landing.

^b APU 1 was used for the FCS checkout.

An APU confidence run was performed on June 8, 1999, during which each of the APUs was operated for 7 minutes 8 seconds. During this run, APU 2 experienced a long startup transient (6.5 seconds) and as a result, a second confidence run of APU 2 was performed on June 22, 1999, during which APU 2 was operated for 7 minutes 11 seconds. It's believed that the long period of inactivity (13.2 months) and the low APU 2 fuel-tank pressure (395 psia) at startup combined to result in the long start transient. The startup transient was nominal for the second run.

The APUs were started during the first scrub of the launch on July 20, 1999. On this date, APU 1 was operated for 6 minutes 11 seconds; APU 2 for 6 minutes 13 seconds; and APU 3 for 6 minutes 15 seconds.

The flight control system (FCS) checkout was performed using APU 1 at 208:01:27:06 G.m.t. (03:20:56:06 MET). The data showed performance was nominal. The checkout lasted for 5 minutes 49 seconds and 18 lb of fuel were consumed. Because of the short run-time of the APU, water spray boiler (WSB) 1 cooling was not required as the APU 1 lubrication oil temperature only reached 219 °F.

At 206:08:06 G.m.t. (02:03:35 MET), after the APU heaters were reconfigured from system A to B, the APU 1 (s/n 208) fuel pump/line/gas generator valve module (GGVM) system B heater thermostat (S27B) was cycling within a 6 to 8 °F deadband, as indicated by the bypass line temperature (V46T0128A). On the previous flight of this APU (STS-79), this thermostat cycled in an 11 °F deadband. This thermostat is located on a fuel line that is attached to the APU. Previous experience has shown that a thermostat located at this position will eventually fail once it begins to show signs of set-point shifting or erratic behavior. Generally, a set-point change is the first step followed by more erratic operation of the thermostat prior to failure. The thermostat will be replaced at KSC prior to the next flight of this APU.

All three APUs were removed from the vehicle following this flight as the Orbiter is to be ferried to Palmdale, CA for the OMDP.

Hydraulics/Water Spray Boiler Subsystem

The hydraulics/WSB subsystem performed nominally throughout the mission. No in-flight anomalies were identified from the data, but two items of interest were noted in the data and are discussed in the following paragraphs. Neither of these items impacted the mission operations.

During ascent, the WSB system 3 GN₂ relief valve exceeded the cracking specification of no-more-than 33.5 psig as specified in File IX of the OMRSD. The actual cracking pressure was 38.0 psig at an altitude of 38,796 feet. Typical relief valve cracking pressures are between 30 and 33.5 psig at an altitude of approximately 20,000 feet or less. The reseating of the relief valve was nominal. The condition was believed to have been caused by minor stiction of the relief valve knife-edge poppet seal or spring seat assembly due to the long time since the previous flight of this WSB (October 1994). The fact that the relief valve cracked along with a nominal reseating pressure was a good indication that subsequent operations would be nominal. To confirm the suspected cause of the high cracking pressure, it was requested that KSC perform an OMRSD File III requirement to verify proper operation of the relief valve. This testing has been completed and the valve functioned nominally.

During entry, the right main gear brake line temperature C sensor failed to track the other three sensors. The other three sensors indicated a temperature range of approximately 90 to 130 °F. This particular measurement indicated 44 °F for most of entry. Similar signatures have been observed in the past on previous flights of OV-102. Prior to this flight, the sensor was removed and replaced due to its performance history. Troubleshooting will be performed.

Electrical Power Distribution and Control Subsystem

The performance of the electrical power distribution and control (EPDC) subsystem satisfied all mission requirements; however, one significant in-flight anomaly was denoted and it is discussed in the following paragraphs.

Approximately 5 seconds after the liftoff of the vehicle, an electrical short of approximately 0.5-second duration occurred on AC bus 1 (Flight Problem STS-93-V-01). Coincident with the short, the SSME 1 (center engine) controller (DCU) A and the SSME 3 (right engine) controller (DCU) B were disqualified. This condition

removed the controller redundancy from these two SSMEs. The AC 1 bus amperes read off-scale high (>20 amperes) and the bus voltage fell from 114 to 21.5 Vac during the short period. After 440 milliseconds, the short cleared and all voltages and current values returned to nominal levels with only the main propulsion subsystem reporting malfunctioning equipment. The crew was asked to look at the circuit breakers on the panel supplying power to the SSME controllers and reported that they were closed. As discussed in a later paragraph, a closer look later in the mission determined that the circuit breaker for AC 1 phase A power to the SSME 1 controller was actually open.

Data evaluation indicated that the short had occurred on phase A of AC bus 1. An extensive review of the Orbiter components that were being powered by AC bus 1 during the event was performed. This review showed that there were effects of the resulting AC bus 1 undervoltage caused by the short, but all of the Orbiter equipment operating at the time of the short operated nominally following the short. One of the effects seen was the high pH indication received by fuel cell 1 when the sensor performed a self test that was initiated by the undervoltage transient. The sensor indicated high pH for 32 seconds. The data evaluation revealed a step increase in the current on each fuel cell (73 ampere total increase) for 0.42 second. The fuel cell 1 coolant pump and hydrogen pump, which are also powered by the AC 1 bus, were not affected. The data evaluation concluded that AC bus 1 was satisfactory for unrestricted use, and the bus performed satisfactorily for the remainder of the mission.

As mentioned previously, during flight day 3, the crew reported that the AC bus 1 phase A circuit breaker for SSME 1 controller A was actually open and transmitted photographs of the circuit breaker to the ground. With these data, the source of the short was isolated to a point downstream of the circuit breaker, either in the Orbiter aft compartment wiring or the SSME 1 controller/wiring. The AC 1 phase B and C circuit breakers for SSME 1 controller A were opened for entry to protect against an inadvertent powering of the controller.

Postflight troubleshooting isolated the cause of the short to a damaged wire in the Orbiter port wire tray at the midbody bay 11/12. Analysis of the damaged wire indicated that the damage was the result of a single mechanical event. It was initially suspected that the damage was caused by vibration-induced chaffing against the head of a torque-set screw used to secure the wire tray to the frame. At the short location, the screw head showed obvious signs of arcing. Wire damage at a second screw head (about 2 inches away) was also observed, but there was no evidence of arcing.

At the time of this report, wiring in all of the vehicles in the fleet were being inspected, and, if required, repaired and modified to provide protection.

Atmospheric Revitalization Pressure Control Subsystem

The atmospheric revitalization pressure control subsystem (ARPCS) performed normally throughout the duration of the flight with the exception of the loss of the system 1 gaseous oxygen flow indication discussed in the following paragraph.

At 205:04:31 G.m.t. (01:00:00 MET), the pressure control system (PCS) 1 gaseous oxygen (O₂) flow sensor failed to indicate flow during several periods when O₂ flow was selected. However, this sensor did indicate flow earlier in the mission (between 6 and 10 hours MET) and briefly indicated flow late in the mission at approximately 208:14:07 G.m.t. (04:09:30 MET). KSC troubleshooting found that O₂ flow was being

indicated, although the accuracy of the indicated flow was not measured. A suspect condition exists in the wiring of the O₂/N₂ control panel on the OV-105 vehicle. As a result, the panel from the OV-102 vehicle is being moved to the OV-105 vehicle. The PCS 1 O₂ flow sensor, which is on this panel, will be flown as-is since there are currently no spare flow sensors available and there is not a supplier for these sensors.

As a result of the failure of the PCS 2 GN₂ flow indication on the previous flight of this vehicle, the pressure control system was not configured to PCS 2 for the in-flight redundant component/subsystem checkout. This switchover normally occurs at mid-mission. Although the flow sensors are functional criticality 3, they do provide the earliest indication of a cabin leak. Since the system is configured for N₂ flow-only during crew sleep, mission operations personnel chose not to use PCS 2 with the failed N₂ flow sensor. As with the O₂ flow sensors, there is no replacement sensor or a sensor supplier.

Atmospheric Revitalization Subsystem

The atmospheric revitalization subsystem (ARS) performed satisfactorily throughout the mission with no subsystem in-flight anomalies noted during the data evaluation. All parameters remained within nominal limits throughout the flight.

Prior to performing the 2 psid cabin integrity checks during the first two launch attempts, the avionics bay 1 fan differential pressure (ΔP) toggled near 4.2 inches of water (the LCC for avionics bay fan ΔP is 4.3 inches of water). The greater occurrence of these pressure toggles was noted during the second launch attempt, which saw ΔP s slightly higher than the 4.18 inches of water seen during the first launch attempt. The cabin pressure during the first attempt was 14.76 psia, and during the second attempt was slightly lower at 14.69 psia. The ΔP during the preflight activities of the launch was 4.22 inches of water. The LCC fan ΔP was increased from 4.3 inches of water to 4.4 to avoid an alarm during ascent. The higher than previously seen ΔP during the preflight activities as well as the flight is attributed to the new avionics fans in both the A and B fan locations and was not considered to be a problem.

Numerous components of the ARS were affected by the AC 1 phase A short; however, the data signature of each parameter returned to the before-incident readings after the short cleared.

Active Thermal Control Subsystem

The active thermal control subsystem (ATCS) operation was satisfactory throughout the mission.

Because the flash evaporator system (FES) high-load duct temperatures dropped off sharply during ascent on several previous flights of this vehicle since STS-78, the FES was launched on the primary B controller and the high-load duct heaters were switched to the A/B position just prior to launch. During ascent, the high-load inboard duct temperature dropped to 232 °F just prior to MECO and recovered slightly before decreasing to 124 °F at liftoff plus 15 minutes. The temperature response was not as smooth as would be expected for dual heater operations. STS-87 was the last flight of this vehicle where the system A and B high-load duct heaters were activated and the FES was in the primary B mode of operation. During that ascent, the high-load inboard

duct temperature only dropped to 233 °F by liftoff plus 12 minutes. The temperature normally remains above 190 °F with only one heater activated. Throughout the STS-93 occurrence, the evaporator temperatures were stable. It is suspected that excess water carry-over has been the cause of the duct-temperature drop. The FES was taken back to the primary A controller at 204:06:24 G.m.t. (00:01:53 MET). No mission impact resulted from this condition, and the FES performed nominally for the remainder of the mission. This FES will be removed from the vehicle during the OMDP and returned to the vendor for refurbishment.

Radiator flow was initiated at 204:05:54 G.m.t. (00:01:23 MET), and the payload bay doors were fully open 14 minutes later. Since there was no actively cooled payloads, the flow proportioning valves on the Freon coolant loops (FCLs) remained in the interchanger position throughout the flight. Radiator deployment was not required during the flight.

The radiator cold-soak provided cooling throughout entry and to landing plus 3 minutes at which time the radiators were taken to the high set point. The ammonia boiler system (ABS) A was activated on the secondary controller approximately 5 minutes after landing and operated for 42 minutes. ABS B was activated for approximately 3 minutes before it was turned off in preparation for connecting the ground cooling.

Supply and Waste Water Subsystem

The supply and waste water subsystem performed nominally throughout the flight. By the completion of the mission, all of the scheduled in-flight checkout requirements were satisfied.

Supply water was managed through the use of the FES and the water dump system. Two supply water dumps were performed at an average rate of 1.68 percent per minute (2.77 lb/min). The supply water dump line temperature was maintained between 69 and 110 °F throughout the mission with the use of the line heater.

Waste water was gathered at about the predicted rate. One waste water dump was performed at an average rate of 1.93 percent per minute (3.19 lb/min). The waste water dump line temperature was maintained between 60 and 78 °F throughout the mission. The vacuum vent line temperature was maintained between 60 and 75 °F.

Waste Collection Subsystem

The waste collection subsystem (WCS) performed nominally during STS-93.

Airlock Support Subsystem

Use of the airlock support subsystem was not required as no extravehicular activity was performed during the mission. The active system monitor parameters indicated normal outputs throughout the flight.

Smoke Detection and Fire Suppression Subsystem

The smoke detection system showed no indications of smoke generation during the entire duration of the flight. Use of the fire suppression system was not required.

Flight Data Subsystem

The flight data system performed satisfactorily throughout the mission.

At 204:05:03:15 G.m.t. (00:00:32:15 MET), the backup flight system (BFS) annunciated a CRT BITE 3 message. The BFS was polling the display electronics unit (DEU) at the time, with the BFS/cathode ray tube (CRT) select switch in the 3+1 position. The BITE status words indicated a DEU central processing unit (CPU) memory parity error. The crew performed the malfunction procedure and verified the memory parity error. CRT 3 was recovered and remained selected and powered for the remainder of the mission. All of the CRTs and DEUs will be removed from OV-102 following the mission prior to ferrying the vehicle to Palmdale for OMDP.

Flight Software

The flight software performed satisfactorily with no in-flight anomalies identified in the data evaluation.

Flight Control System

The FCS performed nominally throughout the flight. All external sensors performed nominally and their data were incorporated into the onboard navigation state with good residuals. During approach and landing, BFS navigation tracked the primary avionics software system (PASS) navigation well with the exception that the PASS processed microwave scanning beam landing system data while the BFS continued to process Tactical Air Navigation (TACAN) data.

Postflight data evaluation determined that TACAN 2 failed the OMRSD File IX criteria in that it did not lock-on in bearing and range before 300 nmi. In addition, bearing lock-on at 40 degrees occurred numerous times as well as numerous incidents of breaking bearing-lock. Data analysis has shown that antenna-look angles, related to vehicle attitude, contributed to this condition. TACAN 2 antenna look angles are not as good as the look angles are for positions 1 and 3. A thorough ground check was performed at KSC, and this TACAN passed all requirements. It is believed that this TACAN would not have experienced the number of bearing lock problems if it had been in positions 1 or 3. As a result, it has been decided to install this TACAN (S/N 15064) in position 1 when OV-102 has completed the OMDP at Palmdale. In addition, more extensive than normal ground checks of this TACAN will be performed during the normal receiving-inspection testing at KSC.

The inertial measurement unit (IMU) performance was nominal throughout the flight. During the flight, compensations were uplinked for two of the three IMUs. Also, the performance of the star trackers was nominal throughout the mission.

The FCS checkout was performed using APU 1 at 208:01:27:06 G.m.t. (03:20:56:06 MET). The data showed performance was nominal.

Displays and Controls Subsystem

The displays and controls subsystem performed satisfactorily during the flight. No in-flight anomalies were identified during the review of the data.

Communications and Tracking Subsystem

The communications and tracking subsystem performed nominally throughout the mission with no in-flight anomalies identified in the data evaluation.

During the countdown for the launch on July 23, 1999, a communications problem occurred that resulted in the loss of the forward link with the vehicle. The problem was corrected at the Merritt Island Launch Area (MILA) ground facility and communications were restored. This problem resulted in a seven-minute delay in the launch to 12:31 a.m. e.d.t. on July 23, 1999.

The Ku-Band antenna was deployed at 204:12:16:00 G.m.t. (00:07:45:00 MET) and the initial self-test failed due to a known and expected condition. After the initialization was complete, the system was switched to the communications mode, and the antenna operated nominally throughout the flight. Ku-band antenna stowage was accomplished at about 208:07:05 G.m.t. (04:02:34 MET) with nominal dual motor run times.

Operational Instrumentation/Modular Auxiliary Data Subsystems

The operational instrumentation/modular auxiliary data subsystems performed nominally throughout the mission. No in-flight anomalies were identified from the data review.

The initial launch attempt of the STS-93 vehicle, scheduled for 12:36 a.m. e.d.t. on July 20, 1999, was scrubbed when the hazardous gas sample reading in the Orbiter aft compartment indicated a hydrogen concentration of 640 ppm, which exceeded the LCC limit of 600 ppm. Ignition of the three SSMEs was manually inhibited at approximately T-8 seconds in the final countdown.

The cause of the indicated increase in the aft compartment hydrogen concentration was a problem in the hazardous gas detection system. No Orbiter corrective actions were required and the launch was rescheduled for July 22, 1999.

Structures and Mechanical Subsystems

The structures and mechanical subsystems performed satisfactorily throughout the mission. There was one mechanical subsystem item of interest that is discussed in the following paragraph. The landing and braking parameters for this flight are shown in the table on the following page.

When the right vent door 3 was closed during deorbit preparations at 09:01:54:10 G.m.t. (04:21:23:17 MET), the data indicate that the door closed in dual motor time and both the close 1 and close 2 microswitch indications were seen. However, approximately 6 seconds later, the close 1 indication transferred off where it remained for approximately one minute and 30 seconds. Following that period, the close 1 indication transferred back on and continued to indicate correctly. The right

LANDING AND BRAKING PARAMETERS

Parameter	From threshold, ft	Speed, keas	Sink rate, ft/sec	Pitch rate, deg/sec
Main gear touchdown	2695.7	195.0	-1.07	N/A
Nose gear touchdown	5457.4	148.8	N/A	-3.53
Brake initiation speed		117.2 knots		
Brake-on time		32.48 seconds		
Rollout distance		6776.9 feet		
Rollout time		43.29 seconds		
Runway		33 (Concrete) KSC		
Orbiter weight at landing		202721.0 lb		
Brake sensor location	Peak pressure, psia	Brake assembly	Gross energy, million ft-lb	
Left-hand inboard 1	1402	Left-hand inboard	20.40	
Left-hand inboard 3	1402			
Left-hand outboard 2	1402	Left-hand outboard	20.17	
Left-hand outboard 4	1402			
Right-hand inboard 1	1713	Right-hand inboard	20.60	
Right-hand inboard 3	1713			
Right-hand outboard 2	1756	Right-hand outboard	20.93	
Right-hand outboard 4	1756			

vent door 3 was subsequently opened prior to landing and closed post landing and the indicated performance was nominal. KSC troubleshooting was unable to duplicate the anomaly.

The main landing gear tires were in good condition for having landed on the KSC concrete runway. Three of the four tires exhibited ply under-cutting.

The ET/Orbiter (EO) separation devices EO-1, EO-2 and EO-3 functioned normally. No ordnance fragments were found on the runway beneath the umbilicals. The EO-2 and EO-3 fitting retainer springs were in the nominal configuration. No umbilical closeout foam or white room temperature vulcanizing (RTV) material adhered to the umbilical plate near the LH₂ recirculation line disconnect.

During the walkdown of the runway after landing, all components of the drag parachute system that were deployed were recovered and the drag parachute system worked normally. All pyrotechnic devices that were to fire had been expended.

Integrated Vehicle Heating and Thermal Interfaces

The prelaunch thermal interface purges were normal with no problems noted. The ascent aerodynamic and plume heating was normal. The entry aerodynamic heating on the SSME nozzles was also normal. A postflight inspection showed that the damage was similar to that observed on the last two missions.

The acreage heating on the vehicle was nominal with the lower surface structural temperatures typical for this vehicle.

Localized heating was normal. Minor tile slumping was noted in the left-hand and right-hand elevon gap areas.

Thermal Control Subsystem

The thermal control subsystem (TCS) performed satisfactorily with subsystem heaters maintaining temperatures within the desired limits.

One off-nominal thermal issue arose and it concerns the FES high-load duct temperature which dropped below the fault detection and annunciation (FDA) limit of 150 °F during ascent. The temperature dropped as low as 124 °F before recovering to the normal thermostat control point. This problem is not a duct heater issue and is discussed in more detail in the Active Thermal Control Subsystem section of this report.

Aerothermodynamics

Data indicate that a symmetrical and normal boundary layer transition occurred. Aileron data, wing skin temperature and yaw thruster firings were all normal. Skin temperature rise data indicate a turbulent-to-laminar flow transition time of 1276 seconds. No protruding AMES gap fillers were reported.

Thermal Protection Subsystem and Windows

The TPS and windows performed nominally with no in-flight anomalies identified. Entry heating was normal based on structural temperature rise data. Modular Auxiliary Data System (MADS) data showed a nominal transition from turbulent-to-laminar flow that occurred at Mach 7.1, which was 1276 seconds after entry interface. The left wing transition onset ranged from 1218 seconds to 1255 seconds after entry interface. All indications from the data are that the transition was symmetrical, although no thermocouples exist on the right wing to verify the transition.

The Orbiter TPS sustained a total of 208 damage sites (hits) during the mission. Of this total, 49 had a major dimension of 1-inch or larger. The total does not include the numerous damage sites on the base heat shield that are attributed to SSME vibration/acoustics, exhaust plume recirculation, and the flame arrestment sparkler system. A comparison of these numbers to 71 missions of similar configuration indicates that the total number of damage sites was significantly greater than the fleet average, and the number of damage sites greater than 1-inch was also significantly greater than the cumulative fleet average. The table at the top of the following page provides the data for the total number of damage sites on the STS-93 Orbiter.

The 161 total hits on the lower surface were concentrated from the nose gear to the main landing gear wheel wells on both the left and right chines. The damage sites that were on the chines and outboard of the wheel wells followed a similar location/pattern that has been documented on the previous eight missions. The inspection showed that a maximum of three lower-surface tiles may be scrapped because of debris damage. The damage sites around the LH₂ and LO₂ EO umbilicals were also typical. A

comparison of Orbiter lower surface tile damage statistics since STS-86 is shown in the second table on this page.

TPS DAMAGE SITES

Orbiter Surfaces	Hits > 1 Inch	Total Hits
Lower Surface	42	161
Upper Surface	0	4
Right Side	1	8
Left Side	1	5
Right OMS Pod	0	3
Left OMS Pod	0	6
Window Area	5	21
Total	49	208

COMPARISON OF DAMAGE SITE DATA FROM LAST EIGHT FLIGHTS

Parameter	STS -86	STS -87	STS -89	STS -90	STS -91	STS -95	STS -88	STS -96	STS -93
Lower surface total hits	100	244	95	76	145	139	80	160	161
Lower surface hits > 1 in.	27	109	38	11	45	42	21	66	42
Longest damage site, in.	7	15	2.8	3.0	3.0	4.0	4.5	6.0	6.0
Deepest damage site, in.	0.4	1.5	0.2	0.25	0.5	0.4	0.5	0.5	0.5

Less than the usual amounts of tile damage occurred to the base heat shield. All SSME dome-mounted heat shield closeout blankets were in excellent condition. No unusual tile damage was apparent on the OMS pod leading edges and the vertical stabilizer. A 2-inch by 0.75 inch by 0.25 inch deep damage site was located on the +Y side of the vertical stabilizer near the root attach point, and this damage may have been caused by the SSME start-up vibration.

Hazing and streaking of the forward-facing windows was moderate. Damage sites on the window perimeter tiles were less than usual in quantity and size.

The postlanding walkdown of the runway did not produce any debris concerns.

Gas Sample Bottle Analysis

The gas sample bottles performed satisfactorily during the STS-93 ascent phase. The hardware provided the program with six excellent gas samples on this the twenty-seventh flight of the redesigned system. The data obtained during ascent was

nominal with all six bottle pressures in the range expected. The hydrogen concentration was within the data base for all Space Shuttle vehicles. The oxygen data were within the bands of error as determined by the argon measurement, and the amount detected can be attributed to air.

GOVERNMENT FURNISHED EQUIPMENT/FLIGHT CREW EQUIPMENT

The government furnished equipment/flight crew equipment (GFE/FCE) performed nominally with the one exception noted in the following paragraph.

Several times during the mission, the crew experienced tape jamming problems on the Canon L1 camcorder. They also had problems recording and reported later in the mission that the viewfinder display was blank during use. The crew used gray tape to identify the camcorder and the problems they experienced with it. The unit was returned to Houston for failure analysis.

CARGO INTEGRATION

The analysis of data for the cargo integration hardware revealed satisfactory operation of all hardware with no in-flight anomalies noted.

POSTLAUNCH PAD INSPECTION

An additional inspection of the launch pad drains was made following the first scrub on July 20, 1999. This was required because of the igniters having operated and the deluge water system having been activated. No anomalous conditions or damage were noted in any areas of the vehicle or launch pad.

The postlaunch inspection of the launch pad area revealed no evidence of flight hardware. Overall damage to the launch pad was minimal. The inspection of the pad acreage, Orbiter flame trench and Solid Rocket Booster (SRB) flame trench revealed no flight hardware and minimal damage.

No evidence of stud hang-ups was noted and data showed that the vehicle liftoff lateral acceleration was below the threshold (0.14g) for stud hang-ups. The SRB hold-down post blast covers and T-0 umbilical exhibited typical exhaust-plume damage. Both SRB's aft skirt gaseous nitrogen (GN_2) purge lines were intact; however, the protective tape was eroded away, and the braid line was damaged. The left GN_2 purge flex line was also kinked.

The tail service masts (TSM's) appeared undamaged, and the bonnets were closed properly. Likewise, the Orbiter access arm was undamaged.

The mobile launch platform (MLP) deck was in good shape with no significant debris apparent. Many paint chips were scattered about the platform that were white on one side and gray on the other. These chips appeared to be from the facility and not the vehicle.

The gaseous hydrogen (GH_2) vent line was latched properly. The gaseous oxygen (GO_2) vent seals were in excellent shape with no indications of plume damage.

During the inspection of the pad acreage and flame trenches, an extra effort was made to find the Space Shuttle main engine (SSME) 3 liquid oxygen post plug which may have caused the nozzle leakage noted in the films and the postflight inspection. No such plug was found.

**DEVELOPMENT TEST OBJECTIVES/DETAILED SUPPLEMENTARY OBJECTIVES
AND RISK MITIGATION EXPERIMENT**

DEVELOPMENT TEST OBJECTIVES

DTO 260 - Shuttle Radar Topography Mission Fly Casting Maneuver - The Shuttle Radar Topography Mission (SRTM) Fly Casting technique was designed to minimize structural loading of the 60-meter extendible boom antenna that will be flown on the STS-99 mission. During this experiment, the crew performed a sequence of Orbiter thruster firings to minimize the dynamics of the vehicle during trim maneuvers. This Development Test Objective (DTO) was performed as planned, and no anomalies were reported.

DTO 631 - Digital Video Camcorder Demonstration - The Digital Video Camcorder Demonstration was performed to demonstrate a state-of-the-art camera that could complement or replace the aging camcorders now used by the Shuttle Program. This DTO was performed as planned.

DTO 700-17 - High Definition Television Camcorder Demonstration - The High Definition Television Camcorder Demonstration was performed to verify that integrating this new capability with the existing analog system caused no engineering anomalies, and none were reported. Scenes were televised with both an analog camera and the high definition camera for comparison and evaluation. Postflight evaluation will be required to determine the success of this demonstration.

DTO 805 - Crosswind Landing Performance - The Crosswind Landing Performance DTO-of-opportunity was not performed because the crosswinds at landing were not of sufficient magnitude to evaluate.

DETAILED SUPPLEMENTARY OBJECTIVES

DSO 331 - Interaction of the Space Shuttle Launch and Entry Suit and Sustained Weightlessness on Egress Locomotion - This Detailed Supplementary Objective (DSO) will identify the impact of the launch and entry suit (LES)/advanced crew escape suit (ACES) and sustained weightlessness on the mechanical efficiency of crewmembers egress locomotion as measured by oxygen consumption and gait alteration, as well as other parameters. This DSO was performed preflight and postflight only. The results will be published in other documentation.

DSO 493 - Monitoring Latent Virus Reactivation and Shedding in Astronauts - This DSO involved collecting preflight samples of saliva, blood and urine, as well as saliva samples during the flight. This DSO was performed as planned. The results will be published in other documentation.

DSO 496 - Individual Susceptibility to Post-Spaceflight Orthostatic Intolerance - The goal of this DSO is to discover the mechanisms responsible for the postflight orthostatic intolerance that affects crew members. Data for this DSO were collected only during the preflight and postflight periods. The results of the analysis of the data will be published in other documentation.

DSO 498 - Space Flight and Immune Function - This DSO will prove or disprove the hypothesis that space flight alters the immune response to infectious agents. The DSO involved preflight and postflight activities only. The results of this DSO will be published in other documentation.

DSO 631 - Integrated Measurement of the Cardiovascular Effects of Space Flight (Entry Only) - The purpose of this DSO was to assess the stroke volume changes in the cardiovascular system. These data were collected only during entry. The results of this DSO will be published in other documentation.

RISK MITIGATION EXPERIMENT

RME 1318 - Treadmill Vibration Isolation and Stabilization System - This Risk Mitigation Experiment (RME) was not completed to the planned levels because of crew interruptions for other duties, and data were lost from one run because of a failure of a camcorder. The outcome of this RME will be determined from the postflight analysis of the data. The results will be published in other documentation.

PHOTOGRAPHY AND TELEVISION ANALYSIS

LAUNCH PHOTOGRAPHY AND VIDEO DATA ANALYSIS

All of the launch photography and video data were reviewed and the only anomalous condition found was the hot-wall hydrogen leak from Space Shuttle main engine (SSME 3). This leak appeared as an orange spike from the nozzle of the engine; the Mach diamond was irregular in shape; and these conditions were easily visible on many of the films. The postflight inspection of SSME 3 revealed a hole in three tubes in the nozzle area which were the source of the hydrogen leak. This anomaly is discussed in greater detail in the Space Shuttle Main Engine section of this report.

The video from the cameras mounted on the SRBs was analyzed for divots in the insulation. Some of the findings from the -Y side were that there were fewer divots in the vented area compared to the non-vented area. Also, divots in the vented area were generally smaller than divots in the non-vented area. More than 100 divots were identified, and all divots appeared to be shallow with no prime substrate visible. Most divots appeared near the rib side-walls and the top edges. A vapor release was observed from the outboard side of a rib at 101 seconds, but with no detectable foam loss.

Video from the +Y side of the Solid Rocket Booster (SRB) provided basically the same findings as the video from the -Y side with over 100 divots identified.

This vehicle was equipped with three EO umbilical well cameras, two 16 mm and one 35 mm. Analysis of the film did not reveal any anomalous conditions.

ON-ORBIT PHOTOGRAPHY AND VIDEO DATA ANALYSIS

A total of 3.7 minutes of hand-held video of the ET was received and analyzed. The ET was farther away than typically seen because the crew had to wait until the ET came into sunlight before acquiring the imagery. This increased distance resulted in decreased resolution, but no anomalous conditions were observed in the analysis.

A total of 35 images of the ET were acquired using the hand-held 35 mm camera with the 400 mm lens. Views of the aft dome, nose, and all sides of the ET were obtained. Twelve of the photographs were of the shadowed side of the ET and were very dark. Again, as in the video, the ET was farther away than on previous mission photography because of the wait for the ET to be in sunlight. No anomalous conditions were observed in the photographs. The tumble rate of the ET appeared to be faster than that typically seen on previous missions.

LANDING PHOTOGRAPHY AND VIDEO DATA ANALYSIS

The videos of the landing sequence as well as one landing film were reviewed and no anomalies were noted from the review. The landing film also was used to obtain the sequence of landing events times.

TABLE I.- STS-93 SEQUENCE OF EVENTS

Event	Description	Actual time, G.m.t.
APU Activation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	204:04:26:17.558 204:04:26:19.482 204:04:26:21.387
SRB HPU Activation ^a	LH HPU System A start command LH HPU System B start command RH HPU System A start command RH HPU System B start command	204:04:30:31.944 204:04:30:32.100 204:04:30:32.264 204:04:30:32.424
Main Propulsion System Start ^a	ME-3 Start command accepted ME-2 Start command accepted ME-1 Start command accepted	204:04:30:53.406 204:04:30:53.546 204:04:30:53.647
SRB Ignition Command (Liftoff)	Calculated SRB ignition command	204:04:30:59.984
Throttle up to 104 Percent Thrust ^a	ME-3 Command accepted ME-1 Command accepted ME-2 Command accepted	204:04:31:03.845 204:04:31:03.846 204:04:31:03.865
Throttle down to 67 Percent Thrust ^a	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	204:04:31:33.046 204:04:31:33.145 Note ^b
Maximum Dynamic Pressure (g)	Derived ascent dynamic pressure	204:04:31:49
Throttle up to 104 Percent ^a	ME-3 Command accepted ME-2 Command accepted ME-1 Command accepted	204:04:31:59.286 204:04:31:59.386 Note ^b
Both RSRM's Chamber Pressure at 50 psi ^a	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	204:04:32:58.584 204:04:32:58.784
End RSRM Action Time ^a	RH SRM chamber pressure mid-range select LH SRM chamber pressure mid-range select	204:04:33:01.054 204:04:33:01.194
SRB Physical Separation ^a	LH rate APU A turbine speed - LOS LH rate APU B turbine speed - LOS RH rate APU A turbine speed - LOS RH rate APU B turbine speed - LOS	204:04:33:03.264 204:04:33:03.664 204:04:33:03.264 204:04:33:03.664
SRB Separation Command	SRB separation command flag	204:04:33:04
Throttle Down for 3g Acceleration ^a	ME-3 command accepted ME-2 command accepted ME-1 command accepted	204:04:38:29.853 204:04:38:29.949 Note ^b
3g Acceleration	Total load factor	204:04:39:14.0
Throttle Down to 67 Percent Thrust ^a	ME-3 command accepted ME-2 command accepted ME-1 command accepted	204:04:39:21.374 204:04:39:21.470 Note ^b
SSME Shutdown ^a	ME-3 command accepted ME-2 command accepted ME-1 command accepted	204:04:39:27.575 204:04:39:27.670 Note ^b
MECO	MECO command flag MECO confirm flag	204:04:39:28 204:04:39:29
ET Separation	ET separation command flag	204:04:39:47

^aMSFC supplied data

^bSSME 1 data lost at 204:04:31:05.006 G.m.t.

**TABLE I.- STS-93 SEQUENCE OF EVENTS
(Continued)**

Event	Description	Actual time, G.m.t.
APU Deactivation	APU-1 GG chamber pressure APU 2 GG chamber pressure APU 3 GG chamber pressure	204:04:46:41.979 204:04:46:54.942 204:04:47:03.316
OMS-1 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	Not performed - direct insertion trajectory flown
OMS-1 Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	
OMS-2 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	204:05:12:07.0 204:05:12:07.0
OMS-2 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	204:05:14:23.0 204:05:14:23.0
Payload Bay Doors (PLBDs) Open	PLBD right open 1 PLBD left open 1	204:06:08:35 204:06:09:56
Chandra Release	Payload solenoid 1 latch 1A release ind. Payload solenoid 1 latch 2A release ind.	204:10:13:20.1 204:10:13:20.2
OMS-3 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	204:12:02:25.3 N/A
OMS-3 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	204:12:02:59.7 N/A
OMS-4 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 205:01:42:05.2
OMS-4 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	N/A 205:01:42:20.8
OMS-5 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	205:07:09:35.1 N/A
OMS-5 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	205:07:09:45.3 N/A
OMS-6 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	205:11:05:56.1 205:11:05:56.2
OMS-6 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	205:11:06:01.3 205:11:06:01.4
OMS-7 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	206:05:49:01.3 N/A
OMS-7 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	204:11:49:11.3 N/A
OMS-8 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 206:07:09:31.2
OMS-8 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	N/A 206:07:09:41.4
OMS-9 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	204:10:32:16.1 N/A
OMS-9 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	204:10:32:26.3 N/A
OMS-10 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 207:07:09:34.2
OMS-10 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	N/A 207:07:09:44.4

**TABLE I.- STS-93 SEQUENCE OF EVENTS
(Continued)**

Event	Description	Actual time, G.m.t.
OMS-11 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 207:10:34:16.2
OMS-11 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	N/A 207:20:34:26.4
Flight Control System Checkout APU 1 Start APU 1 Stop	APU 1 GG chamber pressure APU 1 GG chamber pressure	208:01:27:02.077 208:01:32:52.008
OMS-12 Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	N/A 208:04:48:59.2
OMS-12 Cutoff	Right engine bi-prop valve position Left engine bi-prop valve position	N/A 207:04:49:09.2
Payload Bay Doors Close	PLBD left close 1 PLBD right close 1	208:23:37:33 208:23:39:36
APU Activation for Entry	APU-2 GG chamber pressure APU-1 GG chamber pressure APU-3 GG chamber pressure	209:02:14:06.524 209:02:36:17.301 209:02:36:21.426
Deorbit Burn Ignition	Left engine bi-prop valve position Right engine bi-prop valve position	209:02:19:00.1 209:02:19:00.2
Deorbit Burn Cutoff	Left engine bi-prop valve position Right engine bi-prop valve position	209:02:21:13.7 209:02:21:14.0
Entry Interface (400K feet)	Current orbital altitude above	209:02:48:48
Blackout end	Data locked (high sample rate)	No blackout
Terminal Area Energy Mgmt.	Major mode change (305)	209:03:13:59
Main Landing Gear Contact	RH main landing gear tire pressure 2 LH main landing gear tire pressure 2	209:03:20:35 209:03:20:35
Main Landing Gear Weight on Wheels	LH main landing gear weight on wheels RH main landing gear weight on wheels	209:03:20:36 209:03:20:36
Drag Chute Deployment	Drag chute deploy 1 CP volts	209:03:20:37.1
Nose Landing Gear Contact	NLG LH tire pressure 1	209:03:20:44
Nose Landing Gear Weight On Wheels	NLG weight on wheels 1	209:03:20:44
Drag Chute Jettison	Drag chute jettison 1 CP Volts	209:03:21:05.2
Wheel Stop	Velocity with respect to runway	209:03:21:19
APU Deactivation	APU-1 GG chamber pressure APU-2 GG chamber pressure APU-3 GG chamber pressure	209:03:36:08.581 209:03:36:21.962 209:03:36:30.836

TABLE III.-STS-93 MSFC PROBLEM TRACKING LIST

No.	Title	Time	Comments
STS-93-E-01	Liquid Oxygen Low-Level Cutoff	203:04:31:00 G.m.t 00:00:00:00 MET	<p>Approximately 5 seconds after engine start and prior to liftoff, SSME 3 experienced a shift in performance that was the result of a 3.7 lb/sec hydrogen leak in the engine nozzle hot-wall surface (Flight Problem STS-93-E-01). The hydrogen leak from the SSME 3 nozzle was also observed in postlaunch photography. The leak was caused by the loss of a main injector liquid oxygen (LO₂) post-deactivation pin impacting the nozzle and rupturing three nozzle hydrogen coolant tubes. The expulsion of a main injector LO₂ post deactivation pin was previously believed to be a benign failure based on Program hot-fire history. The hydrogen leak caused an off-nominal mixture ratio that resulted in low engine performance, which in turn caused a compensating increase in the flow of oxygen, and that in turn resulted in the low-level oxygen cutoff. The low-level oxygen cutoff of the three SSMEs resulted in a 16 ft/sec underspeed at Main Engine cutoff (MECO).</p>
STS-93-B-01	Right-Hand SRB Tilt Hydraulic Pressure Sensor Erratic	203:04:31:00 G.m.t 00:00:00:00 MET	<p>At liftoff, the right SRB hydraulic supply pressure sensor 2 was erratic and drifting low. By 30 seconds into the flight, the sensor had drifted to 0 psia. At 31 seconds into the flight, the sensor returned to a nominal reading of 3200 psia. At approximately 70 seconds, the sensor drifted low to approximately 1600 psia and returned to a nominal reading at 100 seconds into the ascent. The worst-case impact of this type of failure would be a launch scrub as the Launch Commit Criteria red-line requires the hydraulic pressure to remain between 2800 and 3486 psia from T-17 seconds to T-10 seconds. KSC: Perform troubleshooting on recovered SRB.</p>

TABLE II- SPACE SHUTTLE VEHICLE ENGINEERING OFFICE IN-FLIGHT ANOMALY LIST

No.	Title	Reference	Comments
STS-93-V-01	AC1 Phase A Short	204:04:31:05 G.m.t. 00:00:00:05 MET IPR 102V-0003	<p>Approximately 5 seconds after liftoff, a momentary short occurred on AC1 phase A. The duration of the short was approximately 500 milliseconds. A current spike in excess of 20 amperes and a voltage drop from 114 to 21 Vac was observed on AC1 phase A. Coincident with the short, the SSME 1 (center engine) controller A and SSME 3 (right engine) controller B failed. Additionally, the H₂O loop light on the caution and warning F7 panel was momentarily activated and a fuel cell 1 pH backup flight system (BFS) message was received. After main engine cutoff (MECO), the crew checked the circuit breakers on panel L4 and reported that none were out of position.</p> <p>Data evaluation determined that there was no loss of function in any of the Orbiter equipment that was powered by AC1 during ascent. Both the H₂O loop light and the fuel cell 1 pH message were determined to be symptoms of the undervoltage on AC1 phase A and resulted from the short. The was in-flight restriction on the use of the AC1 bus for the remainder of the mission.</p> <p>During flight day 3, the crew reported that the AC1 phase A circuit breaker for SSME 1 controller A was actually open. With this information, the source of the short could be isolated between the circuit breaker and the SSME 1 controller A. The AC1 phase B and C circuit breakers for SSME 1 controller A were opened for entry to protect against an inadvertent powering of the controller.</p> <p>A postflight troubleshooting plan was developed and it was determined early that the short was on the Orbiter side of the SSME 1 interface panel. The short was isolated to a damage wire in the port wire tray at the midbody bay 11/12 frame. Analysis of the damaged wire indicated that the damage was the result of a single mechanical event. It was initially suspected that the damage was caused by vibration-induced chaffing against the head of a torque-set screw used to secure the wire tray to the frame. At the short location, the screw head showed obvious signs of arcing. Wire damage at the second set screw head (about two inches away) was also observed, but there was no evidence of arcing. Additional inspections found damage on a wire at the same location in the starboard wire tray. The damage appeared to be caused by wear. As a result of the failure, the decision was made to inspect and protect the wire harnesses in all vehicle of the fleet.</p> <p>KSC: Inspection and repair of the vehicles is in progress.</p>

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 (CSR) Daily Science Reports, and Final CSR Report
4. Mission Evaluation Room (MER) Daily Reports
5. MER Mission Summary Report
6. MER Problem Tracking List
7. MER Event Times
8. Subsystem Manager Reports/Inputs
9. MOD Systems Anomaly List
10. MSFC Flash Report
11. MSFC Event Times
12. MSFC Interim Report
13. Crew Debriefing comments
14. Shuttle Operational Data Book
15. STS-93 Summary of Significant Events
16. Contractor Reports of Subsystem Operation

ACRONYMS AND ABBREVIATIONS

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

ABS	ammonia boiler system
AC or ac	alternating current
ACES	advanced crew escape suit
APU	auxiliary power unit
ARPCS	atmospheric revitalization pressure control system
ARS	atmospheric revitalization system
ATCS	active thermal control system
AXAF-I	Advanced X-Ray Astrophysics Facility - Imaging
BFS	backup flight system
BRIC	Biological Research in Canisters
CCM	Cell Culture Module
CDR	Commander, U. S. Navy
CGBA	Commercial Generic Bioprocessing Apparatus
CPU	central processing unit
CRT	cathode ray tube
CXO	Chandra X-Ray Observatory
DCU	digital computer unit
DEU	display electronics unit
DSO	Detailed Supplementary Objective
DSP	digital signal processor
DTO	Developmental Test Objective
ΔP	differential pressure
ΔV	differential velocity
EO	ET/Orbiter
EPDC	electrical power distribution and control
e.d.t.	eastern daylight time
ET	External Tank
FCE	flight crew equipment
FCL	Freon coolant loop
FCP	fuel cell powerplant
FCS	flight control system
FDA	fault detection and annunciation
FES	flash evaporator system
FLM	fluorescent light module
ft/sec	feet per second
g	gravity
GFE	Government furnished equipment
GGVM	gas generator valve module
GH ₂	gaseous hydrogen
G.m.t.	Greenwich mean time
GN ₂	gaseous nitrogen
GO ₂	gaseous oxygen
GOSAMR	Gelation of Sols:Applied Microgravity Research

>	greater than
H ₂ O	water
HGDS	hazardous gas detection system
IFM	in-flight maintenance
IMU	inertial measurement unit
IPS	Integral Propulsion System
I_{sp}	specific impulse
IUS	Inertial Upper Stage
JSC	Johnson Space Center
keas	knots estimated air speed
km	kilometer
KSC	Kennedy Space Center
kW	kilowatt
kWh	kilowatt/hour
lbm	pound mass
lb/min	pound per minute
LCC	Launch Commit Criteria
LES	launch/entry suit
LFSAH	Light Weight Flexible Solar Array Hinge
LH ₂	liquid hydrogen
LMSO	Lockheed Martin Space Operations
LO ₂	liquid oxygen
LPS	Launch Processing System
MADS	Modular Auxiliary Data System
MCC	main combustion chamber
MECO	main engine cutoff
MEDS	multifunction electronic display system
MEMS	Micro-Electro-Mechanical Systems
MET	mission elapsed time
MILA	Merritt Island Launch Area
MLP	Mobile Launch Platform
MPS	main propulsion system
MSFC	Marshall Space Flight Center
MSX	Midcourse Space Experiment
NASA	National Aeronautics and Space Administration
nmi.	nautical mile
NSLD	NASA Shuttle Logistics Depot
NSTS	National Space Transportation System (i.e., Space Shuttle Program)
OMDP	Orbiter Maintenance Down Period
OMRSD	Operations and Maintenance Requirements and Specifications Document
OMS	orbital maneuvering subsystem
OPOV	oxidizer preburner oxidizer valve
O ₂	oxygen
PAL	protuberance air load
PASS	primary avionics software system
PCS	pressure control system
PGF	plant growth facility
PGIM	Plant Growth Investigations in Microgravity
pH	parts hydrogen
PMBT	propellant mean bulk temperature

ppm	parts per million
PRSD	power reactant storage and distribution
psi	pound per square inch
psid	pound per square inch differential
psig	pound per square inch gravity
RCS	reaction control subsystem
RM	Redundancy Management
RME	Risk Mitigation Experiment
RSRM	Reusable Solid Rocket Motor
RTV	room temperature vulcanizing (material)
S&A	safe and arm
SAREX II	Shuttle Amateur Radio Experiment II
SIMPLEX	Shuttle Ionospheric Modification with Pulsed Local Exhaust
SLF	Shuttle Landing Facility
SLWT	super lightweight tank
S/N	serial number
SRB	Solid Rocket Booster
SRSS	Shuttle range safety system
SRTM	Shuttle Radar Topography Mission
SSME	Space Shuttle main engine
SSVEO	Space Shuttle Vehicle Engineering Office
STL-B	Space Tissue Loss-B
STS	Space Transportation System
SWAR	sea water activated release
SWUIS	Southwest Ultraviolet Imaging System
TACAN	tactical air navigation
TCD	thermal control device
TCS	trajectory control sensor/thermal control system
TPS	thermal protection system/subsystem
TSM	tail service mast
Vac	Volts alternating current
Vdc	Volts direct current
WCS	waste collection system
WSB	water spray boiler
WSTF	White Sands Test Facility